EFFECT OF DIFFERENCES IN LIVE WEIGHT ON FEED REQUIREMENTS OF PREGNANT NON-LACTATING GRAZING DAIRY COWS

A thesis presented in partial fulfilment of the requirements
for the degree of Master of Agricultural
Science in Animal Science at
Massey University,
Palmerston North,
New Zealand

J.G. GARCÍA-MUÑIZ

1994

EFFECT OF DIFFERENCES IN LIVE WEIGHT ON FEED REQUIREMENTS OF

PREGNANT NON-LACTATING COWS.

(1) I give permission for my thesis to be made available to readers in Massey University Library under conditions determined by the Librarian.

(2) I agree that my thesis, or a copy, may be sent to another institution under conditions determined by the Librarian.

(3) I agree that my thesis may be copied for Library use.

Signed

Date 1994

NAME AND ADDRESS DATE

ABSTRACT

The effect of differences in live weight (LW) on feed requirements of pregnant non-lactating cows was assessed during a 41-day grazing experiment. Thirty eight dry pregnant Friesian and Jersey cows (28 Friesian cows differing in live weight and 10 Jerseys) at similar stages of pregnancy (range 190 to 230 days pregnant) and averaging 5.8 years of age were used. The cows were grouped according to their initial LW in three size-groups, i.e. Big Friesians (BF; n=14, LW = 526 kg), Small Friesians (SF; n=14, LW = 415 kg) and Jerseys (J; n=10, LW = 362 kg). Within each size-group the cows were randomly allocated to one of two levels of daily herbage dry matter (DM) allowance (HA), calculated to meet either maintenance and pregnancy (i.e. HA of 7.7 to 11.0 kg DM/cow/day), or the gain of 1 kg of maternal live weight above maintenance and pregnancy (i.e. HA of 17.1 to 22.5 kg DM/cow/day).

The cows provided individual records of their daily liveweight gain (LWG, kg/cow), total liveweight gain (ΔLW) and total condition score change (ΔCS) achieved during the 41-day experimental period. Group average herbage dry matter intake (DMI) and herbage DM allowance were calculated for each treatment group from herbage mass (HM) assessed by cutting-washing-drying and weighing, and by means of two calibration equations, one for each level of feeding, relating HM to the average of 30 plate meter readings (PMR) taken every day before and after grazing. These two calibration equations were:

(1) for the *ad libitum* level of feeding:
HM (kg DM/ha) = 764.0 (*s.e.* 212.0) + 158.0 (*s.e.* 12.7) * PMR
(r = 0.98; CV = 24%; r.s.d. = 548 kg DM), and

(2) for the maintenance fed cows:
HM (kg DM/ha) = 171.0 (*s.e.* 3.5) * PMR
(r = 0.98; CV = 21.6%; r.s.d. = 442 kg DM).

The energy content of the herbage (MJ ME/kg DM) apparently grazed by the cows and their metabolizable energy intake (MEI) were calculated from the *in vitro* digestibility analyses of pasture samples plucked randomly from each of the grazing areas. Least squares means were calculated for group average herbage dry matter intake (DMI), herbage DM allowance (HA), metabolizable energy intake (MEI), and for the variables derived from the animals' performance (ΔLW, LWG, ΔCS) and differences between levels of feeding and size-groups were tested for significance using analysis of variance.

Differences in average live weight between the three size-groups were highly significant ($P<0.001$) throughout the experimental period (i.e. BF = 552 kg; SF = 442 kg; J = 377 kg). Heavier cows had: (1) significantly higher daily herbage DM allowances (BF, 16.7; SF, 14.4; J, 12.4 kg/cow/day); (2) higher daily DMI (BF, 10.2; SF, 8.6; J, 7.5 kg/cow/day); (3) higher MEI (BF, 117; SF, 100; J, 87 MJ/cow/day), and (4) lower stocking densities (BF, 240; SF, 262; J, 305 cows/ha/24 hours). However, when HA, DMI and MEI where expressed on a metabolic weight basis, none of these variables were significantly different between the three size-groups.

From the least squares means of LWG, ΔCS, DMI and MEI calculated for each treatment group, feed requirements for zero ΔCS or maintenance (i.e. ME_m) and feed requirements for ΔCS were calculated by means of linear regression analyses. The ME_m calculated pooling the three size-groups was 0.648 MJ ME/LW$^{0.75}$/day for zero ΔCS; and an average intake of 167 kg DM or 1986 MJ ME/cow above maintenance was required for the gain of one condition score unit/cow during the 41 days of experimental period, which was equivalent to a total liveweight change of 52.7 kg/cow. From these estimates it was calculated that cows heavier by 100 kg required an extra intake for maintenance of 10.5 MJ ME/cow/day or about 0.95 kg herbage dry matter intake/cow/day. The results of the present experiment were used to assess the effect of farming large-size cattle on the productive efficiency of pasture-based dairy systems.

ACKNOWLEDGEMENTS

I would like to thank my supervisors Dr. C. W. Holmes and Dr. G.F. Wilson for their advice and assistant with this project.

My special acknowledgement is given to Dr. C. W. Holmes for all the time and effort he devoted to help me with the experiment. For his invaluable help in the preparation and revision of the manuscript, and for his very nice and special way of encouraging me to get this project finished.

This work would not have been possible without the help of Mr. G. S. Purchas, who collected all the grass cutting data of the experiment; the skilful assistance of Messrs. M. and B. Chesterfield in animal husbandry practices; the help of the members of the Nutrition Laboratory of the Animal Science Department, who analyzed all the grass and faecal samples, and the help of Mr. D. Fountain in running the experiment. All their help was invaluable and very much appreciated.

I would also like to thank the staff members of the Animal Science Department for their help and assistance they gave me during these two years at Massey University. My special thanks to Dr. P. C. H. Morel for his advice and help in statistical analyses, and to Dr. S. W. Peterson for his valuable suggestions to improve the standard of presentation of the final document.

My thanks are also given to Dr. C. Matthew, of the Plant Science Department, for his help in some agronomic aspects of this project.

My special thanks are given to the New Zealand Ministry of external relations and Trade, for awarding me an scholarship to undertake a two-year master programme at Massey University, and for looking after me and my family all this time.

This New Zealand Experience was possible thanks to the Departamento de Zootecnia, Universidad Autónoma Chapingo, México, that proposed me as a candidate and allowed me the time required to undertake this master programme.

Finally, I would like to thank my wife Marcela and my son José Alberto for all their support and for making me so happy during all this time in New Zealand.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF PLATES

Page

LIST OF ABBREVIATIONS AND SYMBOLS

□	Group of Big Friesian cows fed at maintenance.
■	Group of Big Friesian cows fed *ad libitum*.
◊	Group of Small Friesian cows fed at maintenance.
♦	Group of Small Friesian cows fed *ad libitum*.
✡	Group of Jersey cows fed at maintenance.
★	Group of Jersey cows fed *ad libitum*.
>	Greater than.
*	Significant at $P<0.05$.
**	Significant at $P<0.01$.
***	Significant at $P<0.001$.
α	Constant term of simple or multiple regression equations.
4% FCM	4% Fat corrected milk yield (kg).
b	Linear regression coefficient.
BF	Big Friesian cows.
B_i	Partial regression coefficient.
BI	Breeding index.
ΔCS	Total condition score change (CS units/cow/41 days experiment).
ΔLW	Total liveweight change (kg/cow/41 days experiment).
C.V.	Coefficient of variation (%).
CF	Correction factor for the recovery rate of the indigestible marker.
CP	Crude protein (%).
Cr_2O_3	Chromium oxide.
CRC	Controlled release chromium capsule.
CSG	Condition score gain (CS units/cow/day).
D	Herbage digestibility (%).

d	days.
DCP	Digestible crude protein (%).
DE	Digestible energy (MJ/kg DM).
DM	Dry matter (%).
DMD	Dry matter digestibility (%).
DMI	Dry matter intake (kg/cow/day).
DOMD	Digestible organic matter expressed as a proportion of the DM.
e	Base of the natural logarithm.
EB	Energy balance.
EEI	Estimated energy intake (MJ/day).
ENE	Estimated net energy intake (Mcal/day).
EV_g	Energy value of the gain (MJ/kg).
FCS	Final condition score (CS units/cow).
FEI	Feed energy intake (MJ/day).
FHP	Fasting heat production (MJ/day).
FLW	Final live weight (kg/cow).
FM	Fasting metabolism (MJ/cow/day).
FO	Faecal output.
FPCM	Fat and protein corrected milk yield (kg).
FU_m	Feed units for maintenance.
FW	Fasted live weight (kg).
g	Grams.
GE	Gross energy.
GBF	Big Friesians fed *ad libitum*.
GFE	Gross feed efficiency (%).
GJer	Jersey cows fed ad libitum.
GSF	Small Friesians fed *ad libitum*.
h^2	Heritability (%).

ha	hectare.
HA	Herbage allowance (kg DM/cow/day).
HM	Herbage mass (kg DM/ha).
$HM^{f,e}$	Herbage mass measured in exclosure areas (kg DM/ha).
hr	Hour.
I	Intake.
ICS	Initial condition score (CS units/cow).
ILW	Initial live weight (kg/cow).
J	Jersey cows.
kg	kilogram.
k_g	Efficiency of utilization of ME for growth and fattening (%).
$k_{g(l)}$	Efficiency of utilization of ME for body tissue deposition when the cow is lactating (%).
k_l	Efficiency of utilization of ME for milk and tissue energy deposition (%).
km	Kilometre.
k_m	Efficiency of utilization of ME for maintenance (%).
k_p	Efficiency of utilization of ME for pregnancy (%).
k_{p1}	Efficiency of utilization of ME for the synthesis of uterine tissue and uterine contents (%).
k_{p2}	Efficiency of utilization of ME for oxidation due to pregnancy (%).
k_{p3}	Efficiency of utilization of ME for foetal maintenance and increased maternal fasting metabolism due to pregnancy (%).
LW	Live weight.
$LW^{0.75}$	Metabolic weight.
LWG	Liveweight gain (kg/cow/day).
M/D	Energy concentration of the pasture (MJ ME/kg DM).
MBF	Big Friesian cows fed at maintenance.
Mcal.	Megacalories.
ME	Metabolizable energy (MJ/kg DM).
MEA	Metabolizable energy allowance (MJ).
ME_g	Metabolizable energy intake for liveweight gain (MJ/day).

MEI	Metabolizable energy intake (MJ/cow/day).
MEI	Metabolizable energy intake (MJ).
ME_m	Metabolizable energy for maintenance (MJ/LW$^{0.75}$/day).
ME_p	Metabolizable energy for pregnancy (MJ/day).
ME_Y	Metabolizable energy used for milk yield.
MF	Milkfat (kg).
MJ	Megajoules.
MJer	Jersey cows fed at maintenance.
MLWG	Maternal liveweight gain (kg/cow/day).
MSF	Small Friesian cows fed at maintenance.
N	Nitrogen (%).
NE_g	Net energy of the gain made (MJ/kg liveweight gain).
NE_p	Net energy for pregnancy (MJ/day).
N_{p1}	Net energy stored in uterus and the uterine contents (MJ/day).
N_{p2}	Net energy lost as 'Heat increment of gestation' (MJ/day).
N_{p3}	Net energy for foetal maintenance and the increased maternal fasting metabolism due to pregnancy (MJ/day).
OMD	Organic matter digestibility (%).
P	Protein content of the organic matter (g/kg).
PHM	Pre-grazing herbage mass (kg DM/ha).
q	Metabolizability [i.e. (DE/ME)*100].
qL	Metabolizability determined at any level of feeding.
qm	Metabolizability determined at a maintenance level of feeding.
r	Repeatability (%).
r	Correlation coefficient.
r.s.d.	Residual standard deviation.
r^2	Coefficient of determination.
RHM	Post-grazing or residual herbage mass (kg DM/ha).
RR	Recovery rate of the indigestible marker in faeces (%).

S.D.	Standard Deviation.
s.e.	Standard error.
SF	Small Friesian cows.
t	Day of gestation.
t	tonne.
TDN	Total digestible nutrients (%).
TEG	Tissue energy gain (MJ/day).
TEL	Tissue energy loss (MJ/day).
W_0	The amount of component of tissues of pregnancy at day zero of gestation.
W_t	The amount of component of tissues of pregnancy at day t of gestation.
Y_E	Energy deposited as milk (MJ/day).
$Y_{E(C)}$	Energy deposited as milk, adjusted by positive (TEG) or negative (TEL) tissue energy change.

LIST OF APPENDICES

Chapter 1

Introduction

Dairy farming in New Zealand is one the most important agricultural-based industries. About 80% of the total milk annually produced in the country is exported as processed milk products, earning about 21% of the export receipts. This strong dependence on the export market requires a competitive dairy industry based on low-cost dairying systems. The New Zealand low-cost dairying system is the result of a temperate climate with mild winters that allows high quality temperate pastures to grow all year round, the almost exclusive use of grazed pastures as the main source of feed, and the high number of cows managed per labour unit (Bryant, 1990).

The dependence on grazed pasture determines that milk production is seasonal, and about 95% of the 14,700 dairy herds in the country calve their cows in late winter-early spring (Maughan & Holmes, 1992). The aims of such a seasonal system are to match as closely as possible cow requirements with pasture growth, and also to 'harvest' through the grazing cow as much of the pasture grown per unit area as possible. By doing this, the dairy farmer aims to achieve, at the lowest possible cost, the highest output per unit area of land and the highest output per labour unit.

This very simple but successful philosophy to achieve high output per unit area of farmland, was first suggested by McMeekan more than 35 years ago (McMeekan, 1956). He stated that, 'for pasture-based dairying systems, the main determinants of high output per hectare are pasture productivity, stocking rate and cow quality'. The components of pasture productivity are the total amount of dry matter grown per unit area, its content of energy and protein, and its seasonal pattern of growth, that should match as closely as possible the seasonal pattern of feed requirements of the dairy herd. Stocking rate or the number of cows/ha of grazed pasture/year has its main influence on how much of the feed grown is actually harvested, and as such is a powerful management tool to increase overall farm productivity. Cow quality is mainly concerned with the efficiency with which the dairy cow transforms the feed eaten into milk. For the New Zealand dairy system the main determinants of cow quality are the cow's genetic merit for the production of milk and milk components, and its body size (L.I.C. 1991). Cow body size is a common component of both stocking rate and individual cow efficiency, and as such it has a direct effect on overall farm productivity.

Cow body size, and particularly its live weight, can directly affect cow feed efficiency through the amount of feed directed to meet maintenance (Wallace, 1956 b; Holmes, 1993). Larger cows tend to produce more milk because live weight is positively correlated both genetically (Ahlborn & Dempfle, 1992; Hooven *et al.*, 1968) and phenotypically (Hooven *et al.*, 1968; Sieber *et al.*, 1988) with milk yield. However, due to their higher live weight, larger cows also need more feed to meet their maintenance requirements. Thus selecting solely on the basis of high milk yield may bring about a correlated increase in the cow's average live weight and, through this, to the production of less feed-efficient cows (Yerex *et al.*, 1988).

For the New Zealand pasture-based dairy production system, increased cow live weight would be associated with a negative effect on overall farm profitability, mainly due to a reduction in the stocking rate and the number of animals available for sale (L.I.C., 1991). Thus, assessing the extent to which increases in cow live weight affect the amount of feed directed to meet maintenance is an important issue for such pasture-based dairy system. The experiment reported here had the main objective of assessing the effect of differences in live weight on feed requirements of pregnant, non-lactating, grazing dairy cows. Additionally, the information generated in the experiment was also used to assess the effect of an extra 100 kg live weight on cow feed requirements for maintenance, average farm stocking rate, and on the amount of extra pasture required on farms stocked with heavier cows.

Chapter 2

Literature review

2.1. The energy content of pasture.

The grazing cow uses the nutrients from the feed to meet its requirements for maintenance of body functions, the construction of body tissues, the synthesis of milk and for conversion to mechanical energy used for walking and other activities related to the grazing situation. All these functions require energy, and when the requirements of energy are met it is usually assumed that other needs (protein, minerals and vitamins) are also met (Geenty & Rattray, 1987; Holmes & Wilson, 1987).

The gross energy contents of many different forages are similar, averaging about 18.4 MJ/kg DM (C.S.I.R.O., 1990). Some of this energy is lost as faeces, and the remaining digestible energy (DE), which is proportional to the digestibility of the herbage consumed, is converted into metabolizable energy (ME) after an average loss of about 18 to 19% of DE as urine and methane (Holmes & Wilson, 1987). Thus, the energy value of forage feeds can be expressed by their ability to supply usable energy for the different body functions. This is often called the amount of megajoules (MJ) of metabolizable energy (ME) per kg of dry matter (DM), measured at a level of feeding equivalent to maintenance, and is designated as the M/D value (Geenty & Rattray, 1987). This energy value, however, does not consider the functions for which energy is used (i.e. lactation, pregnancy, growth and fattening). It is calculated as,

$$\text{ME (MJ/kg DM)} = \text{Gross energy} - (\text{Faeces energy} + \text{Urine energy} + \text{Methane energy}) \quad .. \; 2.1$$

Describing the energy value of each feed or diet by a single ME value, i.e. M/D at maintenance, might lead to inaccuracies when these figures are used in calculating the maintenance requirements of cows fed at levels of feeding well above maintenance

(A.R.C., 1980; Holmes & Wilson, 1987). This is because higher levels of feeding often lead to higher rumen outputs, higher heat production, a decrease in apparent digestibility and a reduction in methane production (A.R.C., 1980; Trigg *et al.*, 1980; Grainger *et al.*, 1985).

2.2. Some conversion factors to assess the energy content of pasture.

Throughout the development of this review it was necessary to use some conversion factors to obtain the M/D value of the feed and to express the information from the literature on a common basis as much as possible. The following section more fully describes some of these conversion factors.

The M/D value of the feed divided by its gross energy content constitutes what is referred to as the **Metabolizability (q)** of the gross energy of the feed. Metabolizability values calculated at maintenance are denoted as **qm**, and as **qL** at any feeding level (ARC, 1980). Metabolizability values can be derived from organic matter digestibility (OMD, %) values by using the following equation (I.N.R.A., 1978; cited by Ketelaars & Tolkamp, 1992):

$$\mathbf{q} = 0.0091*\mathrm{OMD} - 0.086 \quad (r^2 = 0.995, \mathrm{r.s.d.} = 0.004) \; .\;.\;.\;. \; 2.2$$

A common situation, however, is that of having only dry matter digestibility (DMD, %) values. Under these circumstances, OMD(%) can be calculated from the following equation (Ketelaars & Tolkamp, 1992):

$$\mathrm{OMD}(\%)=1.01*\mathrm{DMD}+1.69 \qquad (r^2 = 0.98, \mathrm{r.s.d.}=1.06) \; .\;.\;.\;. \; 2.3$$

Metabolizability values can be converted to metabolizable energy concentrations (i.e. the M/D values of the feed) by multiplying them by 18.4 (A.R.C, 1980; C.S.I.R.O., 1990), i.e.

$$\mathrm{ME\ (MJ/kg\ DM)} = 18.4*\mathrm{q} \; .\;.\;.\;.\;. \; 2.4$$

Geenty and Rattray (1987) made use of an alternative set of equations given by MAFF (1984) to estimate the M/D value of pastures. This approach uses the usual DMD(%) and OMD(%) values of the pasture and also a third parameter denoted as Organic-matter digestibility of dry-matter (DOMD), which is calculated as:

$$DOMD(\%) = \frac{(\text{Feed OM} - \text{Faeces OM})}{\text{Feed DM}} \quad \ldots\ldots 2.5$$

If DOMD is not known, it can be calculated from either of the following two equations:

$$DOMD = 0.98*DMD - 4.8 \quad \ldots\ldots 2.6$$

$$DOMD = 0.92*OMD - 1.2 \quad \ldots\ldots 2.7$$

And the M/D value of the pasture can then be calculated as:

$$M/D = 0.16\ DOMD \quad \ldots\ldots 2.8$$

Table 2.1 summarizes some estimations of the energy content of the feed related to some measurements of herbage digestibility. The averages obtained were equivalent to 10.8 MJ ME/kg herbage dry matter (DM), 15.2 MJ ME/kg herbage digestible dry matter (DDM), and a fairly representative average of 15.7 MJ ME/kg digestible organic matter (DOM).

Table 2.1 . Some estimates of the concentration of metabolizable energy (MJ/kg) in the feed as reported by several authors in the literature.

Source	Unit of reference and type of pasture	MJ ME
Blaxter & Graham, 1956	1 kg DOM[1] of chopped dried grass.	15.0
Jagusch & Coop, 1971	1 kg DOM of ryegrass-white clover pasture	15.5
	1 kg DM[2] of ryegrass-white clover pasture	10.5
Joyce, 1971	1 kg DM of ryegrass-white clover pasture.	10.9
	1 kg DOM of ryegrass-white clover pasture.	16.7
Joyce *et al.*, 1975	1 kg DDM[3] of ryegrass-white clover pasture.	15.2
	1 kg DOM of ryegrass-white clover pasture.	15.9
Hutton, 1963	1 kg DOM of ryegrass-white clover pasture.	15.9
Hutton, 1971	1 kg DM of ryegrass-white clover pasture.	10.9
Lambourne & Reardon, 1962	1 kg DOM of *Phalaris tuberosa*-white clover	16.7
Langlands *et al.*, 1963	1 kg DOM of perennial ryegrass pasture.	15.2
Geenty and Rattray, 1987	1 kg DOM of ryegrass-white clover pasture	15.6
Van Es, 1978	(i) 1 kg DOM of forages with low protein content (i.e. DOM/DCP[4] > 7), such as green fodders, conserved green fodders but not: roots, tubers, straw or chaff.	15.1
	(ii) 1 kg DOM maize silage	15.5

	MJ ME/kg DOM[5]	MJ ME/kg DM	MJ ME/kg DDM
Mean ± Standard Deviation (S.D.)[6]	15.7±0.63 (9)	10.8±0.23 (3)	15.2 (1)
Coefficient of variation (C.V., %)	4.0	9.2	

[1] DOM = Digestible Organic Matter;
[2] DM = Dry Matter;
[3] DDM=Digestible Dry Matter;
[4] DCP= Digestible Crude Protein;
[5] Without considering in the calculation the figure given for maize silage;
[6] In brackets the number of observations to calculate the mean.

As it would be expected the values calculated in Table 2.1 may change according to season of the year and botanical composition of the pasture; the estimates, however, appear to be very consistent and can be taken as representatives of the energetic content of the pasture. These averages can then be used along with an estimate of the daily herbage intake to calculate the intake of ME. The following section describes some of the methods used to assess the daily herbage intake by free grazing ruminants.

2.3. Estimation of herbage intake by grazing cattle.

The herbage intake of grazing ruminants can be assessed by using indigestible markers like chromium oxide (Cr_2O_3) to assess the daily faecal output of individual animals (Parker *et al.*, 1989), or by assessing the amount of herbage mass (HM) (kg DM/ha) present before and after grazing, either by means of the sward technique (Meijs *et al.*, 1982) or by means of indirect methods of pasture assessment (Holmes, 1974; Stockdale & Kelly, 1984; Vickery *et al.*, 1980; Vickery & Nicol, 1982). Some details of these two methods are reviewed in the following section.

2.3.1. Herbage intake assessed from faecal output.

The estimation of individual herbage intake by free grazing cows can be accomplished by assessing their daily faecal output (FO). This can be achieved by measuring the total daily FO by the animal or by measuring the concentration of an indigestible marker in the faeces, and then calculating the feed intake from FO and an estimate of the digestibility of the herbage eaten. Herbage intake (I) is then calculated by manipulating the digestibility relationship as shown below (Le Du & Penning, 1982):

$$\text{Herbage digestibility (D)} = \frac{\text{Intake (I) - Faecal output (FO)}}{\text{Intake (I)}} \quad \ldots\ldots 2.9$$

$$I = \frac{FO}{(1 - D)} \quad \ldots\ldots 2.10$$

From equation 2.10, it is clear that an accurate estimation of herbage intake will depend on accurate estimation of FO and D. An error in estimating FO leads to an equivalent error in I, but errors in the determination of D lead to proportionally larger errors in (1-D) and consequently in intake (Parker *et al.,* 1990). Some of the methods to assess FO and D are described below:

2.3.1.1. Methods to estimate daily faecal output.

i) Total faeces collection.

Total faeces collection can be measured by harnessing animals and fitting them with bags to collect all the faeces voided. This method gives an unbiased estimate of total faeces produced provided none are lost. The simplicity of this method is often overridden by the high requirements of labour and the possible adverse effect of poorly designed harnesses on the animal's grazing behaviour (Le Du & Penning, 1982). A less labour demanding method consists on assessing the daily FO of animal dosed with an indigestible marker, as described below:

ii) Use of indigestible markers.

The use of faecal markers to predict intake relies on the estimation of faecal output and on assumptions about the digestibility of the feed consumed (Parker *et al.*, 1992). Daily faecal output of free grazing animals can be estimated by dosing them with a known amount of an indigestible marker and assessing its concentration in the faeces voided. Although there are available several external markers used to estimate the daily faecal output of free grazing ruminants, the ideal marker to estimate it should have the following characteristics (Raymond & Minson, 1955):

i) It should be quantitatively recovered in the faeces (i.e. neither absorbed nor abnormally retained in the digestive tract);
ii) It should be non-toxic;
iii) It should be readily analyzed by physical or chemical methods;
iv) It should be present only in small amounts in the original diet.

Chromium oxide (Cr_2O_3) has been used extensively as the preferred external marker to estimate daily FO. It can be administered by means of different carriers: (1) in gelatin capsules (or pills) containing 1 g or 10 g Cr_2O_3 in an oil base (Le Du & Penning, 1982); (2) in paper impregnated with known quantities of Cr_2O_3 (Corbett *et al.*, 1958); (3) incorporated into a known quantity of feed (usually concentrate) individually offered to the animal (Greenhalgh *et al.*, 1966), and (4) in controlled-release devices, such as controlled release capsules (CRC) (Parker *et al.*,1989; Brandyberry *et al.*,1991).

When Cr_2O_3 is administered in discrete doses as in the first three options listed above, its concentration in the faeces may show considerable diurnal fluctuations (Lee *et al.*, 1990). This has lead to the convention of allowing a preliminary dosing period of 7 days to ensure a steady state of the marker in the rumen before faecal sampling (Le Du & Penning, 1982), and dosing of the animals at approximately 8 and 16-hour intervals and faeces samples taken at the same time over at least a 5-day period (Lambourne, 1957). Daily faecal output can then be estimated from the following relationship (Le Du & Penning, 1982):

$$\text{FO (g/day)} = \frac{\text{Weight of marker given (g/day)} \times \text{RR}}{\text{Mean concentration of marker in faeces (g /g faeces DM)}} \quad \text{2.11}$$

where RR is the recovery rate of the marker, which is calculated as:

$$\text{RR (\%)} = \frac{\text{Total weight of the marker excreted in faeces (g)}}{\text{Total weight of marker given (g)}} \times \frac{100}{1} \quad \text{2.12}$$

From experiments reported in the literature which included cattle and sheep, and that used chromium oxide (Cr_2O_3) as the indigestible marker, different types of feed, types of carriers for Cr_2O_3, preliminary dosing periods and frequencies of dosing and sampling, Le Du & Penning (1982) found the mean RR to be 96.5% (S.D. ± 5.6), which is similar to the 95-98% range in Cr_2O_3 recovery rates suggested by Parker *et al* (1990). From these results, and assuming that 100% of the chromium administered to the animal is recovered, a recovery factor of 1.042 is therefore suggested (Parker *et al.,* 1990).

Controlled-release capsules (CRC), which provide for continuous and uniform delivery of the indigestible marker Cr_2O_3 into the rumen, can minimise the excessive diurnal variation of faecal Cr_2O_3 excretion associated with once-a-day or twice-a-day pulse dosing procedures (Brandyberry *et al.*,1991; Parker *et al.*, 1989). CRC also gives greater flexibility for time sampling, reducing considerably the requirements of labour (Lee *et al.*, 1992; Parker *et al.*, 1990). When controlled-release devices such as CRC are used to deliver Cr_2O_3 into the animal's rumen, the marker reaches a steady state 5-8 days after its administration (Parker *et al.*, 1990). However, for practical purposes it is suggested that collection of faecal samples for intake determinations should start after the 8th day of the CRC insertion (Parker *et al.*, 1989). FO is then calculated from the following equation (Parker *et al.*, 1990):

$$FO = \frac{R}{C \times CF} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 2.13$$

where FO is faecal dry matter output (g/day); R is the expected daily release rate of chromium from the CRC (g Cr/day), C is the concentration of chromium in faecal dry matter (g Cr/g faeces DM), and CF is a recovery correction factor which, as stated before, is taken to be 1.042 for controlled release capsules (Parker *et al.*, 1990).

2.3.1.2. Accuracy of Cr_2O_3 in estimating faecal output.

Le Du & Penning (1982) reviewed experiments from the literature where total faecal output, estimated from administering Cr_2O_3 via procedures other than the use of controlled release capsules (i.e. in gelatin capsules, paper impregnated with chromium, chromium mixed with the supplement, etc.), was compared with the faecal output actually measured; they found the Cr_2O_3 faecal output estimate to be 96.1% (S.D.±6.2) of that actually measured. They concluded that using Cr_2O_3 as an indigestible marker will on average estimate faecal output to within 6%. Carruthers & Bryant (1983) administered twice a day 10 g Cr_2O_3 in a gelatin capsule to lactating dairy cows fed fresh cut pasture indoors, and sampled their faeces at the time of dosing. They found that FO calculated from the concentration of Cr_2O_3 in faeces overestimated actual intake by about 14%.

Reports regarding the accuracy of faecal output estimates derived via controlled-release Cr_2O_3 capsules (CRC) have been contradictory. Reasonably accurate estimates of faecal output were obtained when Cr_2O_3 was administered via CRC (Barlow *et al.*, 1988; Laby *et al.*, 1984; Momont *et al.*, 1980). However, Cr_2O_3 administered in this way was found to overestimate actual faecal output by sheep (Buntinx *et al.*, 1990) and beef steers (Brandyberry *et al.*, 1991). In the latter study, Brandyberry *et al.* (1991) compared different methods of continuous marker administration and different external markers for estimating FO of fistulated crossbred steers fed near maintenance. Faecal output, estimated from the continuous administration of cobalt (Co-EDTA) or Ytterbium ($YbCl_3$) using a portable peristaltic-infusion pump, was not different from total faecal collection. In contrast, FO estimates obtained from the Cr_2O_3 delivered via CRC were greater than those obtained by total faecal collection.

2.3.1.3. Estimation of herbage digestibility.

Direct estimation of herbage digestibility *in vivo* is not possible with free grazing ruminants and, as a result, a number of indirect methods have been developed. From the large number of methods available, the *in vitro* procedures are, at the present time, the most accurate and the most widely used. The major difficulty associated with each of these procedures, however, is the initial selection of the herbage and the accuracy with which it represents that actually consumed by the grazing animal (Le Du & Penning, 1982). The success of the *in vitro* techniques rests, therefore, upon the adequacy of the herbage sampling methods. Herbage samples can be collected either by hand plucking or by the collection of extrusa from oesophageal fistulated animals. Both procedures require the collection of samples at a number of points through the grazing period to ensure the material collected is representative of that being eaten (Le Du & Penning, 1982).

2.3.2. Herbage Intake assessed by sward methods.

Herbage intake assessed by measuring the sward can be accomplished by using the following general relationship (Meijs *et al.,* 1982):

Herbage intake = herbage offered (PHM) - herbage refused (RHM) 2.14

This relationship can be assessed by measuring the following variables:

(a) the amount of herbage dry matter (DM) yield per unit area before grazing (kg/ha) or pre-grazing herbage mass (PHM);

(b) the amount of herbage DM remaining immediately after grazing (kg/ha)or post-grazing herbage mass (RHM), and

(c) the amount of herbage DM yield per unit area in areas protected from grazing at the end of a grazing period ($HM^{f,e}$).

The latter measurement ($HM^{f,e}$) is taken to correct for the growth taking place during the grazing period (if it is more than one day). Individual intakes can only be assessed when animals are kept in individual plots. However, to obtain a normal pattern of grazing behaviour and to reduce the labour requirement, intake studies are usually carried out with groups of animals (Le Du & Penning, 1982). An additional advantage of this method is that without extra labour requirement, it also provides information on: (1) herbage mass (i.e. total mass of herbage per unit area of ground); (2) herbage allowance (i.e. the weight of herbage per unit of animal live weight), and (3) the efficiency of grazing (i.e. herbage consumed expressed as a proportion of the herbage accumulated).

Pre- and post-grazing herbage mass can be measured by using either direct or indirect methods. The direct method requires cutting-washing-drying-weighing of a known area of the pasture. The indirect methods include: (1) eye estimation, (2) sward height and/or density measurements (Meijs *et al.,* 1982), and (3) the measure of one or more non-vegetative attributes of the plant, such as capacitance (Vickery *et al.*, 1980; Vickery & Nicol, 1982). These methods measure one or more attributes of the sward (eg. height, density, etc.) in the grazing area before and after grazing and predict herbage mass with a regression equation. They also require some sample cuts to correlate with, and to obtain the appropriate calibration equation. A brief description of these methods is given below (Meijs *et al.,* 1982):

2.3.2.1. Measurements of sward height and density.

Herbage mass is estimated from the separate measurements of height and/or density after having first calibrated these parameters against actual herbage mass by cutting and weighing. Height is normally defined as maximum or mean height and is measured by a ruler. Density is defined as percentage of ground cover and is estimated by point quadrat or visual appraisal (Meijs *et al.,* 1982). Alternatively, a rising plate meter can be used which provides an integrated measurement of height and density, and in this case a calibration equation is also needed (Holmes, 1974; Stockdale & Kelly, 1984; Earle & McGowan, 1979).

2.3.2.2. Measurements of non-vegetative attributes of the sward.

Herbage mass can be estimated from non-vegetative plant attributes such as capacitance, after having first calibrated the respective parameter with actual herbage mass by cutting, washing, drying and weighing. The meter (pasture probe) measures the change in capacitance caused by introducing vegetation into a capacitance system (Vickery *et al.,* 1980; Vickery & Nicol, 1982). Ideally this change in capacitance should be proportional to herbage mass.

2.4. Feed requirements of dairy cows.

The following section reviews the information on the feed requirements of dairy cattle obtained by means of energy balances (EB), stall feeding trials, and grazing experiments. Feed requirements are expressed as MJ ME/LW$^{0.75}$ and are for maintenance, liveweight gain and pregnancy.

2.4.1. Maintenance requirements.

Maintenance is the state of the animal in which there is neither a net gain nor a loss of body energy in its tissues (or milk, or the products of conception). At an ME intake of maintenance (ME_m), all ME is oxidised to support essential body functions and ME_m equals heat production (Geenty & Rattray, 1987; Holmes & Wilson, 1987). Maintenance requirements of energy are estimates of the amount of ME required to achieve such an equilibrium.

2.4.1.1. ME_m assessed by energy balance trials (calorimetry).

The maintenance requirement of a ruminant animal for metabolisable energy can be estimated by means of energy balance (EB) trials either using linear regression of EB on MEI (Moe *et al.*, 1970; Tyrrell *et al.*, 1970; Grainger *et al.*, 1985) or using information on Fasting metabolism (FM) and the efficiency of utilization of dietary ME for maintenance purposes (k_m) (A.R.C., 1980).

A. ME_m estimated from fasting metabolism data.

This is the approach followed in the A.R.C. (1980) publication. It consists of using both an estimate of the FHP of an animal fasted and kept in a thermo-neutral environment in a calorimeter, which is taken as the net energy required for maintenance, and an estimate of k_m. Taking this information together, metabolizable energy for maintenance (ME_m) can then be calculated as:

$$ME_m = \frac{FHP}{k_m} \quad \ldots\ldots \quad 2.15$$

i) Fasting metabolism.

Fasting metabolism corresponds to the amount of heat produced (MJ/day) by a fasted animal kept in standard conditions. It is composed of the fasting heat production (FHP), which represents the minimum energy required (MJ/day) for maintaining essential body functions. These include service functions like circulation, excretion, respiration, etc., and those related to cell maintenance like ion transport and protein and lipid turnover (A.R.C., 1980; C.S.I.R.O., 1990; Holmes & Wilson, 1987). For practical purposes, fasting metabolism for cattle can be derived from the animals live weight, by means of the following equation (A.R.C., 1980):

$$FM = 0.53\ FW^{0.67} \quad . . . . . .2.16$$

where FM is fasting metabolism (MJ/day) and FW is the animal's fasted live weight (kg). Following A.R.C. (1980), FW is calculated from live weight (LW) as:

$$FW = LW/1.053 \quad . . . . . .2.17$$

MAFF (1984) relates FM to the animal's live weight by means of the following general equation for growing cattle:

$$FM = 5.67 + 0.061\ LW \quad . . . . .2.18$$

In addition, this equation normally requires an extra allowance of about 10% of the fasting metabolism to allow for physical activity. In practice however, fasting metabolism, and therefore the ME required for maintenance, is affected by length of fast, previous plane of nutrition, season, age, light, species, breed, environmental temperature, sex, physiological state and body size (Flatt & Coppock, 1965). Although larger animals have higher fasting metabolism and therefore higher maintenance requirements, the relationship is not linear, and it is conventional to express fasting metabolism in terms of the animal's metabolic weight, i.e. live weight raised to the 0.75 power (Kleiber, 1961, 1965). Expressed in this way, fasting metabolism does increase in direct proportion to metabolic weight (Geenty & Rattray, 1987).

ii) Efficiency of utilization of ME_m (k_m).

The efficiency of utilization of ME for maintenance (k_m) can be regarded as the efficiency with which nutrients from the feed replace body fat and protein as a source of energy for maintenance. This efficiency term is affected by factors associated with different attributes of the feed (Holmes & Wilson, 1987) and by the level of feeding at which k_m is assessed (A.R.C., 1980). For instance, Factors like the digestibility and nitrogen content of the feed and the amount and relative proportion of end products of rumen digestion (i.e. volatile fatty acids, microbial protein, undegraded protein) directly affect: (a) the energy costs associated with the muscular work required for the propulsion of food through the gastrointestinal tract; (b) the efficiency of energy capture from different patterns of absorbed nutrients, and (c) the energy costs associated with protein breakdown and excretion (Holmes & Wilson, 1987).

In practice, k_m can be calculated from attributes of the feed by means of the equations summarized in Table 2.2. As a way of comparing these equations for predicting the k_m value of pastures, values of dry matter digestibility of 80% (Ulyatt, 1981), crude protein of 24% (Holmes & Wilson, 1987), and organic matter content of the dry matter of 92% (Blaxter & Graham, 1956; Cox *et al.*, 1956; Holmes & Jones, 1965) were assumed for a typical ryegrass-white clover spring pasture. The corresponding values of digestible organic matter (DOM, %), digestible crude protein (DCP, %) and metabolizability (q) were obtained by using the appropriate equation (see Section 2.2). The equations produced very similar results and all the values grouped around a mean k_m value of 0.73±0.02, which is virtually the same as that obtained by applying the equation given by A.R.C. (1980). The equation given by Tolkamp & Ketelaars (1992) yielded the lowest value.

Table 2.2. Generalised Equations for predicting k_m from attributes of the feed.

Source	Equation predicting k_m	Predicted k_m value	Equation number
A.R.C., 1965	$k_m = 0.30*q + 0.546$	0.745	2.19
A.R.C., 1980	$k_m = 0.35*q + 0.503$	0.735	2.20
Blaxter, 1989[1]	$k_m = 0.947 - 0.00010(P/q) - 0.128/q$	0.715	2.21
C.S.I.R.O., 1990	$k_m = 0.02*M/D + 0.500$	0.744	2.22
Tolkamp & Ketelaars, 1992	$k_m = 0.207*q + 0.560$	0.697	2.23
Van Es, 1975	$k_m = 0.287*q + 0.554$	0.744	2.24
Mean ± S.D.		0.73±0.02	
C.V. (%)		2.7	

[1] P = protein content of the organic matter (g/kg).

From the k_m values predicted by these equations, it is clear that efficiency of utilization of metabolizable energy for maintenance (k_m) is relatively high. Holmes & Wilson (1987) give a k_m value of 0.73 as a representative average, which is consistent with both the average calculated from Table 2.2 and that calculated by applying the equation given by A.R.C. (1980). With the exception of Blaxter's equation (Blaxter, 1989), none of the equations given in Table 2.2 for predicting the k_m value of the feed considers the different energy costs associated with differing values of crude protein in the diet. In this respect, at least for sheep and beef cattle, there is evidence (Geenty & Rattray, 1987) that their maintenance requirements are increased by about 20% when they are fed on high crude protein diets (20-30% v 10-12% CP). This increase is apparently because dietary protein is less efficiently used for energy production but also due to the high energy cost of converting excess protein to urea excreted in the urine.

iii) Calculated ME_m for dry cows of different live weight.

Table 2.3 compares equations 2.16 and 2.18 given above to estimate the fasting metabolism from live weight data. Dry pregnant cows differing in live weight by about 100 kg were assumed for this example. Both the A.R.C. (1980) and the MAFF (1984) equations yield higher FM as the cow's live weight increases. The calculated ME_m increased as the cow's live weight increased only when the MAFF (1984) equation was used, and exactly the contrary occurred when the A.R.C. (1980) equation was used to derive the estimated FM.

Table 2.3. ME_m for dry pregnant cows of different body size (live weight) calculated using fasting metabolism equations.

Cows' live weight (kg)	Equation used to estimate fasting metabolism[1] (1) $FM=5.67+0.061LW$	(2) $FM=0.53FW^{0.67}$	Estimated ME_m ($MJ/LW^{0.75}/day$) assuming a k_m = 0.73. (1)	(2)
	Estimated fasting metabolism (MJ/cow/day)			
377	28.7	27.3	0.459	0.453
442	32.6	30.3	0.464	0.448
552	39.3	35.2	0.473	0.440

[1] The calculations do not include an allowance increase due to activity.

B. ME_m estimated by regression analyses.

An estimate of the ME_m can also be calculated by using either simple or multiple linear regression analyses of metabolizable energy intake (MEI) on energy balance (EB), or by the inverse regression (Moe *et al*., 1970). By using this approach, total dietary energy intake (MEI) is expressed as MJ $ME/LW^{0.75}/day$, energy balance (EB) is given as milk energy yield (Y_E) (if the cow is lactating) plus body tissue energy change [positive (TEG) or negative (TEL)], and metabolic weight is given as body weight in kilograms raised to the 0.75 power ($LW^{0.75}$). The model equations describing the relationship between EB and MEI, and metabolic weight as an scaling factor are developed as follows: If ME intake (MEI, MJ $ME/LW^{0.75}/day$) and energy balance (EB, MJ $ME/LW^{0.75}/day$) are known, the relationship between the two variables can be expressed by the following equations (A.R.C., 1980; Moe *et al.,* 1970):

$$EB/LW^{0.75} = b_1\ (MEI/LW^{0.75}) - a \quad \ldots\ldots\ 2.25$$

$$MEI/LW^{0.75} = (1/b_1)\ (EB/LW^{0.75}) + \alpha \quad \ldots\ldots\ 2.26$$

$$MEI/LW^{0.75} = (1/b_1)\ EB + b_2 LW^{0.75} \quad \ldots\ldots\ 2.27$$

where b_1 is the efficiency with which dietary ME is used for body energy synthesis (when the cow is non-lactating) or for milk and tissue energy synthesis (when the cow is lactating); a and α are intercepts; and maintenance (i.e. when EB = 0) is given by a/b_1, α or b_2 in equations 2.25, 2.26 and 2.27, respectively. Whichever equation is used, the values obtained for b_1 and the maintenance requirement of metabolizable energy by using these three regression models will agree only if the variable being used as the independent variable is free of error (A.R.C., 1980). However, this is unlikely to happen due to the very many sources of error involved in the determination of both energy retention and metabolizable energy intake. Nevertheless, regression analysis to partition the intake of energy into the different body functions seems to be the most appropriate (Moe *et al.*, 1972).

I) ME_m for non-lactating cows.

Table 2.4 summarizes some estimates of ME (MJ) required for maintenance of non-lactating dairy cows obtained in experiments of energy balance trials and analyzed by means of regression analyses. On average about 0.597 MJ ME/kg $LW^{0.75}$ were required to meet the maintenance requirements of non-lactating cows. Both the mean and the variability of the sample were greatly increased by the high estimates reported by Grainger *et al.* (1985).

These higher estimates might be the result of fresh pasture with high crude protein content being the sole fed (Geenty & Rattray, 1987). Without considering these values the average maintenance requirement of non-lactating cows was about 0.459 MJ ME/$LW^{0.75}$/day, which is comparable to those presented in Table 2.3 obtained using the equations to derive fasting metabolism and k_m.

Table 2.4. ME_m (MJ ME/$LW^{0.75}$/day) for non-lactating dairy cows obtained by means of energy balance trials and using regression analyses.

2

Reference	Experimental conditions and type of animal	(MJ ME/$LW^{0.75}$/d)
Grainger *et al*., 1985	Pregnant-dry- Friesian cows fed on fresh cut ryegrass-clover pasture. Regression of EB/$LW^{0.75}$ on MEI/$LW^{0.75}$, EB adjusted by pregnancy:	
	- High and low breeding index cows, 210-d pregnant. Energy required to maintain maternal live weight.	0.790
	- High and low breeding index cows, 230-d pregnant. Energy required to maintain maternal live weight.	0.800
	- High breeding index Friesian cows. Energy required for zero change in condition score.	0.780
	- Low breeding index Friesian cows. Energy required for zero change in condition score.	0.710
Grainger *et al*., 1978	Stall-fed dry pregnant cows (5th month of pregnancy), zero change in cow condition score. Regression of EB/$LW^{0.75}$ on MEI/$LW^{0.75}$.	0.490
Moe *et al*., 1970	Energy balance trial of Holstein cows fed on concentrate:hay diets. Hay (alfalfa, bromegrass, orchardgrass or timothy) from 20-30% of the ration. Maternal live weight change adjusted for pregnancy. Regression of MEI on $LW^{0.75}$ and body TEG:	
	- Dry cows losing weight.	0.428
	- Dry cows gaining weight.	0.418
	- Dry cows either gaining or losing weight.	0.420
Tyrrell *et al*., 1970	EB trial with dry Holstein cows. Regression of EB on MEI $LW^{0.75}$, positive excess nitrogen (g/$LW^{0.75}$/day), and digestible energy content of the ration (Mcal./kg DM).	0.542

Mean ± S.D.[3]	0.597±0.17 (9)[1]	0.459±0.05 (5)[2]
C.V. (%)	28.0	11.8

[1] Considering data given by Grainger *et al.*, 1985;
[2] Without considering the data of Grainger *et al.*, 1985;
[3] In brackets the number of observations used to calculate the mean.

II) ME_m for lactating cows.

A great deal of information on the maintenance requirements of dairy cattle assessed by means of EB trials has been developed by the USA Department of Agriculture (Moe *et al.*, 1970; Moe & Flatt, 1969; Tyrrell & Moe, 1971). Table 2.5 summarizes some of this information along with some other estimates obtained under European conditions

(Bickel & Landis, 1978; Van Es, 1974; Van Es, 1975). The estimates obtained covered a wide range of conditions in regard to cow age, stage of pregnancy, live weight, stage of lactation, level of milk production and diet composition, and can be regarded as a representative sample for calculating the ME_m of lactating cows. From this sample of values, on average lactating cows required about 0.525 MJ ME/$LW^{0.75}$/day to meet their maintenance requirements.

Table 2.5. ME_m (MJ ME/$LW^{0.75}$/day) for lactating dairy cows obtained by means of EB trials and using regression analyses.

Reference	Experimental conditions and type of animal	MJ ME/ $LW^{0.75}$/day
Bickel & Landis,1978	Lactating cows fed at 2.38 times maintenance. Derivation of feeding standards.	0.488
Flatt *et al.*, 1969a	EB trial of lactating Holstein cows (0 to 251 days pregnant, 436 to 509 kg LW, 24-52 months of age). Regression of EB/$LW^{0.75}$ on MEI/$LW^{0.75}$. Cows fed on:	
	- Purified diets (15% crude protein, and q = 83%).	0.508
	- Natural ration (13.4% crude protein, and q = 84%).	0.596
Flatt *et al.*, 1969b	EB trial, lactating Holstein cows (460-870 kg LW), fed on alfalfa: concentrate, proportions varying from 20:80 to 60:40:	
	- Regression of EB/$LW^{0.75}$ on MEI/$LW^{0.75}$.	0.590
	- Regression of MEI/$LW^{0.75}$ on EB/$LW^{0.75}$.	0.621
Moe & Flatt, 1969	EB trials of lactating, non-pregnant Holstein cows losing LW:	
	- Regression of MEI /$LW^{0.75}$ on Y_E/$LW^{0.75}$ and tissue EB/$LW^{0.75}$.	0.573
	- Regression of Y_E/$LW^{0.75}$ on MEI/$LW^{0.75}$ and tissue EB/$LW^{0.75}$.	0.528
Moe *et al.*, 1970	EB trial with lactating Holstein cows fed on concentrate:hay diets. Maternal LWG adjusted for pregnancy. Regression of MEI on $LW^{0.75}$, Y_E, and body tissue energy:	
	- Cows losing weight.	0.535
	- Cows gaining weight.	0.495
	- Cows either gaining or losing weight.	0.511
Moe *et al.*, 1972	EB of lactating Holstein cows, pooled results of 32 diets ranging from all forage to all concentrate:	
	- EB corrected for tissue energy loss:	
	. Regression of MEI on [$Y_{E(c)}$].	0.561
	. Regression of [$Y_{E(c)}$] on MEI.	0.503
	- EB corrected for tissue energy loss and gain, excess nitrogen intake and pregnancy:	
	. Regression of MEI on [$Y_{E(c)}$].	0.511
	. Regression of [$Y_{E(c)}$] on MEI.	0.466

Table 2.5. (Cont.) ME_m (MJ ME/$LW^{0.75}$/day) for lactating dairy cows obtained by means of EB trials and using regression analyses.

Reference	Experimental conditions and type of animal	MJ ME/ $LW^{0.75}$/day
Tyrrell & Moe, 1971	EB trials with Holstein cows in early, mid and late lactation fed on high or low concentrate rations and maize silage. Data corrected for tissue energy change, pregnancy and nitrogen in excess of maintenance. Regression of $Y_{E(c)}$/$LW^{0.75}$ on MEI/$LW^{0.75}$:	
	- Ration with 70:30 maize silage:concentrate.	0.464
	- Ration with 40:60 maize silage:concentrate.	0.396
Tyrrell *et al.*, 1970	EB trial with lactating Holstein cows. Regression of EB on MEI (Mcal), $LW^{0.75}$, positive or negative excess nitrogen (g/$LW^{0.75}$/day), and digestible energy (Mcal/kg DM):	
	- Cows consuming negative excess nitrogen.	0.691
	- Cows consuming positive excess nitrogen.	0.596
Van Es, 1974	Lactating cows eating a diet with q=56%, fed at 2.38 maintenance.	0.443
Van Es, 1975	Lactating cows, energy balance trials. Adjusted milk energy yield [$Y_{E(c)}$] as the dependent, MEI as the independent variable.	
	- Survey of world literature.	0.488
	- Long forage rations.	0.494
	- Long forages and pellets.	0.346
	- Fresh or frozen grass.	0.674
Mean ± S.D.		0.525±0.08
C.V. (%)		15.5

2.4.1.2. ME_m calculated by means of stall-feeding trials.

Some estimations of ME required for maintenance in dairy cattle obtained by stall-feeding trials are summarized in Table 2.6. Most of the data corresponds to trials carried out with non-lactating cows; however, some results obtained with lactating cows are also presented as they are relevant to the New Zealand conditions. From this sample of estimates, lactating cows had an average maintenance requirement of 0.851 MJ ME/$LW^{0.75}$/day, which was 52% higher than the 0.562 MJ ME/$LW^{0.75}$/day calculated for non-lactating cows managed under comparable conditions. A higher average ME_m of about 0.802 MJ ME/$LW^{0.75}$/day was calculated from those reports where the cows were fed on pasture, compared with only 0.531 MJ ME/$LW^{0.75}$/day calculated from those where cows were fed mixed diets.

Table 2.6. ME_m (MJ ME/LW$^{0.75}$) of lactating and dry cows assessed by means of stall-feeding trials.

Reference	Experimental technique and type of animal	(MJ ME/LW$^{0.75}$/day)
Byers *et al.*, 1985	Mature stall-fed dry Holstein cows:	
	- ME required for weight equilibrium.	0.498
	- ME required for energy equilibrium.	0.484
	Mature stall fed dry Jersey cows:	
	- ME required for weight equilibrium.	0.636
	- ME for energy equilibrium.	0.588
Gibb *et al.*, 1977	Stall-fed dry pregnant cows, zero change in LW.	.4-.58
Holmes *et al.*, 1993[1]	Lactating Friesian and Jersey cows differing in size, similar milk yield, fed on fresh cut grass:	
	- $MEI/LW^{0.75} = \beta_1$ Milk energy $+\beta_2 LW^{0.75} + \beta_3$ LWG.	
	. Friesians	0.610
	. Friesians and Jerseys	0.840
	- $MEI/LW^{0.75} = \alpha + \beta_1$ Milk energy $+\beta_2 LW^{0.75} + \beta_3$ LWG.	
	. Friesian and Jerseys	1.000
Hutton, 1962[1]	Dry Jersey cows fed on fresh cut pasture, zero change in LW (6 hr indoors and 18 hr either muzzled on a bare paddock or housed in an open barn). Regression of $DOMI = b_1 LW^{0.73}$.	0.535
Hutton, 1962[1]	Fully-fed dry Jersey cows on fresh cut pasture (12 hr indoors and 12 hr muzzled on a bare paddock). regression of $DOMI = \beta_1 LW^{0.73} + \beta_2$ LWG.	0.780
Hutton, 1962[1]	Lactating crossbred Jersey cows fully-fed; stall fed on ryegrass-white clover fresh cut pasture. Regression of $DOMI = \beta_1 FCM + \beta_2 LW^{0.73} + \beta_3$ LWG.	1.060
Wallace, 1961[1]	Lactating twin Jersey cows, stall-fed on fresh cut grass (part time outdoors):	
	- Regression of $DOMI = \beta_1 FCM + \beta_2 LW^{0.73} + \beta_3$ LWG.	0.702
	- Regression of $DOMI = \beta_1 FCM + \beta_2 LW^{0.73}$.	0.892

	Lactating cows	Dry cows	Pasture fed cows	Cows fed mixed diets
Mean ± S.D.[2]	0.851±0.19(4)	0.562±0.11(7)	0.802±0.18(8)	0.531±0.08(6)
C.V. (%)	23.0	20.3	22.8	16.2

[1] Assuming 1 kg DOM =15.6 MJ ME (Geenty & Rattray, 1987).
[2] In brackets the number of observations used to calculate the mean.

2.4.1.3. ME_m assessed by means of grazing trials.

In spite of providing conditions to obtain more accurate results in assessing the partition of ME intake, neither the energy balance trial nor the stall-feeding trial represent the actual conditions of grazing animals. The grazing animal has an extra expenditure of energy mainly due to the grazing activity (Holmes & Wilson, 1987). Average values regarding the energetic cost of activities related with the grazing situation are given in the following table (A.R.C., 1980; C.S.I.R.O., 1990):

Table 2.7. Energy costs above maintenance associated with the grazing activities

Activity	Energy required/kg LW
Standing compared with lying	0.0100 MJ/per day
Walking (horizontal movement)	0.0020 MJ/km
Walking (vertical movement)	0.0280 MJ/km
Eating (ie. prehension and chewing)	0.0025 MJ/hr
Ruminating	0.0020 MJ/hr

Under these circumstances it is likely that the free grazing ruminant will have higher maintenance requirements than those obtained for similar animals in the stall-feeding trial or the energy balance trial with the calorimeter. Thus, the grazing trial might represent more realistically the conditions under which the animal is expected to perform. However, its accuracy heavily rests on reliable assessments of the amount of daily herbage intake (see Section 2.3) and the ability to estimate changes in live weight without incurring great errors due to differences in gut fill. In addition, most of the grazing experiments make use of multiple regression techniques to partition the intake of ME into the different body functions (i.e. maintenance, liveweight gain, milk yield, etc.). The procedure, however, is not completely free of errors. A detailed discussion of the problems encountered when assessing the maintenance requirements of free grazing cattle by means of multiple regression analyses was given by Curran & Holmes (1970). Among the most important are the high degree of auto-correlation between the independent variables and errors in the determination of herbage intake when using indicator substances as indigestible markers to assess faecal output.

Table 2.8 summarizes some estimates of the MEI_m required by grazing cattle. Where the results were given in pounds and metabolic live weight given as $LW^{0.73}$, the appropriate factors were used to convert pounds to kilograms and $LW^{0.73}$ to $LW^{0.75}$. From this sample of estimates, on average lactating and dry cows required for maintenance, respectively, 1.08 and 0.91 MJ MEI/$LW^{0.75}$/day.

Table 2.8. ME_m (MJ ME/$LW^{0.75}$/day) of grazing dairy cattle assessed by multiple regression analyses.

Reference	Type of animal, type of sward and method of assessing intake	Maintenance (MJ ME/$LW^{0.75}$/d)
Cox *et al.*, 1956[1]	Lactating cows grazing individual plots, herbage intake assessed by cutting.	0.622
Greenhalgh *et al.*, 1966[2]	Lactating Ayrshire cows grazing on a ryegrass-cocksfoot dominant sward, chromium gelatin capsules.	
	- Regression of DOMI $=\beta_1 LW^{0.73}+\beta_2 FCM+\beta_3 LWG$.	0.858
Holmes & Jones, 1965[2]	Lactating cows grazing on a timothy-meadow Fescue pasture. Chromium gelatin capsules.	
	- Regression of DOM= $\alpha+\beta_1 FCM+\beta_2 LW^{0.73}$.	1.185
	- Regression of DOM = $\alpha+\beta_1 FCM+\beta_2 LW^{0.73}+\beta_3 LWG$.	0.997
	- Regression of DOM = $\beta_1 FCM+\beta_2 LW^{0.73}+\beta_3 LWG$.	1.092
Holmes & McLenaghan, 1980	Dry pregnant cows (8th month) grazing ryegrass-white clover pasture. Zero change in condition score.	1.020
Holmes *et al.*, 1993[2]	Lactating Friesian and Jersey cows differing in size but similar milk yield grazing on ryegrass-W.clover pasture. Chromium gelatin pills and slow release Cr capsules. Regression of:	
	- MEI/$LW^{0.75}$ = β_1 Milk energy $+\beta_2 LW^{0.75}+\beta_3$ LWG.	
	. Friesians	1.20
	. Friesians and Jerseys	1.27
	- MEI/$LW^{0.75}$ = $\alpha + \beta_1$ Milk energy $+\beta_2 LW^{0.75}+\beta_3$ LWG.	
	. Friesians	1.38
	. Friesians and Jerseys	1.20
Hutton, 1968[2]	Dry Jersey twin cows, chromium capsules.	0.80
Jones *et al.*, 1965[2]	Dry (556 kg LW), low yielding (493 kg LW) and high yielding (479 kg LW) Ayrshire cows grazing on Festuca-Phleum- W. clover pasture. Chromium gelatin capsules:	
	- Regression of DOMI = $\beta_1 FCM+\beta_2 LW^{0.73}+\beta_3 LWG$:	
	. Experiment 1.	1.126
	. Experiment 2.	1.036
	- Regression of DOMI = $\beta_1 FCM+\beta_2 LW^{0.73}$.	
	. Experiment 1.	1.126
	. Experiment 2.	1.081
Wallace, 1956a[2]	Lactating grazing Holstein and Jersey cows differing in size production potential and rate of liveweight gain (average of 6 years). Chromium gelatin capsules. Regression of DOMI= $\beta_1 FCM+\beta_2 LW^{0.73}+\beta_3$ LWG.	0.892

	Lactating	Non-lactating
Mean ± S.D.[3]	1.08±0.19(11)	0.91±0.15(2)
C.V. (%)	17.7	17.0

[1] Assuming 1 kg pasture DM=10.87 MJ ME (Hutton, 1971); [2] Assuming 1 kg DOM =15.6 MJ ME (Geenty & Rattray, 1987); [3] In brackets the number of observations used to calculate the mean.

Table 2.9 compares the averages of the estimates of ME_m calculated by the three methods reviewed. The size of the estimators of ME_m follows the order lactating > non-lactating cows; grazing trials> stall feeding trials> EB trials, and fresh cut grass > mixed diets. The higher estimate for lactating cows appears to be associated with an increase in the cow's basal metabolism due to the energy demanding process of milk synthesis (Moe *et al.,* 1972). The higher estimates for both the stall-feeding and the grazing trial might be the result of the extra activity they involve or because errors of measurement are more likely to occur in these trials. Finally, the higher estimates calculated for the experiments in which the cows were fed exclusively on fresh cut pasture might be the result of lower efficiencies of utilization of the dietary ME, and the associated extra energy expended for the excretion of excess nitrogen (common with fresh cut pasture) as urea in the urine (Geenty & Rattray, 1987).

From this comparison it is evident that in spite of representing more closely the actual conditions of the grazing animal, the grazing trial often lacks the accuracy with which both the stall-feeding trial and the energy balance trial are performed. This is so because individual feed intake is difficult to assess accurately under free grazing conditions.

Table 2.9. Estimates of the ME_m (MJ ME/$LW^{0.75}$/day) of lactating and non-lactating dairy cows assessed by different methods (mean±S.D.)[1]

Method of assessment	Physiological state or system of feeding	Maintenance estimate (MJ ME/$LW^{0.75}$/day)
Energy balance trial	Lactating	0.525±0.08 (23)
	Dry	0.459±0.05 (5)
	Fed exclusively on fresh cut pasture [2]	0.750±0.05 (5)
	Fed on mixed diets [2]	0.514±0.07 (25)
Stall-feeding trial	Lactating	0.851±0.19 (4)
	Dry	0.562±0.11 (8)
	Fed exclusively on fresh cut pasture [2]	0.802±0.18 (8)
	Fed on mixed diets [2]	0.531±0.08 (6)
Grazing trial	Lactating	1.020±0.18 (11)
	Dry	0.910±0.15 (2)

[1] In brackets the number of observations used to calculate the mean.
[2] Lactating and dry cows pooled data.

2.4.2. ME required for liveweight gain.

The MEI required for liveweight gain (ME_g) depends on the rate of liveweight gain (LWG, kg/day), the net energy deposited in each kg of liveweight gain (NE_g) and on the efficiency with which the cow uses the dietary ME for growth and fattening purposes (k_g) (A.R.C., 1980), i.e.

$$ME_g = \frac{NE_g}{k_g} \quad \ldots\ 2.28$$

2.4.2.1. Energy value of the liveweight gain.

The NE deposited as liveweight gain (MJ/kg) is the product of the weight of the LWG and its energy value (EV_g), i.e.

$$NE_g = LWG \times EV_g \quad \ldots\ 2.29$$

For cattle, the energy value of gain (MJ/kg) is related to the live weight in kg (LW) by the following equation (MAFF, 1984):

$$EV_g = 6.28 + 0.3\ NE_g + 0.0188\ LW \quad \ldots\ 2.30$$

By combining equation 1 and 2 the NE deposited in the gain made can be calculated as:

$$NE_g\ (MJ) = \frac{LWG\ (6.28 + 0.0188\ LW)}{(1 - 0.3\ LWG)} \quad \ldots\ 2.31$$

For an adult cow weighing 450 kg live weight, equation 2.31 predicts an average NE content of 21.0 MJ/kg live weight when the cow has an average LWG of 1 kg/day, and 26.8 MJ/kg live weight when cows of the same size are gaining 1.5 kg live weight/day. This is in line with the average values given in A.R.C. (1980). For adult cattle A.R.C. (1980) states that muscle consists roughly of 80% water and 20% protein, while adipose tissue contains about 20% water and 80% fat. Their average caloric values are 39.3 MJ/kg fat and 23.6 MJ/kg protein, and an average value of 26 MJ/kg of body weight (i.e. composed of fat and protein) is suggested.

2.4.2.2. Efficiency of utilization of ME for growth and fattening (k_g).

The efficiency of utilization of ME for the deposition of energy as liveweight gain (mainly as fat and protein) in non-lactating animals (k_g) is considerably lower and more likely to be affected by the nutrient concentration of the feed than k_m (A.R.C., 1980). The efficiency of utilization of ME energy for growth and fattening (k_g) can be predicted by using the generalised equations summarized in Table 2.10.

As was the case with the equation given by Blaxter (1989) to predict the k_m value, his equation to predict k_g given in Table 2.10 also takes into account the protein content of the organic matter (**P**, g/kg). These two equations were based on about 1000 energy balance trials, and provide a good basis to predict k_m and k_g for adult cattle and sheep in which most of the energy is retained as fat (Blaxter, 1989).

The equations predicting k_g were compared in the same way and using the same assumptions as when comparing those predicting k_m. The corresponding k_g values yielded by each equation are presented in Table 2.10. The equations produced very similar results, and on average all the values grouped around a mean k_g value of 0.535±0.02.

Table 2.10. Equations for predicting the efficiency of utilization of metabolizable energy for growth an fattening (k_g) in adult sheep and caitle.

Source	Equation predicting the k_g value of the feed	Predicted k_g value	Equation number in text
A.R.C., 1965	$k_g = 0.81*q + 0.03$	0.568	2.31
A.R.C., 1980	$k_g = (MD/18.4)*0.78+0.006$	0.524	2.32
Blaxter, 1989	$k_g = 0.951 + 0.00037(P/q) - 0.336/q$	0.544	2.33
Blaxter, 1974	$k_g = 0.78 *q + 0.006$	0.524	2.34
C.S.I.R.O., 1990	$k_g = (0.042*M/D) + 0.006$	0.520	2.35
C.S.I.R.O., 1990	$k_g = 0.043*M/D$	0.526	2.36
Tolkamp & Ketelaars, 1992	$k_g = 1.32*q - 0.318$	0.559	2.37
Mean ± S.D.		0.535±0.02	
C.V. (%)		3.4	

Table 2.11 summarizes results from the literature where the efficiency with which dietary ME was utilized for body tissue gain (k_g) in experiments with dry pregnant dairy cows. From this information ME was utilized with an average efficiency (k_g) of about 56%, which is slightly higher than the average of the equations summarized in Table 6, but very similar to both the k_g value predicted by the generalised equations given by A.R.C., (1965) and that given by Tolkamp & Ketelaars (1992).

Table 2.11. Efficiency of utilization of ME for growth and fattening (k_g) in non-lactating dairy cows as reported in experiments from the literature.

Source	Type of animal and experimental conditions	Estimated k_g value
Grainger *et al.*, 1985	Energy balance trial. Pregnant-non-lactating Friesian cows.	
	- High breeding index cows at 210 days of pregnancy, fed on fresh cut pasture.	0.52
	- Low breeding index Friesian cows at 230 days of pregnancy, fed on fresh pasture.	0.52
Moe *et al.*, 1970	Energy balance trial of Holstein cows. Maternal liveweight change adjusted by pregnancy:	
	- Dry cows gaining liveweight.	0.59
	- Dry cows either gaining or losing weight.	0.60
Mean ± S.D.		0.56±.04
C.V. (%)		7.8

Taking together the values of the energy content of the liveweight gain as 26 MJ/kg (A.R.C., 1980) and both the average k_g calculated from the generalized equations given in Table 2.10 and that obtained from the experiment summarized in Table 2.11, the non-lactating dairy cows of this sample required on average 47 to 48 MJ/cow/day for the daily gain of 1 kg live weight.

Table 2.12 summarises results from the literature of either stall-fed or grazing cattle where the amount of metabolizable energy necessary to gain 1 kg of live weight was calculated. Results of experiments with lactating cows are also given, as they are relevant to the New Zealand situation. From these reports, lactating cows required about 35.5 MJ ME/kg LWG, compared with an average requirement of about 49.0 MJ ME/kg LWG for non-lactating cows. The lower average ME_g calculated for lactating cows might be due to the fact that when the lactating cow is in positive energy balance (i.e. gaining weight), the efficiency with which dietary ME is used for body tissue deposition [$k_{g(l)}$] is considerably higher than that achieved when the cow is non-lactating (k_g) (C.S.I.R.O., 1990; Moe *et al.*, 1970). However, the reasons for this more efficient restoration of body reserves during lactation are still unclear.

In deriving these estimates it has to be remembered, however, that changes in liveweight gain are difficult to obtain accurately without appropriate fasting because of high differences in gut fill. Nevertheless, these values provide a sample of a size and variability such that the calculated averages agree rather well with other published estimates (A.R.C., 1980; MAFF, 1984).

Table 2.12. ME required for liveweight gain (MJ ME /kg liveweight gain) by lactating and non-lactating dairy cattle calculated by means of multiple regression analyses.

Reference	Comments	MJ ME/ kg LWG
Bhuvaneshwar, 1993[2]	Lactating grazing Holstein and Jersey cows differing in size but with similar production potential. Regression of $MEI/LW^{0.75} = \beta_1$ Milk energy$+\beta_2 LW^{0.75}+\beta_3$ LWG.	33-40
Cox *et al.*, 1956[1]	Lactating cows grazing individual plots, herbage intake assessed by cutting. Regression of DOMI $=\beta_1$ FCM$+\beta_2 LW^{0.73}+\beta_3$ LWG.	23.0
Holmes & Jones, 1965[2]	Lactating cows grazing on a timothy-meadow fescue pasture. Regression DOMI$= \alpha+\beta_1$ FCM$+\beta_2 LW^{0.73}+\beta_3$ LWG.	22.3
Hutton, 1962[2]	Lactating crossbred Jersey cows fully-fed; stall fed on ryegrass-white clover fresh cut pasture. Regression of DOMI $= \beta_1$ FCM$+\beta_2 LW^{0.73}+\beta_3$ LWG.	25.6
N. Z. Dept. Agr., 1951[2]	15 sets of identical twins mob-grazed throughout the lactation on ryegrass-white clover pasture. Chromium gelatin capsules. Regression of DOMI $= \beta_1$ FCM$+\beta_2 LW^{0.73}+\beta_3$ LWG.	61.1
Wallace, 1956a[2]	Lactating-grazing Friesian and Jersey cows differing in size, production potential and rate of liveweight gain (average of 6 years). Chromium gelatin capsules. Regression of DOMI$=\beta_1$ FCM$+ \beta_2 LW^{0.73}+\beta_3$ LWG.	46.8
Wallace, 1961[2]	Lactating twin Jersey cows stall fresh cut grass (part time outdoors). Regression of : DOMI$=\beta_1$ FCM$+\beta_2 LW^{0.73}+\beta_3$ LWG.	31.2
Grainger *et al.*,1985	Energy balance trial. High and low breeding index dry-pregnant Friesian cows (210-230 days pregnant) fed on fresh cut ryegrass-clover pasture. Regression of $EB/LW^{0.75}$ on $MEI/LW^{0.75}$.	51.9
Hutton, 1962	Fully-fed non-lactating Jersey crossbred cows stallfed on fresh cut pasture (12 hs indoors and 12 hs muzzled on a bare paddock). Regression of : DOMI $= \beta_1 LW^{0.73} + \beta_2$ LWG.	45.6

	Lactating	**Non-lactating**
Mean ± S.D[4]	35.4±13.4 (10)	48.8±4.5 (2)
C.V. (%)	38.0	9.1

[1] Assuming: 1 kg pasture DM = 10.87 MJ ME (Hutton, 1971);
[2] 1 kg DOM = 15.6 MJ ME (Geenty & Rattray, 1987);
[3] 1 kg OM = 12.55 MJ ME;
[4] In brackets the number of observations used to calculate the mean.

2.4.3. ME requirements for pregnancy.

The pregnant cow requires energy for its own maintenance and for the maintenance of the developing foetus, in addition to the energy that stored in the foetus, its associated membranes and in accrued uterine tissues. (MAFF, 1984). Unlike the relatively high value of k_m of about 73%, the efficiency with which metabolizable energy is used for pregnancy (k_p) is relatively low (Geenty & Rattray, 1987; Holmes & Wilson, 1987). Most authors agree that $k_p = 0.13$ (see Table 2.13), which means that only about 13% of extra energy above maintenance is deposited to pregnancy.

The surprisingly low efficiency of utilization for such an important function, probably arises from a method that yields gross efficiency rather than net efficiency (C.S.I.R.O., 1990). The simple reason for the very low partial efficiency of energy use for conceptus growth is that more than half of the extra energy is used to support metabolically active, non-growing tissues, particularly the placenta (Bell, 1993). In addition, such estimate also contains the energy requirement for maintenance of the foetus. Table 2.13 summarizes results from the literature where k_p for dairy cows and for ewes was estimated by means of multiple regression.

Table 2.13. Average values of k_p for ewes, dairy and beef cows.

Source	Type of animal	Estimated k_p
Moe *et al.*, 1970	dairy cows	11.0-12.0
Moe *et al.*, 1971	dairy cows	10.5
Henseler *et al.*, 1973[1]	dairy cows	14.9
Graham, 1964 a[1]	ewes	13.0
Sykes & Field, 1972 c[1]	ewes	12.4-14.2
Rattray *et al.*, 1974 a[1]	ewes	12.0-13.5
Robinson *et al.*, 1980	ewes	13.0
Ferrell *et al.*, 1976 a	beef heifers	12.9
Mean ± S.D.		12.67±1.3
C.V. (%)		10.2

[1] Cited in A.R.C., 1980.

Ferrell *et al.* (1976 b) made use of multiple regression analyses to describe the growth of various tissues or components of various tissues of pregnancy during gestation. These authors used non pregnant and pregnant (at different stages of pregnancy) Hereford heifers and a regression model of the form;

$$W_t = W_o\, e^{(b1 + b2\,t + b3\,L)\,t} \quad \ldots\ldots\ 2.38$$

where:

t = day of gestation;

L = level of feeding (Kcal ME/$LW^{0.75}$);

W_o = the amount of component on day zero of gestation;

W_t = the amount of component on day t of gestation;

b_1, b_2 and b_3 are constants, and

e = base of the natural logarithm.

Applying regression analyses these authors developed prediction equations to estimate the amount of components of tissues of gestation. Table 2.14 summarizes the equations that describe the relationship for fresh weight and gross energy of foetus, conceptus and gravid uterus, along with their corresponding efficiencies of utilization of ME for energy retention.

Table 2.14. Relationships of some components of foetus, conceptus or gravid uterus to day of gestation, and their corresponding efficiencies of utilization of ME for energy retention (After Ferrell *et al.*, 1976a, 1976b).

Tissue	Component	Estimating equation	Estimated k_p
Foetus[a]	Fresh weight	$W_t = 5.839\ e^{(.0512\ -\ .0000707t)\ t}$	
	Gross energy	$E = 0.5499\ e^{(.0674\ -\ .0000942t)\ t}$	12.2%
Conceptus[b]	Fresh weight	$W_t = 470.1\ e^{(.0217\ -\ .0000161\ t)\ t}$	
	Gross energy	$E = 2.197\ e^{(.0588\ -\ .0000804\ t)\ t}$	12.5%
Gravid uterus[c]	Fresh weight	$W_t = 743.9\ e^{(.0200\ -\ .0000143\ t)\ t}$	
	Gross energy	$E = 69.73\ e^{(.0323\ -\ .0000275\ t)\ t}$	14.0%

[a] t = day of gestation, W = weight in g, E = gross energy in kcal;
[b] Conceptus = foetus plus foetal fluids plus foetal membranes;
[c] Gravid uterus = Conceptus plus uterus.

The metabolizable energy intake required to meet pregnancy can then be calculated from an estimate of the gross energy content of the conceptus and an estimate of k_p. MAFF (1984), calculates metabolizable energy requirements for pregnancy (ME_p) as:

$$ME_p = \frac{NE_p}{k_p} \quad \ldots\ldots \quad 2.38$$

where NE_p is the net energy requirement for pregnancy and k_p is the efficiency with which ME is used for pregnancy purposes. The net energy requirements for pregnancy (NE_p) involve the following components:

a) the energy stored daily in the uterus and the uterine contents (N_{p1}), which can be estimated by the following equation:

$$N_{p1} = 0.03\ e^{0.0174t} \quad (\mathrm{MJ/day}). \ldots .2.39$$

with corresponding efficiency $k_{p1} = 1$; t = the number of days after conception, and e = 2.718, the base of the natural logarithm.

b) the energy oxidized and lost as heat due to a 'Heat increment of gestation' (N_{p2}), i.e. heat production in pregnant cows is greater than expected for non-pregnant cows of similar weight. This component can be estimated as follows:

$$N_{p2} = 0.904\ e^{0.01t} \quad (\mathrm{MJ/day}). \ldots .2.40$$

with corresponding efficiency $k_{p2} = 1$, and *e* and *t* as defined previously.

c) the energy associated with foetal maintenance and the increased maternal fasting metabolism due to pregnancy (N_{p3}). This component is assumed to be about half of the heat increment of gestation (i.e. 1/2 N_{p2}), and to have the same efficiency of utilization of ME as maintenance (k_m). It is calculated as:

$$N_{p3} = \frac{0.904\ e^{0.01\,t}}{2 \times k_m} \quad . \ . \ . \ . \ 2.41$$

The remainder of the heat increment associated with pregnancy arises from the synthetic processes producing the foetus and associated structures. Thus the ME requirement for the growth of the foetus and associated structures (MJ/day) will be the sum of N_{p1} and 1/2 N_{p2}. Then the extra ME energy requirement for pregnancy will therefore be:

$$ME_p = N_{p1} + \frac{N_{p2}}{2} + \frac{N_{p2}}{2 \times k_m} \quad . \ . \ . \ . \ . \ . \ 2.42$$

Assuming $k_m = 0.73$ and substituting N_{p1} and N_{p2} for their respective values this expression becomes:

$$ME_p\ \text{(MJ/day)} = 0.03\ e^{0.0174\,t} + 1.19\ (0.904\ e^{0.01t}) \quad . \ . \ . \ . \ . \ 2.43$$

For cows averaging 200 days pregnant and producing a calf weighing 40 kg at birth, equation 2.43 predicts an average daily requirement of about 9.8 MJ ME/cow to meet the requirement of pregnancy.

2.5. Efficiency of production of dairy cattle.

Efficiency can be defined as the ratio of output (Y_i)/input (X_i), with output and input given in a variety of units, biological, physical or financial (Østergaard *et al.*, 1990), i.e.

$$\text{Efficiency} = \frac{Y_i}{X_i} \quad \text{or} \quad \frac{Y_{1\text{-}n}}{X_{1\text{-}n}} \text{(or its inverse)} \quad \ldots\ldots\ 2.44$$

Efficiency of production as has been applied to the dairy cow corresponds to an estimate of biological efficiency. It is normally calculated as (Milk E)/(Feed E) (where E = energy, or heat of combustion, of milk and food). However, as Holmes *et al.* (1981) pointed out gross feed efficiency (GFE) as an estimate of lactational efficiency is often too simple because it does not take into account the contribution made by changes in body tissue. It is assumed that the total energy consumed is partitioned into that energy used for maintenance purposes (ME_m) and that used for the synthesis of milk energy (ME_y), i.e.

$$\text{Gross feed efficiency} = \frac{\text{Milk Energy (MJ)}}{[ME_m + ME_y]} \quad \ldots\ldots\ 2.45$$

However, during lactation the synthesis of milk energy comes from the dietary energy that becomes available after the energy requirement of maintenance has been met. This amount of energy may either be supplemented by energy coming from the mobilisation of body tissue energy (TEL), or be reduced by the diversion of dietary energy towards the synthesis of body tissue energy (TEG), i.e.

$$\text{Lactational efficiency} = \frac{\text{Milk Energy (MJ)}}{ME_m + (ME_y + TEL - TEG)} \quad \ldots\ldots\ 2.46$$

Thus lactational efficiency in the dairy cow is influenced both by milk production and associated fluctuations in body tissue gain and loss and by the live weight of the cow (metabolic weight), as this determines the amount of energy directed to meet maintenance (Holmes *et al.*, 1981; Holmes *et al.*, 1993).

2.5.1. Some estimates of gross feed efficiency in dairy cattle.

The calculation of gross feed efficiency in dairy cattle requires both an estimate of amount of energy being deposited as milk and of the energy eaten. The yield of milk and milk components (fat, protein, lactose) are often measured for individual cows as these traits are widely used for selection and breeding purposes, and from them an estimate of the energy content of milk energy can be derived (Tyrrell & Reid, 1965). Feed intake or the intake of energy by individual cows can also be measured, but it is expensive to do so and, in some studies it has been estimated from production and liveweight data using current feeding standards in reverse order (Madgwick *et al.*, 1991; Sieber *et al.*, 1988). The estimated individual feed intake either actually measured or indirectly assessed can then be used to assess efficiency of production on an individual cow basis.

A summary of estimates of gross feed efficiency (GFE) of dairy cattle, obtained under American, Canadian and New Zealand conditions, is presented in Table 2.15. With the exception of the estimated GFE given by Yerex *et al.* (1988), the American and the Canadian estimates were calculated as the ratio NE milk/estimated NE eaten. Calculated in this way, GFE ranged between 47% to 61%. This range of variation is higher than that of 18% to 25% calculated by Hutton (1963) for Jersey cows stallfed on fresh cut grass over a 300-day lactation. This difference might be due to Hutton's (1963) estimate of GFE being calculated as the ratio NE milk/GE eaten.

Table 2.15. Estimates of gross feed efficiency of dairy cattle as reported by several authors in the literature.

Source	Comments	Gross efficiency (%)
Dickinson *et al.*, 1969	First calving Ayrshire, Brown swiss and Hosltein Friesian cows fed on a forage:concentrate ration. GFE calculated as NE Milk/Estimated NE intake:	
	- Ayrshires	60.3
	- Brown swiss	54.3
	- Holstein Friesians	61.0
Graham *et al.*, 1991	Stall-feeding trial, first calving Holstein heifers fed during lactation on high (1-140 days), medium (141-240 days), and low (241-305 days) energy total mixed ration. GFE calculated as NE milk/Estimated NE intake.	
	- Daughters of top Canadian Friesian sires.	59.0
	- Daughters of top N. Z. Friesian sires.	58.0
Legates, 1990	First lactation Holstein cows bred either for high production or for average production. Cows fed on a hay:silage:concentrate ration. Concentrate was given according to production, and individual feed intake and efficiency were calculated for the period 71 to 120 days of lactation. GFE was calculated as NE milk/ Estimated NE intake:	
	- Selected group.	51.0
	- Unselected group.	47.0
Sieber *et al.*, 1988	Holstein cows. Estimated feed efficiency was expressed as the ratio NE milk/Estimated NE intake:	
	- First calving cows.	58.7
	- Second calvers.	57.0
	- Third calvers.	57.8
	- Fourth calvers.	57.7
	- ≥ Fifth calvers.	57.3
	- All cows.	57.9
Yerex *et al.*,1988	First lactation Holstein cows bred for either high production and large-size or for high production and small size. Gross Feed efficiency calculated as kilograms of TDN consumed per kg of 4% FCM produced:	
	- Large-size cows.	58.5
	- Small-size cows.	55.7
Hutton, 1963	Jersey cows (300 to 400 kg LW) stall-fed on fresh cut grass and producing 160 kg MF during a 300-day lactation. GFE calculated as NE milk/GE eaten.	20.0

2.5.2. Between breed differences in gross feed efficiency.

There is evidence of significant differences in gross feed efficiency between different breeds of dairy cattle. Dickinson *et al* (1969) compared the gross feed efficiency of Ayrshires, Brown Swiss and Holstein-Friesians. Brown swiss were the least efficient (54.3%), Holstein-Friesians were the most efficient (61.0%), and Ayrshires were intermediate between the two (60.3%) (Table 2.15). Madgwick *et al.* (1991) found Jersey to be significantly more feed-efficient than Friesians by 0.15 kg fat+protein/1000 MJ energy intake (approximately 2%). They attributed the difference to the much smaller body size of Jerseys requiring less ME_m, without a corresponding decrease in production level. In that study, Jerseys produced less fat+protein (about 30 kg or 21%) than Friesians, but they weighed approximately 100 (about 21%) kg less than Friesians. Similarly, Bhuvaneshwar (1993) found Friesian cows to be less feed-efficient than Jersey cows. In that experiment Friesian cows were 114 to 127 kg heavier than Jerseys and, from the combined information of an indoor feeding and a grazing period, Friesians ate 13.5 to 20.5% more DM, produced 5.7 to 8.4% more NE milk, but were 5 to 15% less feed-efficient than the Jerseys. Gibson (1986) found that over a whole lactation food conversion efficiency of Jerseys was 7.8% higher than Friesians. Similarly, Campbell (1977) found Jerseys to be 3% more feed efficient than Friesian x Jersey crossbred cows when they were grazed as a single herd.

L'Huillier *et al.* (1988) compared the productive performance of Friesian and Jersey cows in mid-lactation (14th to 17th week of lactation) grazing at daily herbage allowances of 10, 20, 30 or 40 kg DM/cow/day. The results indicated that Friesians lost more live weight (8.4 *vs* 5.3 kg), had a higher percentage of herbage DM utilization (i.e. 50 *vs* 46%), grazed pastures lower and more evenly than did Jerseys, ate 13% more herbage DM, produced 26% more milk, 6% more milkfat, 13% more protein and 24% more lactose, but were 8.4% less feed-efficient than Jerseys (61.2 *vs* 67.0 g MF/kg DM consumed). At a common live weight there was no difference in milk yield between breeds, but at higher stocking intensities, Friesians produced less milkfat and total solids than did Jerseys. In that study the average live weights of the cows were not given, but presumably the Jersey cows were offered higher daily herbage allowances/$LW^{0.75}$ due to their smaller size, which might have influenced the results obtained.

L'Huillier *et al.* (1988) also compared the energy metabolism of Friesian and Jersey cows during the 8th to 16th weeks of lactation. They found that Friesians, when fed *ad libitum*, ate more herbage DM/cow/day, but less per unit live weight than Jerseys (3.2 *vs* 3.7% respectively). Friesians lost significantly more ME as heat increment than did Jerseys and had a lower efficiency of utilization of ME for milk and tissue deposition (energy balance) than Jerseys (0.48 *vs* 0.58 respectively).

2.5.3. Within breed differences in gross feed efficiency.

The experiment reported by Dickinson *et al.* (1969) ranked the three dairy breeds for gross feed conversion efficiency in the order Holstein>Ayrshires>Brown swiss (Table 2.15). If compared within breeds, however, cows of smaller size or weight and cows that gained less weight in their first lactation were significantly more efficient than cows of larger size or greater weight or weight gain. Similarly, Bhuvaneshwar (1993) found that smaller Friesian cows (80 kg lighter) ate 3.9% less DM, produced 2.8% less NE as milk, but were 2.6% more feed efficient than their larger Friesian counterparts.

Madgwick *et al.* (1991) suggested that within a particular breed of dairy cattle, differences between animals in feed conversion efficiency are largely a function of the level of production, feed intake capacity and cow's body size (primarily live weight). There is also evidence to show that differences between individual cows in gross feed efficiency are heritable (Persaud *et al.,* 1990; Madgwick *et al.,* 1991; Van Arendonk *et al.,* 1991) (Table 2.16). This might suggest that selection of cows for improved gross feed efficiency is possible. However, the cost involved in recording such a trait for a large number of animals makes it impractical, and often selection is carried out on production traits on the hope that selection for high yield will bring about a correlated improvement in cow feed efficiency (Freeman, 1975; Legates, 1990).

Table 2.16. Heritability (h^2±S.E.) and repeatability (r) estimates for feed efficiency in dairy cattle.

Source	Comments	Efficiency as	h^2	r
Persaud *et al.*,1990	Weekly records of individual intakes, Friesian cows fed *ad libitum* on a forage: concentrate diet.	Milk E/FEI[1]	0.13±0.09[a] 0.13±0.09[b]	0.41[a] 0.60[b]
Madgwick *et al.*,1991	Friesian and Jersey cows from commercial farms. ME Intake estimated from live weight and production data using the A.R.C. (1980) standards in reverse order.	Fat+Prot(kg)/EEI[2]	0.25	
Van Arendonk *et al*.,1991	First calving Friesian cows fed roughage *ad libitum* and 6 kg of concentrate/cow/day.	FEI/FPCM[3]	0.37	

[1] FEI = Calculated feed energy intake (MJ);
[2] EEI = Estimated Energy Intake (MJ);
[3] FPCM = Fat Protein Corrected Milk yield (kg), i.e. FPCM=(0.349+0.107%fat+0.067%protein)*kg milk;
[a] Estimated for a 26 week lactation period;
[b] Estimated for a 38 week lactation period.

2.6. Relationships between cow efficiency, intake and body size.

Cow body size (either live weight or any of the body measurements used to describe size) shows a very high positive phenotypic correlation with milk yield and yield of milk components (Table 2.17). For the dairy farmers this means that they will generally observe their larger cows to be higher producers. Consequently, large-size cattle appear desirable to them, and if selection practices are primarily based on volume of production, then genetically larger cows with higher requirements of ME_m will be the result (Wickham, 1993). Thus, selection for increased milk yield is expected to result in improved gross feed efficiency due to a 'dilution' of the ME_m (Freeman, 1975). However, this will only be true if there is not a correlated increase in the body weight of the cows selected for high yield (Madgwick *et al.,* 1991).

Freeman (1967, 1975) stated that selecting for milk yield alone was expected to give between 75 and 95% of the response of selection for gross feed efficiency. To reach this conclusion he assumed a genetic correlation between milk yield and efficiency of 0.75

to 0.95. Such estimates in which obtained from experiments where cows were fed concentrates according to production (Mason *et al.*, 1957; Hooven *et al.*, 1972) and as a result the calculated genetic correlations might be over-estimated. Recent evidence obtained for cows feed *ad libitum* (Persaud *et al.*, 1990) suggest that selecting for fat+protein yield will bring a correlated change in efficiency of between 47 and 74%.

Body size shows both a high negative phenotypic correlation (Table 2.17) and a high negative genetic correlation (Table 2.18) with gross feed efficiency. The high genetic correlation between live weight and gross feed efficiency suggest that body weight is a good predictor of efficiency, and can be used for selection purposes along with production traits to increase the overall farm profitability (Ahlborn & Dempfle, 1992). In a recent experiment with Friesian cows fed *ad libitum* on a forage:concentrate diet, Persaud *et al.* (1990) compared different selection criteria for genetic improvement of gross feed efficiency. Selection on an index of fat+protein yield and live weight was predicted to be much more accurate than selection for yield or efficiency alone.

In a 14-year selection experiment with Holstein for large and small body size reported an approximate 2.8% advantage in feed efficiency for the small line on a lactation basis and a 5.0% advantage during 60 through 180 days of lactation (Yerex *et al.*, 1988) . Thus, selecting for high yield whilst body size remains constant appears the best way to genetically improve gross feed efficiency (Yerex *et al.*, 1988; Madgwick *et al.*, 1991).

Table 2.17 . Phenotypic correlations among measures of intake, efficiency, yield and body size in dairy cattle.

	Measure of intake		Measure of efficiency			Measure of body size							
	Total ENE	DMI[2]	MilkE/ ENE (Mcal)	FCM/ENE (Mcal)	MilkE/ FEI (MJ)	Average live weight	Heart girth	Paunch girth	Wither height	Chest depth	Pelvic length	Pelvic width	Body length
<u>Parameter</u>													
▸Yield													
. FCM[3]	0.72[a] 0.68[b]		0.63[f]	0.82[b]		0.44[c] 0.22[f]	0.02[d] 0.20[f]	0.28[f]	0.23[f]	0.24[f]	0.21[f]	0.28[f]	0.22[f]
. Milk	0.70[a]	0.46[e1] 0.53[e2]	0.61[f]		0.80[e1] 0.85[e2]	0.42[c] 0.20[f]	0.18[f]	0.26[f]	0.22[f]	0.22[f]	0.19[f]	0.27[f]	0.21[f]
. Fat			0.62[f]			0.24[f]	0.21[f]	0.29[f]	0.24[f]	0.25[f]	0.22[f]	0.29[f]	0.23[f]
. Fat + protein		0.56[e1] 0.60[e2]			0.81[e1] 0.86[e2]								
▸Intake													
. Total ENE[1]				0.17[a] 0.14[b]		0.41[a]							
. DMI(kg/cow)					0.02[e1] 0.14[e2]	0.24[e1] 0.11[e2]							
▸Efficiency													
. FCM/ENE						-0.04[c]							
. Milk E/FEI[4]						-0.38[e1] -0.50[e2]							
. FCM/100 FU_m[5]							-0.29[d]						
. Milk E/ENE (Mcal)						-0.33[f]	-0.31[f]	-0.23[f]	-0.18[f]	-0.23[f]	-0.22[f]	-0.23[f]	-0.20[f]

[a] Miller *et al.*, 1972.
[b] Hooven *et al.*, 1972.
[c] Hooven *et al.*, 1968.
[d] Syrstad, 1966.
[e1] Persaud *et al.*, 1990 (26-week lactation period).
[e2] Persaud *et al.*, 1990 (38-week lactation period).
[f] Sieber *et al.*, 1988.
[1] ENE= Estimated Net Energy intake.
[2] DMI=Dry matter intake.
[3] FCM=Fat corrected milk.
[4] FEI= Feed Energy Intake (MJ).
[5] FU_m=Feed Units for maintenance.

Table 2.18 . Genetic correlations among measures of intake, efficiency, yield and body size in dairy cattle.

	Measure of intake		Measure of efficiency			Measure of body size			
Parameter	Total ENE[1]	DMI[2]	Fat+Prot/ENE (kg/MJ)	FCM/ENE (Mcal)	MilkE/FeedE (MJ)	Average body weight	Body weight (score)	Stature (score)	Heart girth
▸ Yield									
. FCM[3]	0.82[a] 0.86[b] 0.83[c]			0.93[b]		0.28[d]			-0.08[f]
. Milk	0.77[a] 0.76[c]	0.54[e1] 0.47[e2]	0.02[h]		0.61[e1] 0.52[e2]	0.30[d]	0.39[g1] 0.29[g2]	0.34[g1] 0.43[g2]	
. Fat							0.34[g1] 0.34[g2]	0.25[g1] 0.42[g2]	
. Fat + protein		0.74[e1] 0.65[e2]	0.80[h]		0.60[e1] 0.44[e2]				
▸ Intake									
. Total ENE				0.50[a]		0.44[a]			
. DMI					-0.05[e1] -0.41[e2]	0.34[e1] 0.46[e2]			
▸ Efficiency									
. FCM/ENE						-0.17[d]			
. Milk E/Feed E						-0.82[e1] -0.81[e2]			
. FCM/100 FU_m[4]									-0.55[f]
. Fat+Prot(kg)/ENE(MJ)						-0.46[h]		-0.32[h]	

[a] Miller *et al.*, 1972.
[b] Hooven *et al.*, 1972.
[c] Miller, 1972 (cited by Freeman, 1975).
[d] Hooven *et al.*, 1968.
[e1] Persaud *et al.*, 1990 (26-week lactation period).
[e2] Persaud *et al.*, 1990 (38-week lactation period).
[f] Syrstad, 1966.
[h] Madgwick *et al.*, 1991 (Friesian and Jersey, pooled data).
[g1] Ahlbom & Dempfle, 1992 (First-calving Friesians).
[g2] Ahlbom & Dempfle, 1992 (First-calving Jerseys).
[1] ENE= Estimated Net Energy intake.
[2] DMI=Dry matter intake.
[3] FCM=Fat corrected milk (kg).
[4] FU_m=Feed Units for maintenance.

2.7. Cow feed efficiency and dairy farm productivity.

More than 35 years ago McMeekan (1956) stated that for a pasture-based dairy production system the three main determinants of high output per unit of area of farmland are pasture productivity, stocking rate and cow quality. The components of pasture productivity are the total amount of feed annually grown/ha, its content of nutrients (i.e. energy and protein) and its seasonal pattern of growth that should match as closely as possible the seasonal pattern of feed requirements of the dairy herd. The stocking rate (i.e. number of cows/ha/year) has a direct effect on the amount of feed grown that is actually harvested, and as such is a powerful management tool to increase dairy farm productivity. Finally, cow quality plays its role on the efficiency with which the feed eaten is transformed into milk (i.e. cow efficiency). For the New Zealand dairy industry the main determinants of cow quality are the cow's genetic merit for the production of milk and milk components and its body size (either assessed as live weight or as stature) (L.I.C., 1991).

2.7.1. Ranking cows according to efficiency.

The importance of cow size on efficiency of production on the New Zealand pasture-based system has been long recognized (Wallace, 1956 b), and more recently (Holmes *et al.*, 1993) the issue has taken renewed interest as more precise devices to assess the individual intake of free grazing dairy cows become available (Parker *et al.*, 1990), and also due to the recognition of a negative impact of genetically large dairy cows on total farm profitability (Ahlborn *et al.*, 1990; L.I.C., 1991). Cow size, and particularly its metabolic live weight ($LW^{0.75}$), can directly affect cow efficiency through effects on the maintenance component (Wallace, 1956 b; Holmes *et al.*, 1993).

Ranking cows according to efficiency on a pasture-based system without requiring an estimate of the cow's individual feed intake can be a very useful tool for management and selection purposes. Wallace (1956 b) suggested that dividing the total cow yield over the square of its chest girth (minimum circumference) gives a reasonable estimate of the relative efficiency of the cows in a herd, those animals with the higher values being the more efficient producers. By doing this, the farmer does not even need to obtain the cow's live weight. More recently, Holmes *et al.* (1993) suggested a 'feed conversion efficiency index' to rank cows within and across herds. The index is effectively a measure of the yield of milk energy per MJ ME eaten, and can be calculated from the data recorded on milk yield and composition and information about the cow's live weight, i.e.

$$\frac{\text{Yield of milk energy (M)}}{(\text{M} \times 1.5) + (\text{LW}^{0.75} \times 0.8)} \quad \ldots\ldots \quad 2.47$$

where the bottom line is an approximate estimate of the cow's total energy requirement, i.e. it is assumed feed energy is utilized for the synthesis of milk and tissue energy with an efficiency k_l of 66%, and the requirement for maintenance to be 0.8 MJ ME/LW$^{0.75}$/day.

2.7.2. Cow size and feed requirements.

The New Zealand Livestock Improvement Corporation (L.I.C.) in a recent publication (L.I.C., 1991) estimates that the effect of increasing the cows' live weight by 50 kg from 425 to 475 kg, increases the cow's annual feed requirement for maintenance by 200 kg DM. Assuming an average energy content of 11.0 MJ ME/kg pasture DM (Hutton, 1971) the increased DMI due to higher cow live weight is equivalent to a daily intake of about 12.0 MJ ME/100 kg live weight. From an experiment using large and small Friesians and Jersey cows either fed indoors or grazing, Holmes *et al.* (1993) calculated that an increase of 100 kg live weight (in the range 350 to 550 kg) was associated with an increased energy requirement of 15.0 MJ ME/day. The average calculated by Stakelum & Connolly (1987) from an experiment with large and small lactating Friesian cows (range of cows' live weight from 499 to 583 kg) fed indoors on fresh cut pasture was an increase of 2.2 kg DM/100 kg live weight. With an average M/D of 11.0 MJ/kg herbage DM, this increased DMI was equivalent to 24.2 MJ ME/day for each 100 kg extra live weight/cow.

The latter two estimates were calculated for lactating cows, and the one given in the L.I.C. (1991) publication does not specify if the estimate takes into account different maintenance feed requirements of cows during lactation and the dry period, as well as their relative contribution (i.e. days in milk and days dry) in each lactation cycle. From Table 2.8 (Section 2.4.1.3) lactating and non-lactating grazing cows required for maintenance purposes about 1.08 and 0.91 MJ MEI/$LW^{0.75}$/day, respectively. Assuming a lactation length of 262 days as typical of the New Zealand pasture-based dairy system (Ahlborn & Dempfle, 1992), a M/D of 11 MJ ME/kg herbage DM (Hutton, 1971) and a range in cow live weight between 350 and 550 kg, the maintenance cost of an extra 100 kg live weight/cow can be assessed as shown in the following table:

Table 2.19. Effect of an extra 100 kg live weight on the maintenance requirements of grazing dairy cows.

Cow live weight (kg)	Daily metabolizable energy intake (MEI, MJ ME/cow/day) or DM intake (DMI, kg DM/cow/day) required for maintenance during:					
	Lactation		The dry period		Average [1/]	
	MEI	DMI	MEI	DMI	MEI	DMI
350	87.4	7.9	73.6	6.7	83.5	7.6
450	105.5	9.6	88.9	8.0	100.8	9.2
550	122.7	11.2	103.4	9.4	117.2	10.7
Extra DM or ME intake for maintenance/100 kg LW [2/]					16.8	1.53

[1/] Weighted average for days of lactation (262) and days dry (103).

[2/] Calculated by linear regression of DMI or MEI on cow liveweight.

Thus, for cows in the range 350 to 550 kg LW, an extra 100 kg live weight on a pasture-based dairying system is equivalent to an increase in the cow's maintenance requirement of about 558 kg herbage dry matter/cow/year. This estimate agrees rather well with those summarized in Table 2.20. In spite of the assumptions made to derive these values, the estimates presented in Table 2.20 clearly show the effect that larger cow size has on increasing the ME_m. The important thing is that this extra dry matter ads up as the herd becomes larger (L.I.C., 1991).

Table 2.20. Effect of increasing live weight by 100 kg/cow on the energy (MJ ME) or dry matter (kg) required for maintenance of dairy cows, as reported by several authors in the literature.

Source	Extra energy (MJ MEI) or extra herbage dry matter intake (kg) required to maintain an extra 100 kg liveweight/cow:		
	MJ/day	kg DM/cow/day	kg DMI/cow/year
Cox *et al.*, 1956	12.9[2]	1.17	427
Holmes *et al.*, 1993	15.0	1.28[1]	470
Joyce *et al.*, 1975[4]	14.3	1.30[2]	475
L.I.C., 1991	12.0[2]	1.10	400
Stakelum & Connolly, 1987	24.2[2]	2.20	803
Wallace, 1956 b	17.2[2]	1.56	570
Calculated from this review[3]	16.8	1.53	558

1 From an herbage with 11.65 MJ ME/kg DM (Bhuvaneshwar, 1993);
2 Assuming 11 MJ ME/kg herbage DM;
3 Weighted average for days of lactation (262) and days dry (103) and assuming literature averages for ME_m (see Section 2.4.1.3, Table 2.8);
4 Grazing beef cattle.

2.7.3. Large size cows and dairy farm profitability.

In most dairy production systems feed is the largest variable cost for milk production (Østergaard *et al.,* 1990). Even for the New Zealand pasture-based dairying system, feed is also the largest expense on the farm. Feed costs comprise about 48% of farm working expenses and includes the cost of fertilizer, hay and silage making, and weed spraying (L.I.C., 1991). The New Zealand dairy farmer, through the stock and appropriate grazing management, aims at a high utilization of the amount of feed grown on the farm. Stocking rate plays a decisive role on the amount of feed grown that is actually harvested (Holmes & Parker, 1992), while the cows genetic merit for milk production largely dictates how much of the feed eaten is directed to the synthesis of milk and milk products. Cow size is a common component of both stocking rate and cow efficiency of production, and as such it has a direct effect on the overall farm productivity.

Larger cows require more food than smaller ones because they have higher maintenance requirements. Size and milk yield are positively genetically correlated (see Table 2.18) and larger cows tend to produce more milk and meat per animal, i.e. larger cull cows and bobby calves (Bryant & Macmillan, 1985). However, for a typical New Zealand dairy farm with fixed amount of physical resources such as land and often high cost of supplementary feeds, the extra feed required for growth and maintenance of larger cows often reduces the average stocking rate of the farm. In this way the negative impact of larger cows in farm profitability is through a reduction of the number of animals available for sale and the number of cows in the herd (Wickham, 1993).

The Livestock Improvement Corporation assessed the effect of cow size (live weight, kg) on dairy farm profitability (L.I.C., 1991). The results of the report indicate that for a 70 ha farm with 245 milking cows (stocking rate 3.5 cows/ha) with an average 425 kg live weight, producing 160 kg of milkfat/cow (560 kg MF/ha), an increase of 50 kg live weight/cow with no change in the average herd's genetic merit for milk production (i.e. payment breeding index) lead to a 5% reduction of the stocking rate (i.e. from 3.5 to 3.2 cows/ha), and an average total loss in farm income of $4421. On the other hand, an average reduction of 25 kg in the cow's live weight at the same payment BI lead to a 3% increase in the average farm stocking rate (i.e. from 3.5 to 3.6 cows/ha) and, a total gain in farm income of $2542.

The dairy sire evaluation system currently employed in New Zealand takes into consideration the production traits (i.e. fat, protein, volume), traits other than production (i.e. cow temperament, udders, etc.) and maintenance traits (i.e. the economic importance of cow's live weight) to calculate a single figure of the sire's breeding value called 'Total Breeding Index' (TBI). In this sense TBI is an estimate of the sire's breeding value for total farm profitability, is easy to use and is the most important breeding tool for the farmer (L.I.C., 1991).

From this review is evident that cow size is a very important component that directly affects the efficiency of the dairy cow. This effect is mainly due to the amount of ME directed to meet maintenance for cows differing in live weight. Thus, for pasture-based dairy production systems, cow size, through its effects on stocking rate and cow gross feed efficiency, can play a key role in determining overall farm profitability.

Chapter 3

Materials and methods

3.1. Location of the experimental area.

The experiment was carried out at the Dairy Cattle Research Unit, Massey University, from May the 22nd to June the 26th, 1992 .

3.2. Animals and treatments.

38 dry-pregnant cows in the range 190-230 days of gestation and averaging 5.8 years age were used. Of these, 28 cows were Holstein-Friesian differing in live weight (LW) and 10 were Jerseys. The Holstein group was further divided into two groups differing by approximately 100 kg in live weight.

Two levels of feeding were allowed:

(1) *ad libitum* level of feeding allowing for 1 kg maternal liveweight gain cow^{-1}day^{-1} (in addition to gain from conceptus), and

(2) a maintenance level of feeding.

(see section 3.5 for details)

This layout yielded six treatment groups not replicated. The Friesian groups were made up each of 7 cows and the Jersey groups of 5 cows each.

Big Friesians	*ad libitum*	GBF
Big Friesians	Maintenance	MBF
Small Friesians	*ad libitum*	GSF
Small Friesians	maintenance	MSF
Jersey	*ad libitum*	GJer
Jersey	Maintenance	MJer

3.3. Pastures.

Eleven paddocks from a predominantly ryegrass-white clover pasture were used. Six paddocks were used by the cows on the *ad libitum* level of feeding and the remaining five paddocks were used by the maintenance fed cows.

3.4. Experimental design.

A completely randomised block design with two treatments (two levels of feeding: 1 = *ad libitum*; 2 = maintenance) and three blocks given by three groups of non-lactating, pregnant dairy cows differing in live weight (1 = Big Friesians; 2 = Small Friesians; 3 = Jerseys) was utilized. Within each size, the cows were randomly allocated to their respective level of feeding. The average live weight (kg), metabolic weight ($LW^{0.75}$, kg), the stage of gestation and the number of cows per each treatment group at the start of the experimental period is presented in Table 3.1.

Table 3.1. Mean values (±S.E.) for live weight (kg), metabolic weight ($LW^{0.75}$, kg) and days since conception at the start of the experimental period for the different treatment groups.

Level of feeding	Size	n[1]	Live weight (kg)	Metabolic weight ($LW^{0.75}$, kg)	Days since conception
Ad libitum	Big Friesians	7	523 ± 13.7	109 ± 2.3	185 ± 6.5
	Small Friesians	7	417 ± 13.7	92 ± 2.3	182 ± 6.5
	Jerseys	5	363 ± 16.2	83 ± 2.7	176 ± 7.7
Maintenance	Big Friesians	7	530 ± 13.7	108 ± 2.3	181 ± 6.5
	Small Friesians	7	412 ± 13.7	91 ± 2.3	165 ± 6.5
	Jerseys	5	360 ± 16.2	81 ± 2.7	178 ± 7.7

[1] number of cows in each treatment group.

3.5. Calculation of herbage allowances.

The information from Table 3.1 was used to calculate the amount of dry matter required for each treatment group. Herbage dry matter allowance for cows in the maintenance level of feeding was calculated to meet maintenance and pregnancy. It was assumed that foetal growth at this stage of pregnancy was about 0.2 to 0.3 kg per day (Ferrel *et al.*, 1976 b). In contrast, herbage allowance for the *ad libitum* level of feeding was calculated to meet the requirement of 1 kg of maternal liveweight gain in addition to the requirement for maintenance and pregnancy.

Table 3.2 contains the calculated requirements for metabolizable energy (ME), herbage dry matter (DM) and the corresponding herbage DM allowance (HA) to meet these requirements. The calculations show that herbage allowance for the *ad libitum* level of feeding was about 2.25 times the amount offered to the maintenance level of feeding.

Table 3.2. Calculated requirements of ME (MJ/cow/day), DM (kg/cow/day) and HA (kg/cow/day) for each treatment group at the start of the experimental period.

Level of feeding	Size[1]	n[2]	ME required (MJ/cow/day)			Daily DM intake required (kg/cow)[5]	Daily herbage DM allowance required[6]	
			Mainte-nance+ preg-nancy[3]	Live weight gain[4]	Total		kg per cow	kg per group
Ad libitum	BF	7	77	50	127	11.5	17.0	119
	SF	7	66	50	116	10.6	16.0	112
	J	5	61	50	111	10.0	14.0	70
Maintenance	BF	7	77	0.0	77	7.0	8.0	56
	SF	7	66	0.0	66	6.0	7.0	49
	J	5	60	0.0	60	5.5	6.0	30

[1] BF = Big Friesians, SF = Small Friesians, J = Jersey.

[2] Number of cows per treatment group.

[3] Maintenance was assumed to be 0.6 MJ ME/kg $LW^{0.75}$, and pregnancy requiring about 11 MJ ME/day.

[4] For the gain of 1 kg of maternal liveweight/day.

[5] Assuming 11 MJ ME/kg pasture DM (Hutton, 1971).

[6] Cows in the *ad libitum* level of feeding were allowed about 1.45 times the daily DM intake required, and cows on the maintenance level of feeding were allowed about 1.15 times the daily DM intake required (Holmes & McLenaghan, 1980).

3.6. Grazing management.

Cows received only pasture during the trial and no drinking water was provided. The three groups of cows on one level of feeding were grazed side by side in the same paddock (Figure 1). Break grazing by using electric fences was utilised to achieve the desired level of pasture allowance. The cows spent 24 hours in their respective allowance, and every day each group of cows was given access to a new area of fresh pasture. A backfence was used to avoid regrazing of areas already utilised. The herbage allowance required per group (Table 3.2) was used to calculate the daily area required by each group of cows in the following way:

1) The per group herbage allowances were expressed as a ratio of the total allowance calculated within each level of feeding;
2) The ratios calculated in step one were used to calculate the width of the area allocated to each treatment group from paddocks on average 60 m width;
3) The per group herbage allowance together with an estimate of the pre-grazing herbage mass (t DM/ha) made with the rising plate meter were used to calculate the daily area required for each treatment group.

Table 3.3. Information used to calculate the daily areas required by each treatment group.

Level of feeding	Size[1]	n[2]	DM herbage allowance: Per treatment group (kg/day)[3]	DM herbage allowance: As a ratio of 1 within feeding level	Width of the break (m) from a paddock 60 m in width	Area required if pre-grazing herbage mass in paddock is 3.3 t DM/ha (m^2/group/day)	Length of the daily break (m)
Ad libitum	BF	7	119	0.40	24	363.6	15.3
	SF	7	112	0.37	22	339.4	15.3
	J	5	70	0.23	14	212.0	15.3
Maintenance	BF	7	56	0.41	25	169.7	6.8
	SF	7	49	0.36	22	148.5	6.8
	J	5	30	0.23	13	91.0	6.8

[1] BF=Big Friesians, SF= Small Friesians, J=Jerseys.
[2] number of cows per treatment group.
[3] Taken from Table 3.2.

Throughout the experimental period, the cows from each treatment group were grazed on ryegrass-white clover pasture, with an average pre-grazing herbage mass of about 3.3 t DM ha^{-1} (see Table 4.1 in Chapter 4). Break grazing with daily shifting of electric fences was used to manage the groups according to the layout presented in Figure 1.

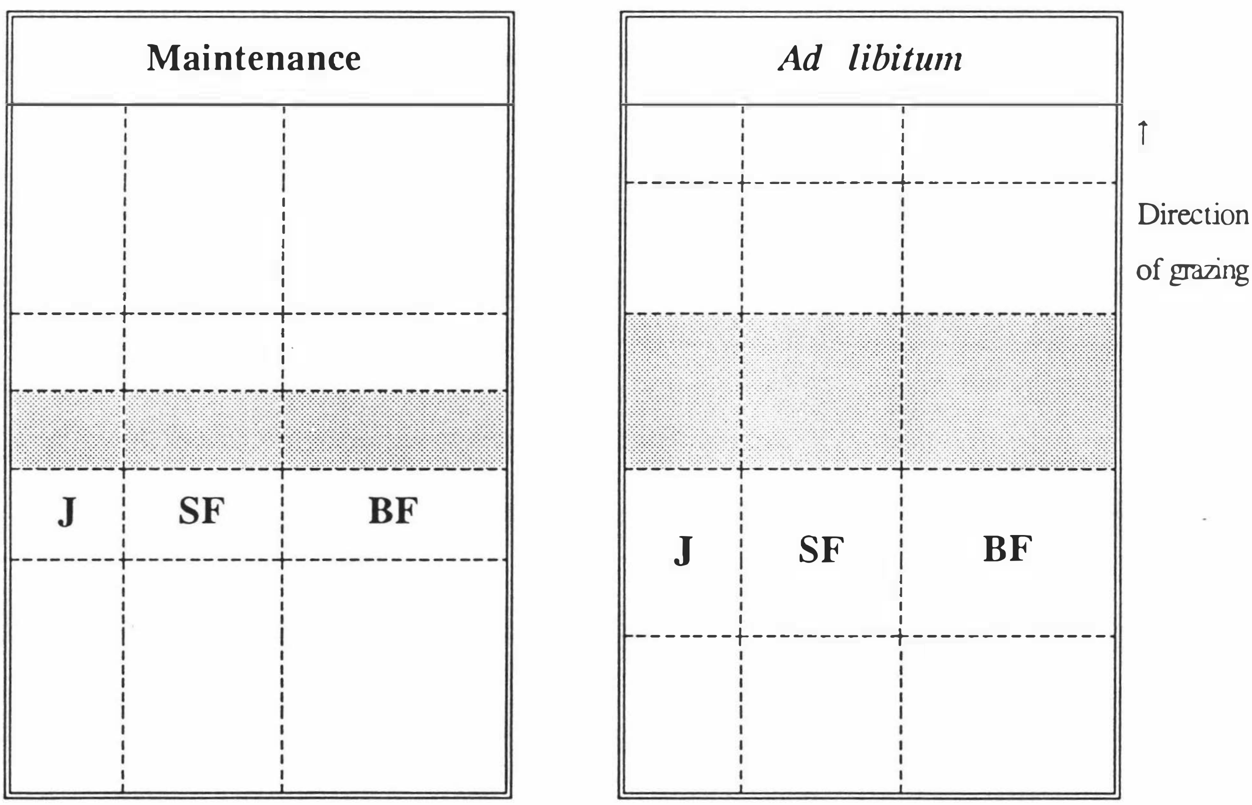

Fig. 1. Diagram of the paddocks being grazed by the herds in each treatment group; double lines represent boundary fences, broken lines represent temporary electric fences; first subdivision represent the area of pasture already utilized; second subdivision represent the area being grazed by the treatment groups [J= Jersey (5 cows); SF= Small Friesian (7 cows); BF = Big Friesian (7 cows)]. The shaded area corresponds to the area to be grazed the following day, and the following subdivision is an extra strip of pasture set up ahead of the cows.

3.7. Variables measured and generated in the experiment.

3.7.1. Live weight and condition score.

Four days before the experiment started and three days after the end of the experiment, all the cows were grazed together as a single herd at an allowance sufficient for maintenance in order to equalize gut fill. On both occasions each cow was individually weighed and condition scored using a scale 1 (very thin) to 10 (very fat) (Holmes & Wilson, 1987) by the same scorer and at the same time each morning. Each cow then had four weighings and four condition scores at the beginning, and three weighings and three condition scores at the end of the trial.

3.7.2. Cow age, previous calving date and days since conception.

Individual records for each cow provided information on cow age, date of the last mating and previous calving date. The latter two variables were used to calculate the average time of gestation during the experiment for each individual cow.

3.7.3. Pre-grazing and post-grazing herbage mass.

3.7.3.1. Herbage mass assessed by cutting.

On every third day a motorised sheep-shearing handpiece was used to cut at ground level 3 random quadrats from each of the six areas corresponding to each treatment group; the herbage was then washed and oven dried at 100 °C for 24 hr for determination of dry matter percentage.

3.7.3.2. Herbage mass assessed by plate meter.

Pre-grazing (PHM) and post-grazing or residual herbage mass (RHM) (t DM/ha) were also determined daily for each treatment group by taking 30 readings with a metallic square (40 x 40 cm) rising plate meter (Ashgrove, N.Z., LTD), as described by Holmes (1974) and Earle & McGowan (1979). For the determination of the daily areas to be grazed by each group of cows, the rising plate meter reading (PMR) was related to the standard equation (Holmes, pers. comm.):

$$\text{kg DM/ha} = 200 + 158 * \text{PMR}$$

However, for the final calculations of daily herbage allowance (HA) and daily herbage intake a final calibration equation relating plate meter reading (MR) with a value of herbage mass (kg dry matter/ha) was obtained using the following information:

1) The average herbage mass (HM, kg DM/ha) either as PHM or RHM obtained for each sampling day by cutting 3 random quadrats from each of the grazing areas allotted to the treatment groups, and

2) The average of the 30 PMR taken before and after grazing from each of the grazing areas before the cutting of the quadrats on the same days.

These respective averages were used to obtain a regression equation of herbage mass (HM) on plate meter reading (PMR) for the data collected in the current experiment, as shown below:

$$\text{HM (kg/DM/ha)} = \alpha + b \text{ PMR} \quad . \; . \; . \; . \; . \; 3.1.$$

The linear regression coefficient, *b*, in equation 3.1. represents the average increase in kg DM/ha of herbage mass per each unit increase in plate meter reading (see Figure 2 in Chapter 4).

3.7.4. Daily herbage allowance.

Herbage allowance for each treatment group was calculated retrospectively either from the pre-grazing herbage mass obtained by cutting the grass on every third day or on a daily basis by taking 30 readings with a rising plate meter and using the average of these 30 readings with the standard equation given in section 6.3.2. These daily calculations were used to maintain the desired herbage allowances for the treatment groups throughout the 41 days of experimental period.

3.7.5. Daily herbage intake.

Daily herbage intake for each treatment group was calculated from the PHM and the RHM, either calculated by cutting or by the calibration equation obtained for the rising plate meter (see also section 3.8).

3.7.6. Efficiency of grazing.

Efficiency of grazing was calculated using the estimates of pre-grazing and post-grazing herbage mass in the following way:

$$\text{Efficiency of grazing} = \frac{\text{Pre-grazing herbage mass - Post-grazing herbage mass}}{\text{Pre-grazing herbage mass}} \quad .. 3.2$$

3.7.7. Stocking density.

The daily stocking rate (cows/ha/24 hs) or stocking density was calculated from the number of cows per treatment group and the daily area allocated to each of these groups during the 41 days of the experimental period.

3.7.8. Herbage sampling and analysis.

On every third day and before the cow's daily move to a new area of fresh pasture, samples of pasture were plucked randomly from each of the six areas assigned to each treatment group. Samples were collected so as to simulate the height at which the corresponding group of cows had grazed the previous days area. These samples, labelled with the date, the treatment group and the corresponding paddock number, were bulked on a per paddock basis and stored into the freezer immediately after sampling for later analysis of total nitrogen, ash content, and *in vitro* digestibility. The *in vitro* determination of herbage digestibility was carried out according to the procedures described by Roughan and Holland (1977).

These analyses provided estimates of the predicted *in vivo* digestibility of the dry matter (IVDMD), *in vivo* digestibility of the organic matter (IVOMD), and *in vivo* digestibility of the digestible organic matter digestibility (IVDOMD). These results of herbage digestibility were used to calculate the energy content of the herbage (M/D) by means of the generalised equations given by Geenty & Rattray (1987). The herbage M/D value was calculated by using the following equation:

$$\text{MJ ME/kg DM} = 0.16 * \text{DOMD} \quad \ldots\ldots\ldots 3.3$$

where the DOMD value used in equation 3.3 was the one directly calculated from the digestibility analysis (IVDOMD).

3.8. Estimation of intake by individual cows from daily faecal output.

The initial plan was to estimate faecal output using chromium oxide (Cr_2O_3) in two periods, using controlled release Cr_2O_3 capsules (CRC) given to each cow. In the first period the CRC (Captec New Zealand Limited) was given on the 3rd day of the trial; twice daily faeces collection started seven days later and continued for eight days. However a high proportion of the CRC capsules were regurgitated by the cows; consequently in the second period all the cows in the experiment were dosed once a day at 08:00 hours with a chromium gelatin pill containing 10 g Cr_2O_3 (R.P. Sherer Pty Limited). The cows started their daily doses on day 20th of the trial; faeces collection started after a seven day stabilising period and continued for eight days. Faecal samples for each cow were collected twice daily in the field, one in the morning between 10:00 to 12:00 and the other in the afternoon between 3:00 to 5:00 pm. The daily faecal samples of each cow were stored in the freezer, sub-sampled and bulked on a per period basis. The concentration of chromium in the faeces was measured by means of atomic absorption spectroscopy according to the procedure described by Parker *et al.* (1989).

3.9. Statistical analysis.

Differences between the treatment groups were subjected to analysis of variance by making use of the procedure GLM of the SAS programme. For the variables derived either from individual animals (liveweight change, condition score change, age, days pregnant) or from the pasture (herbage mass, herbage dry matter allowance, herbage intake, metabolizable energy intake), least squares means were calculated for the main effects and the interaction by making use of the following two-way model equation:

$$y_{ijk} = \mu + F_i + S_j + FS_{ij} + \varepsilon_{ijk} \quad \ldots\ldots \; 3.6$$

Where y_{ijk} is the kth value of any of the response variables (either derived from individual animals or from the pasture) listed above, belonging to the jth size in the ith feeding level; F_i is the effect of the ith feeding level (1 = *Ad libitum*, 2 = maintenance); S_j is the effect of the jth size (1= Big Friesians, 2= Small Friesians, 3=Jerseys), FS_{ij} is the interaction term, and ε_{ijk} is residual associated with each observation of any of the response variables. Except the error term, all the effects considered in model equation 3.6 were regarded as fixed.

Following Conniffe (1976) and Johnstone (1979), the analysis of variance for the variables derived from individual animals was carried out considering each individual cow within a treatment group as the experimental unit, and analysing the information as a randomised block design. Appendix I shows how the F tests for the main effects (i.e. feeding level and size) and the interaction term were accomplished. For the variables derived from the pasture assessments the analysis of variance was carried out using the day to day variation in the measurements as an estimate of the error term.

Finally, from the results obtained from the analyses of variance for both the pasture and the animal related variables, regression analyses were carried out to partition the intake of dry matter or metabolizable energy into maintenance and liveweight change or condition score change for non-lactating pregnant cows differing in live weight. The results of such analyses were used to assess the effect of an extra 100 kg in the cow's live weight on its feed requirements for maintenance, and on the amount of extra pasture required on farms stocked with heavier cows.

Chapter 4

Results

4.1. Introduction.

The information generated in this experiment has been used for the following two purposes:

i) Primarily to investigate differences in feed requirements of non-lactating dairy cows which differed in live weight,

ii) And also to assess the effect of cow live weight on the amount of feed required on pasture based systems.

The results are presented under five main headings corresponding to (1) the estimation of herbage dry matter intake or metabolizable energy intake and the variables derived from the pasture, (2) the variables derived from the animals' performance, (3) the calculation of daily feed requirements of pregnant, non-lactating grazing dairy cows differing in live weight, (4) the calculation of feed requirements using the pooled information generated in the experiment, and (5) the estimation of the effect of increasing the cow's live weight by 100 kg on its daily feed requirements for maintenance.

4.2. Estimation of herbage dry matter intake.

The daily herbage dry matter intake was estimated by using the following three techniques: (1) by using chromic oxide (Cr_2O_3) as an indigestible marker to assess the daily faecal output (FO) of individual cows; (2) by cutting three random quadrats every third day from the grazing areas allocated to each treatment group, or (3) by assessing both the PHM and the RHM using the plate meter every day.

4.2.1. Estimation of daily faecal output using chromium oxide (Cr_2O_3).

Daily faecal output and hence dry matter intake from each individual cow could not be measured during the first period because most of the cows regurgitated their chromium capsule. During the second period of assessment, each cow was dosed once a day with a single chromium gelatin pill. The concentration of chromium appearing in the faeces collected was too small as to give realistic figures of daily faecal output. The remaining of the analyses, therefore, refers to the estimation of average group intakes assessed by combining the results of cutting with the plate meter readings.

4.2.2. Estimation of daily herbage DM intake by the plate meter.

The averages for PHM and RHM (tonne DM/ha) calculated by cutting three quadrats every third day from the grazing areas allocated to each treatment group are presented in Appendix II. This information on herbage mass (HM) was used together with the average of 30 plate meter readings (PMR) taken before and after grazing from the same areas on the same days to obtain a calibration equation, which related the HM to PMR. Figure 2 shows the relationship between these two variables. In this case PHM and RHM each with their corresponding average PMR are plotted together. The best description of the data was obtained by fitting the following two regression equations (Appendices III-3.12 and III-3.13) one for each level of feeding:

Y_1 = 158.0 (s.e.12.7) PMR + 764.0 (s.e. 212) . . . . 4.1.
(r = 0.79; C.V. = 29.3%; r.s.d.= 845 kg; P<0.0001)

Y_2 = 171.0 (s.e. 3.5) PMR . . . . 4.2.
(r = 0.98; C.V. = 21.6%; r.s.d. = 442 kg; P<0.0001)

where Y_1 and Y_2 are herbage mass (pre-grazing and post-grazing) for the *ad libitum* and the maintenance level of feeding respectively, and PMR is the average reading (cm) obtained with the rising plate meter. These regression equations are plotted in Figure 2. The major effect of level of feeding was to change the regression intercept by +764 kg

DM/ha for the *ad libitum* level of feeding. However, the slopes of the two lines were not significantly different from each other. This is not an unexpected result due to the fact that cows on each level of feeding were grazed on a different set of paddocks with significantly different PHM and RHM (see Chapter 3, section 3.3).

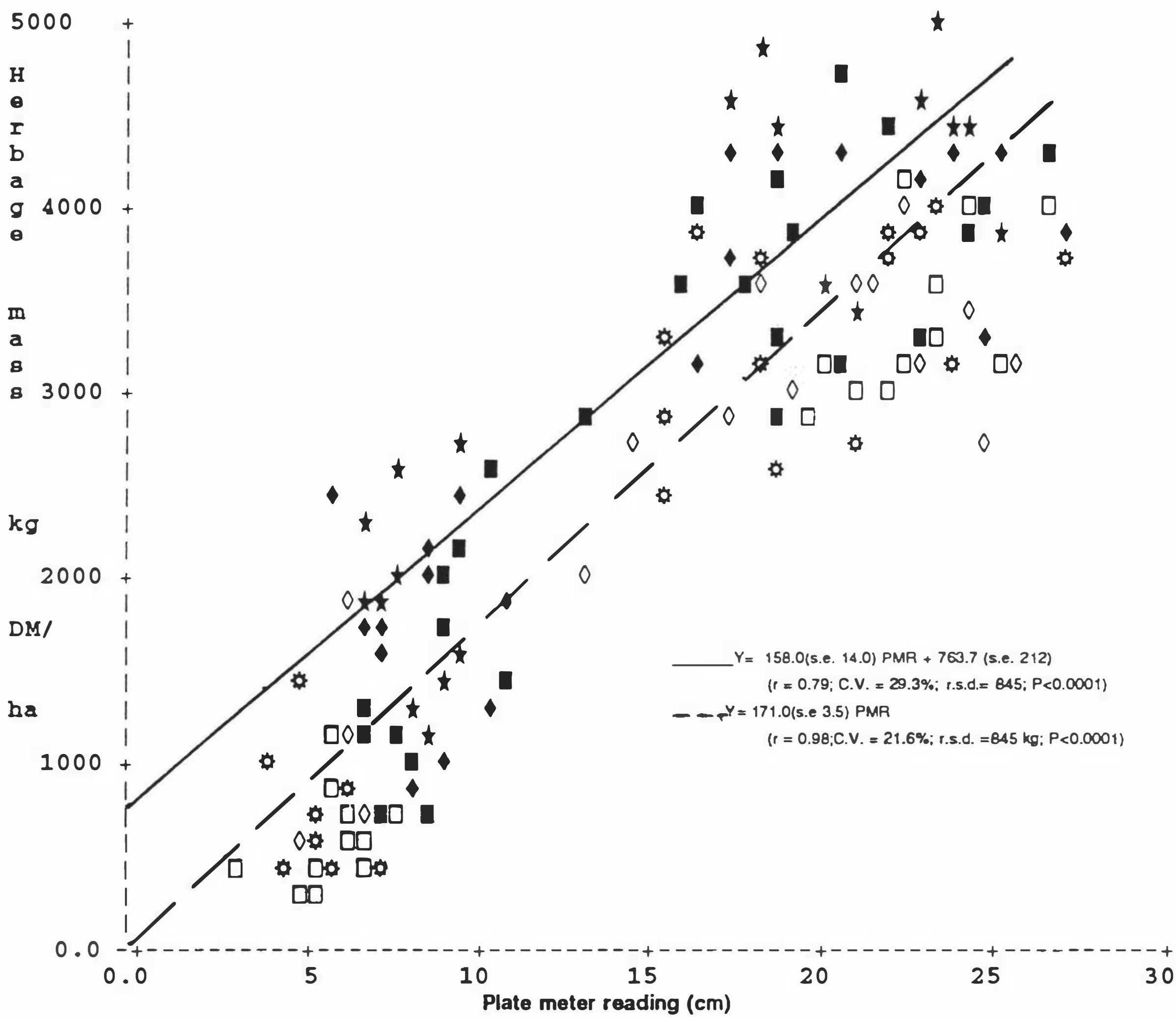

Fig. 2. Relationship between plate meter reading (cm) and herbage mass (kg DM/ha) pre and post-grazing assessed by cutting. Each symbol represents a daily observation of a treatment group for Big Friesians: □,■; Small Friesians: ◊,♦, or Jersey cows: ✿,★, fed at maintenance or *ad libitum*, respectively. The broken regression line corresponds to the maintenance level of feeding and the continuous regression line to the *ad libitum* level of feeding.

These calibration equations were then used within each level of feeding to assess the PHM, the RHM, the daily herbage allowance, and the daily herbage intake for each treatment group from their corresponding average plate meter reading. Assessed in this way, the estimated daily herbage dry matter intake refers to the average herbage disappearance rate for each treatment group.

4.2.2.1. Pre-grazing and post-grazing herbage mass.

The least square means with their corresponding standard errors obtained from the analysis of variance (Appendices IV-4.1 and IV-4.2) for PHM and RHM, averaged across paddocks, are presented in Table 4.1. The PHM of the paddocks allocated to the *ad libitum* fed cows was significantly higher (P<0.05) than that of those allocated to the maintenance fed cows. As expected, cows fed *ad libitum* left behind higher RHM (P<0.001). On average cows fed *ad libitum* left behind 1.7 t DM/ha from paddocks with an average PHM of 3.7 t DM/ha, compared with only 0.784 t DM/ha left behind by the cows on the maintenance level of feeding grazed on paddocks with an average PHM of 3.2 t DM/ha.

Table 4.1. Least squares means and standard errors for pre-grazing and post-grazing herbage mass (t DM/ha) for each treatment group during the experimental period.

Feeding level	Size	n[1]	Herbage mass (t DM/ha)[2]	
			Pre-grazing	Post-grazing
A. *Ad libitum*	Big Friesians	7	3.72 ± 0.073^a	1.73 ± 0.026^a
	Small Friesians	7	3.65 ± 0.086^a	1.71 ± 0.030^a
	Jerseys	5	3.70 ± 0.076^a	1.70 ± 0.027^a
B. Maintenance	Big Friesians	7	3.40 ± 0.073^b	0.783 ± 0.026^b
	Small Friesians	7	3.16 ± 0.072^c	0.813 ± 0.025^b
	Jerseys	5	3.03 ± 0.073^c	0.754 ± 0.026^b
Significance of the difference[3]				
Main effects: Feeding level			A>B*	A>B ***
Size			NS	NS
Individual treatments[4]				
Interaction			NS	NS

[1] Number of cows on each treatment group.
[2] Calculated from 41 pasture assessments made with the rising plate meter.
[3] * =P<0.05; **= P<0.01; ***= P<0.001; ****=P<0.0001; NS = Not significant.
[4] Means in the same column with different superscripts are different (P<0.05).

4.2.2.2. Herbage dry matter allowance.

The daily herbage dry matter allowance was calculated as described in Chapter 3. The estimate was obtained from the herbage mass (kg DM/ha) calculated from the plate meter assessment, the number of cows in each treatment group and an estimate of the daily area (m^2) allocated for each treatment group. The least squares means with their corresponding standard errors obtained from the analysis of variance (Appendices IV-4.3, IV-4.4 and IV-4.5) for herbage allowance expressed as kg DM/cow/day, kg DM/100 kg live weight/day, or as g DM/$LW^{0.75}$ are presented in Table 4.2. From these results could be calculated that cows on the *ad libitum* level of feeding were offered more than twice (i.e. 19.6 *vs* 9.5 kg DM/cow/day) the amount of herbage DM allowed to the maintenance fed cows ($P<0.001$). Big Friesians were offered more herbage DM than Jerseys ($P<0.05$) when herbage allowance was expressed as kg DM/cow/day. However, after herbage DM allowance had been scaled either by live weight or metabolic weight the significant effect of size and that of the interaction were removed.

Table 4.2. Least squares means and standard errors for daily herbage dry matter allowance (HA) for each treatment group during the experimental period (HA expressed either as kg DM/cow/day, kg DM/100 kg live weight or g DM/$LW^{0.75}$).

Feeding level	Size[1]	Daily herbage dry matter allowance[2]		
		kg/cow	%LW	g/kg $LW^{0.75}$
A. *Ad libitum*	BF	22.5 ± 0.29^a	4.0 ± 0.06^b	196 ± 2.3^a
	SF	19.3 ± 0.34^b	4.3 ± 0.07^a	197 ± 3.5^a
	J	17.1 ± 0.30^c	4.5 ± 0.07^a	198 ± 3.1^a
B. Maintenance	BF	11.0 ± 0.29^d	2.0 ± 0.06^c	97 ± 3.0^b
	SF	9.6 ± 0.29^e	2.2 ± 0.06^c	101 ± 2.9^b
	J	7.7 ± 0.29^f	2.4 ± 0.06^c	92 ± 3.0^b
Significance of the difference[3]				
Main effects: Feeding level		A>B **	A>B**	A>B **
Size		BF>J *	NS	NS
Individual treatments[4]				
Interaction		*	NS	NS

[1] BF= Big Friesians (7 cows in each treatment group); SF= Small Friesians (7 cows in each treatment group); J= Jerseys (5 cows in each treatment group).
[2] Calculated from 41 pasture assessments made with the rising plate meter.
[3] * =P<0.05; **= P<0.01; ***= P<0.001; ****=P<0.0001; NS = Not significant.
[4] Means in the same column with different superscripts are different (P<0.05).

4.2.2.3. Apparent herbage dry matter intake (average for each treatment group).

The results of the analysis of variance (Appendices IV-4.9, IV-4.10 and IV-4.11) are presented in Table 4.3. Cows on the *ad libitum* level of feeding ate about 47% more DM/cow/day (i.e. 10.5 *vs* 7.0 kg DM/cow/day) than those on the maintenance level of feeding ($P<0.01$). Differences in herbage intake (kg DM/cow) due to size were highly significant with heavier cows eating more than smaller ones. After the scaling of DMI either by live weight or metabolic weight differences between levels of feeding still remained but the differences in intake due to size were removed.

Table 4.3. Least squares means and standard errors for herbage dry matter intake (DMI) for each treatment group (DMI expressed as kg DM/cow/day, kg DM/100 kg live weight, and as g DM/LW$^{0.75}$/day).

Feeding level		Size[1]	Daily herbage dry matter intake[2]		
			kg/cow	%LW	g/kg LW$^{0.75}$
A. *Ad libitum*		BF	12.0 ± 0.26^{a}	2.1 ± 0.05^{b}	104 ± 2.6^{a}
		SF	10.2 ± 0.30^{b}	2.7 ± 0.07^{ab}	105 ± 3.0^{a}
		J	9.2 ± 0.26^{c}	3.1 ± 0.06^{a}	106 ± 2.7^{a}
B. Maintenance		BF	8.4 ± 0.26^{d}	1.7 ± 0.06^{c}	74 ± 2.6^{b}
		SF	7.1 ± 0.25^{e}	2.0 ± 0.05^{c}	75 ± 2.6^{b}
		J	5.8 ± 0.26^{f}	1.9 ± 0.06^{c}	69 ± 2.6^{b}
Significance of the difference[3]					
Main effects:	Feeding level		A>B**	A>B**	A>B**
	Size		BF>SF ***	NS	NS
			BF>J ***		
			SF>J **		
Individual treatnents[4]					
Interaction			NS	NS	NS

[1] BF= Big Friesians (7 cows in each treatment group); SF= Small Friesians (7 cows in each treatment group); J= Jerseys (5 cows in each treatment group).

[2] Calculated from 41 pasture assessments made with the rising plate meter.

[3] * =P<0.05; **= P<0.01; ***= P<0.001; ****=P<0.0001; NS = Not significant.

[4] Means in the same column with different superscripts are different (P<0.05).

4.2.2.4. Efficiency of grazing, daily area and stocking density.

The least squares means for daily area (m^2/cow/day), daily stocking rate or stocking density (cows/ha/24 h) and efficiency of grazing (%) are presented in Table 4.4. Cows fed *ad libitum* were offered significantly much larger (P<0.01) areas (53 m^2/cow/day) than those fed at maintenance (29 m^2/cow/day). Similarly the stocking density of 347 cows/ha/24 h for the maintenance fed cows was much higher (P<0.005) than the 191 cows/ha/24 h of the *ad libitum* fed cows. Moreover, within level of feeding lighter cows were offered smaller areas of pasture (P<0.01) and tended to graze at significantly higher stocking densities (P<0.01). Efficiency of grazing was very similar between treatment groups within the *ad libitum* level of feeding, but it was higher (P<0.05) for Big Friesians than for Jerseys within maintenance level of feeding (P<0.05). Between levels of feeding, the maintenance fed cows achieved a higher efficiency of grazing of 75% than the 53% achieved by the *ad libitum* fed cows (P<0.01) (Appendices IV-4.12, IV-4.16).

Table 4.4. Least squares means and standard errors for daily area (m^2/cow), stocking density (cows/ha/24 hours) and efficiency of grazing (%).

Feeding level		Size[1]	Daily Area[2] (m^2/cow)	Stocking[2] Density (cows/ha/24 h)	Efficiency of grazing (%)
A. *Ad libitum*		BF	61 ± 1.08^a	166 ± 5.0^a	53.0 ± 0.97^b
		SF	54 ± 0.86^b	190 ± 5.9^b	52.7 ± 1.15^b
		J	47 ± 0.83^c	216 ± 5.2^c	53.3 ± 1.01^b
B. Maintenance		BF	33 ± 0.54^d	312 ± 5.0^d	76.4 ± 0.97^a
		S	31 ± 0.66^d	334 ± 4.9^e	73.6 ± 0.96^b
		J	26 ± 0.30^e	393 ± 5.0^f	74.5 ± 0.97^{ab}
Significance of the difference[3]					
Main effects:	Feeding level		A>B**	A>B**	A>B****
	Size		NS	J>BF*	NS
Individual treatments[4]					
Interaction			****	**	NS

[1] BF= Big Friesians (7 cows in each treatment group); SF= Small Friesians (7 cows in each treatment group); J= Jerseys (5 cows in each treatment group).
[2] Calculated from 41 assesements of daily area or stocking density.
[3] * =P<0.05; **= P<0.01; ***= P<0.001; ****=P<0.0001; NS = Not significant.
[4] Means in the same column with different superscripts are different (P<0.05).

4.3. Estimation of metabolizable energy allowance and ME intake.

4.3.1. Herbage digestibility and ME content.

Table 4.5 presents the results of the *in vitro* digestibility analyses of the herbage samples and the calculated ME content of the herbage dry matter derived from them. The results are presented for each paddock as values for the herbage samples bulked within each paddock. The energy content of the herbage dry matter was calculated as described in Chapter 3.

Table 4.5. Herbage organic matter content (OM, %), nitrogen content (N, %), predicted *in vivo* digestibility of the dry matter (DMD, %), predicted *in vivo* digestibility of the organic matter expressed as a proportion of the dry matter (DOMD, %) and predicted *in vivo* digestibility of the organic matter (OMD, %).

Feeding level	Paddock number	OM (%)	N (%)	DMD (%)	DOMD (%)	DOM (%)	ME (MJ/kg DM)
Ad libitum	02	87.7	3.6	78.7	70.6	80.8	11.5
	04	88.6	3.4	81.6	73.3	83.2	11.2
	32	86.3	3.5	76.5	68.6	79.4	11.6
	34	88.4	4.1	79.7	71.6	81.3	11.2
	56	88.7	3.5	77.3	70.0	79.5	11.5
	57	89.0	3.5	80.0	72.5	82.0	11.5
Maintenance	03	86.1	3.2	79.0	70.0	80.6	11.9
	05	87.7	3.5	79.7	71.3	81.6	11.7
	08	86.5	4.2	76.2	68.1	78.8	11.4
	09	87.7	3.6	78.7	70.6	80.8	11.7
	10	87.7	3.6	78.7	70.6	80.8	11.5
			Mean±S.E.				
Ad libitum		88.1	3.63	79.0	71.0	81.0	11.4
		±0.4	±0.1	±0.8	±0.7	±0.6	±0.07
Maintenance		87.1	3.60	78.4	70.0	80.5	11.6
		±0.3	±0.16	±0.6	±0.5	±0.5	±0.08
Total		87.7	3.61	78.7	70.6	80.8	11.5
		±0.3	±0.08	±0.5	±0.5	±0.4	±0.06

4.3.2. Metabolizable energy allowance.

The least squares means for the daily metabolizable energy allowance (MEA) obtained from the analysis of variance (Appendices IV-4.6, IV-4.7 and IV-4.8) are presented in Table 4.6. Cows on the *ad libitum* level of feeding were offered a significantly higher ($P<0.001$) MEA of 2.3 MJ ME/LW$^{0.75}$/day compared with only 1.1 MJ ME/LW$^{0.75}$/day offered to cows on the maintenance level of feeding. Big Friesians were offered higher ($P<0.05$) MEA than Jersey when MEA was expressed as MJ/cow/day. However, within level of feeding after the data had been scaled by metabolic weight the significant effect of size and that of the interaction were removed. Within the *ad libitum* level of feeding MEA (MJ/LW$^{0.75}$/day) was similar for the three treatment groups; within the maintenance level of feeding, however, the Small Friesians had significantly higher MEA than Jerseys but similar to Big Friesians.

Table 4.6. Least squares means and standard errors for metabolizable energy allowance (MEA) for each treatment group (MEA expressed as MJ/cow/day, MJ/100 kg LW or MJ/LW$^{0.75}$).

		Daily metabolizable energy allowance		
Feeding level	Size[1]	MJ/cow	MJ/100 kg LW	MJ/ kg LW$^{0.75}$
A. *Ad libitum*	BF	259.6 ± 3.3^{a}	46.7 ± 0.73^{c}	2.27 ± 0.033^{a}
	SF	223.3 ± 3.9^{b}	49.6 ± 0.86^{b}	2.29 ± 0.039^{a}
	J	198.7 ± 3.5^{c}	52.0 ± 0.76^{a}	2.30 ± 0.035^{a}
B. Maintenance	BF	125.6 ± 3.3^{d}	23.0 ± 0.73^{e}	1.10 ± 0.033^{bc}
	SF	109.7 ± 3.3^{e}	25.3 ± 0.72^{d}	1.15 ± 0.033^{b}
	J	88.6 ± 3.3^{f}	23.8 ± 0.73^{de}	1.04 ± 0.033^{c}
Significance of the difference[2]				
Main effects:	Feeding level	A>B**	A>B**	A>B***
	Size	BF>J*	NS	NS
Individual treatments[4]				
Interaction		***	**	NS

[1] BF= Big Friesians (7 cows in each treatment group); SF= Small Friesians (7 cows in each treatment group); = Jerseys (5 cows in each treatment group).

[2] * =P<0.05; **= P<0.01; ***= P<0.001; ****=P<0.0001; NS=Not significant.

[4] Means in the same column with different superscripts are different (P<0.05).

4.3.3. Metabolizable energy intake.

The results of the analysis of variance (Appendices IV-4.13, IV-4.14, and IV-4.15) for the daily intake of metabolizable energy (MEI) achieved by each treatment group are presented in Table 4.7. MEI was expressed either as MJ/day, MJ/100 kg LW/day or as MJ/kg $LW^{0.75}$/day. Cows on the *ad libitum* level of feeding had a higher ($P<0.01$) estimated MEI of 1.21 MJ ME/$LW^{0.75}$/day compared with only 0.82 MJ ME/$LW^{0.75}$/day achieved by those cows in the maintenance level of feeding. Heavier cows had significantly higher daily MEI than lighter cows when MEI was expressed as MJ/cow/day, but the difference was removed when MEI was scaled either by live weight or metabolic weight.

Table 4.7. Least squares means and standard errors for metabolizable energy intake (MEI) (MEI given as MJ/cow/day, MJ/100 kg LW or MJ/$LW^{0.75}$).

		Daily metabolizable energy intake		
Feeding level	Size[1]	MJ/cow	MJ/100 kg LW	MJ/$LW^{0.75}$
A. *Ad libitum*	BF	138.0 ± 3.0^{a}	25.0 ± 0.66^{b}	1.20 ± 0.030^{a}
	SF	118.0 ± 3.5^{b}	26.3 ± 0.78^{ab}	1.21 ± 0.036^{a}
	J	106.0 ± 3.1^{c}	28.0 ± 0.69^{a}	1.23 ± 0.031^{a}
B. Maintenance	BF	96.5 ± 3.0^{d}	17.6 ± 0.66^{c}	0.85 ± 0.030^{b}
	SF	81.4 ± 2.9^{e}	18.8 ± 0.65^{c}	0.85 ± 0.030^{b}
	J	66.4 ± 3.0^{f}	18.0 ± 0.66^{c}	0.78 ± 0.030^{b}
Significance of the difference[2]				
Main effects:	Feeding level	A>B***	A>B*	A>B**
	Size	BF>SF*** BF>J *** SF>J**	NS	NS
Individual treatments[4]				
Interaction		NS	NS	NS

[1] BF=Big Friesians (7 cows in each treatment group); SF= Small Friesians (7 cows in each treatment group);J= Jerseys (5 cows in each treatment group).

[2] * =P<0.05; **= P<0.01; ***= P<0.001; ****=P<0.0001; NS=Not significant.

[3] Means in the same column with different superscripts are different (P<0.05).

4.4. Variables derived from the animals' performance.

4.4.1. Cow age and stage of pregnancy.

The results of the analysis of variance for cow age and days since conception are presented in Table 4.8, and Appendix VII gives the individual values for each cow. For days since conception there were no significant differences either between feeding levels or sizes; for cow age, however, Big Friesians were significantly older than Small Friesians (P<0.05).

Table 4.8. Least squares means and standard errors for cow age and days since conception for each group of cows during the experimental period.

Feeding level		Size[1]	Cow age (years)	Days pregnant
A. *Ad libitum*		BF	6.95 ± 0.55^{ab}	205 ± 6^{a}
		SF	4.39 ± 0.55^{c}	202 ± 6^{ab}
		J	5.63 ± 0.66^{bc}	196 ± 8^{ab}
B. Maintenance		BF	8.12 ± 0.55^{a}	201 ± 6^{ab}
		SF	4.23 ± 0.55^{c}	185 ± 6^{b}
		J	5.43 ± 0.66^{bc}	198 ± 8^{ab}
Significance of the difference[3]				
Main effects:	Feeding level		NS	NS
	Size		BF>SF*	NS
Individual treatments[4]				
Interaction			NS	NS

[1] BF = Big Friesians; SF = Small Friesians; J = Jersey.
[2] Number of cows per treatment group.
[3] *= P<0.05; ** = P<0.01; *** = P<0.001; **** = P<0.0001; NS = Not significant.
[4] Means in the same column with different superscripts are different (P<0.05).

4.4.2. Liveweight change.

The results of the analysis of variance for initial live weight (ILW) (kg/cow) final live weight (FLW) (kg/cow), total liveweight gained (kg/cow) during the 41 days of experimental period (ΔLW), and the corresponding average daily liveweight gain (LWG) (kg/cow) for cows in each treatment group are given in Table 4.9. Appendix V gives the corresponding individual values for each cow. The results of the analyses indicated no differences between sizes in either ΔLW or LWG; however, cows on the *ad libitum* level of feeding gained twice the amount of liveweight gained by the cows on the maintenance level of feeding ($P<0.05$). On average, cows fed *ad libitum* gained about 57 kg/cow during the 41 days the experiment lasted, compared with only 32 kg/cow for cows in the maintenance level of feeding. The corresponding figures for LWG were 1.38 and 0.78 kg/cow/day for the *ad libitum* and the maintenance level of feeding, respectively.

Within each level of feeding Big Friesians and Small Friesians tended to have similar rates of liveweight gain and significantly higher than the Jerseys. As expected, due to the random allocation of cows from each size-group to the treatment groups, differences in initial live weight were not significant, but highly significant between sizes for both initial and final live weight.

Table 4.9. Least squares means and standard errors for initial live weight, final live weight, total liveweight change, and daily liveweight gain (kg/cow, unadjusted for pregnancy) during the experimental period.

Feeding level	Size[1]	Initial LW (kg)	Final LW (kg)	ΔLW (kg)	Daily LWG (kg)
A. *Ad libitum*	BF	523 ± 13.7^a	588 ± 14.7^a	65 ± 4.3^a	1.59 ± 0.10^a
	SF	417 ± 13.7^b	483 ± 14.7^b	66 ± 4.3^a	1.60 ± 0.10^a
	J	363 ± 16.2^c	402 ± 17.4^c	39 ± 5.0^b	0.95 ± 0.12^b
B. Maintenance	BF	530 ± 13.7^a	567 ± 14.7^a	37 ± 4.3^b	0.90 ± 0.10^b
	SF	412 ± 13.7^b	452 ± 16.0^b	35 ± 4.6^b	0.86 ± 0.10^b
	J	360 ± 16.2^c	384 ± 17.4^c	23 ± 5.0^c	0.57 ± 0.12^c
Significance of the difference[2]					
Main effects:	Feeding level	NS	A>B*	A>B*	A>B*
	Size	BF>SF***	BF>SF***	NS	NS
		BF>J ***	BF>J****		
		SF>J **	SF>J**		
Individual treatments[3]					
Interaction		NS	NS	NS	NS

[1] BF= Big Friesians (7 cows in each treatment group); SF= Small Friesians (7 cows in each treatment group); J= Jerseys (5 cows in each treatment group).
[2] * =P<0.05; **= P<0.01; ***= P<0.001; ****=P<0.0001; NS = Not significant.
[3] Means in the same column with different superscripts are different (P<0.05).

4.4.3. Condition score change.

The results for initial cow condition score (ICS), final cow condition score (FCS), total condition score change during the 41 days of experimental period (ΔCS), and average daily CS gain (CSG) for each treatment group are summarized in Table 4.10. The individual cow values for each of these variables are given in Appendix VI. The results of the analysis of variance indicated no differences for either ICS or FCS due to feeding level or size. In contrast, both ΔCS and CSG were higher ($P<0.05$) for the *ad libitum* fed cows. On average, cows fed *ad libitum* gained 1.12 CS units compared with only 0.41 CS units gained by cows on the maintenance level of feeding.

Table 4.10. Least squares means and standard errors for initial condition score, final condition score, total condition score change and average daily condition score gain during the experimental period.

Feeding level	Size[1]	Initial CS	Final CS	ΔCS	Daily CSG
A. *Ad libitum*	BF	4.9 ± 0.17^{a}	6.2 ± 0.28^{a}	1.3 ± 0.17^{a}	0.031 ± 0.004^{a}
	SF	4.5 ± 0.17^{ab}	5.5 ± 0.28^{ab}	1.0 ± 0.17^{ab}	0.024 ± 0.004^{ab}
	J	4.3 ± 0.20^{b}	5.4 ± 0.33^{ab}	1.1 ± 0.20^{a}	0.026 ± 0.005^{a}
B. Maintenance	BF	4.6 ± 0.17^{ab}	4.8 ± 0.28^{b}	0.26 ± 0.17^{b}	0.006 ± 0.004^{b}
	SF	4.5 ± 0.17^{ab}	5.0 ± 0.30^{b}	0.48 ± 0.19^{b}	0.011 ± 0.004^{b}
	J	4.3 ± 0.20^{b}	4.8 ± 0.33^{b}	0.50 ± 0.20^{b}	0.012 ± 0.005^{b}
Significance of	the difference[2]				
Main effects:	Feeding level	NS	NS	A>B*	A>B*
	Size	NS	NS	NS	NS
Individual treatments[3]					
Interaction		NS	NS	NS	NS

[1] BF=Big Friesians (7 cows in each treatment group); SF= Small Friesians (7 cows in each treatment group);J=Jerseys (5 cows in each treatment group).
[2] * =$P<0.05$; **= $P<0.01$; ***= $P<0.001$; ****=$P<0.0001$; NS = Not significant.
[3] Means in the same column with different superscripts are different ($P<0.05$).

4.5. Relationship between ΔCS and liveweight change.

Liveweight change and condition score change were the only two variables in this experiment that provided both individual cow data and group means data. The regression of total liveweight change (kg/cow) (ΔLW) on total condition score change (CS units/cow) (ΔCS) during the experimental period (Appendices III-3.3, III-3.4 and III-3.5) using individual cow data yielded the following equations for each size-group:

Big Friesians:	$\Delta LW = 37.8 + 17.3\ \Delta CS$ ($r = 0.59$; $P<0.02$)	4.3
Small Friesians:	$\Delta LW = 39.3 + 16.3\ \Delta CS$ ($r = 0.52$ $P<0.05$)	4.4
Jerseys:	$\Delta LW = 16.2 + 18.9\ \Delta CS$ ($r = 0.67$ $P<0.03$)	4.5

The equations for Big Friesians and Small Friesians were not statistically different from each other. However, they both were different to that calculated for the Jersey group. The three equations had similar slope but the Jerseys had a significantly lower intercept. For comparative purposes with other studies where both Friesian and Jersey cows were used, a pooled regression equation for individual cow data without regard to size and one using group means were also calculated (Appendices III-3.6 and III-3.7). These equations are presented below:

Pooled regression:	$\Delta LW = 33.0 + 17.0\ \Delta CS$ ($r = 0.51$; $P<0.001$) . .	4.6
Regression using group means:	$\Delta LW = 52.7\ \Delta CS$ ($r = 0.95$; $P<0.001$) . . .	4.7

These regression equations are plotted in Figure 3(a) and 3(b). From these results, the gain of one CS unit was equivalent to 55.1 kg ΔLW for Big Friesians, 55.6 kg ΔLW for Small Friesians and 35.0 kg ΔLW/Δ one CS unit for Jerseys. The pooled regression yielded an estimate of 50 kg and the regression using group means one of 52.7 kg ΔLW/ΔCS unit.

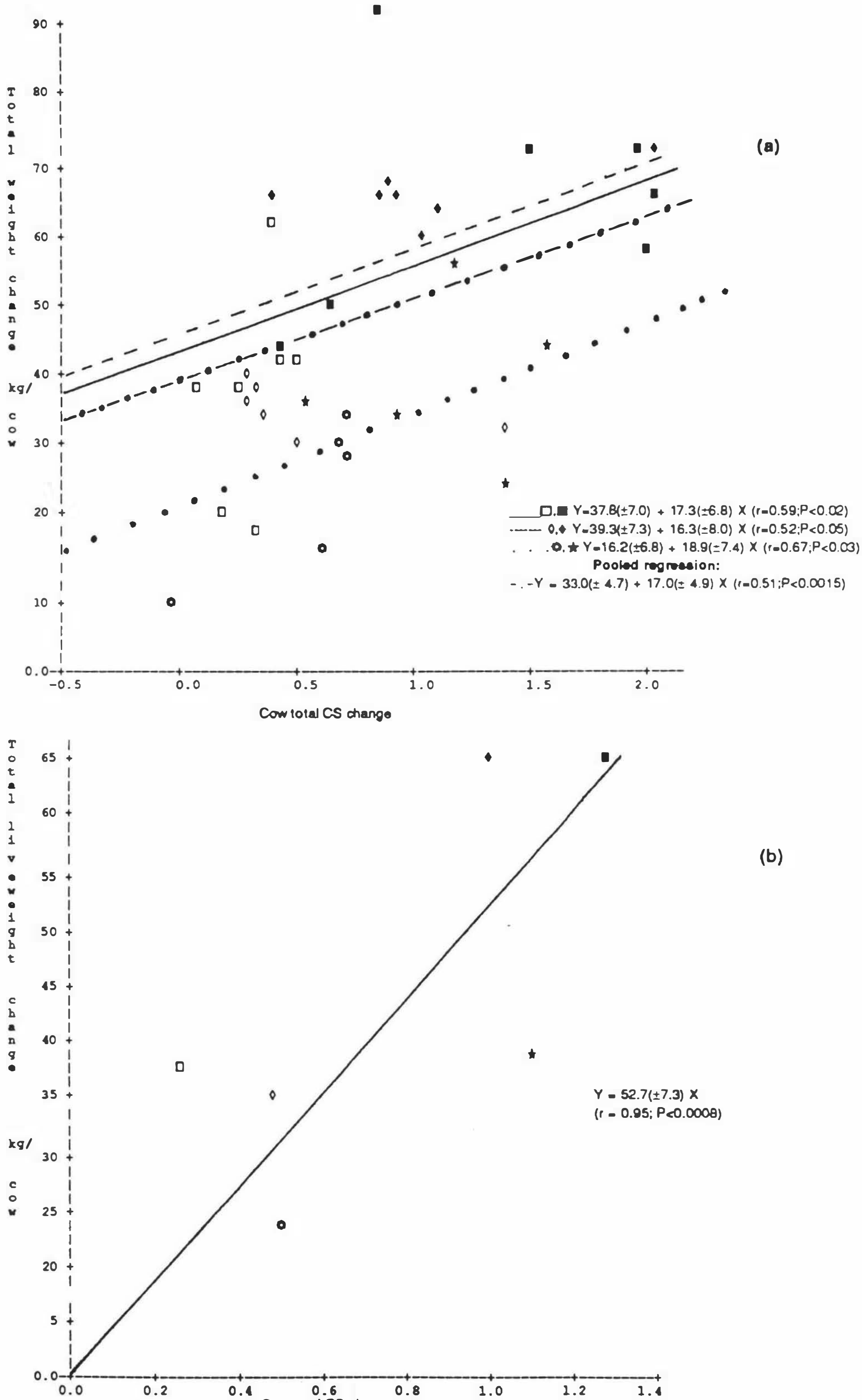

Fig. 3. Relationship between total liveweight gain (kg/cow/41 days experimental period) and total condition score change. Each symbol represents either an observation for an individual cow (a) or the mean of a treatment group (b) of Big Friesians: □,■; Small Friesians: 0,♦, or Jersey cows: O, ★, fed at maintenance or *ad libitum*, respectively.

Equations 4.3 to 4.5 also predict that zero change in condition score corresponds to a ΔLW of 37.8, 39.3 and 16.2 kg/cow, for BF, SF, and J respectively. This liveweight change at zero CS can be regarded as an estimate of the gain in weight of the gravid uterus (i.e. foetus + foetal fluids + foetal membranes + uterus), if it is assumed that zero ΔCS equals zero maternal liveweight gain (MLWG) (Carruthers, 1980); and hence can be used as an estimate of the average daily LWG at which the cow is at maintenance. Table 4.11 presents the estimated weight change of the gravid uterus calculated from equations 4.3 to 4.5 and calculated by means of the prediction equation given by Ferrell *et al.* (1976 b). Along with these estimates, Table 4.11 also presents the least squares means calculated for average days pregnant and the cow's 'total' daily liveweight gain, and the estimated maternal liveweight change derived from these estimates.

Table 4.11. Least squares means for average days pregnant and total daily LWG (i.e. maternal + gravid uterus weight gain); gravid uterus and maternal liveweight gain estimated from regression equations relating ΔLW to ΔCS or predicted as by Ferrell *et al* (1976 b).

Size-group	Regression equation	Average days pregnant	Daily LWG (kg/cow)[1]	Weight change of the gravid uterus (kg/day)[2]		Maternal LWG[3]	
				Estimated	Predicted	Estimated	Predicted
Big Friesians	ΔLW=37.8+17.3ΔCS	203	1.24	0.922	0.583	0.318	0.656
Small Friesians	ΔLW=39.3+16.3ΔCS	193	1.23	0.960	0.505	0.270	0.724
Jerseys	ΔLW=16.2+18.9ΔCS	197	0.76	0.395	0.535	0.365	0.224

[1] Total liveweight gain (i.e. maternal + gravid uterus weight gain).
[2] Estimated from the intercept of the regression equations of Δ LW on ΔCS or predicted using Ferrell's *et al.* (1976 b) prediction equation.
[3] I.e. Actual daily LWG - Estimated or predicted gravid uterus weight gain.

4.6. Feed requirements for zero ΔCS calculated separately for each size-group.

Feed intake requirements for maintenance were calculated separately for each size-group as the daily amount required for the average weight gain of the gravid uterus (derived in Table 4.11 above) and using the group means of live weight and intake. Fig. 4(a) shows the relationship between LWG and daily metabolizable energy intake (MJ ME/LW$^{0.75}$/day) using group means. For each size-group the average weight gain of the gravid uterus estimated from the intercepts of equations 4.3 to 4.5 are also given. Fig. 4(b) shows the relationship between the same variables, but in this case the weight gain of the gravid uterus corresponds to that estimated using Ferrell's *et al.* (1976 b) prediction equation.

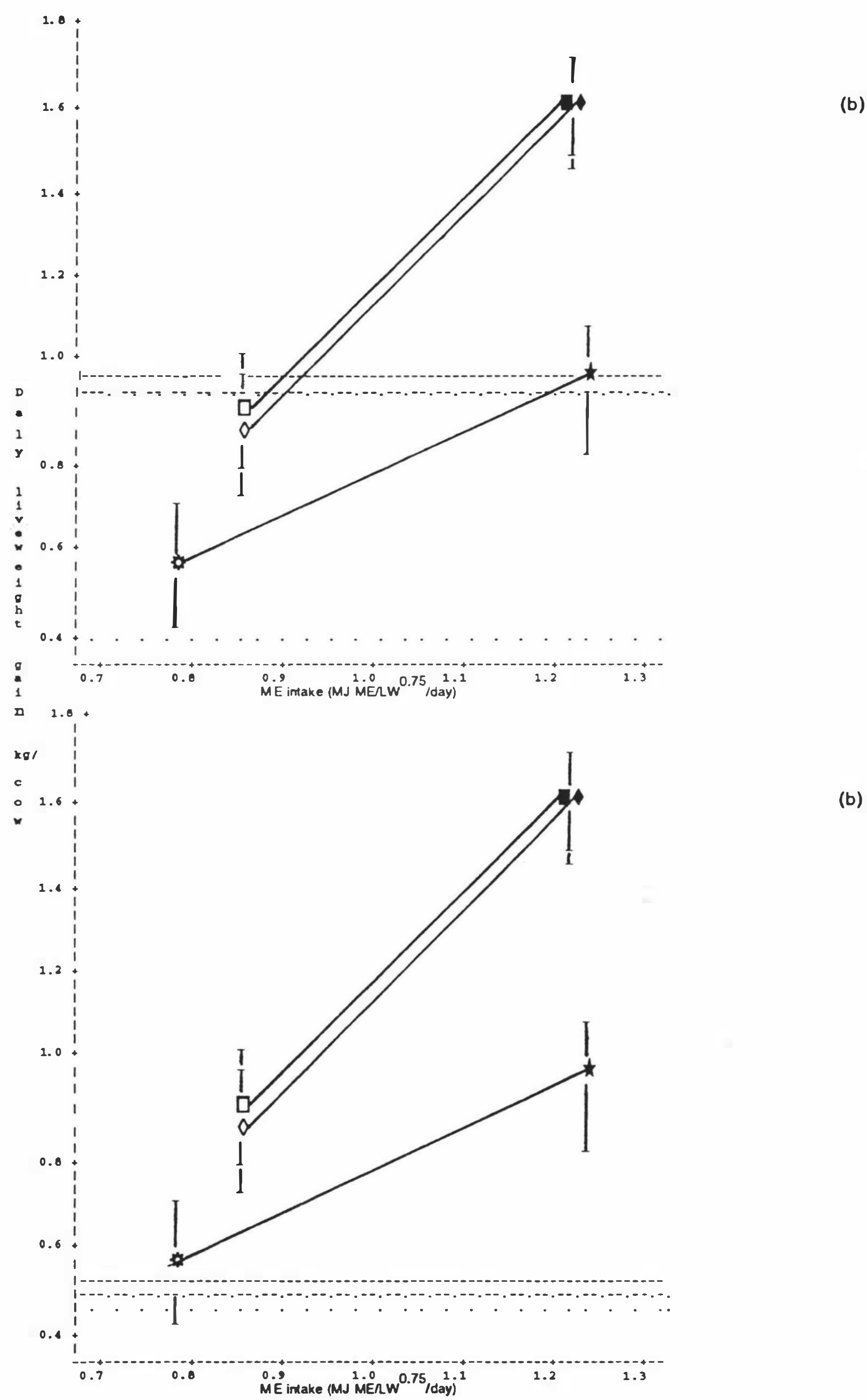

Fig. 4. Relationship between daily liveweight gain (kg/cow) and MEI (MJ ME/LW$^{0.75}$/day) using group means for Big Friesians:□,■; Small Friesians:◇,◆, or Jersey cows:✪,★, fed at maintenance or *ad libitum*, respectively. Vertical bars at the top and at the bottom of each symbol represent the standard error of the mean, and the horizontal dotted lines represent the estimated (a) and the predicted (b) daily weight gain of the gravid uterus for each group-size (J= . . . . ; SF=-.-.-.;BF = - - -).

Table 4.12 summarizes the predicted daily feed intake requirements for maintenance of each size-group. Feed required for zero ΔCS assessed from the average weight gain of the gravid uterus calculated by regression analyses of ΔLW on ΔCS appeared to be higher for heavier cows (i.e. BF, 0.868; SF, 0.902 and J, 0.599 MJ ME/$LW^{0.75}$/day).

When zero ΔCS was assessed as the average weight gain of the gravid uterus predicted by Ferrell's equation, the predicted ME_m for the three size-groups was very similar (i.e. BF, 0.695; SF, 0.683 and J, 0.750 MJ ME/$LW^{0.75}$/day). However, both ways of assessing ME_m separately for each size-group required a great deal of extrapolation, which might affect the accuracy of the estimates calculated.

Table 4.12. Estimated daily intake of dry matter or metabolizable energy required for maintenance[1].

Size-group	Weight gain of the gravid uterus (kg/day)[2]		Estimated daily intake required for maintenance calculated from (a) the estimated or (b) the predicted weight gain of the gravid uterus: kg DM/cow		g DM/$LW^{0.75}$		MJ ME/$LW^{0.75}$	
	a	b	a	b	a	b	a	b
Big Friesians	0.922	0.583	8.6	6.9	75.8	61.3	0.868	0.695
Small Friesians	0.960	0.505	7.5	5.6	78.7	60.4	0.902	0.683
Jerseys	0.395	0.535	4.4	5.5	52.8	66.2	0.599	0.750

[1] Assuming maintenance is equal to the calculated average gain in weight of the gravid uterus;
[2] Calculated from regression analyses of LW on CS (a) or predicted from Ferrell's *et al.* (1976 b) equation (see Table 4.11).

4.7. Feed requirements for the average ΔLW or the average ΔCS calculated separately for each size-group.

Total daily intake of feed and total daily allowance requirements (i.e. for maintenance + pregnancy + liveweight gain or CS gain) of dry matter or metabolizable energy for cows differing in live weight were calculated using the group means for these variables and either cow condition score or liveweight change. Total feed requirements were calculated as the daily amount required for either the mean change in condition score or the mean change in liveweight. The same procedure also was followed to calculate the daily herbage allowance required to meet these requirements.

4.7.1. Feed Intake requirements.

The relationships between LWG and daily metabolizable energy intake (MJ ME/LW$^{0.75}$/day) using group means is plotted in Figure 5. The corresponding relationship between ΔCS and the same variable is plotted in Figures 6. Table 4.13 summarizes the predicted daily feed requirements for each size-group, calculated either for the average liveweight gain or the average condition score gain achieved by all the cows involved in the experiment.

For the mean liveweight change the Jersey cows had both the higher estimated total daily herbage DMI requirement (kg/cow/day) and the higher MEI requirement (MJ/LW$^{0.75}$/day) (see Table 4.13). However, the range in daily liveweight gain for the Jerseys was outside the average for which the prediction was made (see Figure 5 below), which might affect the accuracy of the estimates obtained by this method.

Table 4.13. Estimated daily amount of dry matter intake or metabolizable energy intake required to achieve (a) the mean change in liveweight or (b) the average change in total condition score.

Size-group[1]	Daily intake required for:					
	(a)[2]			(b)[3]		
	kg DM/ cow	g DM/ LW$^{0.75}$	MJ ME/ LW$^{0.75}$	kg DM/ cow	g DM/ LW$^{0.75}$	MJ ME/ LW$^{0.75}$
Big Friesians	9.5	84.0	0.965	10.2	89.5	1.03
Small Friesians	8.2	85.0	0.979	8.9	91.5	1.05
Jerseys	10.6	123.0	1.430	7.4	86.0	1.00

[1] Average live weight of the cows (kg): BF=552; SF =442; J= 377.
[2] Mean daily liveweight gain for all the groups during the experimental period = 1.12 kg/cow/day.
[3] Mean total condition score change during the experimental period = 0.77 C.S units/cow.

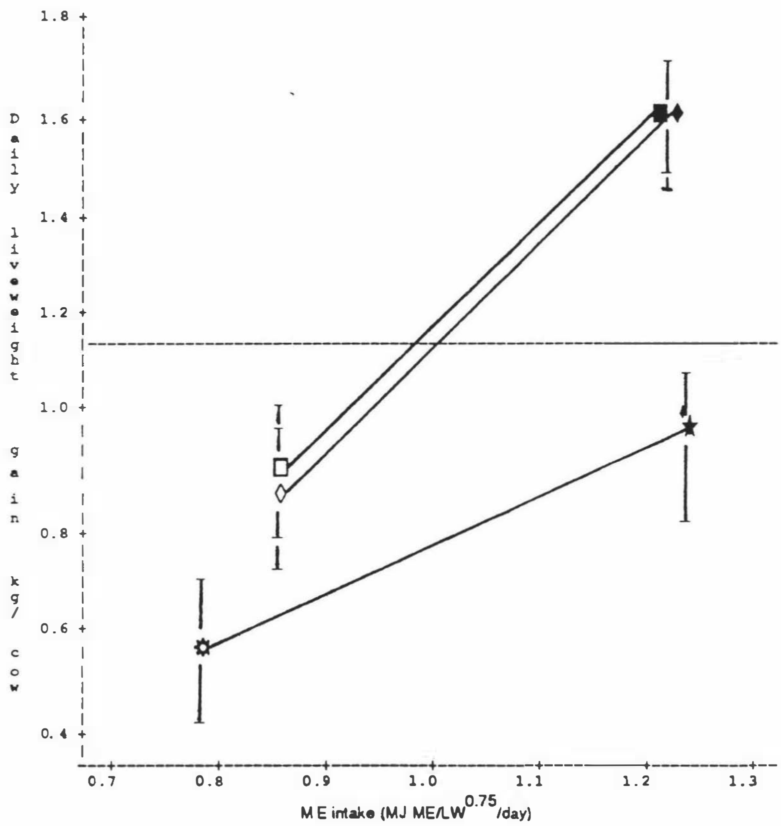

Fig. 5. Relationship between daily liveweight gain (kg/cow) and daily MEI (MJ ME/LW$^{0.75}$/day). Each symbol represents the average of the group over the experimental period for Big Friesians:□,■; Small Friesians:◊,♦, or Jersey cows:✪,★, fed at maintenance or *ad libitum*, respectively. Vertical bars at the top and at the bottom of each symbol represent the standard error of the mean, the horizontal dotted line at the middle of the graph represents the average liveweight gain for all the treatment groups during the experimental period.

In contrast, for the average condition score change all the size-groups were within the range of the prediction (See Figure 6). Calculated by this method, the Jersey cows had the lowest daily herbage DMI requirement (kg/cow/day), Big Friesians the highest, with Small Friesians being intermediate between the two. However, when their feed intake requirements were expressed as MJ ME/LW$^{0.75}$/day, the values obtained for the three size-groups were virtually the same (i.e BF, 1.03; SF, 1.05, and J, 1.00 MJ ME/kg LW$^{0.75}$/day; see Table 4.13).

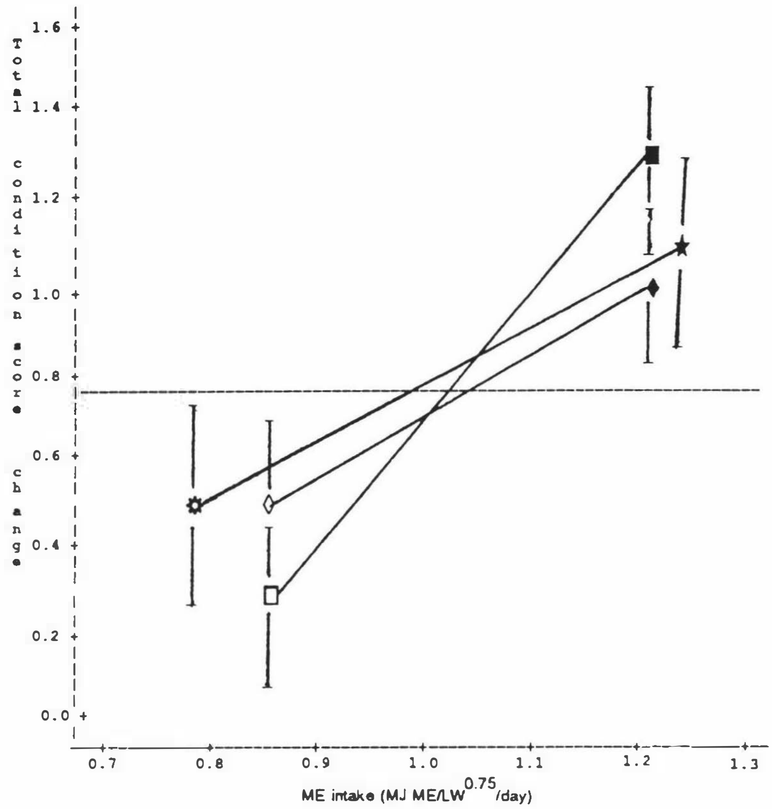

Fig. 6. Relationship between total condition score change (CS units/cow/41-day experiment) and MEI (MJ/LW$^{0.75}$/day). Each symbol represents the average of the group over the experimental period for Big Friesians:□,■;Small Friesians:◊,♦, or Jersey cows:✡,★, fed at maintenance or *ad libitum*, respectively. Vertical bars at the top and at the bottom of each symbol represent the standard error of the mean, the horizontal dotted line at the middle of the graph represents the average condition score gain for all the groups during the experimental period.

4.7.2. Herbage allowance requirements.

The relationships between LWG or ΔCS and daily herbage DM allowance (kg DM/cow/day) using group means are plotted in Figures 7(a) and 7(b). Table 4.14 summarizes the estimated daily allowances required for each size-group to meet the daily requirements either for the mean liveweight change or the mean condition score change obtained in Table 4.13.

For the mean liveweight change, the Jersey group had the highest herbage allowance requirement (21.2 kg DM/cow/day), the group of Big Friesians were intermediate (14.6 kg cow/day) and the Small Friesians had the lowest herbage allowance requirement (13.0

kg/cow/day). When these allowance requirements were expressed on a metabolic weight basis, the Jersey group still had the highest allowance requirement (2.84 MJ ME/LW$^{0.75}$/day), but Big Friesians (1.47 MJ ME/LW$^{0.75}$/day) and Small Friesians (1.57 MJ ME/LW$^{0.75}$/day) had very similar daily herbage DM allowance requirements.

In contrast, for the mean condition score change, heavier cows appeared to require higher daily herbage DM allowances (i.e. BF, 16.8; SF, 15.0, and J, 12.3 kg herbage DM/cow/day). However, when HA was expressed on a metabolic weight basis, the three size-groups had very similar daily herbage allowance requirements (i.e. SF, 1.8; BF, 1.7, and J, 1.6 MJ ME/LW$^{0.75}$/day).

Table 4.14. Estimated daily amount of either dry matter allowance or metabolizable energy allowance required to achieve (a) the mean change in liveweight or (b) the mean change in total condition score.

Size-group	Daily allowance required for:					
	(a)[1]			(b)[2]		
	kg DM/ cow	g DM/ LW$^{0.75}$	MJ ME/ LW$^{0.75}$	kg DM/ cow	g DM/ LW$^{0.75}$	MJ ME/ LW$^{0.75}$
Big Friesians	14.6	128.0	1.47	16.8	147.0	1.70
Small Friesians	13.0	134.5	1.54	15.0	155.0	1.80
Jerseys	21.2	245.0	2.84	12.3	141.0	1.60

[1] Mean daily liveweight gain for all the groups during the experimental period= 1.12 kg/cow/day.
[2] Mean total condition score change during the experimental period = 0.77 cs units/cow.

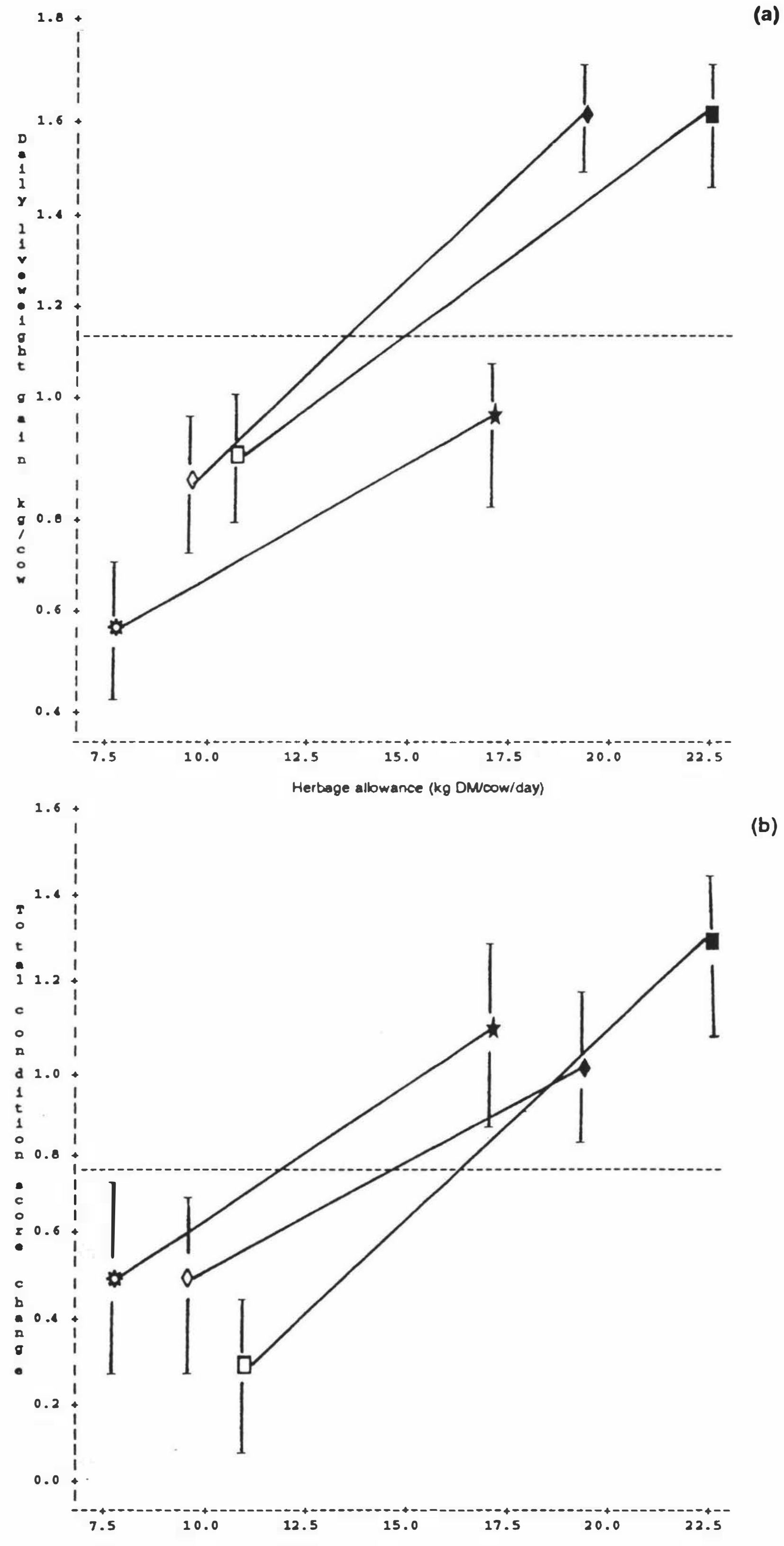

Fig. 7. Relationship between LWG (kg/cow/day) and (a) HA (kg DM/cow/day) and (b) condition score change, using group means for Big Friesians: □,■; Small Friesians: ◇,◆, or Jersey cows: ✡,★, fed at maintenance or *ad libitum*, respectively. Vertical bars at the top and at the bottom represent the standard error of the mean; the horizontal dotted line at the middle of the graph represents the average LWG (a) or the average CS gain (b) for all the groups during the experimental period.

4.8. Feed requirements for zero ΔCS and CS gain pooled for the three size-groups.

The least squares means for group mean intakes obtained from the analyses of variance for herbage dry matter intake, intake of ME, and gain in condition score were used to assess the partition of the daily MEI or DMI towards maintenance, and gain in condition score, by means of regression analyses (see Figure 8). The regression of daily herbage dry matter intake (kg DMI/kg $LW^{0.75}$/day) on ΔCS (CS units/cow/41 days experimental period) using group means (Appendix III-3.2) yielded the following equation:

$$DMI/LW^{0.75} = 0.057 + 0.041\ \Delta CS \quad (r = 0.93;\ P<0.007)\ .\ .\ .\ 4.8$$

From this equation can be calculated that the cows used in this experiment required either 57 g herbage DM/$LW^{0.75}$/day or 5.7 kg DM/cow/day for a 457 kg cow (the average live weight of the cows used in this experiment) to maintain condition score without change; and for the gain of one condition score unit during 41 days of experimental period they required an amount above maintenance of about 167 kg herbage DM/cow/during the 41 days of experimental period. The corresponding regression (Appendix III-3.1) using the group means for metabolizable energy intake (MEI, MJ ME/kg $LW^{0.75}$/day) and ΔCS is indicated below:

$$MEI/LW^{0.75} = 0.648 + 0.490\ \Delta CS \quad (r = 0.93;\ P<0.005)\ .\ .\ .\ .4.9$$

This equation predicts zero change in condition score (i.e. an estimate of the ME_m free of pregnancy) at a daily MEI of 0.648 MJ ME/kg $LW^{0.75}$, and the MEI required above maintenance for the gain of one condition score unit to be about 1986 MJ ME/Δ1 CS unit.

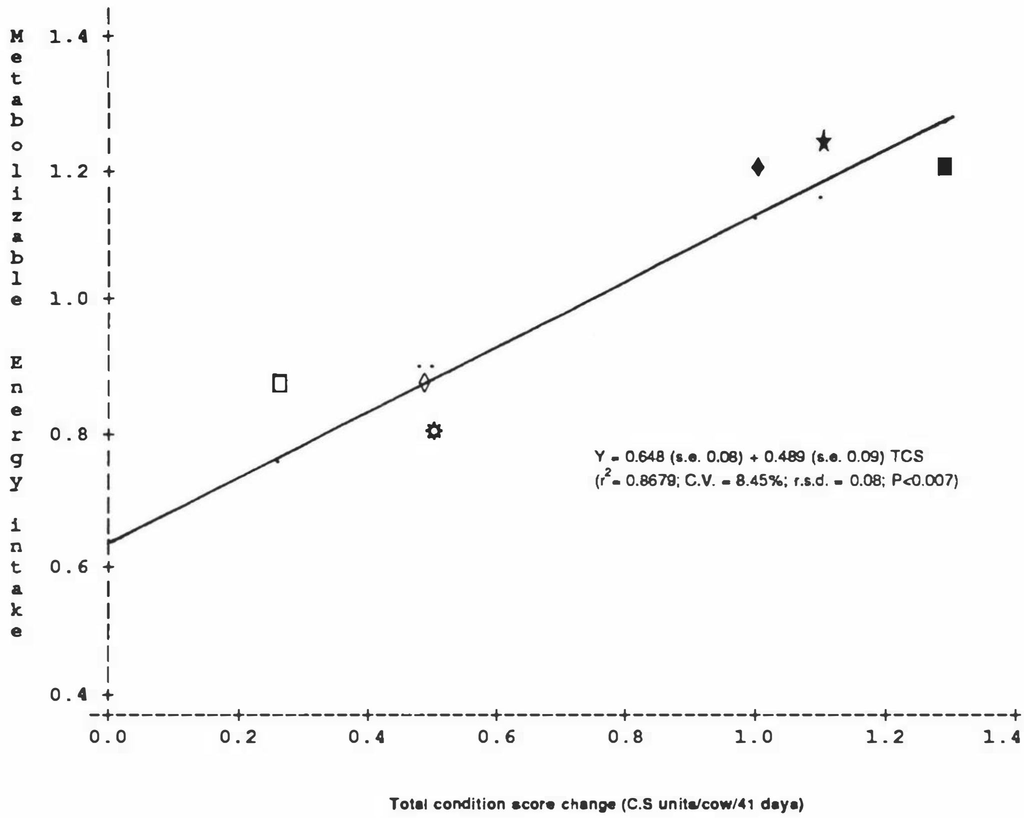

Fig. 8. Relationship between metabolizable energy intake (MEI) (MJ ME/LW$^{0.75}$/day) and total condition score change (CS units/cow/41-day experiment). Each symbol represents the average of a treatment group of Big Friesians:□,■; Small Friesians:◊,♦ or Jersey:✿,★ cows fed at maintenance (empty symbols) or *ad libitum* (filled symbols) respectively.

4.9. Effect of large cow size on daily feed requirements.

The effect of an extra 100 kg cow live weight on cow feed requirements for maintenance (i.e. ME_m) or feed requirements for the average CS change (i.e. $ME_{\Delta CS}$), which was 0.77 CS units/cow/41-day experiment, was calculated by means of linear regression (Appendices III-3.8, III-3.9, III-3.10 and III-3.11). For this purpose, the average live weight of each treatment group and its corresponding estimate of ME_m or $ME_{\Delta CS}$ (given as MJ ME/cow/day) were used.

Figure 9 shows the linear regressions fitted to the estimates of maintenance feed requirements (ME_m) calculated either from the estimated zero maternal LWG (i.e zero ΔCS) using Ferrell's *et al.*(1976 b) prediction equation, (see Table 4.12), or calculated from the pooled regression of MEI/LW$^{0.75}$ on ΔCS. Along with these estimates, Figure 9 also shows the regression equation fitted to the data of feed requirements calculated for the average condition score change ($ME_{\Delta CS}$).

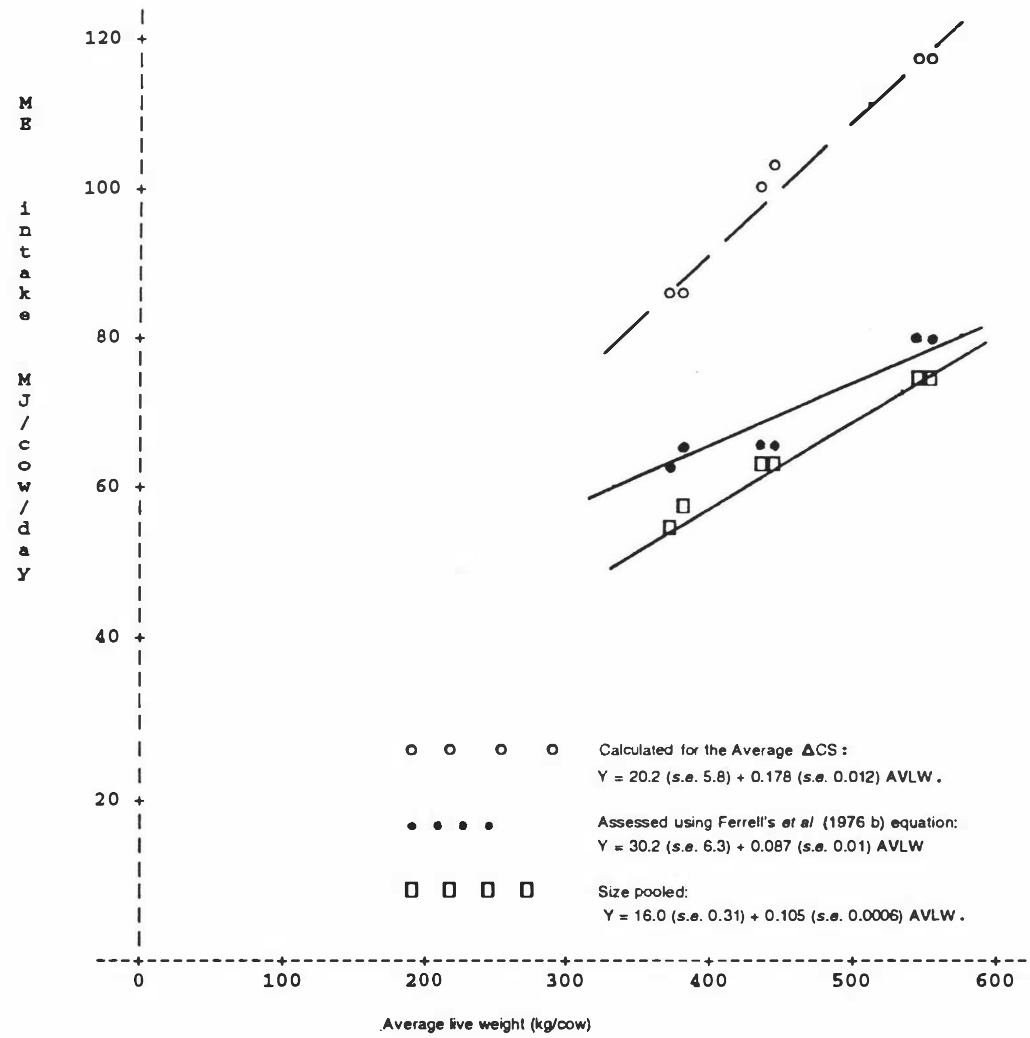

Fig. 9. Relationship between average cow live weight (AVLW, kg) and daily metabolizable energy intake (MJ/cow/day) for maintenance (ME_m) (solid lines) or for the average condition score change ($ME_{\Delta CS}$) (broken regression line). Each point represents the average of a treatment group.

Table 4.15 summarizes the estimated extra intake of ME or DM required for maintenance or for the average CS change calculated from these regression equations. Each value corresponds to the regression coefficient associated with live weight for each method of assessment.

Table 4.15. Effect of an extra 100 kg cow live weight on increasing the intake of metabolizable energy or dry matter required for maintenance (i.e. calculated as zero ΔCS), or for the average condition score gain.

Method of assessing feed requirements	Extra intake required/100 kg cow live weight:	
	MJ ME/cow/day	kg DM/cow/day
Zero ΔCS estimated from the intercept of the regression of ΔLW on ΔCS.	17.5±0.10	1.53±0.08
Zero ΔCS estimated from Ferrell's *et al* (1976b) prediction equation.	8.7±1.30	0.79±0.10
Zero ΔCS estimated from the pooled regression of MEI/LW$^{0.75}$ on ΔCS.	10.5±0.06	0.95±0.006
Feed required for the average ΔCS.	17.8±1.2	1.58±0.13

From these estimates, on average cows which were heavier by 100 kg live weight required an extra intake for maintenance of between 8.7 and 17.5 MJ ME/cow/day or between 0.8 to 1.5 kg DM/cow/day. Calculated for the average condition score change, an extra 100 kg cow live weight required about 18 MJ ME/cow/day or 1.6 kg DM/cow/day.

4.10. Photographs.

Plate 4.1. Allowance layout for the treatment groups fed *ad libitum* (Herbage allowance, 20 kg DM/cow/day; Residual herbage mass, 1800 kg DM/ha/day).

Plate 4.2. Allowance layout for the treatment groups offered an allowance for maintenance (Herbage allowance, 9.5 kg DM/cow/day; Residual herbage mass, 782 kg DM/ha/day).

Plate 4.3. Group of Big Friesian cows fed *ad libitum* (Herbage allowance, 23 kg DM/cow/day; Residual herbage mass, 1835 kg DM/ha/day).

Plate 4.4. Group of Big Friesian cows offered an allowance for maintenance (Herbage allowance, 11.0 kg DM/cow/day; Residual herbage mass, 782 kg DM/ha/day).

Plate 4.5. Group of Small Friesian cows fed *ad libitum* (Herbage allowance, 20 kg DM/cow/day; Residual herbage mass, 1830 kg DM/ha/day).

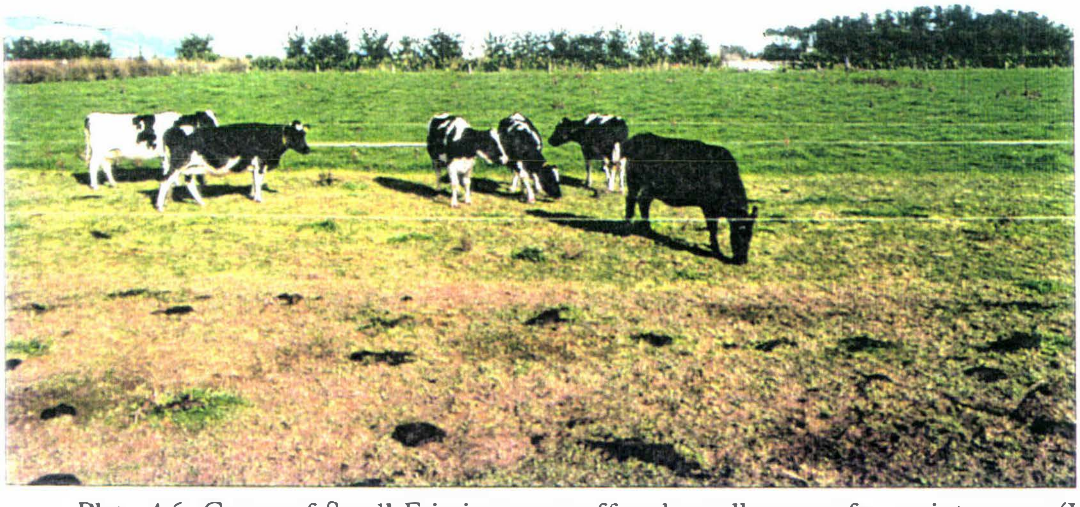

Plate 4.6. Group of Small Friesian cows offered an allowance for maintenance (Herbage allowance, 9.6 kg DM/cow/day; Residual herbage mass, 813 kg DM/ha/day).

Plate 4.7. Group of Jersey cows fed *ad libitum* (Herbage allowance, 17.7 kg DM/cow/day; Residual herbage mass, 1844 kg DM/ha/day).

Plate 4.8. Group of Jersey cows offered an allowance for maintenance (Herbage allowance: 7.8 kg DM/cow/day; Residual herbage mass, 750 kg DM/ha/day).

Chapter 5

Discussion

5.1. Relationship between ΔLW and ΔCS.

These two variables allowed the calculation of the following regression equations of ΔLW on ΔCS: (1) one regression equation for each size-group using the individual cow data; (2) a pooled regression of the individual values without regard to size, and (3) a regression equation calculated using group means (see Figure 3). From these results, the gain of one condition score unit was equivalent to a ΔLW of 55, 55.6, and 35 kg/cow for Big Friesians, Small Friesians and Jerseys, respectively. The corresponding estimates obtained from the pooled regression and the regression using group means were 50.0 and 52.7 kg ΔLW/ΔCS, respectively.

The estimates of Big Friesians and Small Friesians are very similar to that of 55 kg ΔLW/ΔCS obtained by Carruthers (1980) using the same condition scoring system with high and low breeding index Friesian cows of similar stage of pregnancy and from the same herd as those used in this experiment. The estimates, however, differ greatly from the 25 to 35.5 kg ΔLW/ΔCS calculated in some New Zealand (Holmes & Grainger, 1982; Holmes & McLenaghan, 1980; Macdonald and Macmillan, 1993) and Australian (Grainger *et al.*, 1978; Gray *et al.*, 1981) experiments; and are slightly higher than both that of 43.8 kg ΔLW/ΔCS unit given by Grainger *et al.*(1985) for non-lactating pregnant (180 to 240 days pregnant) cows of the same herd, but using an eight point scale system for condition scoring, and that of 44.1 kg ΔLW/ΔCS unit given by Nottingham (1978) for Jersey and Friesian cows of the same herd (6 to 7 months pregnant), but with liveweight change being adjusted by the liveweight gained by the gravid uterus (see also Table 5.2).

The average of 35 kg ΔLW/ΔCS for the Jersey group was slightly higher than both that of 26 kg ΔLW/ΔCS calculated by Grainger *et al.* (1982) for Jersey cows five months pregnant, condition scored using the Ellinbank eight point scoring system (Earle, 1976), and that of 25 kg ΔLW/ΔCS given by Macdonald and Macmillan (1993) for Jersey cows from two to five years of age scored during the first 17 weeks of lactation with the ten point scoring system used at Massey (Holmes & Wilson, 1987) and Ruakura (Macdonald & Macmillan, 1993).

The regression equations for each size-group also provided an estimate of the amount of liveweight necessary to be gained before any gain in condition score occurs. If it is assumed that zero ΔCS equals zero change in maternal liveweight, then the change in liveweight at zero CS should be equal to the gain in weight of the gravid uterus (i.e. foetus + foetal fluids + foetal membranes+ uterus) (Carruthers, 1980).

Table 4.11 (see Section 4.5.) summarizes, for each size-group, the estimated weight gain of the gravid uterus, the estimated maternal liveweight gain (i.e. total LWG - estimated gravid uterus weight gain), and the predicted weight gain of the gravid uterus making use of the relationship developed by Ferrell *et al.*(1976 b) to estimate the fresh weight of the uterus of Hereford heifers from day zero of gestation to day 264 of gestation (see Section 2.4.3, Table 2.14). Also presented in Table 4.11 are the least squares means calculated for total ΔCS, total daily LWG (i.e. maternal + gravid uterus weight gain) and the average day of gestation.

The results obtained in Table 4.11 indicate that all the three size-groups were well above maintenance, as reflected by a positive estimated maternal liveweight gain averaging about 0.317 kg/day or 0.534 kg/cow/day for the three size-groups when MLWG was assessed respectively from the regression equations of ΔLW on ΔCS or when it was predicted from Ferrell's *et al.*(1976 b) equation. The average gravid uterus weight gain estimated from the regression equations for Big and Small Friesians was higher than the one predicted by Ferrell's *et al.* (1976 b) equation, but for the Jerseys the corresponding estimate was lower than the predicted value.

These differences between estimated and predicted gravid uterus weight gain might be due to errors associated with the indirect estimation of weight changes through condition score assessments, or due to differences in the weight of the cows used in the present experiment and those used to derive the prediction equation. Ferrell's *et al.* (1976 b) cows ranged from non-pregnant heifers weighing 265-383 kg to pregnant heifers (134 to 264 days of gestation) weighing 335-412 kilograms. The cows used in the present experiment ranged from as light as 377 kg for the Jersey group to as heavy as 552 kg for the Big Friesians, with the Small Friesians in the middle weighing 442 kg. The cows in the three groups were in the range 190 to 230 days of pregnancy.

5.2. Calculation of feed requirements.

Feed requirements were calculated by using the following three methods: (1) separately for each size-group as the daily amount required for zero ΔCS; (2) pooled for all the three size-groups as the daily amount of feed required/cow/day to achieve zero ΔCS, and (3) separately for each size-group as that amount of feed required/cow/day to achieve either the average change in condition score or the average change in liveweight.

5.2.1. Feed requirements for zero ΔCS calculated separately for each size-group.

The results of the linear regression of ΔLW on ΔCS obtained for each size-group were the basis for calculating separately their maintenance requirements (see section 4.6; Table 4.12), assuming that zero ΔCS (i.e. zero maternal liveweight gain) was equivalent to the estimated gain in weight of the gravid uterus (see Table 4.11).

When zero ΔCS for each size-group was estimated from the intercept of equations 4.3 to 4.5, maintenance requirements appeared to be higher for heavier cows. Small Friesians had the higher estimate with 0.902 MJ ME/LW$^{0.75}$/day, Jerseys the lowest (0.599 MJ ME/LW$^{0.75}$/day) and Big Friesians had an intermediate value of 0.868 MJ ME/LW$^{0.75}$/day. The lower ME_m estimated for the Jerseys might be due to their lower estimate for the average weight gain of the gravid uterus (only 395 g/day), and both the maintenance and the *ad libitum* fed Jersey groups achieved liveweight gains well above this average. Thus, the predicted maintenance requirement fell outside this range, which might affect its accuracy (see Figure 4a).

When zero ΔCS for each size-group was estimated as the average weight gain of the gravid uterus predicted from Ferrell's *et al.*(1976 b) equation, the predicted ME_m for the three size-groups also required some extrapolation (see Figure 4b). However, the estimates of ME_m for the three size-groups were very similar among them and in agreement with most of the maintenance estimates from the literature where feed requirements for dairy cattle were assessed through changes in body condition score (see Tables 5.1 and 5.2).

5.2.2. Feed requirements for the average ΔLW or for the average ΔCS calculated separately for each size-group.

Feed intake and allowance requirements for each size-group were also calculated for the average change in liveweight or the average change in condition score achieved for all the cows in the experiment (see Section 4.7). This was so because the prediction of the ME_m required extrapolation for the Jersey group and for the three size-groups when zero ΔCS was estimated, respectively, from the intercepts of equations 4.3 to 4.6 or by using Ferrell's *et al.*(1976 b) prediction equation (see Section 4.6., Figures 4a and 4b).

Calculating intake and allowance requirements for the average liveweight change did not solve the problem of predicting feed requirements for the Jersey group outside the observed range of intake and LWG (see Section 4.7., Figure 5). In this case, the average liveweight gain of all the treatment groups (i.e. 1.12 kg/cow/day) used for the prediction was even higher than the average liveweight gain achieved by the group of Jerseys fed *ad libitum* (i.e. only 0.90 kg/cow/day).

In contrast, for the average condition score change (which was 0.77 CS units/cow during the 41 days experiment) the prediction of intake and allowance requirements fell within the range of observed values for intake and LWG of the three size-groups (see Figure 6 and 7b). Therefore, it is reasonable to suggest that this method provided the most reliable way to compare the estimated feed requirements of the three size-groups of cows. Calculated by this method, daily feed requirements per kg of $LW^{0.75}$ were virtually the same for the three size-groups (i.e. 1.03, 1.05 and 1.0 MJ ME/$LW^{0.75}$/day for BF, SF and J, respectively).

5.2.3. Feed requirements for zero ΔCS and CS gain pooled for the three size-groups.

The daily feed requirements for zero ΔCS (i.e. maintenance) and for CS gain of cows on this experiment were calculated by means of simple linear regression analyses using the least squares means of DMI, MEI, and total CS change calculated for each size-group (see Section 4.8, Figure 8). Grainger *et al.* (1981) showed that there is close agreement between the estimates of feed energy required for zero maternal liveweight gain (i.e. an estimate of the ME_m free of pregnancy) and zero change in body condition score. The following section discusses the results of estimating the cow's daily intake requirements of DM or ME using ΔCS as the independent variable.

The calculation of feed requirements by using regression analyses of DMI or MEI on ΔCS using group means yielded estimates of both the amount required for maintenance (i.e. taken as the feed intake required for zero ΔCS) and that required above maintenance for the gain of one CS unit. The estimation of the ME_m also required some extrapolation (see Figure 8) because none of the three treatment groups at the maintenance level of feeding were below zero ΔCS (see also Section 4.4.3, Table 4.10). Nevertheless, regression analyses were carried out to obtain the corresponding estimates of maintenance of CS and gain in CS. The following section discusses separately the results obtained for both DMI and MEI.

5.2.3.1. Dry matter requirements.

Cows in this experiment (average CS = 4.9) required about 5.7 kg DM/cow/day to maintain condition score without change. From similar grazing experiments, Carruthers (1980) and Nottingham (1978) obtained corresponding estimates of 5.7 and 5.9 kg/cow/day for zero ΔCS, respectively. The maintenance estimate obtained in the present experiment is also in agreement with that of 5.8 to 6.0 kg/cow/day calculated by means of calorimetric trials given by Holmes & Grainger (1982) for pregnant cows, but lower than the 8.3 kg DM/cow/day given by Holmes & McLenaghan (1980) for grazing cows. Gray *et al.* (1981) also found 5.5 kg DM/cow/day as the amount required for zero ΔCS for dry pregnant cows averaging 6 of CS. However, in the same experiment cows averaging 3 of CS, required 6.3 kg DM/cow/day for zero ΔCS (see Table 5.1). They suggest that the lower maintenance requirements of cows with higher CS probably arise because they have higher proportion of fat, which is less metabolically active than protein.

From the results of the present experiment it was also calculated that for a cow to gain one CS unit (i.e. 1 CS = 52.7 kg live weight from the regression using group means) an average intake of 167 kg herbage DM above maintenance was required. This is equivalent to a daily requirement of between 3.2 kg herbage DM for the gain of one kg of maternal liveweight. This value is in close agreement with the 3.4 kg DM/kg MLWG calculated from Nottingham's (1978) results of 140 kg DM/cow above maintenance for the gain of one CS unit, which was equivalent to 44.1 kg ΔLW. However, the present estimate is about 50% lower than those calculated by Carruthers (1980), Grainger *et al.* (1978) and Holmes & McLenaghan (1980) (see Table 5.1).

Calculated in this way, the amount of dry matter required above maintenance for the gain of one kg of maternal liveweight is likely to vary due to different equivalences of liveweight and CS change brought about by using different body condition scoring systems. The information summarized in Table 5.1 clearly shows the higher averages for ΔLW/ΔCS, kg DM/ΔCS and kg DM/ΔLW for the experiments where the ten point condition scoring system was used.

Table 5.1. Pasture dry matter requirement for maintenance of body condition score and for gain in condition score by dry pregnant dairy cows.

Source	Experimental technique and type of animals	Scoring system (points)	DM required to maintain body C. S (kg)	kgΔLW/ Δ1 CS	kg DM/ Δ1 CS	kg DM/ kg LWG
Holmes & Grainger , 1982	Calorimetry, Friesian cows, 180-242 days pregnant, 400 kg LW, fed on fresh cut grass.	8	5.8-6.0	35.0	171	4.9
Grainger *et al.*, 1978	Stallfed dry-pregnant (150-198 d.), 400 kg LW, fed on fresh cut grass.	8	4.0	35.0	264	7.6
Gray *et al.*, 1981	Stallfed, mixed breeds dry-pregnant (180-230 days) cows, fed on grass and hay.	8	5.5[1] 6.3[2]	35.5 35.5	160 160	4.5 4.5
Hutton, 1962	Stall-fed dry Jersey crossbred, 337 kg LW. maintaining constant LW, fed fresh cut grass.	--	3.6			
Carruthers, 1980	Grazing, Friesian dry-pregnant (197-247 days), 438 kg LW.	10	5.7	55.0	338	6.1
Holmes & McLenaghan, 1980	Grazing, dry-pregnant (195-237), 400 kg LW.	10	8.3	35.0	210	6.0
Hutton & Bryant, 1976	Grazing dry-pregnant cows, 370 kg LW.	10	7.4	50.0[3] 30.0[4]	250 150	5.0 5.0
Nottingham, 1978	Grazing, Friesian & Jersey dry-pregnant (180-215 d.), 370 kg LW.	10	5.9	41.0	140	3.4
Present experiment[5]	Grazing, Friesian & Jersey dry-pregnant (190-230 days)cows 457 kg live weight.	10	5.7	52.7	167	3.2

[1] Cows with an average condition score of 6;

[2] Cows with an average condition score of 3;

[3] Two year old cows;

[4] Cows >two year old.

[5] Calculated from the pooled regression of MEI/LW$^{0.75}$ on ΔCS.

For the ten point scale scoring system, the increase in one condition score unit was equivalent to 45.5 kg live weight gain, it required an average intake above maintenance of 210 kg/cow, and yielded an average feed conversion efficiency of 4.8 kg DM/kg of maternal liveweight gain. The corresponding averages calculated from the experiments where the Ellinbank eight point condition scoring system (Earle, 1976) was used were 35.0 ΔLW/ΔCS unit, 189.0 kg DM above maintenance/ΔCS unit, and an average feed conversion efficiency of 5.4 kg DM/kg of maternal liveweight gain.

5.2.3.2. Metabolizable energy requirements.

The calculated metabolizable energy requirement (Chapter 4, section 4.8.) for zero change in condition score (i.e. an estimate of maintenance) was 0.648 MJ ME/$LW^{0.75}$/day and the corresponding value for the gain of one CS unit during the 41 days of experimental period was 1986 MJ ME. Both the estimated ME for maintenance and that required for the gain of one CS unit agree with most of the estimates summarized in Table 5.2. However, the estimated ME required for the gain of one kg of maternal liveweight was the smallest of those reported in Table 5.2, but very similar to the one of 33 to 40 MJ ME/kg live weight calculated by Bhuvaneshwar (1993) for lactating Jersey and Friesian cows in the same herd.

Gray *et al.*(1981) using the eight point Ellinbank condition scoring system showed that within the range of CS 3 to 6, body composition was significantly affected by change in CS. As body CS improved, fat concentration increased mainly at the expense of water, although protein and ash concentrations decreased slightly; and due to a higher fat content in the body of cows with higher CS, the energy density of the liveweight gained increased. As a result of this, cows with higher body condition scores had lower estimated maintenance requirements per kg of $LW^{0.75}$ than leaner cows (Gibb *et al.*, 1978; Gray *et al.*, 1981).

Table 5.2. Metabolizable energy (MJ/LW$^{0.75}$/day) required for maintenance of body condition score and for gain in condition score by dry pregnant dairy cows.

Source	Experimental technique and type of animals	Scoring system (points)	MJ ME/LW$^{0.75}$ to maintain body C. S.	kgΔLW/ Δ1 CS	MJ ME/ Δ1 CS	MJ ME/ kg LWG
Gibb *et al.*, 1977	Stall-fed cows of mixed breeds, various stages of pregnancy. Fed on a diet 50 hay:50 oats.	8	0.40[1] 0.58[2]			
Grainger *et al.*, 1978	Stall-fed dry-pregnant (150-198 days)cows, fed on fresh cut pasture.	8	0.49	35.0	290	483.0
Gray *et al.*, 1981	Stall-fed mixed breeds, dry-pregnant (180-230 days) cows, fed on a 50% hay:50% silage diet.	8	0.64[1] 0.74[2]	35.5 35.5	1650 1650	46.5 46.5
Hutton, 1962	Stall-fed, dry Jersey crossbred cows, 337 kg LW, fed on fresh cut grass to maintaining constant LW.	--	0.535			
Grainger *et al.*, 1985	- Stall-fed Friesian dry-pregnant (180-240 d), fed on fresh cut grass:					
	. High BI cows.	8	0.78[3]	43.8	1880	43.0
	. Low BI cows.	8	0.71[3]	43.8	2960	67.6
	. Low & high BI cows	8	0.76[3]	43.8	2228	50.9
	- Calorimetry, high & low BI cows at:					
	. 210 days pregnancy	8	0.79[4]			
	. 230 days pregnant	8	0.80[4]			
	. 224 days pregnant	8	0.60[4]			
Holmes & Grainger, 1982	Calorimetry, Friesian cows, 180-242 days pregnant, fed on fresh cut grass.	8	0.74	35.0	1881	53.7
Carruthers, 1980	Grazing, Friesian dry-pregnant (197-247 days) cows.	10	0.72	55.0	3819	69.4
Holmes & McLenaghan, 1980	Grazing, dry-pregnant (195- 237 days)cows.	10	1.02	35.0	2310	66.0
Present experiment[5]	Grazing, Friesian & Jersey dry-pregnant (190-230 days)cows:	10	0.65	52.7	1986	37.7

1 Cows with an average condition score of 6;
2 Cows with an average condition score of 3;
3 Based on changes in condition score;
4 Based on Energy Balance trials after allowance for pregnancy.
5 Calculated from the pooled regression of MEI/LW$^{0.75}$ on ΔCS.

5.3. Effect of large cow size.

Heavier cows required higher herbage DM allowances, had higher herbage DM intakes and had lower stocking densities. However, the three size-groups achieved similar levels of pasture utilization, and left behind similar levels of residual herbage mass (Table 5.3). Thus, the lighter Jersey cows can achieve similar levels of herbage utilization to the much heavier Big Friesian cows provided there is an increase in the average stocking rate of the farm (see Table 5.3. below).

Table 5.3. Least squares means (±S.E) for herbage DM allowance (kg/cow/day), herbage DMI (kg/cow/day), residual herbage mass (kg DM/ha/day), efficiency of grazing (%) and stocking density (cows/ha/24 hs.).

Size-group	Herbage dry matter		Residual herbage mass (t DM/ha)	Efficiency of grazing (%)	Daily stocking density (cows/ha)
	Allowance (kg/cow/day)	Intake (kg/cow/day)			
Big Friesians (552 kg LW)	17.0±0.59	10.3±0.08	1.30±0.02	64.3±0.69	240±8.8
Small Friesians (442 kg LW)	15.0±0.59	8.8±0.08	1.32±0.02	62.7±0.69	262±8.8
Jerseys (377 kg LW)	12.8±0.59	7.5±0.09	1.30±0.02	63.3±0.70	306±8.9
Significance of the difference[1]	BF>J*	BF>SF*** BF>J *** SF>J **	NS	NS	J>BF *

[1] * = P <0.05; ** = P<0.01; *** = P<0.001; NS = Not significant

The following section discusses the effects that large cow size have for pasture-based dairy systems, on the maintenance feed requirements of heavier cows, and on some parameters of the farm, such as the average stocking rate the dairy farm is able to support, the level of herbage utilization and the extra feed required to be grown per hectare.

5.3.1. Effect of large cow size on daily feed requirements.

The results obtained in the present experiment of the extra DMI or MEI required for maintenance of cows which were heavier by 100 kg (in the range 370 to 550 kg) are summarized in Table 5.4. and compared with other estimates published in the literature. When maintenance feed requirements were assessed from the pooled regression of DMI or MEI on ΔCS (see Section 4.8; Equations 4.8 and 4.9), cows which were heavier by 100 kg LW required an average extra feed intake for maintenance of 0.95 kg herbage DM/cow/day or about 10.5 MJ ME/cow/day. These estimates are at the lower end of those summarized in Table 5.4, may be because the lower maintenance requirements of non-lactating cows (used in the present experiment) compared with lactating cows (see Section 2.4.1.3., Tables 2.8 and 2.9).

This method of assessment, however, required some extrapolation to estimate ME_m (see Figure 8). In contrast, feed requirements for each size-group calculated from the average condition score change was the only method that did not require extrapolation (see Figures 6 and 7b). Calculated by this method, cows that were 100 kg heavier required on average 17.8 MJ MEI/cow/day or about 1.6 kg herbage DMI/cow/day for maintenance + the gain of 0.018 CS units/cow/day (i.e. the average daily CSG achieved during the experiment). These values are very similar to those calculated from Wallace's (1956 b) work.

5.3.2. Effect of large cow size on farm management requirements.

Table 5.4 also presents some calculations of the probable effect on the extra pasture required annually on the farm if it is stocked with cows on average 100 kg heavier. The calculations were made for an average New Zealand farm of 50 ha carrying 150 milking cows (i.e. stocking rate 3 cows/ha). The estimates summarized in Table 5.4 show that, farms stocked with heavier cows must either grow more feed or reduce the average stocking rate if cows are to maintain the same level of herbage intake.

Table 5.4. Effect of an extra 100 kg live weight/cow (in the range 350 to 550) on the cow's daily energy (MJ ME) or dry matter (kg) required for maintenance, and on the extra growth of pasture annually required on the farm (t DM/ha).

Source	Extra energy (MJ ME) or extra herbage dry matter (kg) required to maintain an extra 100 kg liveweight/cow:			Extra DM (t/ha/year) required by a 50 ha farm stocked with 150 milking cows.	Physiological status and range in weight (kg) of the cows.
	MJ/day	DM/day	DMI/year		
Cox *et al.*, 1956	12.9[2]	1.17	427	1.28	Lactating (413-635)
Holmes *et al.*, 1993	15.0	1.28[1]	470	1.40	Lactating (350-550)
L.I.C., 1991	12.0[2]	1.10	400	1.20	Lactating (400-475)
Stakelum & Connolly, 1987	24.2[2]	2.20	803	2.40	Lactating (499-583)
Wallace, 1956 b	17.2[2]	1.56	570	1.71	Lactating (295-520)
Present experiment	10.5[3]	0.95	347	1.04	Dry-pregnant(377-552)

[1] From an herbage with 11.65 MJ ME/kg DM (Bhuvaneshwar, 1993);
[2] Assuming 11 MJ ME/kg herbage DM;
[3] Calculated from the pooled regression of $MEI/LW^{0.75}$ on ΔCS, and an average M/D of 11.5 MJ ME (see Section 4.3.1., Table 4.5).

The estimated extra intake for maintenance calculated in the present experiment (i.e. 347 kg herbage DM/100 kg live weight) can be used to assess the effect of larger cow size on 'farm management requirements'. For this purpose, the following information will be used:

(1) the range in weight observed for the three size-groups (i.e. BF = 552 kg, SF = 442, J = 377 kg LW) in the present experiment;

(2) the ME_m of 0.648 MJ $ME/LW^{0.75}$/day (or 0.057 kg $DMI/LW^{0.75}$/day) calculated in Section 4.8;

(3) an average requirement of 5.2 MJ ME/kg 4% FCM (A.R.C. 1980) or about 130 MJ ME/kg MF will be assumed;

(4) cows producing on average 160 kg MF/year regardless of size;

(5) energy content of the pasture 11.5 MJ ME/kg DM (see Section 4.3.1.);

(6) 87.5% assumed level of pasture utilization, obtained with a high standard of pasture management (Holmes & Parker, 1992), and

(7) an average pasture productivity on the farm of 13.0 tonne herbage DM/ha/year.

Table 5.5 summarizes the estimated annual feed requirements for the three size-groups, and shows the effect of large size cows on the average farm stocking rate if the same level of herbage utilization is to be achieved.

Table 5.5. Annual feed requirements of dairy cows of different live weight and stocking rates required to achieve the same level of pasture utilization

Size-group	Annual herbage dry matter requirements/cow for:			Stocking rate (cows/ha)	Annual pasture yield (kg DM/ha)	Herbage harvested (%)
	Maintenance	Yield of MF	Total			
Big Friesians (552 kg LW)	2761	1809	4570	2.50	13,000	87.5
Small Friesians (442 kg LW)	2014	1809	3823	3.00	13,000	87.5
Jerseys (377 kg LW)	1561	1809	3370	3.40	13,000	87.5

Thus, for an average New Zealand Dairy Farm stocked with 3 Small Friesian cows/ha weighing 442 kg, about 11.5 tonne herbage DM/ha will be eaten, which is equivalent to an average herbage utilization of 88.0%.

If the same 50 ha dairy farm is stocked with 150 Big Friesians (i.e. 110 kg heavier than Small Friesians and requiring about 380 kg more DM for maintenance/cow/year), then the farm will need to produce 1.14 tonnes more herbage dry matter/ha/year to achieve 88.0% of herbage utilization as with the SF cows. On the other hand, if pasture productivity remains the same (i.e. 13 t DM/ha/year), the same level of herbage utilization is achieved by reducing the stocking rate from 3 to 2.5 cows/ha, which is equivalent to 25 less cows in the herd.

In contrast, at the same level of pasture productivity (i.e. 13 t DM/ha/year), stocking the farm with Jersey cows (i.e. 65 kg lighter than Small Friesians and requiring about 226 kg less herbage DM for maintenance/cow/year than SF) will need an increase in the stocking rate from 3 to 3.4 cows/ha to achieve the 88.0% herbage utilization. This is equivalent to 20 more cows in the herd.

From these calculations it is evident that lighter cows require higher stocking rates to achieve similar levels of herbage utilization as heavier cows. For the New Zealand pasture-based dairy system, increases in the average stocking rate of the dairy farms has been a very important contributor to the increased yield of milkfat per hectare achieved during the last 60 years (Holmes & Parker, 1992). From the results of the present experiment with pregnant non-lactating cows, it is evident that large size cows can affect total farm productivity in pasture-based dairy systems. Therefore, it would be worthwhile to investigate biological and economical efficiency of big and small cows on a farm scale.

In regard to this, Ahlborn & Bryant (1993) have calculated optimum stocking rates (i.e. the stocking rate for maximum net income) for high production conditions in New Zealand (i.e. stocking rates ranging from 3.0 to 4.5 cows/ha) of about 3.0 and 3.7 cows/ha for Holstein-Friesians and Jerseys, respectively.

At these optimum stocking rates, the net income for Jerseys was 5% higher than that of Holstein-Friesians. In this experiment, Holstein-Friesians were about 100 kg heavier than Jerseys (i.e. the predicted average cow live weights were 437 kg and 339 kg for Holstein-Friesian and Jersey, respectively). However, at 3.0 cows/ha for Holsteins and 4.5 cows/ha for Jerseys, the average live weight per hectare was very similar for the two breeds with 1311 kg for Holstein-Friesians and 1254 kg for Jerseys.

5.5. Limitations of the results obtained.

Although the results of the present experiment agree with most of the results obtained from similar grazing experiments reported in the literature, it is important to draw attention to their possible limitations. The main limitations might be (1) the way in which maintenance requirements were estimated and (2) the way in which herbage intake was estimated. Feed requirements for maintenance were calculated either individually for each size-group as the ME required for zero gain in maternal liveweight (estimated from the average weight gain of the gravid uterus), or as the ME required for zero ΔCS pooled for all the three size-groups. In both cases the estimation of ME for maintenance required some extrapolation. This was not the case, however, when total feed requirements calculated for the average condition score change, and therefore allowed the comparison of the three size-groups at a common level of CS change. The details have been described in sections 4.6, 4.7. and 4.8. The possible limitations with the estimation of herbage intake are discussed below:

5.5.1. Estimation of individual cow intakes.

Herbage intake of individual cows could not be obtained because the majority of the cows regurgitated their chromium capsule. The problem of cows losing their CRC was more noticeable with the group of Big Friesians grazed on the maintenance level of feeding, where almost all the cows regurgitated their CRC at least once. Holmes *et al.* (1993) experienced a similar problem in their grazing experiment with a larger number of the heavier cows with very low concentrations of chromium in the faeces presumably because they had regurgitated their CRC. The dosing of individual cows once daily with one chromium gelatin pill per day in the second period also gave very low concentrations of chromium in the faeces and the calculation of FO was consequently not possible. The latter could be due to 10 g Cr in each pill dosed once a day being not enough to overcome the diurnal variation in chromium excretion associated with these experiments (Le Du & Penning, 1982).

5.5.2. Estimation of group mean intakes.

The original plan of the experiment was to estimate intake by individual cows, but as was stated above, this was not possible due to the failure of estimating FO. The information generated in the experiment was then analyzed using the mean intakes for each group, obtained from the assessments made with the calibration equation calculated from the cutting data and the rising plate meter readings.

5.5.3. Calibration of the rising plate meter.

The group mean herbage DMI was calculated by using two calibration equations obtained from the plate meter reading and the herbage mass assessed by cutting, one for each level of feeding (see Section 4.4.2 and Figure 2). The calibration equation obtained for the maintenance level of feeding was highly significant ($P<0.0001$), with high correlation coefficient ($r = 0.98$), a residual standard deviation (r.s.d.) of only 442 kg DM/ha, and a coefficient of variation (C.V.) of 21.6%. In contrast, the equation obtained for the *ad libitum* level of feeding had a high C.V. (29.3%), a high r.s.d. (845 kg DM/ha) and a comparative lower correlation coefficient ($r = 0.79$) than that for the maintenance level of feeding. As these two equations were used for the prediction of the average herbage mass, herbage allowance and herbage intake, these variables might be predicted less accurately for the *ad libitum* fed groups than for those in the maintenance level of feeding.

The present calibration results are in close agreement with those obtained by Gabriëls & Van der Berg (1993), for a ryegrass sward with observed DM yields (pre-grazing and post-grazing pooled) ranging from 100 to 4000 kg/ha and using a metallic rising plate meter similar to the one using in the present experiment. For their two most practical calibration equations they found C.V. of between 27.0% and 27.8% and an average residual standard deviation of 450 kg DM/ha. These equations used the logarithmic transformation of both the dry matter yield and the plate meter reading and included day of cutting and whether the grass was wet or dry as covariables. In contrast, Stockdale & Kelly (1984) reported much lower coefficients of variation when a calibration equation was used separately for herbage mass before (C.V. = 8.8%) and other equation for herbage remaining after grazing (C.V. = 20.5%).

For the data generated in the present experiment, however, although the regression of post-grazing herbage mass on plate meter reading was significant, there was no significant relationship between herbage mass pre-grazing and plate meter reading. This could be due to the much higher variation for the post-grazing herbage masses as a consequence of the different levels of feeding offered to the treatment groups, and the small variation in the pre-grazing herbage mass of the paddocks used during the 41 days of the experimental period. Pooling the results of pre-grazing and post-grazing herbage mass provided a wider range of variation and the calculation of the two significant calibration equations for each level of feeding.

Chapter 6

Conclusions

The results of the present experiment showed that cow size (live weight) does affect the feed requirements of grazing pregnant, non-lactating cows. Total feed requirements calculated for the average condition score change yielded similar estimates for the three size-groups when expressed per kg of $LW^{0.75}$ (i.e. BF, 1.03, SF, 1.05 and J, 1.00 MJ ME/$LW^{0.75}$/day). These values corresponded to a daily MEI requirement of 117.3, 101.2 and 85.6 MJ ME/cow/day for Big Friesians, Small Friesians and Jerseys, respectively.

The corresponding estimate of ME_m pooled for the three size-groups, calculated from the linear regression of MEI/$LW^{0.75}$ on ΔCS, was an average of 0.648 MJ ME/$LW^{0.75}$/day. This was equivalent to a daily intake of 74.0, 62.5 and 55.5 MJ ME/cow/day for Big Friesians, Small Friesians and Jerseys, respectively.

From analyses of the pooled information of liveweight gain and condition score change of the three size-groups, an increase of about 53 kg live weight/cow during the 41-day experimental period corresponded to the gain of one condition score unit. This was equivalent to an average intake of 167 kg herbage DM or about 1986 MJ MEI/cow above maintenance during the 41-day experimental period.

From the pooled ME_m calculated for the three size-groups it was calculated that an extra 100 kg live weight/cow was associated with an extra intake for maintenance of about 10.5 MJ ME/cow/day or about 0.95 kg herbage DM/cow/day.

The implications of farming large-size dairy cows on overall farm productivity of pasture-based dairy systems are discussed.

References.

A.R.C. (1980). The nutrient requirements of ruminant livestock. Commonwealth Agricultural Bureaux, Slough, Farnham Royal, 351 pp.

A.R.C. (1965). The nutrient requirements of farm livestock, No. 2. Ruminants. Technical Communication, *Agricultural Research Council*, London, 264 pp.

Ahlborn-Breier, G. and Dempfle, L. (1992). Genetic parameters for milk production and body size in New Zealand Holstein-Friesian and Jersey. *Livestock Production Science*, **31**: 205-219.

Ahlborn-Brier, G.; Bishop, S.C. and Wickham, B. W. (1990). Progress in New Zealand Cattle Breeding: The implementation of a selection index for production and traits other than production. *Proceedings of the Australian Association of Animal Breeding and Genetics*. Technology Prospects and Transfer. Hamilton and Palmerston North, New Zealand, pp. 339-343.

Ahlborn, G. and Bryant, A.M. (1993). Production, economic performance and optimum stocking rate of Holstein-Friesian and Jersey cows. *Proceedings of the New Zealand Society of Animal Production*. 52:7-9.

Barlow, R.; Ellis, K. J.; Williamson, P. J. ; Costigan, P.; Stephenson, P. D.; Rose, G. and Mears, P. T. (1988). Dry matter intake of Hereford and first-cross cows measured by controlled release of chromic oxide on three pasture systems. *Journal of Agricultural Science (Cambridge)* **110**: 217-231.

Bell, A. W. (1993). Pregnancy and fetal metabolism. In *Quantitative Aspects of Ruminant Digestion and Metabolism*. C. A. B. International, pp. 405-432. (ed. J. M. Forbes and J. France).

Bhuvaneshwar, S. (1993). Effects of body size on food conversion efficiency in dairy cows. *Master of Agricultural Science Thesis*. Massey University, Palmerston North, New Zealand, 109 pp.

Bickel, H., Landis, J. (1978). Feed evaluation for ruminants. III. Proposed application of the new system of energy evaluation in Switzerland, *Livestock Production Science*, 5:367-372.

Blaxter, K. L. (1974). Metabolizable energy and feeding systems for ruminants. In *Proc. Nutr. Conf. Feed Manuf.* (ed. H. Swan and D. Lewis). Butterworths, London, 7: 3-25.

Blaxter, K. L. (1989). Energy metabolism in animals and man. Cambridge University press, Cambridge, 336 pp.

Blaxter, K. L., Graham, N. McC. (1956). The effect of the grinding and cubing process on the utilization of the energy of dried grass. *Journal of Agricultural Science*, **47**: 207.

Brandyberry, S. D.; Cochran, R. C.; Vanzant, E. S. and Harmon, D. L. (1991). Effectiveness of different methods of continuous marker administration for estimating faecal output. Technical note. *Journal of Animal Science*, **69**: 4611-4616.

Bryant, A. M. and Macmillan, K. L. (1985). Comparative performance of Jerseys and Friesians. *Proceedings of the Ruakura Farmers Conference*, 37:87-93.

Bryant, A. M. (1990). Dairy production in the New Zealand environment. *Proceedings of the Australian Association of Animal Breeding and Genetics*. Technology Prospects and Transfer. Hamilton and Palmerston North, New Zealand, p. 37.

Buntix, S. E.; Pond, K. R.; Fisher, D. S.; Burns, J. C. and Goodwin, T. G. (1990). Prediction of total faecal output of free grazing sheep using Captec Chrome controlled release capsule. *Journal of Animal Science*, **68** (Suppl. 1): 562 (Abstr.).

Byers, F. M.; Schelling, G. T.; Goodrich, R. D. (1985). Maintenance requirements of beef cows with respect to genotype and environment. In: *Proceedings of the 10th Symposium on Energy Metabolism of Farm animals*. EAAP Publication No. 32, Arlie, Virginia (ed. P.W. Moe, H. F. Tyrrell & W. Reynolds).

Campbell, A. G. (1977). Comparative dairy production of Jerseys and Friesian-Jersey crossbreds. *Proceedings of the New Zealand Society of Animal Production*, **37**:25-31.

Carruthers, V. R. (1980). A study of the winter feeding management of dry pregnant high and low breeding index cows in relation to their requirements. *Thesis of Bachelor of Agricultural Science*, Massey University, Palmerston North, New Zealand, 107 pp.

Carruthers, V. R. and Bryant, A. M. (1983). Evaluation of the use of chromic oxide to estimate the feed intake of dairy cows. *New Zealand Journal of Agricultural Research*, **26**:183-186.

Conniffe, G. (1976). A comparison of between and within herd variance in grazing experiments. Irish Journal of Agricultural Research, **15**: 39-46.

Corbett, J. L.; Greenhalgh, J. F. D. and McDonald, A. P. (1958). Paper as a carrier of chromium sesquioxide. *Nature, London*, **182**: 1014-1016.

C.S.I.R.O. (1990). Feeding standards for australian livestock. Standing Committee on Agriculture: Ruminants.

Cox, C. P.; Foot, A. S.; Hosking, Z. D.; Line, C.; Rowland, S. J. (1956). The direct evaluation of pasture in terms of the milk production of individually grazed cows. *Journal of the British Grassland Society*, **11**: 107-118.

Curran, M. K. and Holmes, W. (1970). Prediction on the voluntary intake of food by dairy cows. 2. Lactating grazing cows. *Animal Production*, **12**: 213-224.

Department of Agriculture, New Zealand. (1951). *Report of the Department of Agriculture, N. Z. Animal Research Division* 1950-51, P. 23.

Dickinson, F. N.; McDaniel, B. T. and McDowell, R. E. (1969). Comparative efficiency of feed utilization during first lactation of Ayrshire, Brown Swiss and Holstein cows. *Journal of Dairy Science*, **52**:489.

Earle, D. F. (1976). A guide to scoring dairy cow condition. *Journal of Agriculture, Victoria Department of Agriculture*, **74**: 228-231.

Earle, D. F. and McGowan, A. A. (1979). Evaluation and calibration of an automated rising-plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **19**: 337-343.

Ferrell, C. L.; Garrett, W. N.; Hinman, N. and Grichting, G. (1976 a). Energy utilization by pregnant and non-pregnant heifers. *Journal of Animal Science*, **42**: 937-950.

Ferrell, C. L.; Garrett, W. N. and Hinman, N. (1976 b). Growth, development and composition of the udder and gravid uterus of beef heifers during pregnancy. *Journal of Animal Science*, **42**: 1477-1489.

Flatt, W. P. and Coppock, C. E. (1965). Physiological factors influencing the energy metabolism of ruminants. In *International Symposium on the Physiology of Digestion in the Ruminant* (ed. R. W. Dougherty *et al*) pp. 240-253.

Flatt, W. P.; Moe, P. W.; Oltgen, R. R. Putnam, P. A. and Hooven, N. W. (1969a). Energy metabolism studies with dairy cows receiving purified diets. In *Energy Metabolism of Farm Animals.* (ed. K. L. Blaxter, J. Kielanowski and G. Thorgek). Oriel Press Ltd., New Castle-Upon-Tyne, pp. 109-122.

Flatt, W. P.; Moe, P. W.; Moore, L. A. (1969b). Influence of pregnancy and ration composition on energy utilization by dairy cows. In *Energy Metabolism of Farm Animals.* (ed. K. L. Blaxter, J. Kielanowski and G. Thorgek). Oriel Press Ltd., New Castle-Upon-Tyne, pp. 128-138.

Freeman, A. E. (1967). Genetic aspects of the efficiency of nutrient utilization for milk production. *Journal of Animal Science*, **26**: 976.

Freeman, A. E. (1975). Genetic variation in nutrition of dairy cattle. In: *The Effect of Genetic Variance on Nutritional Requirements of Animals.* National Academy of Sciences. Proceedings of a symposium. Washington, D. C. pp. 19-46.

Gabriels, P. C. J. and Van der Berg, J. V. (1993). Calibration of two techniques for estimating herbage mass. *Grass and Forage Science*, **48**:329-335.

Geenty, K. G. and Rattray, P. V. (1987). The energy requirements of sheep and cattle. In *Livestock feeding on pasture.* New Zealand Society of Animal Production, Occasional Publication No. 10. (ed. A. M. Nicol). Hamilton, New Zealand.

Gibb, M.; Robinson, I. and McGowan, A. A. (1977). Effect of body condition on maintenance requirements and efficiency of liveweight gain of dry dairy cows. *Annual Report, Ellinbank Dairy Research Institute*, Victoria, Australia, p. 38.

Gibson, J. P. (1986). Efficiency and performance of genetically high and low milk-producing British Friesian and Jersey cattle. *Animal Production*, **42**:161-182.

Graham, N. J.; Burnside, E. B.; Gibson, J. P.; Rapita, A. E. and McBride, B. W. (1991). Comparison of daughters of canadian and New Zealand Holstein sires for first lactation efficiency of production in relation to body size and condition. *Canadian Journal of Animal Science*, **71**: 293-300.

Grainger, C. (1980). Responses to extra feed before and after calving. *Dairy Farming Annual.* Massey University, Palmerston North, New Zealand, pp. 65-71.

Grainger, C.; Holmes, C. W. and Moore, Y. F. (1981). Factors affecting the differences in yield of milk solids between genetically high and low producing cows. *Annual Report, Dairy Research Institute*, Ellinbank, Victoria, Australia: 74.

Grainger, C.; Holmes, C. W. and Moore, Y. F. (1985). Performance of friesian cows with high and low breeding indexes. 2. Energy and nitrogen balance experiments with lactating and pregnant, non-lactating cows. *Animal Production*, **40**: 389.

Grainger, C. and McGowan, A. A. (1982). The significance of pre-calving nutrition of the dairy cow. In *Dairy Production from Pasture* (ed. K. L. Macmillan and V. K. Taufa). pp. 134-171. Clark and Matheson, Hamilton, New Zealand.

Grainger, C.; Whilhelms, G. and McGowan, A. A. (1978). Maintenance requirements and efficiency of live weight gain of dry, pregnant dairy cows. *Annual Report, Dairy Research Institute*, Ellinbank, Victoria, Australia: 37.

Grainger, C.; Whilhelms, G. and McGowan, A. A. (1982). Effect of body condition at calving and level of feeding in early lactation on milk production of dairy cows. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **22**:9-17.

Gray, R.; Hodge, A. and McGowan, A. (1981). Evaluation of the effects of body condition on maintenance, efficiency of liveweight gain, body composition and total body energy of dry cows. *Annual Report, Dairy Research Institute*, Ellinbank, Victoria, Australia: 42.

Greenhalgh, J. F. D., Reid, g. W., Aitken, J. N. and Florence, E. (1966). The effects of grazing intensity on herbage consumption and animal production. 1. Short-term effects in strip-grazed dairy cows. *J. Agricultural Science (Cambridge)*, **67**: 13-23.

Holmes, C. W. (1974). The Massey grass meter. *Dairy Farming Annual*, Massey University, Palmerston North, New Zealand, pp. 26.

Holmes, C. W.; Davey, A. W. F. and Grainger, C. (1981). The efficiency with which feed is utilized by the dairy cow. *Proceedings of the New Zealand Society of Animal Production*, **41**: 16-27.

Holmes, C. W. and Grainger, C. (1982). Some estimates of the pasture required to maintain and gain body condition of dry, pregnant cows. In *Dairy Production from Pasture.* New Zealand and Australian Societies of Animal Production (ed. K.L. Macmillan and V. K. Taufa), Clark and Matheson Ltd, Hamilton, New Zealand, pp. 172-173.

Holmes, C. W. and McLenaghan, R. (1980). Feeding dry cows on grazed pasture during winter and changes in body condition. *Dairy Farming Annual*, Massey University, Palmerston North, New Zealand, pp. 60-64.

Holmes, C. W. and Parker, W.J. 1992. Stocking rate and its effects on dairy farm *productivity. Dairy Farming Annual.* Massey University, Palmerston North, new Zealand, pp. 4-15.

Holmes, C. W.; Wilson, G. F.; Kuperus, W.: Buvaneshwa, S.; Wickham, B. (1993). Live weight, feed intake and feed conversion efficiency of lactating dairy cows. *Proceedings of the New Zealand Society of Animal Production*, **53**:95-99.

Holmes, C. W. and Wilson, G. F. (1987). Milk Production from Pasture. Butterworths Agricultural Books, Wellington, New Zealand, 319 p.

Holmes, W., Jones, J. G. W. 1965. The feed intake of milk cows. II. The effect of roughage quality during late pregnancy and lactation. *Animal Production*, **7**:39-51.

Hooven, N. W., Jr.; Miller, R. H., and Plowman, R. D. (1968). Genetic and environmental relationships among efficiency, yield, consumption and weight of Holstein cows. *Journal of Dairy Science*, **51**: 1409.

Hooven, N. W., Jr.; Miller, R. H., and Smith, J. W. (1972). Relationships among whole-and part-lactation gross feed efficiency, fed consumption and milk yield. *Journal of Dairy Science*, **55**: 1113.

Hutton, J. B. (1962). The maintenance requirements of New Zealand dairy cattle. *Proceedings of the New Zealand Society of Animal Production*, **22**: 12-34.

Hutton, J. B. (1963). The effect of lactation on intake in the lactating dairy cow. *Proceedings of the New Zealand Society of Animal Production*, **23**:39-52.

Hutton, J. B. (1963). Variations in dairy cow efficiency. *Proceedings of the Ruakura Farmers Conference*, pp. 195-207.

Hutton, J. B. (1968). Farming two cows per acre: 2_ At Ruakura, three seasons' intensive dairy production. *Proceedings of the Ruakura Farmers Conference*, pp. 215-227.

Hutton, J. B. (1971). Nutrient requirements of New Zealand Dairy Cattle. *Proceedings of the New Zealand Society of Animal Production*, **31**: 211-223.

Hutton, J. B. and Bryant, A. M. (1976). Producing 700 kg butterfat per hectare. *Proceedings of the Ruakura Farmers Conference*. pp. 71-75.

Jagusch, K. T. and Coop, I. E. (1971). The nutritional requirements of grazing sheep. *Proceedings of the New Zealand Society of Animal Production*. 31: 224.

Johnstone, P. D. (1979). A statistical appraisal of a sacred cow. *Proceedings of the New Zealand Society of Animal Production*, **39**: 281 -283.

Jones, J. G. W., Drake-Brockman, R. M., W. Holmes. (1965). The feed intake of grazing cattle. III. The influence of level of milk yield. *Animal Production*, **7**: 141.

Joyce, J. P. (1971). Feed requirements of beef cattle. *Proceedings of the New Zealand Society of Animal Production*, **31**: 196-210.

Joyce, J. P.; Bryant, A. M.; Duganzich, D. M.; Scott, J. D. J. and Reardon, T. F. (1975). Feed requirements of growing and fattening beef cattle: New Zealand experimental data compared with National Research Council (USA) and Agricultural Research Council (UK) feeding standards. *New Zealand Journal of Agricultural Research*, **18**: 295-301.

Ketelaars J. J. M. H. & Tolkamp, B. J. (1992). Toward a new theory of feed intake regulation in ruminants 1. Causes of differences in voluntary feed intake: Critique of current views. *Livestock Production Science*, **30**:269-296.

Kleiber, M. (1961). The fire of life. John Wiley and Sons, Inc. New York.

Kleiber, M. (1965). Metabolic body size. In *Energy Metabolism of Farm Animals*. EAAP Publication No. 11 (ed. K. L. Blaxter), pp. 427-432. Academic Press, London.

L.I.C (1991). Total Breeding Index Information kit. *Livestock Improvement Corporation*, Hamilton, New Zealand, 20 pp.

L'Huillier, P. J.; Parr, C. R. and Bryant, A. M. (1988). Comparative performance and energy metabolism of Jerseys and Friesians in early-mid lactation. *Proceedings of the New Zealand Society of Animal Production*, **48**: 231-235.

Laby, R. H.; Graham, C. A.; Edwards, S. R. and Kauzer B. (1984). A controlled release intraruminal device for the administration of faecal dry matter markers to the grazing ruminant. *Canadian Journal of Animal Science*, **64** (Suppl.): 337-338.

Lambourne, L. J. and Reardon, T. F. (1962). Effect of environment on the maintenance requirements of merino wethers. *Australian Journal of Agricultural Research*, **14**: 272-293.

Lambourne, L. J. (1957). Measurement of feed intake in grazing sheep. 2. The estimation of faeces output using markers. *Journal of Agricultural Science (Cambridge)*, **48**:415-425.

Langlands, J. P.; Corbett, J. L.; McDonald, I. and Pullar, J. D. (1963). Estimates of the energy for maintenance by adult sheep. 1. Housed sheep. *Animal Production*, **5**: 1-9.

Lee, G. J.; Atkins, k. D. and Mortimer, S. I. (1990). Use of controlled release devices as a technique to estimate pasture intake by grazing sheep. *Proceedings of the Australian Association of Animal Breeding and Genetics*. Technology Prospects and Transfer. Hamilton and Palmerston North, New Zealand, pp. 147-150.

Le Du, Y. L. P. and Penning, P. D. (1982). Animal based techniques for estimating herbage intake. In *Herbage intake handbook*. The British Grassland Society, (ed. J. D. Leaver), pp. 37-76.

Legates, J. E. (1990). Efficiency of feed utilization of Holsteins selected for yield. *Journal of Dairy Science*, **73**: 1533-1536.

Macdonald, K. A. and Macmillan, K. L. (1993). Condition score and liveweight in Jersey and Friesian cows. *Proceedings of the Ruakura Farmers Conference*, pp. 47-50.

Madgwick, P.; Beard, K. and Goddard, M. (1991). Possibilities for incorporating selection for feed conversion efficiency into the national dairy herd improvement program. *Proceedings of the Australian Association of Animal Breeding and Genetics*. University of Melbourne, Australia, pp. 24-27.

MAFF. (1984). Ministry of Agriculture, Fisheries and Food, Department of agriculture and Fisheries for Scotland, and Department of Agriculture for Northern Ireland. Energy Allowances and Feeding Systems for Ruminants.Reference Book 433. 2nd Edition. (Her Majesty's Stationery Office: London.).

Mason, I. L.; Robertson, A. and Gjelstad, B. (1957). The genetic connection between body size, milk production and efficiency in dairy cattle. *Journal of Dairy Research*, **24**: 135.

Maughan, B. and Holmes, C. W. (1992). Dairy farm profitability: Historical trends and future developments. *Dairy Farming Annual*, Animal Science Department, Massey University, Palmerston North New Zealand, pp. 91-94.

McMeekan, C. P. (1956). Grazing management and animal production. *Proceedings of the 7th International Grassland Congress*, Palmerston North, New Zealand, pp.146-156.

Meijs, J. A. C.; Walters, R. J. K. and Keen, A. (1982). Sward methods. In *Herbage intake handbook*, The British Grassland Society, (ed. J. D. Leaver), pp. 11-36.

Miller, R. H.; Hooven, N. W. Jr.; Smith, J. W. and Creegan, M. E. (1972). Feed consumption differences among lactating cows. *Journal of Dairy Science*, **55**: 454-459.

Moe, P. W. and Flat, W. P. (1969). Use of body tissue reserves for milk production by the dairy cow. *Journal of Dairy Science*, **52**:928 (Abstr.).

Moe, P. W.; Flatt, W. P.; Tyrrell, H. F. (1972). Net energy value of feeds for lactation. *Journal of Dairy Science*, **55** : 945-958.

Moe, P. W. and Tyrrell, H. F. (1971). Metabolizable energy requirements of pregnant dairy cows. *Journal of Dairy Science*, **55**: 480-483.

Moe, P. W.; Tyrrell, H. F. (1973). Prediction of the net energy value of feeds for lactation. In *Proceedings of the 6th Symposium on Energy Metabolism of Farm Animals*. EAAP. Publication No. 14 (K. H. Menke, H. J. Lantzch & J. R. Reichl, Ed).

Moe, P. W.; Tyrrell, H. F. and Flatt, W. P. (1970). Partial efficiency of energy use of maintenance, lactation body gain and gestation in the dairy cow. *Proceedings of the 5th Symposium on Energy Metabolism of Farm Animals*. EAAP. Pub. No. 13 (ed. A. Schurch and C. Wenk). p. 66.

Moe, P. W., Tyrrell, H. F. Flatt, W. P. (1971). Energetics of body tissue mobilisation. *Journal of Dairy Science*, **54**: 548-553.

Momont, P. A.; Pruitt, R. J.; Emerick, R. J. and Pritchard, R. H. (1990). Evaluation of controlled release chromic oxide boluses and alkaline peroxide lignin as marker methods to determine forage intake of ruminants. *Journal of Animal Science*, **68** (Suppl. 1): 562 (Abstr.).

Nottingham, R. M. (1978). The influence of pasture allowance and yield of pasture remaining after grazing on liveweight and condition score in pregnant, non-lactating dairy cows. *Thesis of Bachelor of Agricultural Science*, Massey University, Palmerston North, New Zealand, 128 pp.

Østergaard, V.; Korver, S.; Solbu, H.; Andersen, B. B.; Oldham, J. and Wiktorsson, H. (1990). Main report-E.A.A.P. Working group on: Efficiency in the dairy cow. *Livestock Production Science*, **24**: 287-304.

Parker W. J.; McCutcheon, S. N. Carr, D. H. (1989). Effect of herbage type and level of intake on the release of chromic oxide from intraruminal controlled release capsules in sheep. *New Zealand Journal of Agricultural Research*, **32**: 537-546.

Parker, W. J.; McCutcheon, S. N. and Garrick, D. J. (1990). The suitability of chromium controlled release capsules for estimating herbage intakes of grazing ruminants. *Proceedings of the Australian Association of Animal Breeding and Genetics*. Technology Prospects and Transfer. Hamilton and Palmerston North, New Zealand, pp. 147-150.

Persaud, P.; Simm, G. and Hill, W.G. (1990). Genetic parameters of feed efficiency and feed intake for dairy cattle fed ad libitum. In *Proceedings of the 4th World Congress on Genetics Applied to Livestock Production*. Edinburgh, Vol. **14**, pp. 237-240.

Raymond, W. F. and Minson, D. J. (1955). The use of chromic oxide for estimating the faecal production of grazing animals. *Journal of the British Grassland Society*, **10**: 282-296.

Roughan, P. G. Holland, R. (1977). Predicted *in vivo* digestibility of herbages by exhaustive enzymic hydrolysis of cell walls. *Journal of Science and Food in Agriculture*, **28**: 1057-1064.

Robinson, J. J.; McDonald, I.; Fraser, C. and Gordon, J. G. (1980). Studies on reproduction in prolific ewes. 6. The efficiency of energy utilization for conceptus growth. *Journal of Agricultural Science (Cambridge)*, **94**:331-338.

Sieber, J.; Freeman, A. E. and Kelley, D. H. (1988). Relationships between body measurements, body weight, and productivity in Holstein dairy cows. *Journal of Dairy Science*, **71**: 3437-3445.

Stakelum, G. and Connolly, J. (1987). Effect of body size and milk yield on intake of fresh herbage by lactating dairy cows indoors. *Irish Journal of Agricultural Research*, **26**: 9-22.

Stockdale, C. R. and K. B. Kelly (1984). A comparison of a rising-plate meter and an electronic capacitance meter for estimating the yield of pasture grazed by dairy cows. *Grass and Forage Science*, **39**: 391-394.

Syrstad, O. (1966). Studies on dairy herd records. IV. Estimates of phenotypic and genetic parameters. *Acta Agriculturæ Scandinavica*, **16**: 79.

Tolkamp, B. J. & Ketelaars, J. J. M. H. (1992). Toward a new theory of feed intake regulation in ruminants 2. Costs and benefits of feed consumption: an optimization approach. *Livestock Production Science*, **30**:297-318.

Trigg, T. E.; Bryant, A. M. and Cox, N. R. (1980). The effect of level of feeding of pasture on its digestion by lactating dairy cows. *Proceedings of the New Zealand Society of animal production*, **40**: 227-230.

Tyrrell, H. F.; Moe, P.W. (1971). Net energy value for lactation of a high and low concentrate ration containing corn silage. *Journal of Dairy Science*, **55** : 1106-1112.

Tyrrell, H. F.; Reid, J. T. (1965). Prediction of the energy value of cow's milk. *Journal of dairy Science*, **48**: 1215-1223.

Tyrrell, H. F.; Moe, P. W.; Oltjen, R. R. (1970). Energetics of growth and fattening compared to lactation in cattle. In *Proceedings of the 6th Symposium on Energy Metabolism of Farm Animals*, EAAP. Publication No. 14 (ed. K.H. Menke, H. J. Lantzch & J. R. Reichl).

Ulyatt, M. J. (1981). The feeding value of temperate pastures. In: *Grazing Animals*, World Animal Science B1. (ed. F. W. H. Morley). Elsevier Scientific Publishing Co. Amsterdam, The Netherlands.

Van arendonk, J. A. M.; Vos, H. and Van der Werf, J. H. J. (1991). Genetic aspects of feed intake and efficiency in dairy cows. *Proceedings of the Australian Association of Animal Breeding and Genetics*. University of Melbourne, Victoria, Australia, pp 24-27.

Van Es, A. J. H. (1974). Energy intake and requirement of dairy cows during the whole year. *Livestock Production Science*, **1**:21-32.

Van Es, A. J. H. (1975). Feed evaluation for dairy cows. *Livestock Production Science*, **2**: 95-107.

Van Es, A. J. H. (1978). Feed evaluation for ruminants. I. The systems in use from may 1977 onwards in the Netherlands. *Livestock Production Science*, **5**: 331-345.

Vickery, P. J. and Nicol, G. R. (1982). An improved electronic capacitance meter for estimating pasture yield: Construction details and performance tests. *Animal Research Laboratories Technical paper No. 9. Australia: Commonwealth Scientific and Industrial Research Organization.*

Vickery, P. J.; Bennet, I. L. and Nicol, G. R. (1980). An improved electronic capacitance meter for estimating herbage mass. *Grass and Forage Science*, **35**: 247-252.

Wallace, L.R. (1956 a). The intake and utilization of pasture by grazing dairy cattle. *Proceedings of the 7th International Grassland Congress*. pp. 134-145.

Wallace, L. R. (1956 b). The relationship of size and yield to efficiency of cows. *Proceedings of the Ruakura Farmers Conference*, 177-185.

Wallace, L. R. (1961). Nutritional requirements of dairy cattle. *Proceedings of the New Zealand Society of animal production*, **21**: 64-78.

Wickham, B. W. (1993). Size and efficiency in Holstein Friesian Animals. *New Zealand Holstein-Friesian Journal*, pp. 68-71.

Yerex, R. P.; Young, C. W.; Donker, J. D. and Marx, G. D. (1988). Effects of selection for body size on feed efficiency and size of Holsteins. *Journal of Dairy Science*, **71**: 1355-1360.

Appendices

Appendix I. Analysis of variance table and expected mean squares for the variables generated in the experiment.

Source of of variation	Degrees of freedom	Sums of squares	Mean squares	Expected mean squares	Calculated F-value
Between F.levels	f-1	SS_F	MS_F	$\sigma^2_\epsilon+\sigma^2_{FS}+\sigma^2_F$	$FC_F=MS_F/MS_{FS}$
Between sizes	s-1	SS_S	MS_S	$\sigma^2_\epsilon+\sigma^2_{FS}+\sigma^2_S$	$FC_S=MS_S/MS_{FS}$
Interaction	(f-1)(s-1)	SS_{FS}	MS_{FS}	$\sigma^2_\epsilon+\sigma^2_{FS}$	$FC_{FS}=MS_{FS}/MS_R$
Residual	$\sum_{i=1}^{n} (n_{ij.}-1)$	SS_R	MS_R	σ^2_ϵ	
Corrected total	$\sum_{i=1}^{n} n_{ijk}-1$				

The main effect Feeding level (F) and Size (S) are tested against the interaction term Feeding level x Size (F*S), and the effect of the interaction term is tested for significance against the residual mean square.

Appendix II. Pre-grazing herbage mass, post-grazing herbage mass, number of cows per treatment group and average plate meter reading for each paddock used in the experiment.

Feeding level[1]	Size[2]	Day of experiment	Cows/ group	Average meter reading: Pre-grazing	Post-grazing	Paddock number	Herbage mass (kg DM/ha): pre-grazing	Post-grazing
1	1	3	7	22.6333	7.8666	2	4030	1965
1	1	6	7	23.5333	9.3000	2	3009	1463
1	1	9	7	25.1667	7.9000	4	4304	1683
1	1	12	7	21.3000	9.1000	34	3864	2520
1	1	15	7	22.0000	6.8666	34	3319	747
1	1	18	7	24.9000	8.1333	34	3784	2101
1	1	21	7	17.6667	5.3333	32	3282	1106
1	1	24	7	18.9000	5.6000	32	4776	697
1	1	27	7	18.7667	5.4000	56	3165	1318
1	1	30	7	17.1667	6.4333	56	4200	998
1	1	33	7	16.5000	5.5333	57	3513	718
1	1	36	7	16.7000	6.3666	57	2800	1101
1	1	39	7	14.9667	7.5666	57	3977	1948
1	2	3	7	23.5000	8.3000	2	4304	2114
1	2	6	7	26.2333	8.6666	2	2761	1279
1	2	9	7	22.4667	7.4000	4	4220	2032
1	2	12	7	23.5333	9.4333	34	3343	1925
1	2	15	7	23.8667	7.0000	34	3914	1024
1	2	18	7	21.3000	7.3000	34	4121	2187
1	2	21	7	15.7000	5.4333	32	3692	1755
1	2	24	7	18.9333	6.5000	32	4267	884
1	2	27	7	17.0667	6.1000	56	4246	1676
1	2	30	7	16.0000	5.8667	57	4334	1508
1	2	33	7	15.0000	4.7667	57	3117	2405
1	2	36	7	16.1000	8.1000	57	5306	2405
1	3	39	5	19.5667	7.4000	2	3457	1482
1	3	3	5	22.2000	6.3333	2	3078	1295
1	3	6	5	22.4667	7.9333	4	4384	1785
1	3	9	5	22.8333	8.2333	34	4417	2651
1	3	12	5	19.0000	7.5667	34	4713	1585
1	3	15	5	22.1667	5.3667	34	3908	2303
1	3	18	5	17.3000	5.4333	32	4471	1802
1	3	21	5	17.9000	6.6667	32	5512	1180
1	3	24	5	16.6667	5.9667	56	4861	1577
1	3	27	5	22.4667	6.2667	56	5009	2030
1	3	30	5	15.7333	6.0000	57	4590	1802
1	3	33	5	21.5000	6.5000	57	4543	2548
1	3	36	5	16.7667	8.9333	57	4539	2548

[1] *Ad libitum* = 1; Maintenance = 2.
[2] Big Friesians = 1; Small Friesians =2, and Jerseys = 3.

Appendix II. (Cont.). Pre-grazing herbage mass, post-grazing herbage mass, number of cows per treatment group and average plate meter reading for each paddock used in the experiment.

Feeding level[1]	Size[2]	Day of experiment	Cows/ group	Average meter reading: Pre-grazing	Post-grazing	Paddock number	Herbage mass (kg DM/ha): pre-grazing	Post-grazing
2	1	3	7	22.1333	7.86667	3	3237	1965
2	1	6	7	20.6333	9.30000	3	3181	1463
2	1	9	7	24.5333	7.90000	3	3968	1683
2	1	12	7	20.8667	9.10000	5	4167	2520
2	1	15	7	18.3000	6.86667	5	3138	747
2	1	18	7	17.6667	8.13333	5	3313	2101
2	1	21	7	22.5333	5.33333	5	3154	1106
2	1	24	7	22.4667	5.60000	5	3978	697
2	1	27	7	17.5000	5.40000	8	2861	1318
2	1	30	7	19.3667	6.43333	8	2972	998
2	1	33	7	21.6333	5.53333	8	3588	718
2	1	36	7	20.4667	6.36667	8	3026	1101
2	1	39	7	17.5667	7.56667	10	2897	1948
2	2	3	7	22.7333	8.30000	3	3372	2114
2	2	6	7	23.3333	8.66667	3	3164	1279
2	2	9	7	19.8333	7.40000	3	3521	2032
2	2	12	7	21.1000	9.4333	5	3091	1925
2	2	15	7	18.5000	7.0000	5	4377	1024
2	2	18	7	16.9000	7.3000	5	3630	2187
2	2	21	7	19.6333	5.4333	5	3571	1755
2	2	24	7	22.3333	6.5000	5	4293	884
2	2	27	6	13.1667	6.1000	8	2773	1676
2	2	30	6	17.9333	5.8667	8	2967	1508
2	2	33	6	20.7000	4.7667	8	3199	2405
2	2	36	6	21.0667	8.1000	8	4044	2405
2	3	39	6	15.6333	7.4000	10	2839	1482
2	3	3	5	19.8000	6.3333	3	3821	1295
2	3	6	5	19.7000	7.9333	3	2661	1785
2	3	9	5	24.6667	8.2333	3	3668	2651
2	3	12	5	21.6000	7.5667	5	3193	1585
2	3	15	5	15.1333	5.3667	5	3869	2303
2	3	18	5	16.9333	5.4333	5	3151	1802
2	3	21	5	20.5667	6.6667	5	3834	1180
2	3	24	5	19.9000	5.9667	5	3658	1577
2	3	27	5	14.1000	6.2667	8	2856	2030
2	3	30	5	17.0333	6.0000	8	3670	1802
2	3	33	5	14.7000	6.5000	8	3306	2548
2	3	36	5	21.9333	8.9333	8	4023	2548

[1] *Ad libitum* = 1; Maintenance = 2.
[2] Big Friesians = 1; Small Friesians =2, and Jerseys = 3.

Appendix III. Analyses of variance tables for the regression equations appearing in the body of the text.

3.1. Analysis of variance table for the regression of Metabolizable energy intake (MEI MJ ME/kg $LW^{0.75}$/day) on Total Condition score Change (TOTCS, CS units/cow/41 days experiment).

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	0.19679	0.19679	26.275	0.0069
Error	4	0.02996	0.00749		
C Total	5	0.22674			

Root MSE	0.08654	R-square	0.8679
Dep Mean	1.02411	Adj R-sq	0.8348
C.V.	8.45037		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEPT	1	0.648296	0.08138576	7.966	0.0013
TOTCS	1	0.489737	0.09554096	5.126	0.0069

3.2. Analysis of variance table for the regression of Daily herbage dry matter intake (DMI, g DMI/kg $LW^{0.75}$/day) on total condition score change (TOTCS, CS units/cow/41 days experiment).

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	1392.78768	1392.78768	26.105	0.0069
Error	4	213.41152	53.35288		
C Total	5	1606.19920			

Root MSE	7.30431	R-square	0.8671
Dep Mean	88.83854	Adj R-sq	0.8339
C.V.	8.22200		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEPT	1	57.221318	6.86915103	8.330	0.0011
TOTCS	1	41.201001	8.06388353	5.109	0.0[illegible]

3.3. Analysis of variance table for the regression of total liveweight change (TWGCH, kg/cow/41 days experiment) on total condition score change (TOTCS, CS units/cow/41 days experimental period)for the group of Big Friesian cows.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1991.373865	1991.373865	6.52	0.0253
Error	12	3667.506521	305.625543		
Corrected Total	13	5658.880386			

R-Square	C.V.	Root MSE	TWGCH Mean
0.351902	34.27469	17.48215	51.0060000

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	37.75271138	5.40	0.0002	6.98485347
TOTCS	17.25367683	2.55	0.0253	6.75927447

3.4. Analysis of variance table for the regression of total liveweight change (TWGCH, kg/cow/41 days experiment) on total condition score change (TOTCS, CS units/cow/41 days experimental period)for the group of Small Friesian cows.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	846.2895264	846.2895264	4.11	0.0675
Error	11	2264.2727908	205.8429810		
Corrected Total	12	3110.5623172			

R-Square	C.V.	Root MSE	TWGCH Mean
0.272070	27.77916	14.34723	51.6474615

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	39.29117668	5.40	0.0002	7.27804143
TOTCS	16 25826955	2.03	0.0675	8.01831046

3.5. Analysis of variance table for the regression of total liveweight change (TWGCH, kg/cow/41 days experiment) on total condition score change (TOTCS, CS units/cow/41 days experimental period)for the group of Jersey cows.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	707.0802994	707.0802994	6.48	0.0345
Error	8	873.5580567	109.1947571		
Corrected Total	9	1580.6383561			

R-Square	C.V.	Root MSE	TWGCH Mean
0.447338	33.47448	10.44963	31.2167000

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	16.20716366	2.40	0.0434	6.76095637
TOTCS	18.90846100	2.54	0.0345	7.43057987

3.6. Analysis of variance table for the pooled regression of total liveweight change (TWGCH, kg/cow/41 days experiment) on total condition score change (TOTCS, CS units/cow/41 days experimental period)for all the three group-sizes.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	3384.850700	3384.850700	11.95	0.0015
Error	35	9915.642940	283.304084		
Corrected Total	36	13300.493641			

R-Square	C.V.	Root MSE	TWGCH Mean
0.254491	36.68389	16.83164	45.8829189

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TOTCS	1	3384.850700	3384.850700	11.95	0.0015
Source	DF	Type III SS	Mean Square	F Value	Pr > F

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	32.84580673	7.02	0.0001	4.67788930
TOTCS	16.88272262	3.46	0.0015	4.88426416

3.7. Analysis of variance table for the regression of total liveweight change (TWGCH, kg/cow/41 days experiment) on total condition score change (TOTCS, CS units/cow/41 days experimental period) pooled for the three size-groups using group averages.

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	12073.38290	12073.38290	52.439	0.0008
Error	5	1151.17868	230.23574		
U Total	6	13224.56158			

Root MSE	15.17352	R-square	0.9130
Dep Mean	44.23595	Adj R-sq	0.8955
C.V.	34.30133		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
TOTCS	1	52.659902	7.27196738	7.241	0.0008

3.8. Analysis of variance table for the regression of metabolizable energy intake for maintenance (MJ/cow/day) (i.e. ME_m assessed from the pooled regression of $MEI/LW^{0.75}$ on CS) on average liveweight.

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	344.59395	344.59395	23915.645	0.0001
Error	4	0.05763	0.01441		
C Total	5	344.65159			

Root MSE	0.12004	R-square	0.9998
Dep Mean	63.92718	Adj R-sq	0.9998
C.V.	0.18777		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEPT	1	16.060942	0.31337495	51.252	0.0001
AVLW	1	0.104745	0.00067732	154.647	0.0001

3.9. Analysis of variance table for the regression of metabolizable energy intake for maintenance (MJ/cow/day) (i.e. ME_m assessed as by Ferrell *et al.*, 1976b) on average liveweight.

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	237.16070	237.16070	40.413	0.0031
Error	4	23.47374	5.86843		
C Total	5	260.63444			

Root MSE	2.42249	R-square	0.9099
Dep Mean	69.88743	Adj R-sq	0.8874
C.V.	3.46627		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEPT	1	30.177710	6.32430239	4.772	0.0088
AVLW	1	0.086896	0.01366909	6.357	0.0031

3.10. Analysis of variance table for the regression of metabolizable energy intake for maintenance (MJ/cow/day) (i.e. ME_m assessed from zero MLWG) on average liveweight.

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	39279.29763	39279.29763	311.891	0.0001
Error	5	629.69529	125.93906		
U Total	6	39908.99292			

Root MSE	11.22226	R-square	0.9842
Dep Mean	79.00931	Adj R-sq	0.9811
C.V.	14.20372		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
AVLW	1	0.174877	0.00990220	17.660	0.0001

3.11. Analysis of variance table for the regression of metabolizable energy intake for the average condition score change (MJ/cow/day) on average liveweight.

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	990.73659	990.73659	202.632	0.0001
Error	4	19.55731	4.88933		
C Total	5	1010.29390			

Root MSE	2.21118	R-square	0.9806
Dep Mean	101.35281	Adj R-sq	0.9758
C.V.	2.18167		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEPT	1	20.190474	5.77266106	3.498	0.0250
AVLW	1	0.177606	0.01247680	14.235	0.0001

3.12. Analysis of variance table for the regression of herbage mass (kg DM/ha) on average plate meter reading (cm) for the ad libitum level of feeding.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	90578544.14	90578544.14	126.81	0.0001
Error	74	52855598.53	714264.85		
Corrected Total	75	143434142.67			

R-Square	C.V.	Root MSE	HMASS Mean
0.631499	29.29501	845.1419	2884.93421

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MR	1	90578544.14	90578544.14	126.81	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
MR	1	90578544.14	90578544.14	126.81	0.0001

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	763.7198039	3.61	0.0006	211.84855871
MR	157.8964428	11.26	0.0001	14.02133338

3.13. Analysis of variance table for the regression of herbage mass (kg DM/ha) on average plate meter reading (MR, cm) for the maintenance level of feeding.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	466410586.8	466410586.8	2385.46	0.0001
Error	77	15055218.2	195522.3		
Uncorrected Total	78	481465805.0			

	R-Square	C.V.	Root MSE	HMASS Mean
	0.968730	21.61662	442.1791	2045.55128

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MR	1	466410586.8	466410586.8	2385.46	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
MR	1	466410586.8	466410586.8	2385.46	0.0001

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
MR	171.0687634	48.84	0.0001	3.50255272

Appendix IV. Results of the analyses of variance for the variables generated in the experiment.

4.1. Dependent variable: Pre-grazing Herbage Mass (PHM, kg DM/ha.)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	26686485.12	5337297.02	21.76	0.0001
Error	237	58125045.35	245253.36		
Corrected Total	242	84811530.48			

	R-Square	C.V.	Root MSE	PHM Mean
	0.314656	14.04006	495.2306	3527.26721

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	23888439.40	23888439.40	97.40	0.0001
S	2	1562670.27	781335.14	3.19	0.0431
F*S	2	1235375.45	617687.73	2.52	0.0827

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	23877252.82	23877252.82	97.36	0.0001
S	2	1538303.63	769151.81	3.14	0.0453
F*S	2	1235375.45	617687.73	2.52	0.0827

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	23877252.82	23877252.82	38.66	0.0249
S	2	1538303.63	769151.81	1.25	0.4454

4.2. Dependent variable: Post-grazing Herbage Mass (RHM, kg DM/ha.)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	67606543.05	13521308.61	432.31	0.0001
Error	237	7412692.62	31277.18		
Corrected Total	242	75019235.67			

R-Square	C.V.	Root MSE	RHM Mean
0.901189	13.57582	176.8536	1302.71009

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	67521335.75	67521335.75	2158.80	0.0001
S	2	23707.38	11853.69	0.38	0.6850
F*S	2	61499.92	30749.96	0.98	0.3757

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	67517728.12	67517728.12	2158.69	0.0001
S	2	22301.72	11150.86	0.36	0.7005
F*S	2	61499.92	30749.96	0.98	0.3757

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	67517728.12	67517728.12	2195.70	0.0005
S	2	22301.72	11150.86	0.36	0.7339

4.3. Dependent variable: Herbage dry matter allowance (HA, kg DM/cow/day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	8106.871511	1621.374302	431.72	0.0001
Error	237	890.088511	3.755648		
Corrected Total	242	8996.960023			

R-Square	C.V.	Root MSE	HA Mean
0.901068	13.03441	1.937949	14.8679533

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	7284.740835	7284.740835	1939.68	0.0001
S	2	764.672208	382.336104	101.80	0.0001
F*S	2	57.458468	28.729234	7.65	0.0006

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	7222.354152	7222.354152	1923.06	0.0001
S	2	768.746998	384.373499	102.35	0.0001
F*S	2	57.458468	28.729234	7.65	0.0006

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	7222.354152	7222.354152	251.39	0.0040
S	2	768.746998	384.373499	13.38	0.0695

4.4. Dependent variable: Herbage DM allowance (HA, kg DM/100 kg liveweight/day.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	332.6984105	66.5396821	366.09	0.0001
Error	237	43.0771602	0.1817602		
Corrected Total	242	375.7755707			

R-Square	C.V.	Root MSE	HA Mean
0.885365	13.11393	0.426333	3.25099655

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	327.6550572	327.6550572	1802.68	0.0001
S	2	3.6116171	1.8058085	9.94	0.0001
F*S	2	1.4317362	0.7158681	3.94	0.0208

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	328.6480573	328.6480573	1808.14	0.0001
S	2	3.6487485	1.8243743	10.04	0.0001
F*S	2	1.4317362	0.7158681	3.94	0.0208

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	328.6480573	328.6480573	459.09	0.0022
S	2	3.6487485	1.8243743	2.55	0.2818

4.5. Dependent variable: Herbage DM allowance (HA, g DM/kg $LW^{0.75}$/day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	711626.3416	142325.2683	370.05	0.0001
Error	237	91153.3731	384.6134		
Corrected Total	242	802779.7147			
	R-Square	C.V.	Root MSE		HA Mean
	0.886453	13.06440	19.61156		150.114551
Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	709907.2441	709907.2441	1845.77	0.0001
S	2	958.4537	479.2269	1.25	0.2895
F*S	2	760.6438	380.3219	0.99	0.3735
Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	710004.1397	710004.1397	1846.02	0.0001
S	2	930.2290	465.1145	1.21	0.3002
F*S	2	760.6438	380.3219	0.99	0.3735
Tests of Hypotheses using the Type III MS for F*S as an error term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	710004.1397	710004.1397	1866.85	0.0005
S	2	930.2290	465.1145	1.22	0.4499

4.6. Dependent variable: Metabolizable energy allowance (MEHA, MJ/cow/day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1103978.590	220795.718	454.31	0.0001
Error	237	115182.041	486.000		
Corrected Total	242	1219160.632			
	R-Square	C.V.	Root MSE		MEHA Mean
	0.905523	12.85353	22.04541		171.512492
Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	994912.5206	994912.5206	2047.14	0.0001
S	2	101216.5912	50608.2956	104.13	0.0001
F*S	2	7849.4785	3924.7392	8.08	0.0004
Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	986493.0040	986493.0040	2029.82	0.0001
S	2	101765.6185	50882.8093	104.70	0.0001
F*S	2	7849.4785	3924.7392	8.08	0.0004
Tests of Hypotheses using the Type III MS for F*S as an error term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	986493.0040	986493.0040	251.35	0.0040
S	2	101765.6185	50882.8093	12.96	0.0716

4.7. Dependent variable: Metabolizable energy allowance (MEHA, MJ ME/100 kg liveweight/day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	45475.67138	9095.13428	388.70	0.0001
Error	237	5545.57839	23.39906		
Corrected Total	242	51021.24977			
	R-Square	C.V.	Root MSE		MEHA Mean
	0.891308	12.89877	4.837258		37.5016969
Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	44796.45209	44796.45209	1914.45	0.0001
S	2	484.10393	242.05197	10.34	0.0001
F*S	2	195.11536	97.55768	4.17	0.0166
Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	44931.95707	44931.95707	1920.25	0.0001
S	2	489.26176	244.63088	10.45	0.0001
F*S	2	195.11536	97.55768	4.17	0.0166
Tests of Hypotheses using the Type III MS for F*S as an error term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	44931.95707	44931.95707	460.57	0.0022
S	2	489.26176	244.63088	2.51	0.2851

4.8. Dependent variable: Metabolizable energy allowance (MEHA, MJ ME/LW$^{0.75}$/day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	97.25132386	19.45026477	392.34	0.0001
Error	237	11.74934226	0.04957528		
Corrected Total	242	109.00066612			
	R-Square	C.V.	Root MSE		MEHA Mean
	0.892209	12.85798	0.222655		1.73164928

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	97.03046632	97.03046632	1957.23	0.0001
S	2	0.11816276	0.05908138	1.19	0.3055
F*S	2	0.10269478	0.05134739	1.04	0.3566

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	97.04586332	97.04586332	1957.55	0.0001
S	2	0.11457490	0.05728745	1.16	0.3166
F*S	2	0.10269478	0.05134739	1.04	0.3566

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	97.04586332	97.04586332	1889.99	0.0005
S	2	0.11457490	0.05728745	1.12	0.4727

4.9. Dependent variable: Herbage DM intake (DMI, kg DM/cow/day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1042.653008	208.530602	71.50	0.0001
Error	237	691.166695	2.916315		
Corrected Total	242	1733.819702			
	R-Square	C.V.	Root MSE		DMI Mean
	0.601362	19.25784	1.707722		8.86767497

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	731.6345584	731.6345584	250.88	0.0001
S	2	309.7671785	154.8835893	53.11	0.0001
F*S	2	1.2512709	0.6256354	0.21	0.8071

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	721.3055300	721.3055300	247.33	0.0001
S	2	309.9661978	154.9830989	53.14	0.0001
F*S	2	1.2512709	0.6256354	0.21	0.8071

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	721.3055300	721.3055300	1152.92	0.0009
S	2	309.9661978	154.9830989	247.72	0.0040

4.10. Dependent variable: Herbage DM intake (DMI, kg DM/100 kg liveweight/day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	32.30523039	6.46104608	46.05	0.0001
Error	237	33.25582081	0.14031992		
Corrected Total	242	65.56105120			
	R-Square	C.V.	Root MSE		DMI Mean
	0.492750	19.29444	0.374593		1.94145594

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	31.07899768	31.07899768	221.49	0.0001
S	2	0.80875601	0.40437801	2.88	0.0580
F*S	2	0.41747669	0.20873835	1.49	0.2280

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	31.23665092	31.23665092	222.61	0.0001
S	2	0.81847040	0.40923520	2.92	0.0561
F*S	2	0.41747669	0.20873835	1.49	0.2280

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	31.23665092	31.23665092	149.65	0.0066
S	2	0.81847040	0.40923520	1.96	0.3378

4.11. Dependent variable: Herbage DM intake (DMI, g DM/kg $LW^{0.75}$/day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	69209.42544	13841.88509	46.56	0.0001
Error	237	70450.89230	297.26115		
Corrected Total	242	139660.31774			
	R-Square	C.V.	Root MSE		DMI Mean
	0.495555	19.23919	17.24126		89.6153162

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	68386.86074	68386.86074	230.06	0.0001
S	2	376.29500	188.14750	0.63	0.5319
F*S	2	446.26971	223.13485	0.75	0.4732

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	68398.63168	68398.63168	230.10	0.0001
S	2	361.40928	180.70464	0.61	0.5453
F*S	2	446.26971	223.13485	0.75	0.4732

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	68398.63168	68398.63168	306.53	0.0032
S	2	361.40928	180.70464	0.81	0.5525

4.12. Dependent variable: Efficiency of grazing (EFGR, %).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	32825.13814	6565.02763	173.64	0.0001
Error	237	8960.34988	37.80738		
Corrected Total	242	41785.48802			
	R-Square	C.V.	Root MSE		EFGR Mean
	0.785563	9.673970	6.148771		63.5599564

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	32640.02279	32640.02279	863.32	0.0001
S	2	106.53063	53.26532	1.41	0.2465
F*S	2	78.58471	39.29236	1.04	0.3553

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	32637.90235	32637.90235	863.27	0.0001
S	2	105.53520	52.76760	1.40	0.2497
F*S	2	78.58471	39.29236	1.04	0.3553

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	32637.90235	32637.90235	830.64	0.0012
S	2	105.53520	52.76760	1.34	0.4268

4.13. Dependent variable: Metabolizable energy intake (MEI, MJ ME/cow day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	144159.8012	28831.9602	72.84	0.0001
Error	237	93809.0946	395.8190		
Corrected Total	242	237968.8958			
	R-Square	C.V.	Root MSE		MEI Mean
	0.605793	19.46141	19.89520		102.228964

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	103012.3242	103012.3242	260.25	0.0001
S	2	40956.9220	20478.4610	51.74	0.0001
F*S	2	190.5551	95.2775	0.24	0.7863

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	101594.8789	101594.8789	256.67	0.0001
S	2	40988.9878	20494.4939	51.78	0.0001
F*S	2	190.5551	95.2775	0.24	0.7863

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	101594.8789	101594.8789	1066.30	0.0009
S	2	40988.9878	20494.4939	215.10	0.0046

4.14. Dependent variable: Metabolizable energy intake (MEI, MJ ME/100 kg liveweight/day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	4557.201209	911.440242	48.02	0.0001
Error	237	4498.017090	18.978975		
Corrected Total	242	9055.218299			
	R-Square	C.V.	Root MSE		MEI Mean
	0.503268	19.46520	4.356487		22.3808928

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	4392.231236	4392.231236	231.43	0.0001
S	2	108.855713	54.427857	2.87	0.0588
F*S	2	56.114261	28.057130	1.48	0.2301

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	4414.062133	4414.062133	232.58	0.0001
S	2	110.199516	55.099758	2.90	0.0568
F*S	2	56.114261	28.057130	1.48	0.2301

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	4414.062133	4414.062133	157.32	0.0063
S	2	110.199516	55.099758	1.96	0.3374

4.15. Dependent variable: Metabolizable energy intake (MEI, MJ ME/LW$^{0.75}$/day).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	9.76020822	1.95204164	48.51	0.0001
Error	237	9.53690986	0.04024013		
Corrected Total	242	19.29711807			
	R-Square	C.V.	Root MSE		MEI Mean
	0.505786	19.41752	0.200599		1.03308478

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	9.65494513	9.65494513	239.93	0.0001
S	2	0.04663957	0.02331978	0.58	0.5610
F*S	2	0.05862352	0.02931176	0.73	0.4837

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	9.65682132	9.65682132	239.98	0.0001
S	2	0.04474724	0.02237362	0.56	0.5742
F*S	2	0.05862352	0.02931176	0.73	0.4837

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	9.65682132	9.65682132	329.45	0.0030
S	2	0.04474724	0.02237362	0.76	0.5671

4.16. Dependent variable: Daily Stocking Rate (SRATE, Cows/ha/24 hours).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1672700.662	334540.132	341.51	0.0001
Error	237	232166.408	979.605		
Corrected Total	242	1904867.070			
	R-Square	C.V.	Root MSE		SRATE Mean
	0.878119	11.57893	31.29864		270.306863

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F	1	1475974.453	1475974.453	1506.70	0.0001
S	2	184106.211	92053.106	93.97	0.0001
F*S	2	12619.998	6309.999	6.44	0.0019

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	1467531.199	1467531.199	1498.08	0.0001
S	2	182451.205	91225.603	93.12	0.0001
F*S	2	12619.998	6309.999	6.44	0.0019

Tests of Hypotheses using the Type III MS for F*S as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F	1	1467531.199	1467531.199	232.57	0.0043
S	2	182451.205	91225.603	14.46	0.0647

Appendix V. Individual cow values for initial live weight, final live weight, total liveweight change during the 41 days of experimental period, and average daily LWG.

COW Number	Feeding Level[1]	Size[2]	Initial LW kg)	Final LW (kg)	Total LW gain gain (kg)	Daily LWG (kg)
1	1	1	489.00	538.667	49.667	1.21139
3	1	3	423.75	468.667	44.917	1.09554
4	2	3	407.00	435.000	28.000	0.68293
5	1	3	345.25	379.000	33.750	0.82317
9	2	3	278.25	311.667	33.417	0.81505
10	1	3	293.50	329.333	35.833	0.87398
17	1	3	335.50	360.333	24.833	0.60568
18	2	3	334.25	351.000	16.750	0.40854
21	1	2	435.25	500.333	65.083	1.58739
22	2	2	439.75	478.000	38.250	0.93293
23	1	3	418.00	474.000	56.000	1.36585
27	2	3	349.25	378.667	29.417	0.71749
31	2	3	431.25	440.500	9.250	0.22561
101 *	2	2	388.25	.	.	.
106	1	2	422.50	495.000	72.500	1.76829
109	1	2	405.75	473.000	67.250	1.64024
111	2	2	415.25	447.333	32.083	0.78251
120	2	2	392.75	422.667	29.917	0.72968
121	1	2	374.75	434.667	59.917	1.46139
126	2	2	413.50	453.667	40.167	0.97968
132	1	2	433.00	498.000	65.000	1.58537
139	2	1	516.00	536.667	20.667	0.50407
140	1	1	530.50	588.000	57.500	1.40244
141	2	1	543.50	584.667	41.167	1.00407
142	1	1	562.00	634.667	72.667	1.77237
152	2	1	552.50	591.333	38.833	0.94715
156	1	1	527.50	572.000	44.500	1.08537
158	1	2	448.00	513.333	65.333	1.59349
166	2	1	521.50	538.667	17.167	0.41871
168	2	2	394.75	431.667	36.917	0.90041
172	2	2	441.75	476.667	34.917	0.85163
175	1	1	522.50	594.667	72.167	1.76017
177	2	1	559.50	597.333	37.833	0.92276
178	1	2	399.25	463.333	64.[illegible]	1.56300
179	1	1	502.75	569.333	66.583	1.62398
184	2	1	539.00	580.000	41.000	1.00000
196	1	1	527.00	619.333	92.333	2.25202
224	2	1	476.00	538.000	62.000	1.51220

[1] *Ad libitum* = 1; Maintenance = 2.

[2] Big Friesians = 1; Small Friesians =2, and Jerseys = 3.

* Cow aborted before the end of the experiment.

Appendix VI. Individual cow values for initial condition score, final condition score and total condition score change during the 41 days of experimental period.

Cow number	Feeding level[1]	Size[2]	Initial CS	Final CS	Total CS Change
1	1	1	4.600	5.200	0.600
3	1	3	5.125	6.666	1.541
4	2	3	5.200	5.866	0.666
5	1	3	4.625	5.500	0.875
9	2	3	3.975	4.666	0.691
10	1	3	4.225	4.733	0.508
17	1	3	3.725	5.100	1.375
18	2	3	3.675	4.233	0.558
21	1	2	4.475	5.366	0.891
22	2	2	4.450	4.733	0.283
23	1	3	3.775	4.933	1.158
27	2	3	3.725	4.366	0.641
31	2	3	4.875	4.800	-0.075
101*	2	2	4.375	.	.
106	1	2	4.500	6.466	1.966
109	1	2	4.650	5.500	0.850
111	2	2	5.250	6.600	1.350
120	2	2	4.375	4.833	0.458
121	1	2	4.550	5.566	1.016
126	2	2	4.250	4.500	0.250
132	1	2	3.875	4.700	0.825
139	2	1	4.875	5.033	0.158
140	1	1	5.375	7.333	1.958
141	2	1	4.525	4.900	0.375
142	1	1	5.100	7.000	1.900
152	2	1	4.425	4.633	0.208
156	1	1	4.925	5.333	0.408
158	1	2	4.675	5.033	0.358
166	2	1	4.175	4.466	0.291
168	2	2	4.250	4.500	0.250
172	2	2	4.525	4.833	0.308
175	1	1	4.725	6.166	1.441
177	2	1	4.350	4.400	0.050
178	1	2	4.625	5.700	1.075
179	1	1	5.150	7.133	1.983
184	2	1	5.350	5.766	0.416
196	1	1	4.150	4.766	0.616
224	2	1	4.350	4.700	0.350

[1] *Ad libitum* = 1; Maintenance = 2.

[2] Big Friesians = 1; Small Friesians =2, and Jerseys = 3.

* Cow aborted before the end of the experiment.

Appendix VII. Cow age and days since conception at the beginning and at the end of the experiment.

Cow Number	Feeding level[1]	Size[2]	Days since conception at: Beginning	End	Cow age (years)
1	1	1	186	226	8.8658
3	1	3	204	244	7.8630
4	2	3	178	218	7.8630
5	1	3	198	238	4.7781
9	2	3	167	207	3.7753
10	1	3	178	218	3.7753
17	1	3	142	182	6.8630
18	2	3	190	230	6.8630
21	1	2	203	243	4.7781
22	2	2	172	212	4.7781
23	1	3	159	199	4.8630
27	2	3	186	226	4.7781
31	2	3	171	211	3.8685
101	2	2	170	200	3.8466
106	1	2	172	212	4.8575
109	1	2	179	219	3.8521
111	2	2	154	194	4.7726
120	2	2	192	232	4.8274
121	1	2	153	193	3.8219
126	2	2	145	185	3.8411
132	1	2	206	246	5.8164
139	2	1	165	205	5.8110
140	1	1	189	229	5.7836
141	2	1	192	232	5.7945
142	1	1	192	232	5.7315
152	2	1	205	245	9.8603
156	1	1	185	225	4.7890
158	1	2	194	234	3.8164
166	2	1	149	189	10.8658
168	2	2	172	212	3.8027
172	2	2	151	191	3.7863
175	1	1	170	210	6.8493
177	2	1	190	230	8.8329
178	1	2	166	206	3.7863
179	1	1	187	227	8.8329
184	2	1	183	223	6.8247
196	1	1	186	226	7.8356
224	2	1	186	226	8.8521

[1] *Ad libitum* = 1; Maintenance = 2.

[2] Big Friesians = 1; Small Friesians =2, and Jerseys = 3.