STUDIES OF HOLSTEIN-FRIESIAN CATTLE BRED FOR HEAVY OR LIGHT MATURE LIVE WEIGHT

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Studies of Holstein-Friesian Cattle Bred for Heavy or Light Mature Live Weight

A thesis presented in partial fulfilment of the requirements for the degree of

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José G. García-Muñiz
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Dedication

I dedicate this Thesis to my wife Marcela and my children José Alberto (5), Ana Victoria (4) and Eduardo (1). For all their love and support, and for putting up with my busy schedule during the first three years of my PhD and with my absence during the last 10 months.

To my mother, Victoria Muñiz, for encouraging me to further my education since the very first day I attended primary school.

Abstract

The new Animal Evaluation Model predicts that heavier live weight (LW) of the lactating cow reduces the profitability of the pasture-based dairying farm in New Zealand, because its effects on increased maintenance requirements are not fully compensated by the extra income generated from selling heavier culled cattle and surplus progeny. The work outlined in this thesis was intended to validate the expected effects of selection for differences in LW on actual LW from birth to maturity and on herbage intake and feed conversion efficiency (FCE) of growing cattle and lactating cows. It also investigated the existence of any associated effects on calving difficulty, calf mortality, onset of puberty and reproductive performance of the two lines of Holstein-Friesian (HF) cattle bred for heavy or light mature LW. These two lines have been developed at the Dairy Cattle Research Unit, Massey University, New Zealand, since 1989. The high genetic merit HF cows from the base herd have been mated to high genetic merit HF sires with either high or low breeding value (BV) for LW but with similar breeding worth (BW) in order to generate the heavy (H) and the light (L) mature LW selection lines. During the period 1994 to 1997, a series of experiments with growing heifers and lactating cows from the H and L lines, and analysis of data collected from the cows were undertaken to compare the two genetic lines.

The BV's for live weight of the sires were 86 kg for the H and 31 kg for the L cows and the actual H animals were heavier at birth (41 *vs.* 35 kg) and at maturity (510 *vs.* 460 kg). In addition the BV's for milk (1037 *vs.* 737 *l*), milkfat (33.0 *vs.* 27.5 kg) and milk protein (31 kg *vs.* 22 kg) of H sires were also higher and the H cows produced significantly more milk (4708 *vs.* 4323 *l*/lactation), more milkfat (207 *vs.* 198 kg/lactation) and more milk protein (157 *vs.* 150 kg/lactation) than the L cows. However, the L sires had slightly higher breeding worth ($ 46 *vs.* $ 37) than the H sires and theoretically calculated and experimentally measured feed intakes and the resultant feed conversion efficiencies, confirmed that the L cows had slightly higher values for FCE than the H cows in three short-term grazing experiments and when FCE was calculated over multiple lactations. Therefore the basic assumptions in the Animal Evaluation Model seem to be correct.

Sires of H cows had a higher proportion of USA Holstein genes in their pedigrees than the L sires. Consequently cows from the H line had a higher (≈27%) proportion of USA Holstein genes compared to cows from the L line (≈7%), whose sires were mainly of New Zealand ancestry. New Zealand bulls are progeny tested under grazing conditions and a very tight seasonal system of reproduction, whereas North American bulls are progeny tested under dairying systems of all year round milk production and feedlot feeding.

There were significant differences in the pattern of grazing behaviour of H and L cows. The L cows displayed a more 'aggressive' pattern of grazing behaviour than H cows given by significantly longer grazing times (520 *vs.* 499 min/d), faster rates of biting (58 *vs.* 52 bites/min), higher number of total bites per day (31053 *vs.* 25046 bites/d), lower rumination times (471 *vs.* 572 min/d), and the selection of herbage of higher digestibility (72.0% *vs.* 69.3%). These results may reflect not only a difference in mature LW between the H and L cows, but may also reflect a strain of Holstein (i.e. NZ *vs.* USA Holstein) difference due to the sires' ancestry referred to above.

There were no differences between H and L cows in the incidence of calving difficulty. However, offspring of bulls with high BV for rump width (i.e. wider pelvises) were more likely to face a difficult calving, and so were daughters of bulls with low BV for rump angle (i.e. less sloping pelvises). There were no differences between H and L cows for calf mortality. However, induced calves were more likely to die or undertake an emergency slaughter, and the H cows had significantly higher induction rates than the L cows (10.5 *vs.* 4.2%).

The H heifers grew faster, ate more feed (4.3 *vs.* 3.8 kg/hd/d) and were heavier (241 *vs.* 221 kg) and older (325 *vs.* 300 d) at puberty than L heifers, and there were no differences between H and L heifers in pregnancy rate, age at first calving and first lactation yield of milk and milk components.

There were only small differences in the reproductive performance of H and L cows after adjusting by differences in induction, calving date and percentage of USA Holstein genes in the cows. The L cows had slightly shorter intervals from first service to conception (13 *vs.* 17 d) and from the start of mating to conception (24 *vs.* 29 d), and slightly higher first service conception rate (65 *vs.* 54%), which translated in a more concentrated calving pattern and lower induction rate (4.2 *vs.* 10.5%) for the L cows.

The results of this thesis indicate that selecting for heavier mature live weight produced the expected results of heavier animals with higher yields of milk and milk components, higher feed requirements and higher herbage intakes and slightly lower feed conversion efficiency than lighter mature live weight cows. However, there were also differences in grazing behaviour in which the L cows displayed a more competitive pattern of grazing behaviour than the H cows. The results of this thesis suggest that for the New Zealand seasonal system of milk production based almost completely on grazed pasture, lighter mature LW HF cows may have an advantage over heavier mature LW cows. Under the conditions of this experiments L cows were slightly more efficient, younger at puberty, had a more concentrated calving pattern, and were less prone to be induced to calve than heavier mature live weight HF cows.

Acknowledgements

A project of this magnitude could not have been completed without the help, input, participation, enthusiasm and foresight of many people. Back in 1987 Associate Professor Colin Holmes from Massey University and Dr. Brian Wickham and Gisele Ahlborn-Brier from the Livestock Improvement Corporation laid the foundations of the present project.

I am particularly grateful to Associate Professor Colin Holmes for giving me the opportunity to study under his supervision. The promptness of reviewing research proposals, ideas, and all the chapters making up this thesis is highly appreciated. I am particularly appreciative of his interest in the development of my Ph.D. program, and the unlimited and unrestricted time he has devoted to helping me during the time I have been under his supervision. I have benefited immensely from his enjoyable style of supervising, which has provided a model I will try to emulate with students under my care in the future. I am grateful to his wife, Dorothy Holmes, for making me feel at home and for trusting me not only with her house but also her 'precious' cats while they were on holiday.

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During two years Yvette Cottam helped me with the collection of blood samples and field data while the heifers were grazing away. The weekly trips we made to collect the data were a delightful experience. During the winter months we were able to taste most of the local chocolate brands available, while in summer we always made sure to call into a Fielding Pub for a bowl of hot 'Nachos' and a cold beer.

I am grateful to Jeff Purchas for his invaluable help in the running of the experiments and skilful handling of the animals. My especial appreciation to Martin L. Chesterfield, manager of the research herd, for his help and strategic support during the running of the experiments. A great lesson I learned from Martin was that a research farm could still be in the top 10% of the high profit farms within the district. The secret: how to accommodate the needs of both the cows and the researchers within the constraints of the dairy farm.

A large number of international students gave their time to participate in the running of the experiments and collection of field data. In no particular order, I will always be grateful to Stuart Crosthwaite (Australia), Lisa Watson (New Zealand), Michelle Jones (Canada), Jan (Holland), Brian Read (U.K), Carolina Realini, Daniel Laborde and Bettina (Uruguay), Pablo Londoño (Colombia), and from México, Nicolás López, David Pacheco, Aurelio Guevara, Mauricio Padilla and Alberto Torres.

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During the last 10 months while I have been without my family, Joyce and Arthur Worboys have become my foster family while in New Zealand. I will certainly miss Arthur's cup of tea and bunch of 'fancy' cookies that kept me going and helped me work until late every single night I spent in their house. Joyce always kept an interest and an open mind about my project, and was willing to listen to my ideas and findings as I was progressing in the analysis of the data and writing of this thesis. As it turns out, at the completion of this thesis she was familiar with my research and did not hesitate in doing the English proofreading of the manuscript. I am particularly grateful for that. However, any mistakes in the present thesis are my sole responsibility. Without any doubt, the completion of this thesis would not have been possible without Joyce and Arthur's help, and I will always be grateful for their support.

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My PhD studies were possible thanks to the financial support of the Mexican National Council of Science and Technology (CONACyT) and Universidad Autónoma Chapingo, Chapingo, México. I am grateful to both institutions for giving me the opportunity to further my education at Massey University. At the end of my PhD program I can only look forward to meeting the challenges that both my academic institution and my country will put before me.

List of Abbreviations and Symbols

Abbreviations

A	mature live weight
a.m.	*ante meridiem*
AI	artificial insemination
ANOVA	analysis of variance
b	constant of integration
BR	biting rate
BS	bite size
BV	breeding value
BW	breeding worth
C_{32}	dotriacontane
C_{36}	hexatriacontane
CFH	calving to first heat
CFS	calving to first service
CI	calving interval
CIDR	controlled internal drug release device
Cr	chromium
CR1st	conception rate to the first service
CR21	21-days first service conception rate
Cr_2O_3	chromium sesquioxide
CRC	controlled release capsule
CS	body condition score
CSH	compressed sward height
d	day
DM	dry matter
DMD	dry matter digestibility
DMI	dry matter intake
DO	days open
DOMD	digestible organic matter in the dry matter (D-value)
DTC	days to calving
FCM	4% fat corrected milk
FO	faecal output
FREQ	frequency
FSCO	first service to conception interval
GL	gestation length
GLM	Generalised Linear Models
GT	grazing time
h	hours
ha	hectare
hd	head
HFRO	Hill Farming Research Organization (Scotland)
HIR28	four-weeks herd in calf rate
HIR49	seven-weeks herd in calf rate
IAB	incisor arcade breadth
k	maturation rate parameter
ln	natural logarithm
$\log_e$	natural logarithm
LW	live weight
$LW^{0.75}$	metabolic weight
LWG	live-weight gain
ME	metabolisable energy
min.	minute
MJ	megajoule
MJME	megajoules of metabolisable energy

MS	mean square
MSY	milksolids yield
N	nitrogen content
n	number of observations
NLIN	non-linear
NM	natural mating
NZ	New Zealand
OM	organic matter
OMD	organic matter digestibility
P	probability
p.m.	*post meridiem*
P_4	progesterone
$PGF_{2\alpha}$	prostaglandin $F_{2\alpha}$
PHREG	proportional hazards regression
PROC	procedure
PSC	planned start of calving
PSM	planned start of mating
SAS	Statistical Analysis System
sec	second
SMCO	start of mating to conception
SMFS	start of mating to first service
SR28	four-weeks submission rate
SR49	seven-weeks submission rate
SSH	sward surface height
t	time (days)
USA	United States of America
vs.	*versus*

Weights, volumes and measures

°C	degrees centigrade
g	gram
kg	kilogram
km	kilometer
l	liter
m	meter
m^2	square meter
mg	milligram
ml	milliliter
ng	nanogram

Statistical terms

*	significant at $P < 0.05$
**	significant at $P < 0.01$
***	significant at $P < 0.001$
†	significant at $P < 0.1$
μ	overall mean
χ^2	chi-square
b	partial regression coefficient
CDF	cumulative distribution function
CI	confidence interval
CV	coefficient of variation
d.f	degrees of freedom
HR	hazard ratio
n	number
NS	not significant
OR	odds ratio
R^2	coefficient of determination
RSD	residual standard deviation
s.e.d	standard error of the difference
SD	standard deviation
SE	standard error of the mean

CHAPTER 1

General introduction to dairying in New Zealand and to the present research

Background

Milk production in New Zealand

Milk production in New Zealand is based on a seasonal system of calving that enables the seasonal supply of pasture to be closely matched with the feed requirements of lactating and growing cattle. Under these circumstances, the profitability of the New Zealand seasonal dairy enterprise is linearly related to the amount of milksolids produced per hectare of grazed grass (Deane, 1993). High production per hectare can only be achieved with high genetic merit cows capable of transforming efficiently the nutrients from pasture into milk, and with the skills of herd managers that make the most from both the cows and the pastures, through manipulations on the farm's stocking rate and the dates of insemination and calving (Holmes, 1990).

New Zealand dairy farmers address these components of their production system by artificially breeding their cows to bulls with high genetic merit for farm profitability, which are proven under the environmental conditions in which their daughters are expected to perform (Harris, 1998). Other key strategies are the breeding of replacements at 14 to 15 months of age, the use of relatively high stocking rates during the milking season (Holmes, 1990) and the attainment of a highly concentrated calving pattern in late winter-early-spring (July-August) (Macmillan, 1979; Macmillan et al. 1984a and 1984b).

A concentrated calving pattern is fundamental for the efficiency of the seasonal system, and will depend on the herd's reproductive performance during the previous season, particularly on the achievement of both a high submission rate and a high conception rate to a single service (Macmillan, 1974; Xu and Burton, 1996). Mating in seasonal herds is carried out during 3 to 5 months from September to January each year. For lactating cows, most farmers use artificial insemination for about seven weeks followed by natural mating during the remaining four to seven weeks of the mating period. Maiden heifers are generally naturally mated at 15 months of age with Jersey or Friesian bulls during a period of 12 weeks that starts one or two weeks before the mating of the lactating cows. This strategy of reproductive management applied throughout the country ensures that the periods of higher feed requirements of the national herd coincide with those of high pasture growth and allow the production of milk at the lowest possible cost through the grazing cow.

The national dairy herd is made up of mainly Holstein-Friesian cattle (57%), with Jersey (16%), Holstein-Friesian x Jersey crosses (18%), Ayrshire (1%) and other breeds (7%) of cattle contributing the remaining proportions. For the 1996-1997 season there were over 3 million cows distributed in 14,741 herds throughout the country. These farms managed an average herd of 208 cows on 86 ha of effective grazing area, at a stocking rate of 2.5 cows/ha. About 87% of the herds and 90% of the cows from the national dairy herd are production recorded through the milk herd testing system carried out by the New Zealand Livestock Improvement Corporation. The average yields of the cows were 3,600 *l* of milk, 173 kg of milkfat and 133 kg of protein during lactations that lasted only 223 days. Eight co-operatively owned dairy companies processed the more than 10 thousand million litres of milk produced each year. About 95% of the national production is processed into a whole range of milk products and specialised ingredients and sold to the international market, with the balance being sold to the local market. Table 1.1 summarises some relevant statistics for the New Zealand dairy industry for the season 1996-1997.

Table 1.1: Summary statistics of the New Zealand dairy industry for the 1996/1997 season.[1]

Item	Units		
Total herds	n	14,741	
Total cows	n	3,064,523	
Average herd size	cows	208	
Percentage of herds tested from total herds	%	87.2	
Percentage of cows tested from total cows	%	89.6	
Use of artificial breeding			
Cows	n	2,573,835	
Yearlings	n	165,093	
Milk processed	million litres	10,339	
Milkfat processed	million kg	506	
Protein processed	million kg	375	
Milksolids processed	million kg	880	
Average milk per cow	*l*	3,641	
Average milkfat per cow	kg	173	
Average protein per cow	kg	133	
Average fat test per cow	%	4.78	
Average protein test per cow	%	3.66	
Average lactation length	days	223	
Average somatic cell count	000 cells/millilitre milk	197	
Average on farm effective area	ha	86	
Average stocking rate	cows/ha	2.5	
Average milkfat per effective hectare	kg	425	
Average protein per effective hectare	kg	316	
Average milk per farm	*l*/year	728,874	
Average milkfat per farm	kg/year	35,436	
Average protein per farm	kg/year	26,387	
Breed composition of herd tested cows			
Holstein-Friesian	n (and % of total herd tested cows)	1,407,164	(55.6%)
Jersey	n (and % of total herd tested cows)	416,691	(16.5%)
Holstein-Friesian x Jersey	n (and % of total herd tested cows)	671,653	(26.6%)
Ayrshire	n (and % of total herd tested cows)	33,058	(1.3%)
Average live weights by breed			
Holstein-Friesian	kg (and number of cows with LW records)	471	(97,988)
Jersey	kg (and number of cows with LW records)	362	(41,086)
Holstein-Friesian x Jersey	kg (and number of cows with LW records)	441	(64,990)
Ayrshire	kg (and number of cows with LW records)	425	(1,953)

[1] Source: Dairy statistics 1996-1997 (Livestock Improvement, 1997a).

The system of genetic evaluation of dairy cattle in New Zealand

The New Zealand system for evaluating the genetic merit of dairy animals is based on a centralised service led by the New Zealand Livestock Improvement Corporation. In this system, high genetic merit cows from pedigree studs as well as cows from commercial farms are eligible to become mothers of bulls, provided they have at least three generations pedigree of AI to registered bulls of the same breed (Macdonald Committee Report, 1992). The Livestock Improvement Corporation identifies these elite cows (active cows) from the national database and makes the results available to artificial breeding companies (and to themselves) to organise contract mating arrangements with the owners of these high genetic merit cows. The young bulls born from these contract matings are then nationally progeny tested across breeds under the conditions in which their daughters are expected to perform in commercial dairy herds, and evaluated on an index of economic feed conversion efficiency (Harris, 1998; Livestock Improvement, 1997b).

The index represents the expected net income per unit of feed (i.e. dollars per 4.5 tonnes of pasture dry matter) an animal is expected to generate through breeding replacements that are efficient converters of feed into profit, relative to the base of zero (Harris, 1998; Livestock Improvement, 1997a). The index is made up of the breeding values (BV) for milk volume (*l*), milkfat (kg), milk protein (kg), LW (kg), and survival (%). Yields of milkfat, protein and survival receive positive economic values whereas milk volume and LW receive negative economic values in the index. For milk volume this is due to its effect on the extra costs of transportation and processing larger volumes. The negative economic value for LW in the index is due to the fact that the cost of the extra dietary energy requirements for maintenance and growth are larger than the benefits from selling heavier culled animals (Dempfle, 1986; Spelman and Garrick, 1997; Visscher et al. 1994).

Effects of selection on cow mature live weight; the present experiment

Experimental information on the effect of cow body size on the feed conversion efficiency of grazing dairy cows is scarce, and no data have been published comparing the milk production efficiency of genetically lighter or genetically heavier Holstein-Friesian cows under grazing conditions. To fully document and justify the assumptions underlying the inclusion of cow live weight in the selection objective of New Zealand dairy cattle, a project was set up at Massey University, New Zealand to generate two lines of high genetic merit Holstein-Friesian cows which differ in mature live weight. During the past 10 years, New Zealand born Holstein-Friesian bulls with high (H) or low (L) breeding value (BV) for LW have been used to develop the H and L lines respectively. Details of the development of the project are given in the following section.

General materials and methods

(Relevant specific details will be presented in each chapter)

Generation of the two genetic lines of cows

The base herd and the mating plan

In 1989, the experimental herd of Holstein-Friesian cows at the Dairy Cattle Research Unit, Massey University, New Zealand provided the foundation cows to develop two lines of cows differing in mature live weight. During the previous ten years the same herd had been used to develop two lines of cows bred for high or low genetic merit for milkfat yield (Holmes, 1995). For the present experiment, only cows from the high genetic merit line (mean ± standard deviation Breeding Index = 126.6 ± 4.0) took part in the development of the H and L lines.

For each of the first three years, multiparous cows from the base herd were blocked by parity, milksolids yield and live weight. Within each block, the heavier cows were mated to bulls with high breeding value for live weight, and the lighter cows to bulls with low breeding value for live weight, respectively. During the first three years (1989-91), cows were allocated to either a group of two H or two L bulls, and to a group of four H or four L bulls during the remaining years (1992-97). Bulls used to inseminate the herd were chosen so as to differ as much as possible in their BV for live weight but with similar payment Breeding Index (years 1989 to 1995) or Breeding Worth (years 1996 to the present date). The aim of the project was to generate two lines of high genetic merit Holstein-Friesian cows with marked differences in mature live weight but with similar genetic merit for farm profitability.

All female calves born from cows mated to H or L bulls were reared as replacements to build up the heavy and light herds. They were naturally mated as yearlings to Holstein-Friesian (1993-97) or Jersey bulls (years 1990-92). From the second mating at approximately 27 months of age and in subsequent years, H-sired and L-sired cows were mated back to H or L bulls, respectively. Figure 1.1 shows the mating plan followed to develop the heavy and the light mature live weight selection lines.

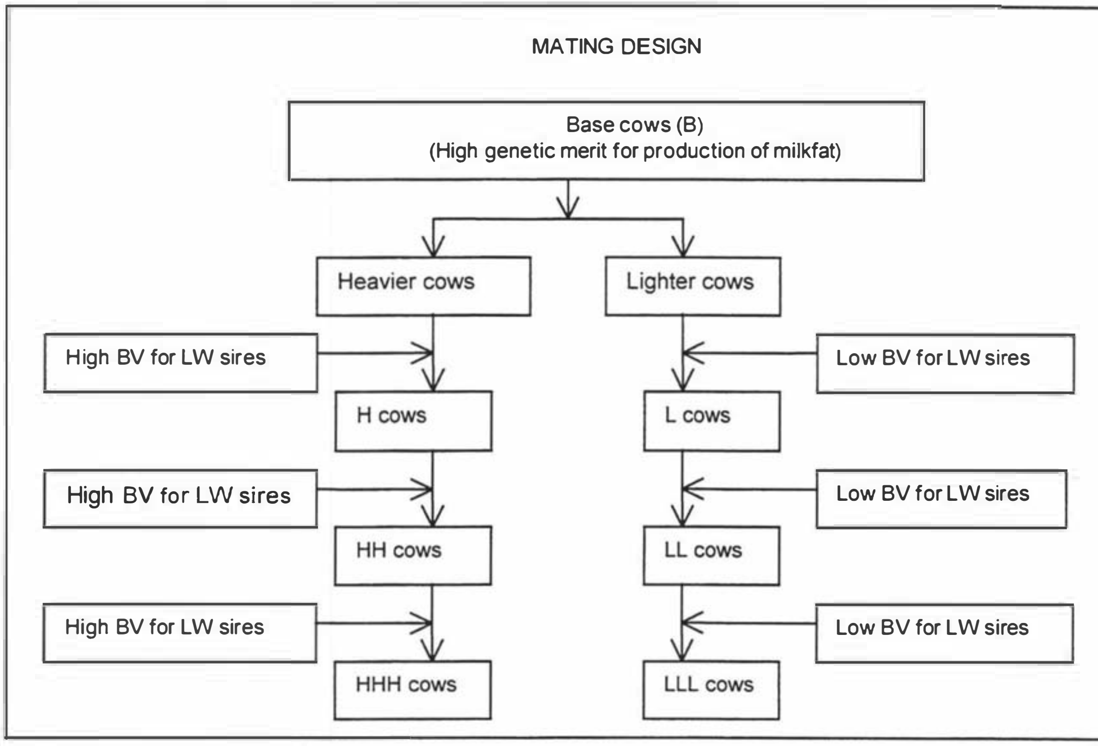

Figure 1.1: Mating design to develop the heavy (H) and the light (L) mature live weight selection lines of Holstein-Friesian cows at Massey University.

Information on the bulls

Bulls used to inseminate the cows were from the team of progeny tested sires owned by the New Zealand Livestock Improvement Corporation. Each bull contributing progeny to the H or L lines had estimates of breeding values for seven production traits and 16 TOP. The BV's represent the genetic merit of an animal for individual traits relative to a base of zero (i.e. a cow born in 1985). The BV's for production traits are given in the units of measurement of the particular trait whereas the BV's for TOP are given in a scale from 1 to 9, where 1 and 9 represent the biological extremes (Livestock Improvement, 1997b).

Breeding values for production traits

Breeding values on bulls contributing progeny to the H and L lines were available for the following production traits: protein yield (kg), milkfat yield (kg), milk volume (*l*), live weight (kg), survival (%), fat (%) and protein (%). The BV's for the first five traits are aggregated into an index for farm profitability known as Breeding Worth (BW). As at June 1997, these BV's were multiplied by the following economic values given in equation [1.1] to obtain the BW (Livestock Improvement, 1997b):

$$\text{BW (\$)} = \$0.541\text{xFBV(kg)} + \$4.042\text{xPBV(kg)} - \$0.052\text{xMBV } (l) - \$0.445\text{xLWBV (kg)} + \$1.093\text{xSBV (\%)} \quad [1.1]$$

Where FBV, PBV, MBV, LWBV and SBV are the breeding values for yield of fat, protein, milk volume, live weight and survival respectively.

During the first six years of the project (From 1989 to 1995) the breeding values for LW of bulls contributing progeny to the H and the L lines were estimated using a scoring system. A scale from 1 to 9, where each score represented 50 kg live weight (1 ≤ 250 kg up to 9 > 600 kg), was used to estimate the cow's live weight (Livestock Improvement, 1995). From 1996 to the present date, weighing of cattle has become more common, and the BV for LW of bulls is now calculated from the actual LW recorded for their daughters from the first lactation onwards.

The least-squares means for the breeding values of sires' of cows for the production traits live weight, milk yield, milkfat yield, milk protein yield, survival and Breeding Worth are presented in Table 1.2. As planned, bulls contributing progeny to the H line had higher BV's for LW than those contributing to the formation of the L line. Bulls with high BV for LW also had significantly higher BV's for yield of milk, milkfat, milk protein, lower BV's for fat percentage, and there was no difference between H and L bulls for survival and Breeding Worth. With the exception of the BV for survival, the average reliability was over 90% for the BV's of the remaining traits (Table 1.2).

Table 1.2: Least squares means for the breeding values for production traits of the bulls used to develop the heavy and light mature live weight selection lines of Holstein-Friesian cows.[1]

		Genetic line					
Item	Units	Heavy		Light		s.e.d[2]	Significance[3]
Number of bulls	n	18		21			
Number of cows[4]	n	89		90			
Breeding values of bulls for:							
Live weight	kg	87.0	(91)	34.0	(94)	2.7	***
Milk yield	*l*	1047.0	(95)	792.5	(97)	47.6	***
Fat yield	kg	33.7	(94)	29.7	(96)	1.0	***
Protein yield	kg	32.4	(94)	23.6	(96)	1.3	***
Fat percentage	%	4.43	(94)	4.62	(95)	0.05	***
Protein percentage	%	3.55	(95)	3.56	(96)	0.02	NS
Survival	%	0.48	(67)	0.65	(70)	0.19	NS
Breeding worth	$	56.0	(94)	54.8	(96)	3.9	NS

[1] Average reliability (%) of sires' breeding values is given in parenthesis.
[2] s.e.d = standard error of the difference.
[3] NS = not significant; ** = P < 0.01; *** = P < 0.001.
[4] Included are 22 two-year-old (10 H and 12 L) and 30 rising one-year-old (17 H and 13 L) replacement heifers.

Breeding values for traits other than production

Bulls used in the project also had breeding values for 16 TOP. In the current evaluation system, daughters are scored for 16 TOP using a linear assessment on a scale from 1 to 9, where 1 and 9 represent the biological extremes. TOP are scored across breeds and they included adaptability to milking, shed temperament, milking speed, farmer's overall opinion, stature, capacity, rump angle, legs, udder support, front udder, rear udder, front teat placement, rear teat placement, udder overall, and dairy conformation. The first four TOP are scored by the farmer and the remaining are scored by trained inspectors. Definitions of the scale for each TOP have been given elsewhere (Cue et al. 1996; Livestock Improvement, 1997b), and are summarised in Appendix 1.1.

Least squares means for BV's of TOP of sires of H and L cows are summarised in Table 1.3. Besides having higher BV for live weight, sires of cows from the H line also had higher BV's for the TOP related to body size such as stature, body capacity and rump width, and all the BV's for udder characteristics but rear teat placement. The average reliability of the BV's for TOP was high at around 90%, but not as high as for the production traits.

Table 1.3: Least squares means for the breeding values for traits other than production of the bulls used to develop the heavy and light mature live weight selection lines of Holstein-Friesian cows.[1]

Item	Genetic line				s.e.d[2]	Significance[3]
	Heavy		Light			
Number of sires	19		21			
Number of cows[4]	89		90			
TOP scored by the farmer						
Adaptability to milking	0.06	(86)	-0.01	(90)	0.04	NS
Farmer's overall opinion	0.19	(86)	0.08	(90)	0.04	**
Milking speed	-0.009	(89)	0.12	(93)	0.05	***
Shed temperament	0.07	(86)	-0.008	(90)	0.05	NS
TOP scored by the inspector						
Capacity	0.38	(90)	-0.02	(93)	0.05	***
Stature	1.25	(93)	0.19	(96)	0.05	***
Dairy conformation	0.38	(89)	-0.08	(93)	0.04	***
Front udders	-0.02	(89)	-0.17	(93)	0.05	***
Rear udders	0.14	(90)	-0.20	(93)	0.05	***
Front teat placement	0.08	(91)	-0.21	(94)	0.04	***
Rear teat placement	0.04	(91)	-0.08	(94)	0.06	NS
Udder support	0.05	(90)	-0.23	(93)	0.06	***
Udder overall conformation	0.08	(90)	-0.27	(93)	0.05	***
Rump angle	-0.10	(90)	-0.004	(93)	0.03	**
Rump width	0.34	(90)	0.084	(93)	0.04	***
Legs	-0.03	(82)	0.02	(86)	0.01	***

[1] Average reliability (%) of sires' breeding values is given in parenthesis.
[2] s.e.d = standard error of the difference.
[3] NS = not significant; ** = P < 0.01; *** = P < 0.001.
[4] Included are 22 two-year-old (10 H and 12 L) and 30 rising one-year-old (17 H and 13 L) replacement heifers.

Bull ancestry's country of origin

The bulls used for the development of the H and L lines were born in New Zealand and progeny tested by the NZ Livestock Improvement Corporation under New Zealand conditions. Three generation pedigrees with details on their ancestor's country of origin were available for each bull. The bull's foreign ancestors were mainly of USA Holstein origin. This information was used to calculate the proportion of USA Holstein genes in both bulls and on their daughters. Data collected for all the females entering the H and L lines since 1990 up to the last crop of female calves recorded in 1997 is summarised in Table 1.4. Bulls contributing progeny to the H line had higher percentages of USA Holstein genes, ranging from 0 to 100% with an average of 46% for the group. This was in contrast with the range of 0 to 50% and an average of 12% for the group of bulls used to develop the L line, which were mainly of New Zealand ancestry. Similarly, the percentage of USA Holstein genes in H cows ranged from 0 to 75% with an average of 28% for the group. The corresponding figures for the L cows was a range of 0 to 25% with an average for the group of 8.9% (Table 1.4).

Table 1.4: Number of sires and cows from the heavy and light mature live weight selection lines at Massey University and percentage of USA-Holstein genes in sires and cows[1]

	Sires			Cows		
Item	n	% of USA-Holstein genes in sires	Average % of USA-Holstein	n	% of USA-Holstein genes in cows	Average % of USA-Holstein
Heavy line	2	0	46.1	3	0	28.0
	5	25		23	12.5	
	6	50		24	25	
	2	75		23	37.5	
	3	100		12	50	
				3	62.5	
				1	75.0	
Total	18			89		
Light line	14	0	12	49	0	8.9
	3	25		19	12.5	
	4	50		20	25	
	0	75		2	37.5	
	0	100		0	50	
				0	62.5	
				0	75.0	
Total	21			90		

[1] Included are 22 two-year-old (10 H and 12 L) and 30 rising one-year-old (17 H and 13 L) replacement heifers.

General information recorded about the cows in both lines

For each cow, the following information was recorded, ancestry pedigree information; sex of the calf at each calving (males, females, and twins); calf fate (reared for replacement, bobbied, and dead at birth or soon after); use of Controlled Internal Drug Release Devices (CIDR™, InterAg, Hamilton, NZ) or hormones (if she was treated for anoestrus); parity number; date of birth; calving dates, insemination and drying off dates; number of pre-mating heats recorded using the tail-paint technique, as recorded by the herd manager; a variable coding for type of calving (normal, abortion, or induced); calving difficulty; and a variable coding for calf presentation at calving (normal or abnormal). Information was also recorded on each cow for yields per lactation of milk (*l*), milkfat (kg), milk protein (kg), milksolids (kg) and milk composition obtained from herd test records carried out by Livestock Improvement Corporation personnel (details given later).

The distribution of births of female calves born to the H and L lines form 1990 to 1997 and the distribution of calvings (lactations) from 1992 to 1997 are given in Table 1.5, along with the number of sires represented in each year of measurement. During the eight years from 1990 to 1997, a total of 91 H and 90 L female heifers sired by 22 H and 23 L sires have been born and kept as replacements to their respective genetic lines. From these, 89 from the H and 90 from the L initiated first lactation. Collectively (i.e. pooling across all age groups) these females have provided 323 lactations (calvings), with 165 for the H and 158 for the L cows (Table 1.5).

Table 1.5: Distribution of births for female calves used as replacements, and lactations/calvings of cows from the heavy and the light live weight selection lines during the years 1990 to 1997.[1]

Item	Year 1990	1991	1992	1993	1994	1995	1996	1997	Total
	Female replacements born to the two lines[1]:								
Heavy	10 (2)	7 (2)	15 (2)	10 (3)	10 (3)	13 (4)	10 (2)	16 (4)	91 (22)
Light	10 (2)	6 (2)	8 (2)	14 (3)	12 (3)	15 (4)	12 (3)	13 (4)	90 (23)
Total	20 (4)	13 (4)	23 (4)	24 (6)	22 (6)	28 (8)	22 (5)	29 (8)	181 (45)
	Lactations/Calvings of cows from the two lines[2]:								
Heavy			10 (2)	16 (4)	27 (6)	31 (9)	36 (12)	45 (13)	165 (46)
Light			10 (2)	16 (4)	20 (6)	30 (9)	35 (12)	47 (16)	158 (43)
Total			20 (4)	32 (8)	47 (12)	61 (18)	71 (24)	92 (29)	323 (89)

[1] Number of sires leaving progeny in each cohort is given in parenthesis.
[2] Number of sires represented at each calving year is given in parenthesis.

The farm

The dairy farm at the Dairy Cattle Research Unit, Massey University, New Zealand comprises 45 hectares and grazes 120 spring calving cows per year, at an average stocking rate of 2.7 cows/ha, managed by the equivalent of 1.5 permanent staff. The pastures are predominantly ryegrass/white clover for most of the year, which are utilized mainly by lactating cattle using rotational grazing. The average production of these cows during the last year of study (1996/97 season) was 386 kg MS/cow or 1034 kg MS/ha. Mating commences at 27th October each year and the planned start of calving is 5th August the following year. Each year approximately 30 heifer calves are reared and about the same number of cows are culled to maintain stock numbers. The soil is classed as Tokomaru silt loam, which is a heavy soil with poor drainage during winter. The average annual pasture production is 12 tonne DM per hectare with a distribution of growth that closely follows that of soil temperature except during the summer (December to May) (Figure 1.2). Any grass surpluses are cut for silage and supplementary feeding in the form of silage is sometimes purchased. The average annual rainfall is 950 mm more or less evenly distributed throughout the year (Figure 1.2).

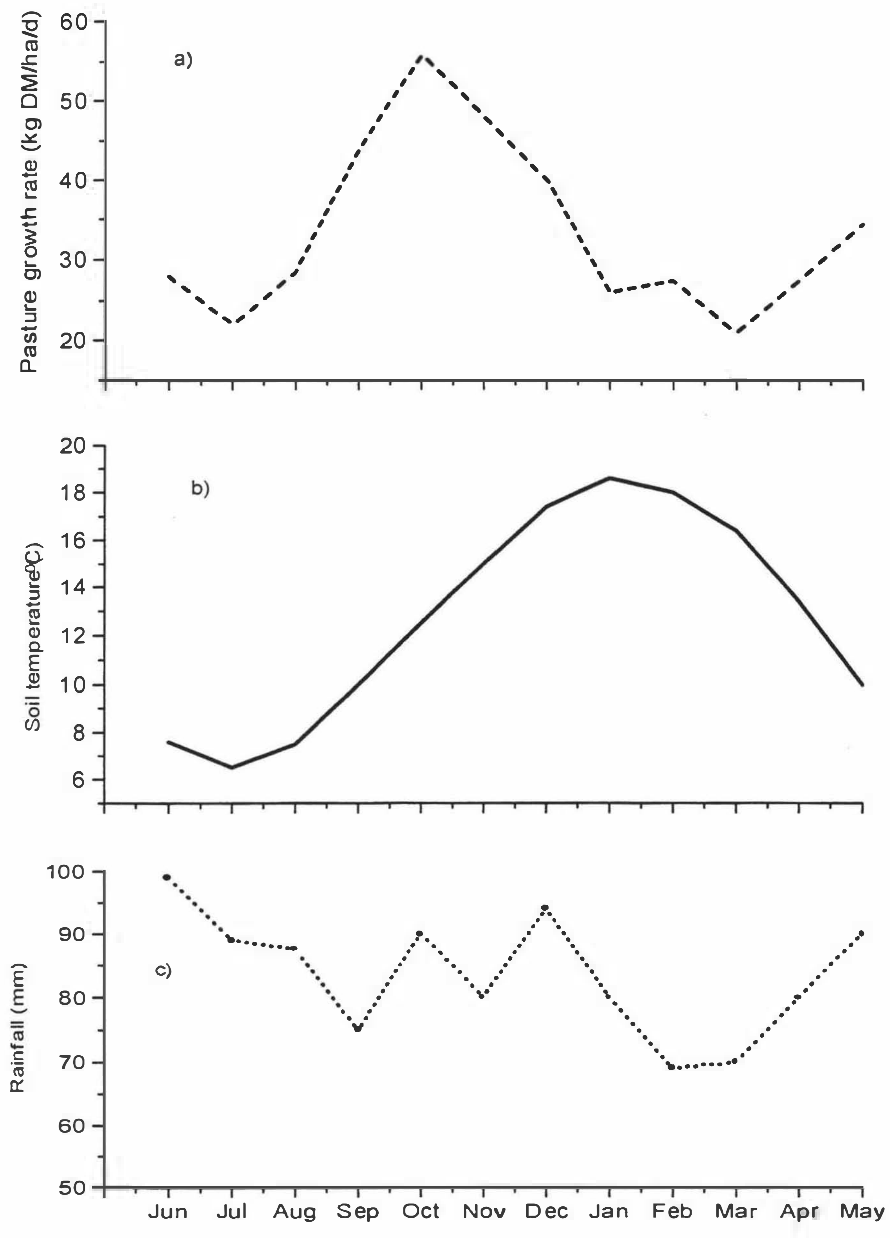

Figure 1.2: Ten year average (1985 to 1995) for pasture growth rate (a), soil temperature at the first 10 cm (b) and rainfall (c) for the Massey University region (Source: Frith Brown, Unpublished).

The original question

The original question when the project was started in 1989 was: How do cows which differ genetically in mature live weight perform when they are managed on grazed pasture and submitted to a seasonal system of reproduction?

The hypotheses

The work described in this thesis was based on the following hypotheses:

- Heavier cows have higher maintenance requirements than lighter cows.
- Heavier cows will therefore be less efficient than lighter cows, if both produce the same yield of milk.
- There are no other differences between the heavier and lighter cows (e.g. in fertility, grazing behaviour or onset of puberty of the replacement heifer).

To test these hypotheses a series of experiments were designed and carried out during 1994 to 1998. These experiments are described in each of the following Chapters.

Objectives and scope of the thesis

This thesis has the objective of measuring the effect that genetic differences in mature live weight have on the productive and reproductive performance of grazing Holstein-Friesian cattle managed under the seasonal system of reproduction in New Zealand. For this purpose, a series of experiments (and analyses of data recorded on individuals born to the H and L lines) was planned and executed during the years 1994 to 1998.

The thesis is structured in three sections that reflect the chronological history of the project regarding the generation and availability of animals from the two genetic lines. The experiments with growing heifers are presented first (Chapters 2 and 3), as they were the first animals for which measurements were recorded. In the following section

(Chapters 4 and 5), the results from short-term grazing experiments with lactating cows are described. And the final section presents results from analyses of data recorded for calving difficulty (Chapter 6), reproductive performance (Chapter 7), and the growth pattern from birth to maturity and the productivity, lactation performance and feed conversion efficiency of cows from the H and L lines (Chapter 8). Except for the present Chapter, each chapter in this thesis is written as a self-contained entity with its own review of the literature, materials and methods, results, discussion and conclusions.

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CHAPTER 2

Herbage intake, liveweight gain, feed conversion efficiency and grazing behaviour of yearling heifers offered high herbage allowances during winter

Abstract

The purpose of this experiment was to measure the herbage intake, live weight (LW), live-weight gain (LWG), feed conversion efficiency and grazing behaviour of yearling heifers from the heavy (H) and the light (L) mature LW selection lines at Massey University, New Zealand. The herbage intakes of 22 rising one-year-old heifers born in 1994 (10 H and 12 L), 29 born in 1995 (14 H and 15 L), and 22 born in 1996 (10 H and 12 L) were measured using controlled release chromium capsules in three short-term grazing experiments during 1995, 1996 and 1997, respectively. Heifers from the two genetic lines were grazed together as a single group each year and offered herbage dry matter (DM) allowances (20 to 30 kg DM/head/day) aimed at achieving daily LWG's of 600 to 900 g. Averaged across experiments, heifers from the H line were heavier (213 *vs.* 195 kg LW; s.e.d. = 4.4; $P < 0.001$) during the experimental periods and ate more herbage DM (4.3 *vs.* 3.8 kg/hd/d; s.e.d = 0.09; $P < 0.001$) than the L heifers. Heifers from both genetic lines achieved similar daily LWG (H = 924 *vs.* L = 922 g/d; s.e.d = 67; $P = 0.52$) and similar feed conversion efficiency (H = 0.219 *vs.* L = 0.229 kg LWG/kg DMI; s.e.d = 0.02; $P = 0.8$). Heifers from the L line grazed for longer during the day (410 *vs.* 381 min/d; s.e.d = 10.3; $P < 0.05$) but shorter during the night (118 *vs.* 153 min/d; s.e.d = 10.0; $P < 0.05$) than H heifers, resulting in similar total grazing time for both genetic lines. Rumination time during the day was significantly longer for H than for L heifers (98 *vs.* 78 min/d; s.e.d = 7.8; $P < 0.05$), but total rumination time was the same for both genetic lines. Heifers from the H line took slightly larger bites than L heifers, and with a similar total number of bites per day and similar grazing time for H and L heifers, H heifers achieved significantly higher intake rates of herbage DM (7.0 *vs.* 6.3 mg/min; s.e.d = 0.26; $P < 0.05$) than L heifers. On average, H and L heifers required 0.65 and 0.56 MJME/kg $LW^{0.75}$ for maintenance and 9.9 and 13.5 MJME/ kg LWG, respectively. Under the conditions of these experiments, H heifers were heavier, had higher daily intakes of herbage DM, and similar daily LWG's and similar feed conversion efficiencies as heifers from the L line.

Introduction

Milk production in New Zealand is based on a seasonal system of reproduction that closely matches the seasonal supply of grass with the requirements of lactating and growing cattle fed solely on grazed pasture. For pasture based dairying systems, live weight of the lactating cow has been identified as a major component affecting the profitability of the dairy farm, and has a negative effect on the profitability of the dairy enterprise (Dempfle, 1986; Visscher et al. 1994). In New Zealand, live weight of the lactating cow is given a negative relative economic value in an index of farm profitability or Breeding Worth that is used to rank animals for breeding (Spelman and Garrick, 1997). The breeding values for live weight of bulls in New Zealand are calculated from the live weights of their daughters recorded from the first lactation onwards, corresponding to estimates of breeding values for mature weight.

During the past 10 years two genetic lines of Holstein-Friesian cattle that differ genetically for mature live weight have been developed at the Dairy Cattle Research Unit at Massey University, New Zealand. The growth curves of cows from the H and the L lines have been published elsewhere (García-Muñiz et al. 1998) and are also described in Chapter 8. This chapter reports the results of three short-term grazing experiments carried out with rising one-year-old heifer calves born to the H and L lines during the years 1994 to 1996. The objectives of these experiments were to evaluate the effect of selection for heavier or lighter mature live weight on live weight, herbage intake, growth rate, feed conversion efficiency and grazing behaviour of growing heifers from the two genetic lines.

Materials and methods

Animals

Twenty-two rising one-year-old Holstein-Friesian heifers born in 1994 (10 H and 12 L), 29 born in 1995 (14 H and 15 L) and 22 born in 1996 (10 H and 12 L) were used in three short-term grazing experiments during the years 1995, 1996, and 1997, respectively. The H heifers were the daughters of nine bulls with high BV for LW while seven bulls with low BV for LW sired the L heifers. Descriptive statistics for live weight at birth and at the experimental date, age and date of birth of H and L heifers are given in Table 2.1. In addition, Table 2.1 contains the BV's of their sires for production traits and traits other than production (TOP) related to size, such as stature and body capacity, as well as the average reliability of the BV's as obtained from the June 1997 sire summary (Livestock Improvement, 1997). Heifers from the H line were born about four days later during the season than L heifers, and age of individuals from the two groups during the experimental periods ranged from 232 to 330 days. As expected from the design of the experiment, heifers from the H line were heavier than the heifers from the L line at birth and at the time when intake was measured. Except for the BV's for survival (reliability range 42% to 85%), the reliability of the BV's of the sires was over 90% for both genetic lines (Table 2.1).

Grazing management

In each experimental year H and L heifers were grazed as a single group using temporary electric fences to provide a two-day break area and an average daily herbage allowance (20 to 30 kg DM/heifer) sufficient to achieve a daily LWG of 600-900 g. During the 1995 and 1996 experiments, pre-grazing and post-grazing sward surface height (SSH) and compressed sward height (CSH) were measured (50 readings each) on each break using the HFRO sward stick (Barthram, 1986) and the Rising Plate Meter (Ashgrove Plate Meter, Ashgove Pastoral Products, Palmerston North, New Zealand), respectively. During the 1997 experiment only the measurements with the rising plate were taken. For all experiments, herbage mass (kg DM/ha) was estimated from quadrat experiments, five pre-grazing and five post-grazing quadrats of pasture (0.18 m^2 each) randomly selected from within each two-day break were cut to ground level using an electric shearing handpiece. Pasture samples were washed and dried at 100 °C for 24 hours to determine pre-grazing and post-grazing herbage mass. In addition, the dried grass samples were used to obtain a calibration equation for the rising plate meter (Earle and McGowan, 1979; Holmes, 1974; Stockdale 1984).

Table 2.1: Descriptive statistics for variables recorded on heifers and on their sires.

	Genetic line			
	Heavy (n = 35)		Light (n = 37)	
Item	Mean[1]	SD	Mean[1]	SD
Birth weight (kg)	37.0	4.5	34.0	3.7
Date of birth[2]	232.0	12.8	228.0	12.0
Age (days)[3]	284.0	18.0	286.0	20.0
Live weight (kg)[3]	209.3	19.8	196.0	18.0
Sire of heifer BV for:				
Live weight (kg)	78.0 (92)	15.0	42.0 (93)	9.2
Stature (cm)	1.0 (93)	0.3	0.3 (94)	0.2
Capacity (units)	0.2 (90)	0.4	0.06 (91)	0.2
Milk (*l*)	1070.0 (95)	243.2	960.0 (96)	252.0
Milkfat (kg)	36.8 (94)	5.8	34.5 (95)	6.2
Milk protein (kg)	36.0 (94)	5.3	27.3 (96)	8.8
Survival (%)	1.0 (63)	1.3	0.7 (59)	0.6
Breeding worth ($)	62.3 (94)	15.7	58.0 (96)	17.0

[1] Average reliability (%) of BV"s is given in parenthesis.
[2] Days since January the 1st in the heifer's year of birth.
[3] Age and live weight during the experimental period.

Insertion of the slow release chromium capsules

In experiment 1 during 1995, heifers were yarded for an overnight fast starting at 16:00 p.m. on June 6th 1995 until 8:00 a.m. the next day (day one of the experiment). After the overnight fast, each heifer was fitted with an intraruminal controlled release chromium (Cr) capsule (CRC, 4.06 cm core, 65% Cr_2O_3, multi-orifice end plate, Captec (NZ) Ltd Auckland) to estimate individual daily faecal output (Morris et al. 1990; Parker et al. 1989 and 1990). After the fitting of the capsules the heifers were held on concrete yards for one hour and observed for CRC regurgitation, and none of them regurgitated the capsule. Experiments 2 and 3 during 1996 and 1997 followed a similar protocol.

Faecal output determination

Six days were allowed for the capsules to reach a steady state of Cr_2O_3 release in the rumen (Morris et al. 1990). Faecal samples were then collected on two consecutive five-day periods. Faecal samples (45.0 ± 12.3 (mean ± SD), g wet weight) were obtained in the morning on each of the 10 sampling days by collecting (from the sward surface) samples from heifers observed defecating. Samples were collected into plastic pottles and stored at -12 °C. After the last day of faeces collection, the frozen samples were thawed and a sub-sample (8-10 g wet weight) of faeces from each day was taken and bulked for each heifer and dried at 100 °C for 24 hours. The dried faecal samples (13.7±3.2 g) were ground using an electric grinder (Thomas Scientific, USA) and passed through a mesh of 1 mm. Replicates of the pooled faecal samples were then used to determine the Cr content of faeces by atomic absorption spectrophotometry as described by Parker et al. (1989). The rates of Cr release from the CRC given by the manufacturer were 640, 1440 and 1490 mg of Cr per day in experiments 1, 2 and 3, respectively. The daily faecal output (FO), and consequently the herbage intake of heifers, was calculated (on an OM basis) as described by Parker et al. (1989) using equation [2.1] below:

$$\text{FO (gOM/cow/day)} = \frac{D_{rr} \times \left[\frac{(2 \times Cr_{AW})}{(2 \times Cr_{AW} + 3 \times O_{AW})}\right]}{(M_f - BC) \times C_f} \qquad [2.1]$$

Where:

D_{rr} Is the capsule's mean release rate (g/day) of the product in the rumen, as given by the manufacturer.

Cr_{AW} Is the atomic weight of chromium (i.e. 51.996).

O_{AW} Is the atomic weight of oxygen (i.e. 15.999).

M_f Is the marker concentration (mg Cr/g OM) in faeces, as determined by atomic absorption spectrophotometry.

BC Is chromium background concentration (mg Cr/g OM), and,

C_f Is a recovery correction factor for the chromium assay (assumed 1.04, considering 95-98% of Chromium in faeces is recovered) (Parker et al. 1989).

Organic matter intake (OMI) was estimated from FO and the organic matter (OM) digestibility of hand plucked pasture samples using the following equation:

$$\mathrm{OMI}\,(\mathrm{kg/cow/day}) = \frac{\mathrm{Faecal\ \ output}}{(1 - \mathrm{OM\ Digestibility})} \qquad [2.2]$$

Herbage digestibility analyses

In each experiment during the three years, hand-plucked samples of herbage (150-200 g wet weight/day), similar to that consumed by the heifers, were collected from within exclosure cages on four days of each of the two five-day periods of faecal collection. Samples were collected into an icebox and then frozen at -12 ^{o}C and subsequently freeze dried. Sub-samples (5-10 g/day) from the dried and ground (passed through a mesh of 1 mm) herbage samples were used to determine herbage digestibility by the *in vitro* method of Roughan & Holland (1977). Six standards of known *in vivo* digestibility ranging from 72.1 to 80.9% were run with each batch, and the dry matter digestibility (DMD), organic matter digestibility (OMD), digestible organic matter in the dry matter (DOMD), and ash content of samples was determined. The metabolisable energy content of the pasture (MJ ME/kg DM) was calculated as 0.16 DOMD (Geenty and Rattray, 1987).

Live weight and live-weight gain

Heifers were yarded on Days 0 and 16 of the experiment to record live weight off pasture (at 16:00 p.m. on Days 0 and 20) and after a 16-h fast (at 08:00 a.m. on Days 1 and 21 of the experiment). Liveweight gain (g/head/day) was calculated as the difference between the initial and the final fasted live weight records divided by the number of days the heifers were in the experiment.

Ingestive behaviour

For the 1995 and 1996 experiments only, twenty-four hour ingestive behaviour was monitored on one occasion during the 10-day period of faeces collection in each experiment. Observers were trained beforehand and allocated working shifts of three hours to avoid fatigue. The animals were accustomed to the presence of observers and little disturbance from the normal pattern of grazing behaviour was expected during the period of observation, which started at 7:00 a.m. Activities recorded for each animal every ten minutes were grazing, ruminating, and idling as defined by Hodgson (1982). Biting rate (bites/min) was derived from records of the time taken to achieve 20 bites, measured using a stopwatch (Jamieson and Hodgson, 1979a). Rates of biting (RB) during peak morning grazing times (from 8:00 a.m. to 11:00 a.m.) were measured on two consecutive days within the 10-day period of faecal collection. Each heifer was recorded at least twice within each recording day. During nocturnal observation, a spotlight was used and heifers were identified from identification numbers painted on their flanks and rumps with fluorescent paint. Letters were used to record the ingestive behaviour parameters as described by Inwood et al. (1992). Grazing activities were recorded using the recording sheet given in Appendix 2.1.

Derived variables

The above measurements of grazing behaviour and herbage intake by individual heifers were used to calculate the following variables (Gong et al. 1996).

$$\text{Biting rate (bites/min)} = \frac{\text{20 bites}}{\text{time spent to take 20 bites (sec)}} \times 60 \qquad [2.3]$$

$$\text{Biteweight (mg DM/bite)} = \frac{\text{dry matter intake (kg/day)}}{\text{biting rate (bites/min)} \times \text{grazing time (min/day)}} \times 1'000{,}000 \qquad [2.4]$$

$$\text{Relative bite weight (mg DM/bite per kg LW)} = \frac{\text{bite weight}}{\text{LW (kg)}} \qquad [2.5]$$

$$\text{Rate of inta e (mg DM/min)} = \text{bite weight} \times \text{biting rate} \qquad [2.6]$$

$$\text{Feed conversion efficiency} = \frac{\text{kg LWG/hd/d}}{\text{daily inta e of herbage DM (OM)}} \qquad [2.7]$$

Statistical analyses

Live weight, herbage intake and grazing behaviour

The information from the three experiments was pooled and analysed using least squares analysis of variance using PROC GLM (SAS, 1989). The data on herbage intake, grazing behaviour and derived variables were analysed using the following linear model:

$$Y_{ijk} = \mu + L_i + E_j + LE_{ij} + bX_{ijk} + e_{ijk} \quad [2.8]$$

Where Y_{ijk} is the response variable being modelled, μ is the overall mean, L_i is the effect of genetic line *i* (heavy or light), E_j is the effect of experimental year *j* (1995, 1996 and 1997), LE_{ij} is the fixed effect of the interaction genetic line by year, *b* is the regression coefficient of age on average live-weight during the experimental period, X_{ijk} is the age at the time of the trial of heifer *k*, from genetic line *i* used during experimental year *j*, and e_{ijk} is the residual. Results are reported as least-squares means and the standard error of the difference for the contrast H *vs*. L.

Relationship between live weight, live-weight gain and metabolisable energy intake

In an attempt to partition the daily intake of metabolisable energy into that required for maintenance and LWG, the heifers' MEI calculated in the present experiments were related to their metabolic live weight and their daily LWG achieved during the experimental periods. For this purpose, multiple regression analysis using PROC REG, (SAS, 1989) was used.

Results

Sward variables

In all three years, the heifers were grazed on high quality ryegrass/white clover swards, as indicated by the *in vitro* digestibility analyses summarised in Table 2.2. Dry matter digestibility and the ME content of the pasture were slightly higher during the first than during the second and third years. The daily herbage allowances were high and ranged from 20 to 30 kg DM/heifer during all three experiments, which ensured the heifers were given the opportunity to achieve maximum daily intake of pasture.

Pre-grazing and post-grazing herbage masses and sward heights are also summarised in Table 2.2. Additionally, the day to day variation of sward height during the experimental periods for experiments 1 and 2 only are depicted in Figure 2.1. The grazing management applied maintained an average residual sward height of about 10-cm during both experiments, which ensured the heifers were fully fed (Hodgson, 1990).

Table 2.2: Characteristics of the swards used for the herbage intake experiments with rising one-year-old heifers (means ± SE).

	Experiment 1		Experiment 2		Experiment 3	
Item	Pre-Grazing	Post-grazing	Pre-grazing	Post-grazing	Pre-grazing	Post-grazing
Sward surface height (cm)	20.3 ± 0.2	9.7 ± 0.1	18.0 ± 0.8	10.8 ± 0.6	-----	-----
Compressed sward height (cm)	20.0 ± 1.1	9.1 ± 1.1	17.7 ± 1.1	10.4 ± 1.2	-----	-----
Herbage mass (t DM/ha)	2.4 ± 0.2	1.7 ± 0.17	3.7 ± 0.5	2.6 ± 42.0	3.0 ± 0.3	1.8 ± 0.2
Herbage allowance						
kg DM/hd/d	21.6 ± 0.43		31.0 ± 1.2		20.0 ± 3.0	
kg OM/hd/d	19.0 ± 0.37		27.3 ± 1.0		17.0 ± 2.8	
In vitro digestibility (%)						
DMD[1]	81.9 ± 0.33		73.2 ± 0.37		75.4 ± 0.7	
OMD[2]	84.4 ± 0.28		75.3 ± 0.27		77.4 ± 0.5	
DOMD[3]	73.8 ± 0.40		68.0 ± 0.25		66.7 ± 0.9	
Nitrogen content (%)	4.0 ± 0.02		4.4 ± 0.06		4.1 ± 0.1	
Crude protein content (%)	25.3 ± 0.11		27.2 ± 0.42		25.7 ± 0.7	
ME (MJ/kg DM)[4]	11.8 ± 0.06		10.9 ± 0.04		10.7 ± 0.1	
Ash (%)	12.2 ± 0.26		12.6 ± 0.19		-----	

[1] DMD = Dry matter digestibility.
[2] OMD = Organic matter digestibility.
[3] DOMD = Digestible organic matter in the dry matter.
[4] ME = 0.16 x DOMD (Geenty and Rattray, 1987).

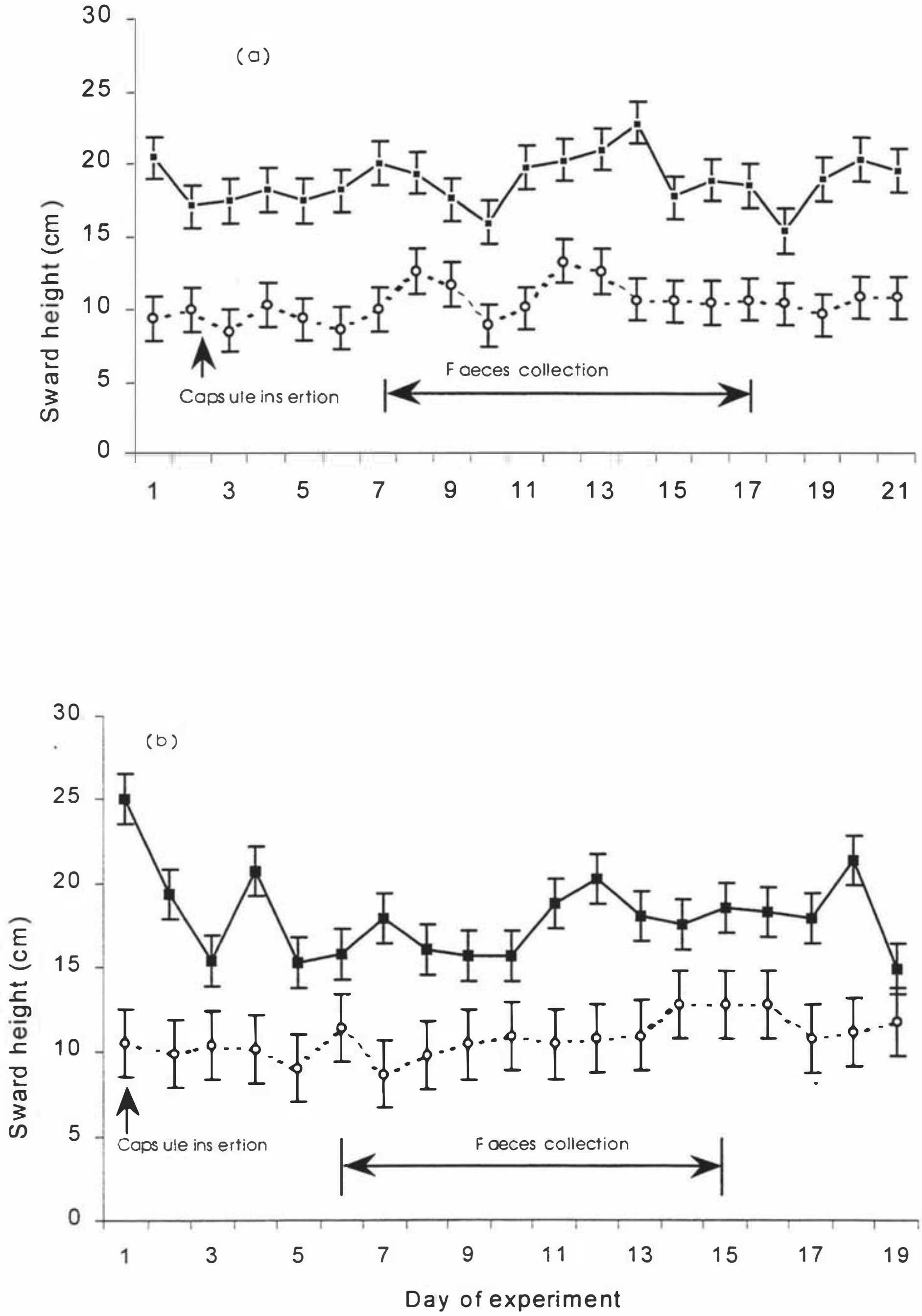

Figure 2.1: Average pre-grazing (—■—) and post-grazing (- - ○ - -) sward height during experiment 1 (a) and experiment 2 (b) with rising one-year-old Holstein-Friesian heifers offered generous herbage allowances.

Herbage intake, live weight and feed conversion efficiency

Faecal output data from two L heifers (one in 1995 and one in 1996) were discarded because of very low chromium content in the faeces. There were no regurgitated capsules during the daily inspection of the areas grazed by the heifers; thus it is assumed that for these two animals their capsules may have been damaged during insertion. After adjusting for differences in age, H heifers were heavier than L heifers by about 20 kg at the end of the experimental periods. H heifers achieved significantly higher intakes of herbage DM (OM) or ME even when intake was scaled by metabolic live weight. However, H heifers gained only slightly more live weight per day than L heifers, and overall the calculated feed conversion efficiency was similar at 0.219 and 0.229 kg LWG/kg DMI for H and L heifers, respectively (Table 2.3).

Table 2.3: Least squares means for herbage intake, live weight and feed conversion efficiency of rising one-year-old Holstein-Friesian heifers

Item	n	Genetic line: Heavy	Genetic line: Light	s.e.d	Significance
Fasted live weight (kg)[1]					
Initial	72	210.4	191.0	4.3	***
Final	72	230.0	211.0	4.6	***
Average	72	213.2	195.0	4.4	***
Daily LWG (g)	72	924.0	922.0	67.0	NS
Daily DM intake[2]					
kg/hd	140	4.3	3.8	0.09	***
g/kg $LW^{0.75}$	140	76.0	72.0	1.42	*
Daily OM intake[2]					
kg/hd	140	4.0	3.6	0.08	***
g/kg $LW^{0.75}$	140	72.4	68.4	1.26	*
Daily ME intake[2]					
MJ/hd	140	46.0	41.7	1.03	**
MJ/kg $LW^{0.75}$	140	0.833	0.795	0.01	*
Feed conversion efficiency					
kg LW/kg DMI	72	0.219	0.229	0.01	NS
kg LW/kg OMI	72	0.228	0.240	0.01	NS

[1] Adjusted by age at weighing as a covariate (Initial weight: b= 0.916±0.14 kg/d, P < 0.001; Final weight: b = 0.908±0.15 kg/d, P < 0.001; Average weight: b = 0.912±0.14 kg/d, P < 0.001).

[2] Adjusted by age as a covariate (DMI: b = 0.0131±0.004 kg/d, P < 0.001; OMI: b = 0.011±0.003 kg/d, P < 0.001; MEI: b = 0.145±0.042 MJ/d, P < 0.001).

Relationship between live weight, LWG and ME intake

As expected, heavier heifers or heifers with higher rates of LWG had higher daily intakes of herbage DM (OM) or ME. The relationships between the daily intake of ME and live weight, and MEI and daily LWG are depicted in Figure 2.2. In the range of live weight from 140 to 260 kg or daily LWG's from 0.25 to 1.75 kg, intake of ME increased linearly with live weight. Results from the multiple regression analysis to partition the daily intake of ME into that required for maintenance and LWG yielded the following regression coefficients, separately for each genetic line and for the pooled data on H and L heifers:

- Heavy line

$$\text{MEI (MJ/hd/d)} = 0.651_{(\pm 0.05)}\,\text{LW}^{0.75} + 9.9_{(\pm 3.2)}\,\text{LWG} \qquad [2.9]$$

$R^2 = 0.98$; RSD = 6.0; CV = 13.3; n = 35; $P < 0.0001$

- Light line

$$\text{MEI (MJ/hd/d)} = 0.560_{(\pm 0.03)}\,\text{LW}^{0.75} + 13.5_{(\pm 1.9)}\,\text{LWG} \qquad [2.10]$$

$R^2 = 0.98$; RSD = 4.4; CV = 10.5; n = 35; $P < 0.0001$.

- Pooled heavy and light

$$\text{MEI (MJ/hd/d)} = 0.605_{(\pm 0.03)}\,\text{LW}^{0.75} + 11.8_{(\pm 1.8)}\,\text{LWG} \qquad [2.11]$$

$R^2 = 0.98$; RSD = 5.4; CV = 12.2; n = 70; $P < 0.0001$.

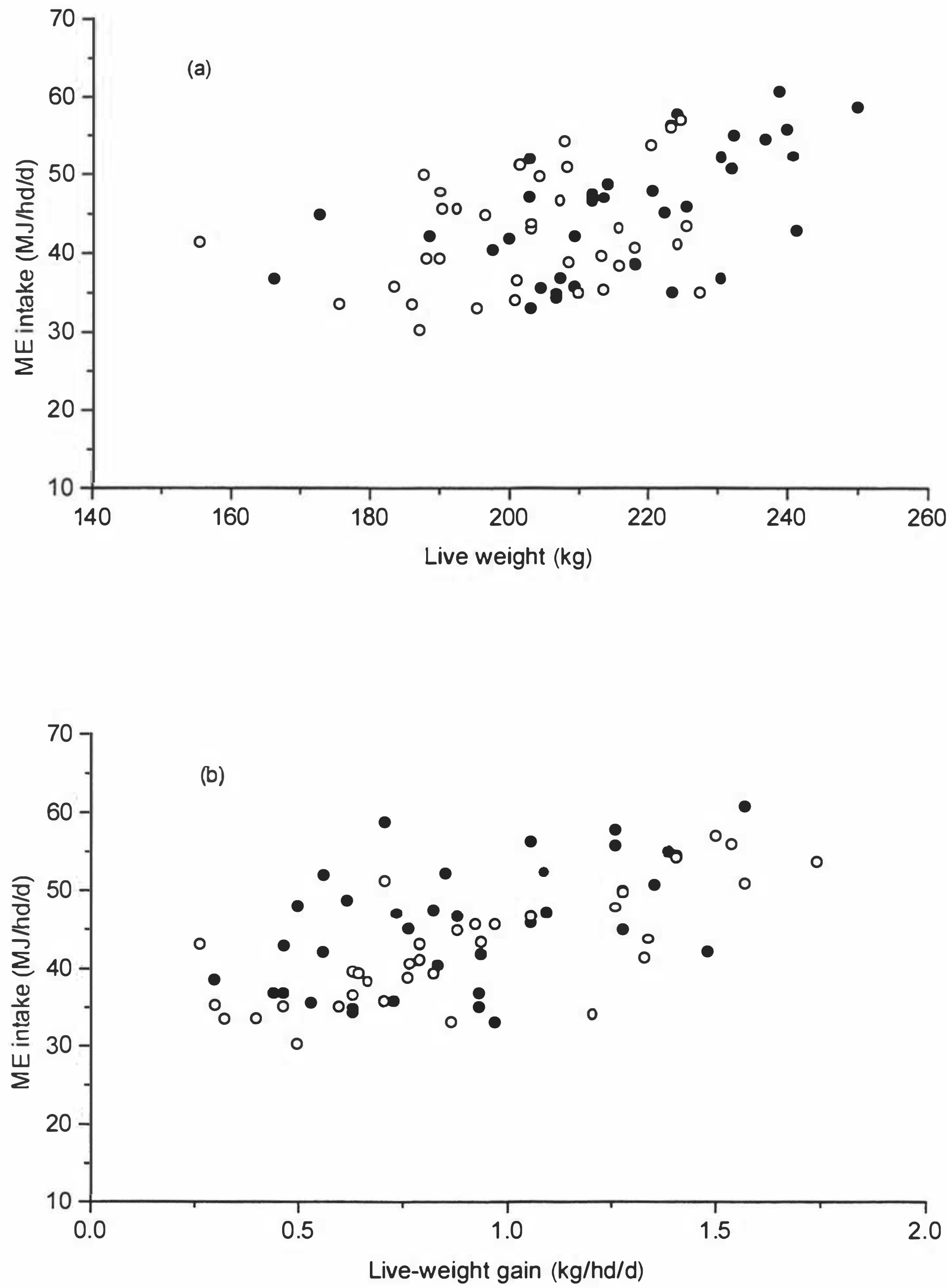

Figure 2.2: Relationship between live weight and daily MEI (a) and between daily live-weight gain and MEI (b) for genetically heavy (●) or light (○) Holstein-Friesian yearling heifers.

Ingestive behaviour

Least squares means for parameters of grazing behaviour are summarised in Table 2.4. Heifers from the H line took slightly larger bites than L heifers, and due to a similar total number of bites per day and similar grazing time for H and L heifers, H heifers achieved significantly higher intake rates of herbage dry matter, organic matter or metabolisable energy. Heifers from the light line grazed for longer during the day but shorter during the night than H heifers, resulting in similar total grazing time for both genetic lines. Rumination time during the day was significantly longer for H heifers, but total rumination time was the same for both genetic lines. Overall, about 73% and 77% of the grazing activity was carried out during the day for H and L heifers, respectively. Similarly, H and L heifers carried out about 75% and 80% of rumination during the night, respectively. During both experiments grazing started just before dawn and stopped just after dusk, with a distinctive peak just before mid-night (Figures 2.3 and 2.4).

Table 2.4: Least squares means for ingestive behaviour parameters of H and L yearling heifers

		Genetic line			
Item	n	Heavy	Light	s.e.d	Significance[1]
Biting rate (Bites/min)	50	49.3	51.3	3.2	NS
Total bites (Bites/d)	50	26264.7	27141.0	1874.0	NS
Bite weight					
mg DM/bite	49	140.0	129.0	8.2	NS
mg OM/bite	49	136.0	125.0	8.0	NS
mg DM/bite/kg LW	49	0.655	0.634	0.04	NS
mg OM/bite/kg LW	49	0.636	0.615	0.04	NS
Intake rate					
g DM/min	49	7.0	6.3	0.26	*
g OM/min	49	6.8	6.0	0.24	*
MJ ME/min	49	0.079	0.072	0.002	*
Grazing time (min/d)					
Day[2]	50	381.0	410.0	10.3	*
Night[3]	50	153.0	118.0	10.0	*
Total	50	534.0	528.0	12.9	NS
Ruminating time					
Day[2]	50	105.0	83.0	7.8	**
Night[3]	50	290.0	318.0	11.0	NS
Total	50	395.0	401.0	13.0	NS
Idling time					
Day[2]	50	119.0	112.0	9.5	NS
Night[3]	50	392.4	400.0	13.8	NS
Total	50	511.4	512.7	16.0	NS

[1]NS = not significant; † = $P < 0.10$; * = $P < 0.05$; ** = $P < 0.01$.

[2]Day = 07:30 - 17:30.

[3]Night = 17:30 - 07:30.

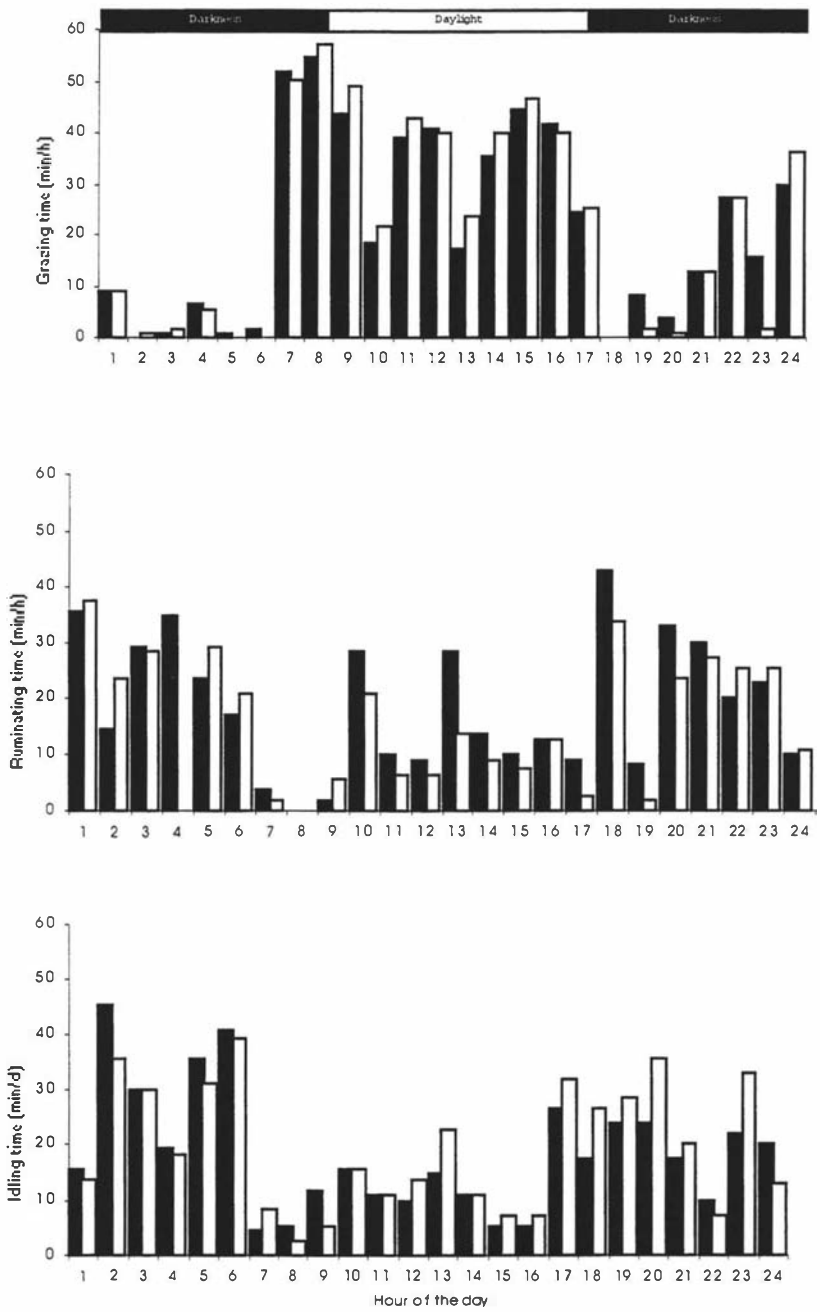

Figure 2.3: Grazing, ruminating and idling time during a 24-hour observational period for genetically heavy (▮) or light (□) Holstein-Friesian yearling heifers grazing generous herbage allowances during the 1995 winter.

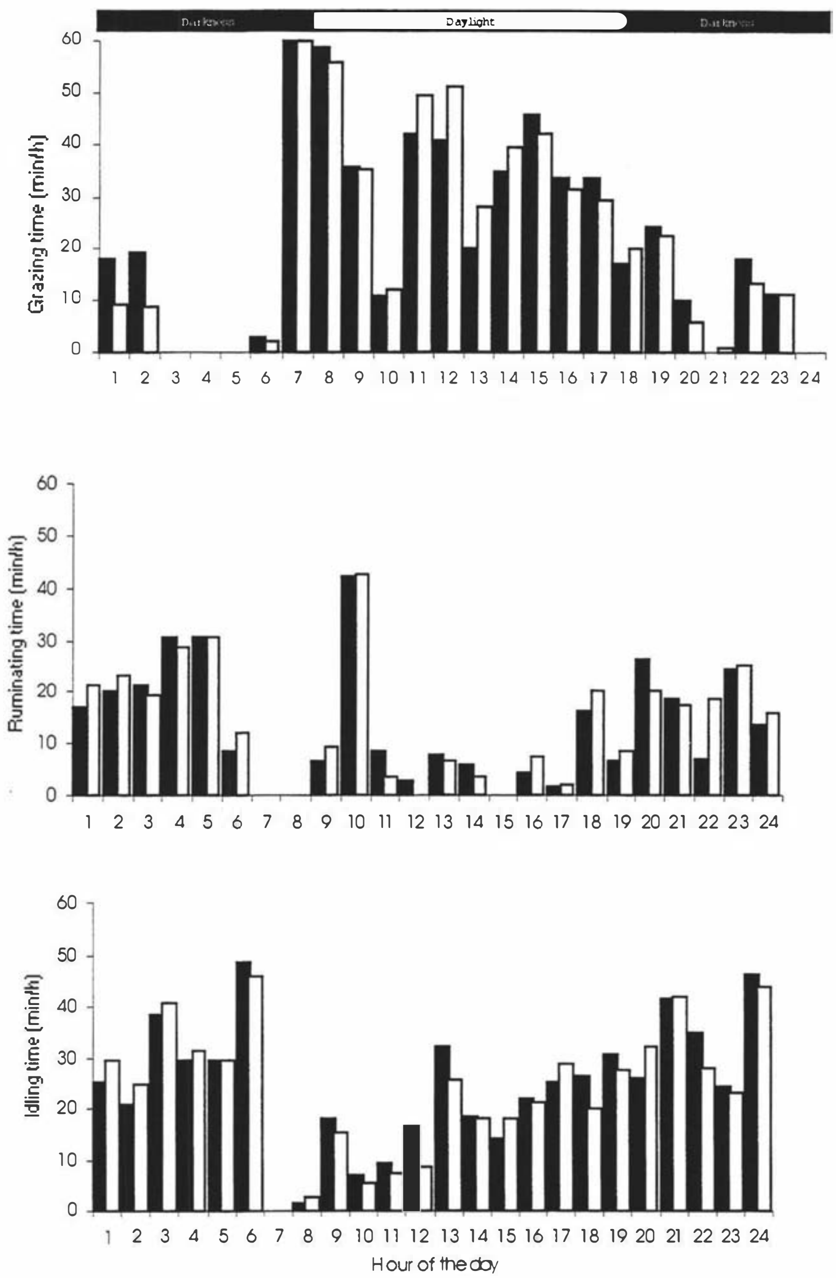

Figure 2.4: Grazing, ruminating and idling time during a 24-hour observational period for genetically heavy (■) or light (□) Holstein-Friesian yearling heifers grazing generous herbage allowances during the 1996 winter.

Discussion

Breeding values of bulls and heifer live weight

As expected from the design of the experiment, bulls with higher BV's for LW sired the H heifers. However, H bulls also had higher BV's for milk, milkfat, milk protein, and for TOP related to body size such as stature and body capacity than the sires of L heifers, and therefore H heifers were heavier at a constant age than L heifers. Despite the large difference in the sire's BV for live weight, sires of H and L heifers had similar breeding worth. The similar breeding worth of their sires implies that H and L heifers are expected to be equally efficient in converting a unit of feed (i.e. 4.5 tonnes of DM) into profit (Harris, 1998).

Intake, feed conversion efficiency and feed requirements

Intake of metabolisable energy

Heifers from the H and L lines were of similar age (about 285 days) and achieved similar daily LWG's (about 920 g/hd/d) during the experimental periods. However, H heifers were 9% heavier (i.e. 213 *vs.* 195 kg), and they were expected to have intakes of herbage dry matter (ME) about 7% higher than those achieved by L heifers, because of higher maintenance requirements. The measured intakes were higher by 11% for the H heifers (i.e. 4.3 *vs.* 3.6 kg/hd/d), and were only slightly lower than expected as calculated from their corresponding requirements using feeding standard formulae (AFRC, 1993). Table 2.5 compares the daily intakes of ME achieved by H and L heifers in the present experiment with those calculated using formulae for feed requirements (AFRC, 1993). Overall, the ME intakes measured in the present experiment were only 4% (H heifers) and 1% (L heifers) higher than those estimated using the AFRC (1993) formulae (Figure 2.5).

Table 2.5: Least squares means (±SE) for ME intake (MJ/hd/d) by heavy and light Holstein-Friesian yearling heifers obtained from faecal output data and calculated from AFRC (1993).

	MEI (MJ/hd/d)		% from FO for:	
ME intake calculated from:	Heavy heifers	Light heifers	Heavy heifers	Light heifers
Chromium & faecal output (FO)	45.9 ± 0.98	42.3 ± 1.00	100	100
AFRC (1993)	43.0 ± 0.52	41.0 ± 0.48	96	99

Feed conversion efficiency

As expected from their higher average LW, H heifers achieved higher daily intakes of DM (OM) or ME than L heifers and these differences persisted even after scaling by metabolic weight. However, the higher MEI by H heifers did not translate into higher daily LWG's, perhaps due to their higher maintenance requirements. Gross feed conversion efficiency was only slightly higher (but not significantly different) for heifers from the L line, and overall, H and L heifers achieved similar gross feed conversion efficiencies.

Estimated feed requirements

The estimated feed requirements for maintenance (MJME/kg $LW^{0.75}$/d) of 0.65 (H heifers) and 0.56 (L heifers) are within the range of estimates from the NZ literature for non-lactating grazing beef (Joyce, 1971; Joyce et al. 1975) and dairy cows (Holmes et al. 1981; Hutton, 1971). The average of these NZ studies being close to 0.55 MJME/kg $LW^{0.75}$/d.

The ME requirements for gain in live weight of growing cattle will vary depending on the composition of the LWG. For example, LWG gain of 10% protein and 90% fat represents 30 MJ energy/kg gain, whereas 30% protein and 70% fat represents 9 MJ energy/kg gain (Geenty and Rattray, 1987). Gibb et al. (1992) derived energy values for lactating Holstein/Friesian dairy cows of 17.3 MJ/kg liveweight loss and 20.9 MJ/kg LWG, with an overall mean of 19.3 MJ/kg liveweight change. Based on these results, AFRC (1993) adopted a mean value of 19 MJ/kg liveweight change in lactating cows. The estimated feed requirements of 9.9 (H heifers) and 13.5 (L heifers) MJME/kg

LWG/d obtained in the present experiment are considerably lower than the above values and the 26.7 MJME/kg LWG reported by Holmes and Wilson (1987). However, given that the heifer calves used in the present experiments were less than one year old, it is possible that protein made up a high proportion of their gains and therefore they needed a lower intake of ME to gain one kg of live weight compared to that required by older cattle to achieve the same LWG, as suggested by Geenty and Rattray (1987).

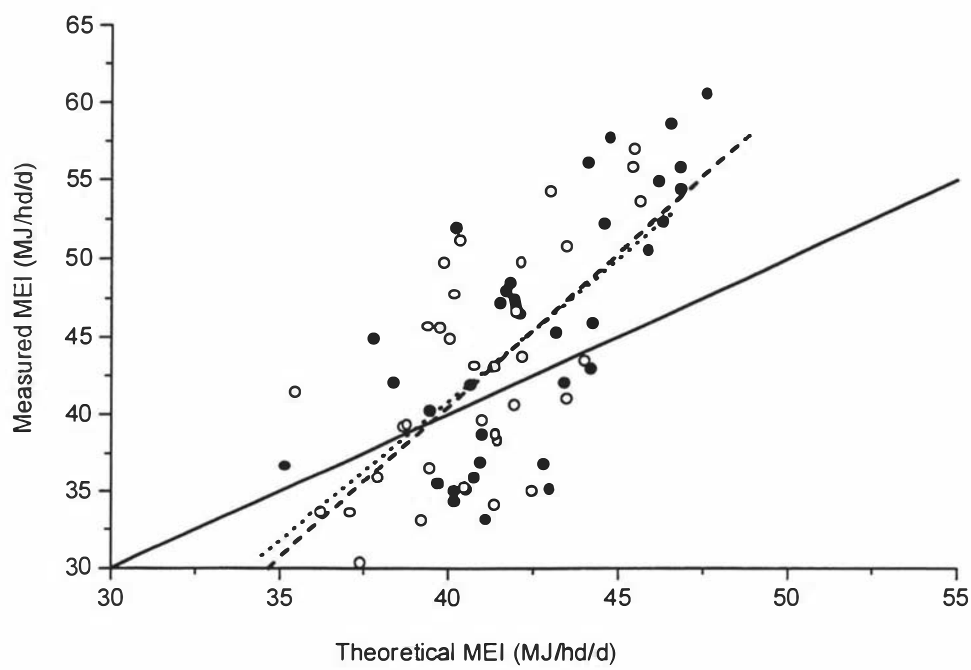

Figure 2.5: Relationship between the daily intake of ME calculated from faecal output data and the theoretical ME intake derived from AFRC (1993) feeding standards for genetically heavy (– ● - -) or light (···○···) Holstein-Friesian yearling heifers. The solid line represents the regression equation y = x.

Ingestive behaviour

The parameters of grazing behaviour obtained in the present experiments are summarised in Table 2.6 and compared to those published in other studies for growing cattle of similar weight and age as the heifers used in the present experiments. Heifers from the H and L lines showed only minor differences in their pattern of grazing behaviour, and their recorded grazing times and total daily bites are all within the range of those reported for the studies summarised in Table 2.6. However, the calculated bite sizes are lower than most of the figures reported in the studies summarised in Table 2.6. This could be due to the different methods used to calculate bite size and the type of animal used in the grazing experiments. In most of these studies bite size was calculated using oesophageally fistulated steer calves whereas in the experiments of this thesis bite sizes were calculated on female calves and by the indirect method using the measured intake and parameters of grazing behaviour. The closest estimate of bite size to the one calculated for H and L heifers in the present experiments was that reported by Jamieson and Hodgson (1979b) when calculated by the indirect method (Table 2.6).

Table 2.6: Published estimates of parameters of grazing behaviour for growing dairy cattle grazed on temperate swards.

Reference	Animal type, age breed and LW (kg)	Sward type	Grazing time (h/d)	Bites per minute	Daily bites[3]	Bite size: mg OM/ bite	Bite size: mg OM /bite/kg LW
Hodgson and Jamieson (1981)[1]	British-Friesian steer calves, 9 mo 126 kg LW.	Ryegrass	8.6	27.8	13.6		2.03
Jamieson & Hodgson (1979a)[1]	British-Friesian steer calves, 6 mo 121 kg LW.	Ryegrass	7.7	49.6		275	
Jamieson & Hodgson (1979a)[1]	British-Friesian steer calves, 9 mo 150 kg LW.	Ryegrass	7.8	51.7		224	
Jamieson & Hodgson (1979b)[1]	British-Friesian steer calves, 7 mo 175 kg LW.	Ryegrass					0.96
Jamieson & Hodgson (1979b)[2]	British-Friesian steer calves, 7 mo 175 kg LW.	Ryegrass	9.2	52.9	28.8		0.84
Elliot and Hughes (1991)	NZ Holstein-Friesian heifer calves, 6 mo 152 kg LW.	Cocksfoot		40.2			3.14[a]
		Ryegrass/White clover		37.0			2.14[a]
		Tall fescue		36.8			4.40[a]
Zoby and Holmes (1983)	British-Friesian steer calves, 7 mo 164 kg LW.	Ryegrass/White clover	9.8	65.6	38.0	157.8	2.56[b]
Present experiment[2]							
Heavy line heifers	NZ Holstein-Friesian Heifer calves, 9.6 mo 214 kg LW.	Ryegrass/White clover	8.9	49.3	26.3	136.0	0.66
Light line heifers	NZ Holstein-Friesian Heifer calves, 9.7 mo 202 kg LW.	Ryegrass/White clover	8.8	51.3	27.1	125.0	0.63

[1] Bite size measured from extusa collection from oesophageally fistulated calves.
[2] Bite size calculated from measured intake and total bites/d.
[3] Total bites x 1000.
[a] mg DM/kg LW.
[b] mg OM/kg $LW^{0.75}$

Conclusions

Heifers from the H line were heavier, had higher intakes of herbage dry matter, and due to the slight differences in grazing behaviour, they also achieved slightly higher intake rates of herbage DM (OM) or ME than L heifers. Despite these differences, H heifers achieved both similar daily LWG's and similar feed conversion efficiency of herbage dry matter into LWG as L heifers. This suggests that the extra dry matter eaten by the H heifers was largely directed to meet their higher maintenance requirements. These results confirm the initial hypothesis that genetically heavier animals will have higher maintenance requirements than genetically lighter ones even at as early an age as that of the animals used in the present experiments.

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CHAPTER 3

Growth and onset of puberty of the replacement heifer and first lactation performance

Abstract

The aim of this study was to measure the onset of puberty and the first lactation performance of Holstein-Friesian heifers from the heavy (H) and the light (L) mature live weight (LW) selection lines at Massey University, New Zealand. Over three successive years, LW was measured from birth to first calving, progesterone (P_4) concentration was measured in blood samples taken weekly from 7 to 14 months of age, and yields of milk and milk components were measured during first lactation. Each year during the three-year experiment, heifers from the H and L lines were grazed together as a single group and managed according to the farm's policy of grazing off replacement stock during the period from weaning to first calving. Averaged across years, heifers from the H line were heavier at birth (38 *vs.* 34 kg; s.e.d = 1.16; $P < 0.001$), at puberty (241 *vs.* 221 kg; s.e.d = 7.3; $P < 0.05$), at first calving (411 *vs.* 386 kg; s.e.d = 11; $P < 0.01$) and at maturity (504 *vs.* 467 kg; s.e.d = 12; $P < 0.01$) than L heifers, and they were also older at puberty (325 *vs.* 300 d; s.e.d = 8.3; $P < 0.05$) than L heifers. Despite the earlier puberty of L heifers there was no difference between genetic lines for calving date, age at first calving or first lactation yields of milk and milk components, under the seasonal system in which the animals were managed. It is concluded that selecting for larger mature LW delayed onset of puberty of H heifers. However, up to this stage of the selection experiment, H heifers were able to conceive and calve at dates and ages similar to those achieved by the smaller mature LW heifers.

Introduction

The seasonal system of milk production in New Zealand is based on the seasonal pattern of pasture growth and is driven by a seasonal system of reproduction of the dairy herd. Mating is carried out during 11 to 12 weeks during September to January each year. For the lactating cows, most farmers use artificial insemination for four to seven weeks, followed by natural mating (NM) with 'clean up' bulls that detect returning and late cycling cows during the remaining four to seven weeks of the mating period. A distinctive feature of the system is the mating of replacement heifers at 13 to15 months of age, to ensure that they calve for the first time in the first 4 to 6 weeks of calving as two-year-olds. Each year, less than 15% of the replacement heifers entering the national dairy herd are artificially inseminated (Hook, 1991). The remaining 85% or more are mated by NM to bulls of unknown genetic background for a period of about 12 weeks that starts one or two weeks before the insemination period of the milking herd. Under this scenario, heifers must reach puberty and conceive before 15 months of age in order to calve as two-year-olds. Early onset of puberty in these heifers will ensure a high proportion of them will be cycling by the time they are joined by the bulls (Penno, 1994). Earlier puberty of dairy heifers managed either on feedlot systems (Hawk et al. 1954; Menge et al. 1960; Dufour, 1975; Little et al. 1981) or on grazed pasture (Dalton et al. 1975; Pleasants et al. 1975) has been associated with faster rates of growth during the prepubertal stage, and with heavier weights for age.

In New Zealand, the growth of many replacement heifers between weaning and 24 months of age or just before first calving, takes place away from the home farm, sometimes under a contractual agreement. Individual farmers or companies who specialise in rearing replacements offer the dairy farmer a series of arrangements, based either on a weekly grazing fee or on performance with target live-weight gains set by the parties involved (Penno, 1994 and 1997). Whatever the agreement, the system aims at providing a better rearing and caring environment for the replacement heifer, often neglected in the past because of lower feed requirements and its perceived lack of immediate money making potential compared to the lactating cow (Penno, 1995a). Poor rearing before mating is often translated into slow growth and low pregnancy rates of the replacement heifers, and low LW at the commencement of mating has been suggested as the main factor affecting the empty rate of Jersey and Holstein-Friesian heifers in New Zealand (Macmillan 1994). However, differences in LW at the commencement of mating can be due either to differences in feeding during the rearing period or due to genetic differences in growth potential, or both. The experiments described in the present chapter were designed to quantify the effect that genetic differences in mature LW have on the pattern of growth, onset of puberty and first lactation performance of the replacement heifer under the New Zealand seasonal system of reproduction.

Materials and methods

Animals and information recorded

Population of animals

Female calves born to the heavy (H) and the light (L) mature LW selection lines at Massey University during the years 1994 to 1996 were used in a series of experiments to measure differences in growth and onset of puberty (in three years) and first lactation performance (only the heifers born in 1994 and 1995). Numbers of animals within each genetic line by year of birth and dam parity number are given in Table 3.1.

Table 3.1: Numbers of heifers within genetic line, year of birth and dam parity number.

		Dam parity number					
Genetic line	Year of birth	2	3	4	5	≥ 6	Total
Heavy	1994	1	3	0	2	4	10
	1995	6	3	2	2	2	15
	1996	2	4	0	3	1	10
	Total						35
Light	1994	1	5	2	2	2	12
	1995	4	3	2	0	4	13
	1996	4	2	3	2	1	12
	Total						37

In total 72 heifers (35 H and 37 L) were followed from birth to the end of mating (all three crops) or to first calving (only those born in 1994 and 1995). Heifers from the H line were the daughters of 10 sires with high breeding value (BV) for LW (mean ± SD, 77.8 ± 17), whereas 7 sires with low BV for LW (mean ± SD, 41.8 ± 9.2) sired the heifers from the light LW line.

Generations of breeding

The heifers used in the present experiments were from the first, second and third generation of breeding to the heavy or the light LW selection lines. Details of the mating plan to generate the H and L lines have been given elsewhere (García-Muñiz et al. 1998b), and have also been described in Chapter 1. Briefly, high genetic merit cows from the base herd were selected, and the heavier cows were mated to bulls with high BV for LW and the lighter cows to bulls with low BV for LW to produce the first generation of heavy (H) or light (L) heifers. After first calving, H-sired and L-sired heifers were mated back to H or L bulls to produce the second generation of heavy (HH) or light (LL) heifers, and so on. The number of heifers by generation and genetic line are summarised in Table 3.2. Details of the BV's for production traits for these heifers have been given in Chapter 2.

Table 3.2: Number of heifers by generation of breeding for the two genetic lines.

	Generation					
Genetic line	H	HH	HHH	L	LL	LLL
Heavy	14	20	1			
Light				17	20	0

Growth data recorded and feeding management

Calves were born in spring each year during the period between 27th July and September the 16th. Cows calved outdoors and calves were identified to their mothers and allowed to stay with their dams for the first 24 hours to drink colostrum. On the following day the calves were put into a calf barn and their birth weight was recorded.

All the bull calves and the heifer calves not required as replacements were sold during the first week of age; the remaining heifer calves were reared as replacements.

The calves spent the first two weeks in the calf barn, where they were bucket-fed on whole milk and colostrum, offered concentrate pellets *ad libitum*, and gradually introduced to drink milk from a calfteria system. After becoming used to this system, they were divided into two groups irrespective of genetic line, on the basis of LW and age to avoid unfair competition. They were then rotated regularly around the farm ahead of the milking herd, always being put into a paddock with leafy grass, and offered concentrate pellets *ad libitum* on a portable plastic feeder. Their LW was recorded when they were weaned from milk at about 12 weeks of age, at the time when they were sent to graze at a neighbouring farm; then fortnightly, during the period of blood sampling to determine onset of puberty, and then every month until first calving. At all times, the heifers from the H and L lines were reared and grazed together as a single group and offered herbage allowances aimed at achieving 600 to 800 g LWG/hd/d.

Blood sampling and progesterone analyses

During the three years of the study, individual blood samples were collected weekly from the tail vein of each heifer. Bleeding began in February each year when the heifers were about 7 months of age, and continued until October just before the bulls joined the heifers for natural mating, when the heifers were about 12 to 13 months old. Blood was collected into heparinized vacutainers (Becton Dickinson, USA) and stored in ice until assayed. Samples were centrifuged at 3000 rpm for 20 minutes, and the serum was harvested and stored at –10 °C. The concentration of progesterone (P_4) in the plasma was measured to determine the time of onset of puberty. A heifer was assumed to have reached puberty when the concentration of P_4 was > 1 ng/ml at two consecutive samplings (Barash et al. 1994; Ringuet et al. 1994). When the progesterone criterion was met, bleeding was discontinued and puberty was assumed to have occurred 5 days before the first day when progesterone concentration was > 1 ng/ml (Linch et al. 1997). Samples from the first two years were analysed for progesterone concentration using a procedure described by Kirkwood et al. (1984). The intra- and inter–assay coefficients of variation (CV) for these replicates were 6.2% and 9.4% respectively. Samples from the third year were analysed using a commercial progesterone kit (Coat-a-Count, Diagnostic Products Corporation, Los Angeles, California, USA) and the corresponding intra- and inter-assay CV were 4.5 % and 6.6%, respectively.

Mating programme

Each year during October, when the heifers were about 14 months of age, Holstein-Friesian bulls joined the heifers for a 90-day NM mating season until the end of January the following year. Two different bulls were used each year at an approximate ratio of one bull per every 20 heifers. Every year, the bulls used for NM were selected from within a large group available at another property dedicated to the production of bull beef using the excess male progeny from the University's dairy herds. The herd manager selected the bulls based on a subjective appraisal of soundness.

Yield of milk and milk components

After first calving H and L heifers joined the milking herd and grazed on ryegrass-white clover pastures at generous herbage allowances in accordance with the grazing management policy on the farm for milking cows. Lactating cows were milked twice a day at 5:30 a.m. and 2:30 p.m., and individual milk volumes were recorded daily using an automated milking system (Westfalia separator). Milk composition of individual cows (fat % and protein %) was assessed on 6 to 10 occasions per lactation by routine herd testing carried out by personnel from the New Zealand Livestock Improvement Corporation. Yield per lactation of milk, milkfat, milk protein, milksolids (fat and protein) and lactation lengths were calculated from the yield and composition data and from dates of calving and drying off, respectively. This information was available only for heifers born in 1994 and 1995, because the 1996 born heifers had not calved at the time of writing (July 1998).

Live weight and body condition score at calving

Live weight and body condition score at calving were recorded within the first 24 hours after calving. LW was recorded using a set of electronic scales (Tru Test, NZ Ltd.), and body condition score was assessed visually by the same observer using a scale from 1 to 10, where 1 represented an emaciated cow and 10 a grossly obese animal (Holmes and Wilson, 1987).

Calving difficulty at birth and at first calving

Calving difficulty records were available for the 72 heifers at their birth (i.e. the heifer as a calf causing a difficult delivery), and for 47 of the 72 heifers when they in turn gave birth to their first calf (i.e. the heifer as a mother facing a difficult calving). Scoring for calving difficulty (1 = difficult calving, 0 = free calving) was at the discretion of the herd manager in all the years in which information was collected (See Chapter 6).

Derived variables

Growth from birth to first calving and puberty attainment

Live weight at birth, at weaning (i.e. calves off milk), at the start (i.e. bulls in) and at the end (i.e. bulls out) of the natural mating period, and at first calving (only for heifers born in 1994 and 1995) were recorded for each heifer. Live weight at puberty was calculated by linear interpolation from the fortnightly LW records taken during the blood-sampling period. From these weights and the corresponding dates, live-weight gains (i.e. absolute growth rates) from birth to weaning and from birth to puberty were calculated for each heifer. Additionally, relative growth rate was also calculated for these three intervals as described by Fitzhugh (1976). The dams' latest insemination date and subsequent calving date were used to calculate the heifer's own gestation length. Dates (Julian) of birth and of first calving, and age at first calving were calculated for each heifer from their corresponding dates of birth and of first calving respectively.

Degree of maturity and mature weight

Degree of maturity in LW (Fitzhugh and Taylor, 1971) was calculated only for heifers born during 1994 and 1995, since the heifers born in 1996 had not calved at the time of writing, and therefore estimates of mature weight were not available for them. For the 1994 and 1995 born heifers, mature weight and degree of maturity of individual heifers was estimated by growth curve analysis using the Von Bertalanffy equation (See Chapter 8).

Annual dry matter intake and feed conversion efficiency

The yields per lactation of milk (*l*), milkfat (kg), milk protein (kg), and the average LW during the first lactation, predicted from each cow's individual growth curve (García-Muñiz et al. 1998b) were used to approximate each heifer's annual dry matter intake as described by Van der Waaij et al. (1997). Feed conversion efficiency was then estimated as kg of milksolids per tonne of DM consumed. A comparison of the H and L lines using records on multiple lactations has been given by García-Muñiz et al. (1998b) and is also presented in Chapter 8.

Statistical analyses

The growth variables recorded and derived were analysed using least squares analysis of variance using PROC GLM (SAS, 1989). The model included the fixed effects of year of birth and genetic line, and the random effect of sire nested within genetic line. Differences between genetic lines were tested using the mean square of sire nested within genetic line as the error term in the corresponding *F*-tests; all other tests of significance used the residual mean square. Ages at weaning and at puberty were included as linear covariates where appropriate. Differences between genetic lines for first lactation data were analysed using a similar model as for the growth data, but in this case lactation length was included as a linear covariate.

The relationship between daily live-weight gain (LWG) up to the onset of puberty and age at puberty was tested by curvilinear regression analysis using PROC GLM (SAS, 1989). Heterogeneity of the regression equations due to genetic line was tested as by Snedecor and Cochran (1980). A similar approach was used to test the relationship between first lactation yield and LW at first calving, at maturity and with daily LWG from birth to puberty. The incidence of calving difficulty at birth and at first calving was compared for the two genetic lines by Chi-square (χ^2) analysis using PROC FREQ (SAS, 1989). The BV's for LW of sires were related by correlation analysis to the LW's at birth, weaning, start and end of mating, first calving, and at maturity of their heifers.

The proportion of heifers becoming pubescent as a function of age was modelled using the following function (Freetly and Cundiff, 1997):

$$f(x) = \frac{100}{1 + \left(\frac{k}{x}\right)^{z}} \qquad [3.1]$$

Where, for each genetic line, $f(x)$ is the cumulative percentage of heifers that have reached puberty at a given age (x), and "k" and "z" are parameters to be estimated. The parameter "k" estimates the age at which 50% of the heifers from each genetic line have expressed puberty, and parameter "z" determines the rate at which the group of heifers becomes pubescent. Equation [3.1] was fitted to the data on each genetic line by non-linear regression using PROC NLIN (SAS, 1989).

Results

Growth from birth to first calving

One heifer from the L line died by accident at 9 months of age before reaching puberty, and only her data on early growth were used for further analysis. During the three years of the experiment, only one heifer (an HH heifer) did not become pregnant during the period of NM. Least squares means for the recorded and derived variables are presented in Table 3.3, whereas the occurrence of the events along the growth curve from birth to first calving is depicted in Figure 3.1. Heifers from the H and L lines were born around the same time of the year and had similar gestation lengths. Heifers from the H line were heavier at birth, but had similar weaning weights as the L heifers. This was so despite the fact that H heifers were off milk at a significantly younger age than L heifers. Live-weight gains from birth to weaning and from birth to puberty were similar for both genetic lines with a mean of 712 and 650 g/hd/d, respectively. However, heifers from the L line had significantly higher 'relative growth rates' from birth to weaning and from birth to puberty than H heifers (Table 3.3). There was no difference between genetic lines for LW or age at the start or at the end of the natural mating period. Heifers from the L line were slightly more mature in LW than H heifers at the start and at the end of the natural mating periods but the differences were not significant.

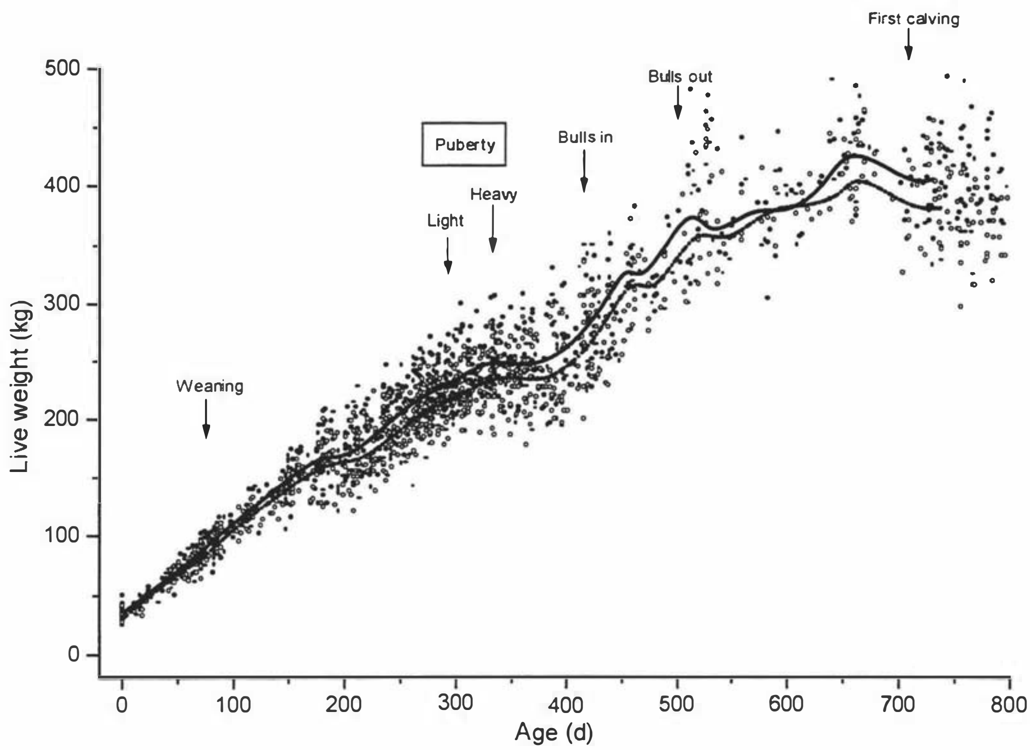

Figure 3.1: Growth pattern of genetically heavy (–●–) or light (–○–) Holstein-Friesian heifers from birth through first calving.

Attainment of puberty

Weight and age at puberty

Regardless of genetic line, animals with heavier weights at puberty (Figure 3.2) were also older. However, this relationship was stronger for L heifers than for the H heifers, as implied by the R^2-values of their respective regression equations. Heifers from the H line were significantly heavier and older at puberty than L heifers by 20 kg and 25 days, respectively. However, both H and L heifers attained puberty at about 47% of their mature LW (Table 3.3).

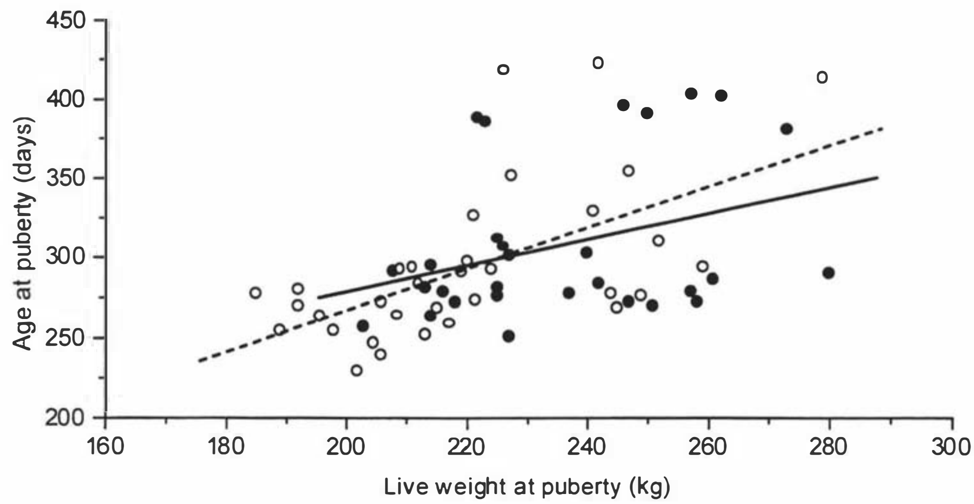

Figure 3.2: Relationship between age at puberty and live weight at puberty of genetically heavy (–●–) or light (–○–) Holstein-Friesian heifers. The regression equations are for the heavy: Y = 115 + 0.819X; $P < 0.10$, R^2 = 11%, n = 29; and for the light: Y = 9.0 + 1.29X; $P < 0.0001$, R^2 = 35%, n = 33.

Live-weight gain prepuberty and age at puberty

The relationship between age at puberty and daily live-weight gain (LWG) prepuberty was negative and curvilinear for both genetic lines (Figure 3.3). Age at puberty declined with increased daily LWG up to a minimum to increase again for higher LWG's. Setting to zero the first derivative of the respective regression equation and solving for LWG approximated the daily LWG that resulted in the youngest age at puberty for each genetic line. In the range of daily LWG's between 350 and 850 g/hd/d, minimum age at puberty was achieved at an average daily LWG of 758 g/hd/d for H heifers and at 726 g LWG/hd/d for L heifers. Despite their later puberty, H heifers calved at the same time of the year and at the same age as the L heifers (Table 3.3).

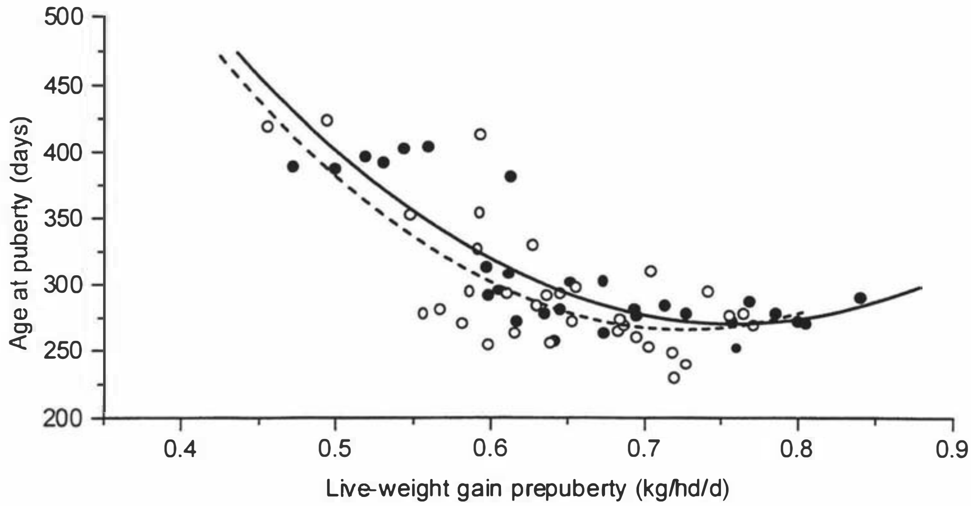

Figure 3.3: Relationship between age at puberty and live weight gain prepuberty of genetically heavy (–●–) or light (–○–) Holstein-Friesian heifers. The regression equations are a) heavy: Y = 1398 – 2977X + 1964X^2; P < 0.0001, R^2 = 73%, n = 29; and b) light: Y = 1462 – 3295X + 2270X^2; P < 0.0001, R^2 = 55%, n = 33.

Age, live weight and degree of maturity at mating

Heifers from the H and L lines were of similar age, LW, and degree of maturity at the start and at the end of the 12-weeks mating period. On average H and L heifers were joined with the bulls and finished the NM period at 14.3 and 16.8 months of age, respectively. Corresponding LW's and degrees of maturity in LW were 278 kg and 58% at the beginning, and 376 kg and 78% at the end of the NM period (Table 3.3).

Age, live weight, body condition score and degree of maturity at first calving

Heavy and light heifers calved for the first time at the same date during the year (i.e. day 228 or August the 16th), and at the same age, being on average 730.5 days or 24 months. However, heifers from the H line were significantly heavier at first calving (post calving LW) and at maturity than L heifers. Despite the difference in LW at first calving, H and L heifers calved for the first time at a similar degree of maturity of about 82% (Table 3.3).

Table 3.3: Least squares means for growth and puberty variables of heavy and light Holstein-Friesian heifers.

		Genetic line			
Item	n	Heavy	Light	s.e.d	Significance
Date of birth[1]	72	231.6	226.9	3.37	NS
Gestation length (d)	72	279.0	278.0	1.44	NS
Birth weight (kg)	72	37.8	33.7	1.16	***
Weaning weight (kg)[2]	72	94.7	92.0	2.49	NS
Weaning age (d)	72	76.3	83.2	2.02	**
Absolute growth rate (g/d)					
Birth to weaning	72	709.0	721.0	26.6	NS
Birth to puberty[3]	69	667.4	636.3	19.0	NS
Relative growth rate (%/d)					
Birth to weaning[4]	72	1.16	1.24	0.038	*
Birth to puberty[5]	63	0.60	0.66	0.028	*
Puberty					
Age (d)	69	324.6	300.0	8.3	*
Live weight (kg)	69	241.0	220.6	7.3	*
Degree of maturity (%)	38	47.0	46.6	1.7	NS
Start of mating period[6]					
Heifer age (d)	71	433.7	438.4	3.3	NS
Heifer live weight (kg)	49	283.0	272.7	7.8	NS
Degree of maturity (%)	46	56.6	58.4	1.8	NS
End of mating period[6]					
Heifer age (d)	49	510.4	515.8	3.3	NS
Heifer live weight (kg)	49	384.0	367.0	9.0	NS
Degree of maturity (%)	46	76.3	78.6	1.9	NS
First calving[6]					
Date[7]	47	228.0	228.0	6.5	NS
Age (d)	47	728.0	733.0	7.8	NS
Live weight (kg)	43	410.8	386.4	10.8	**
Condition score (units)[8]	43	4.96	4.80	0.14	NS
Degree of maturity (%)	42	81.8	82.6	1.9	NS
Mature weight (kg)[9]	46	503.6	466.7	11.9	**

[1] Days since January the 1st in the year the heifer was born.

[2] Adjusted by age at weaning as a covariate (b = 0.853 kg/d; $P < 0.0001$).

[3] Adjusted by age at puberty as a covariate (b = -0.001 kg/d; $P < 0.0001$).

[4] = {[ln (weaning weight) – ln (birth weight)]/age at weaning} x 100.

[5] = {[ln (weight at puberty) – ln (birth weight)]/age at puberty} x 100.

[6] Only for heifers born in 1994 and 1995.

[7] Days since January the 1st in the calving year.

[8] Scale: 1 = emaciated, 10 = obese (Holmes and Wilson, 1987).

[9] Calculated from growth curve analysis using the Von Bertalanffy equation (García-Muñiz et al. 1998b).

Rate of puberty attainment

Heifers from the L line became pubescent at a faster rate than H heifers (Figure 3.4), and on average 50% of L heifers had reached puberty by the age of 288 days, compared to 305 days of age for H heifers. Similarly, 90% reached puberty at 348 days for the L heifers and 390 days for the H heifers. Thus, by one year of age, 83% of the H and 94% of the L heifers had reached puberty. However, when the bulls joined the heifers for natural mating at 14 months of age, these percentages were not significantly different at 96% and 99% for H and L heifers, respectively (Table 3.4).

Table 3.4: Average age (d) when 50% and 90% of heifers become pubescent and percentage of heifers pubescent from the heavy and the light live weight selection lines at one year, and at the start and at the end of mating.

	Parameters of the function		Age at 90%	% Pubescent at:		
Genetic line	k	z	pubescent, d	365 d	Start of mating[1]	End of mating[1]
Heavy	305.0	8.9	390.0	83.3	95.9 (434)	100.0 (510)
Light	287.6	11.6	348.0	94.0	99.2 (438)	100.0 (516)
Significance genetic line			*	*	NS	NS

[1]Average age (d) within parenthesis.

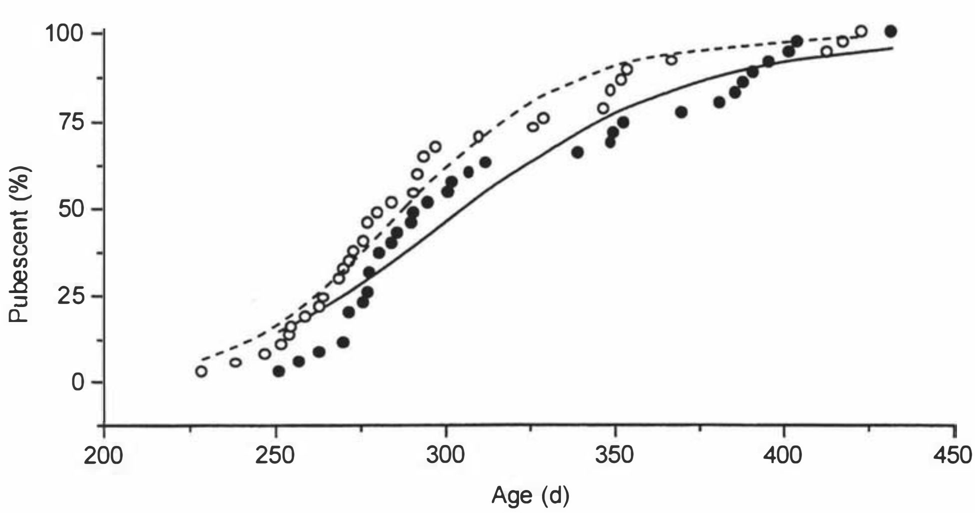

Figure 3.4: Percentage of heifers pubescent as a function of age for heifers from the heavy (–●–) or light (–○–) live weight selection lines. The circles represent the observed values for each heifer and the lines represent the fitting of Equation [3.1] for each genetic line.

First lactation performance

Yield of milk and milk components and estimated feed conversion efficiency

Least squares means for lactation length, yield of milk and milk components, milk composition, estimated annual DMI and feed conversion efficiency for H and L first calving heifers are summarised in Table 3.5. There were no differences between genetic lines for any of the yield, composition, or efficiency variables analysed. On average H and L heifers had calculated annual intakes of 3.6 and 3.5 tonnes of DM, and an estimated feed conversion efficiency of 78 and 82 kg of milksolids/tonne of DM eaten, respectively.

Table 3.5: Least squares means for first lactation performance, estimated annual dry matter intake during lactation, and estimated feed conversion efficiency.

			Genetic line			
Item	Units	n	Heavy	Light	s.e.d	Significance
Yield[1]						
Milk	*l*/lactation	46	3512	3453	161.8	NS
Milkfat	kg/lactation	46	162	161	6.3	NS
Protein	kg/lactation	46	116	116	4.5	NS
Milksolids	kg/lactation	46	278	277	10.4	NS
Composition						
Fat	%	46	4.64	4.67	0.12	NS
Protein	%	46	3.31	3.33	0.07	NS
Lactation length	d	46	198.0	206.0	13.0	NS
Estimated DMI[2]	kg DM/cow/year	46	3569.0	3508.0	172.0	NS
Estimated feed conversion efficiency	MSY/tonne DM	46	77.7	81.6	6.0	NS

[1] Lactation length included as a covariate (milk: b = 17.9 ± 2.1 kg/d; P < 0.0001; fat: b = 0.778 ± 0.08 kg/d; P < 0.0001; protein: (b = 0.605 ± 0.06 kg/d; P < 0.0001; milksolids: b = 1.38 ± 0.13 kg/d; P < 0.0001).

[2] Calculated from Van der Waaij et al. (1997) as: DMI (kg/cow/year) = [1.83* Milk yield (*l*) + 56.10*Fat yield (kg) + 31.77*Protein yield (kg) + 231.26* $LW^{0.75}$]/10.8.

Relationship between yield and live weight and body condition score

There were no significant relationships between yield per lactation of milk or milk components and LW at the start and at the end of mating, at calving, at maturity or with body condition score at calving.

Sire's BV for LW and live weights of the heifers

Product moment correlations between the sires' BV for LW and their daughters LW's at birth, weaning, puberty, start and end of mating, first calving, and at maturity are summarised in Table 3.6. Only the LW's at birth, at puberty and at maturity were significantly correlated to the sire's BV for LW. Birth weight was positively correlated to weight at puberty but not to weaning weight or weights at older ages.

Table 3.6: Product moment correlation coefficients for breeding values of sires for stature and live weight and live weights of the heifers at different ages.

Item	1	2	3	4	5	6	7
1. Sire BV for LW							
2. Birth weight	0.352 **						
3. Weaning weight	-0.109	0.155					
4. Weight at puberty	0.396 **	0.395 **	0.111				
5. Start of mating weight	0.004	0.032	0.424 ***	0.446 **			
6. End of mating weight	-0.085	0.132	0.470 ***	0.464 **	0.917 ***		
7. First calving weight	0.128	0.020	0.427 **	0.459 **	0.805 ***	0.789 ***	
8. Mature weight	0.320 *	0.142	0.373 **	0.530 ***	0.583 ***	0.595 ***	0.706 ***

Calving difficulty

The incidence of calving difficulty at birth (i.e. the heifer as a calf born in a difficult delivery) or at first calving (i.e. the heifer as a mother having a difficult calving) was not significantly different between the H and L heifers (Table 3.7). Calving difficulty at first calving was almost twice as high for L heifers, but with the small number of observations this difference did not approach significance ($P = 0.26$).

Table 3.7: Calving difficulties at their birth and at their first calving for genetically heavy or light Holstein-Friesian heifers.

	Calving difficulty at the stage of:			
	Heifer as a calf		Heifer as a mother	
Genetic line	n	Difficult (%)	n	Difficult (%)
Heavy	35	5.7	24	16.7
Light	37	2.7	23	30.4
Significance genetic line		NS		NS

Discussion

Age and weight at puberty

Heifers from the H line were heavier (+ 20 kg) and older (+ 25 days) at puberty than L heifers. The significantly higher potential for growth of H heifers as well as their higher mature weight (i.e. sired by bulls with higher BV for LW) may mean that they required extra time and weight to be at the same degree of maturity as the L heifers. The average weights at puberty recorded for the H (241 kg) and the L (221 kg) heifers agree with the 220 kg LW for Holstein-Friesian heifers suggested by Penno (1994). These puberty weights are also in agreement with those reported for New Zealand Holstein-Friesian heifers reared under the management policies of the beef breeding herd (Dalton et al. 1975; Pleasants et al. 1975). However, they are much lighter (especially those from the L heifers) than those reported for Holstein heifers from North America (Figure 3.5).

Information from the literature on age and weight at puberty of different strains of Holstein is summarised in Figure 3.5. The plotted values correspond to the treatment means reported in each experiment. In most experiments differences in age and weight at puberty were achieved by subjecting the heifers to different planes of nutrition. The averages obtained in the present study for the H and L heifers are also plotted in Figure 3.5. On average heifers from the present experiment were lighter at puberty than the majority of those from the experiments summarised in the plot. The exception being the weights at puberty of heifers (shown within the dotted square) reported in other studies in New Zealand (Dalton et al. 1975; Pleasants et al. 1975). The lighter mature LW of the New Zealand cattle (García-Muñiz et al. 1998b) and the fact that they are solely fed on grazed pasture might explain these lower LW's at puberty of heifers in the New Zealand experiments. The higher mature LW of heifers from the H line might have contributed to their later puberty, since there is evidence, at least for beef cattle, that breeds of larger mature size achieve puberty at older and heavier weights (Bagley, 1993).

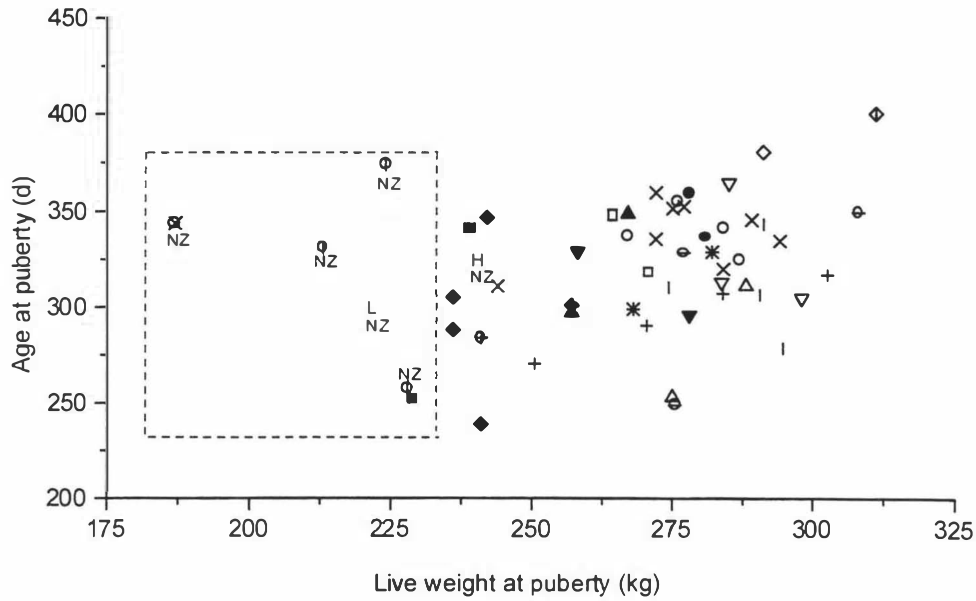

Figure 3.5: Relationship between age at puberty and live weight at puberty for dairy heifers from different strains of Holstein (■ Amir et al. 1967, Israeli Holstein; □ Barash et al. 1994, Israeli Holstein; ● Bortone et al. 1994, USA Holstein; o Capuco et al. 1995, USA Holstein; ▲ Dufour, 1975, Canadian Holstein; Δ Gardner et al. 1977, USA Holstein; ◆ Little et al. 1981, British Friesian; ✧ Murphy et al. 1991, Irish Holstein; | Niezen et al. 1996, Canadian Holstein; θ Peri et al. 1993, Israeli Holstein; φ Pleasants et al. 1975, NZ Holstein-Friesian; ⊕ Sacco et al. 1987, USA Holstein; ▼ Sejrsen et al. 1983, USA Holstein; ∇ Stelwagen and Grieve, 1990, Canadian Holstein; + Ringuet et al.1994, Canadian Holstein; ✱ Tekpetey et al. 1987, Canadian Holstein; ⊗ Dalton et al. 1975, , NZ Holstein-Friesian; x Waldo et al. 1998, USA Holstein; Heavy (H) and Light (L) NZ Holstein-Friesian (Present experiment).

Live-weight gain prepuberty and onset of puberty

The inverse relationship between LW gain prepuberty and age of puberty found in the present experiment has been documented in previous reports with USA Holstein heifers (Hawk et al. 1954; Mengue et al. 1960), and with British Friesian heifers (Little et al. 1981). The curvilinear effect of prepuberty LWG on age at puberty agrees with the observation by Lasley (1962) that the level of feeding has a curvilinear relationship with the onset of puberty with an optimal level somewhere between overfeeding and underfeeding. In the present experiments prepuberty LWG as an indicator of the level of feeding clearly shows this trend. In the range of daily LWG's between 350 and 850 g/hd/d, minimum age at puberty was achieved at a lower average daily LWG of 726 g/hd/d for L heifers compared to 758 g/hd/d for H heifers. In beef heifers, the earlier puberty of faster growing animals has been related to an increased prepubertal secretion of LH as a result of increased energy intake (Hall et al. 1990). Figure 3.6 summarises reports from the literature where both age at puberty and LWG prepuberty were measured for heifers of different strains of Holstein. In these experiments differences in LWG and age and weight at puberty were generated through applying different planes of nutrition to the heifers (Bortone et al. 1994; Capuco et al. 1995; Niezen et al. 1996; Peri et al. 1993; Stelwagen and Grieve, 1990), different photoperiods (Ringuet et al. 1994), or the combination of different planes of nutrition and administration of somatotropin hormone (Murphy et al. 1991; Ringuet et al. 1994). The plotted values correspond to the treatment means reported in each experiment, and the averages obtained in the present experiment for the heavy and the light LW selection lines are also plotted on the graph. In the range of prepuberty LWG's from 0 to 1.3 kg/hd/d, there is a clear negative trend between age at puberty and rate of gain prepuberty. That is, heifers growing at a faster rate during the prepubertal period will achieve earlier puberty.

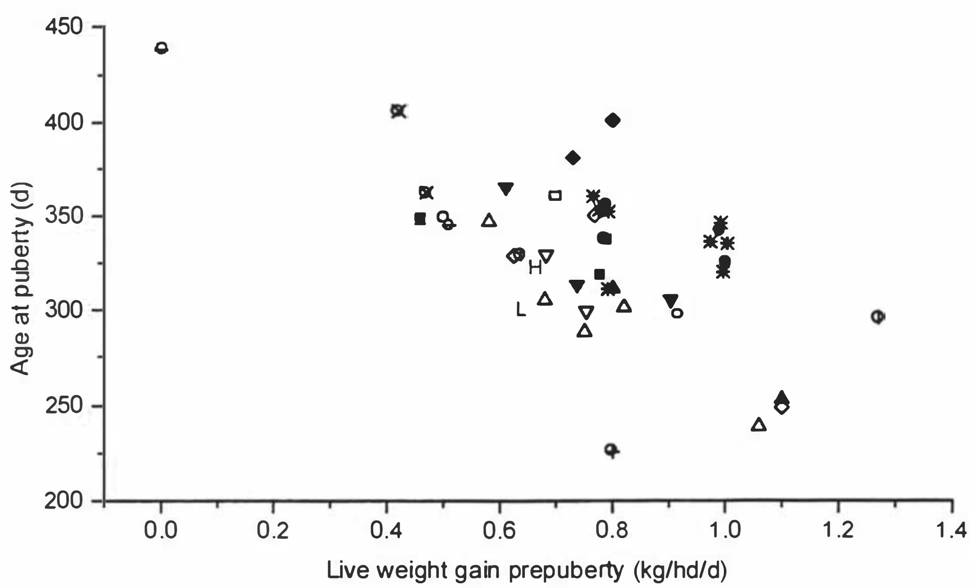

Figure 3.6: Relationship between age at puberty and live weight gain prepuberty of Holstein heifers of different strains (■ Barash et al. 1994, Israeli Holstein; □ Bortone et al. 1994, USA Holstein; ● Capuco et al. 1995, USA Holstein; ο Dufour, 1975, Canadian Holstein; ▲ Gardner et al. 1977, USA Holstein; △ Little et al. 1981, British Friesian; ◆ Murphy et al. 1991, Irish Holstein; ◇ Peri et al. 1993, Israeli Holstein; ⊗ Ramin et al. 1996, Australian Holstein; θ Sandles et al. 1988, Australian Holstein; φ Sejrsen et al. 1983, USA Holstein; ⊕ Sinha and Tucker, 1969, USA Holstein; ▼ Stelwagen and Grieve, 1990, Canadian Holstein; ▽ Tekpetey et al. 1987, Canadian Holstein; ✱ Waldo et al. 1998, USA Holstein; Heavy (H) and Light (L) NZ Holstein-Friesian (present experiment).

Practical implications of delayed puberty

For seasonal systems of reproduction with a short mating season, delayed onset of puberty will be associated with a higher proportion of heifers being prepubertal at the commencement of mating (Penno, 1995b). Thus, this delay may mean some heifers will be conceiving to their pubertal oestrus, at the end of the NM period, or not conceiving at all. Mating heifers at their pubertal oestrus reduces pregnancy rates. For beef heifers, higher pregnancy rates were obtained when they were inseminated to the third oestrus (78%) after puberty, compared to the pubertal (57%) oestrus (Byerley et al. 1987). Up to this stage of the selection experiment, the average delay of 25 days on the attainment of puberty by H heifers has resulted in only one heifer from this line (an HH heifer) not becoming pregnant by the end of the NM period. However, with the observed trend in delayed puberty it is likely that continuing increases in the heifer's BV for LW will eventually result in a much more pronounced difference between the H and L heifers in age at puberty.

Prepuberty live-weight gain and first lactation yield

Yield per lactation of milk and milk components did not differ between H and L heifers, and there were no significant relationships between yield and any measurement of LW made along the growth curve. There was also no relationship between the prepuberty LWG and yield of milksolids in the subsequent lactation. Other studies have shown a decreased first lactation milk yield at faster prepubertal LWG's (Foldager and Sejrsen, 1991; Johnsson, 1988; Little and Kay, 1979; Sejrsen, 1978), apparently because the nutritional status of the replacement heifer between birth and puberty can exert a permanent effect on its ability to produce milk once lactation commences (Johnsson, 1988).

Although the exact mechanisms of how high prepuberty LWG's impair lactation performance have not been fully elucidated, an increased fat deposition in the udder to the detriment of secretory tissue has been quantified and postulated as the most likely cause (Foldager and Sejrsen, 1991; Johnsson, 1988; Little and Kay, 1979; Sejrsen, 1978). During the period from 3 to 9 months of age or LW's of 100 to 300 kg, mammary secretory tissue grows at a rate 3.5 times faster than the body (Sinha and

Tucker, 1969), and this appears to be the 'critical' period in which high rates of live-weight gain are likely to impair future lactation performance (Barash et al. 1994; Johnsson, 1988; Sejrsen, 1978; Waldo et al. 1989). It has been also suggested that for large dairy breeds there is an optimal prepubertal LWG of about 0.7 kg/hd/d, for which subsequent lactation performance is maximised (Barash et al. 1994; Foldager and Sejrsen, 1987; Sejrsen 1978). Table 3.8 summarises information on milk yield from experiments in which prepuberty LWG was manipulated using different levels of feeding, given to different strains of Holstein (USA, Australian, British Friesian, Israeli, Italian) and Danish Jersey, Danish Red and Danish Friesian. First lactation milksolids yield and prepuberty LWG's for genetically heavy or light Holstein-Friesian heifers obtained in the present experiment are also presented.

In addition, Table 3.8 also summarises both the LW and the age interval in which these LWG's were achieved. The LW interval ranged from 79 kg to 350 kg and the age interval from 3 months to 250 days after first calving, which spans the 'critical' period in which fast prepuberty LWG might impair subsequent milk yield. The daily LWG's achieved in these experiments ranged from 0.0 to 1.1 kg/hd/d. Milk yield was significantly reduced due to higher prepuberty LWG's in some experiments (Hohenboken et al. 1995; Little and Harrison, 1981; Little and Kay, 1979; Peri et al. 1983; Sandles et al. 1988; Sejrsen, 1978; Valentine et al. 1987), but not in others (Barash et al. 1994; Capuco et al. 1995; Gaynor et al. 1995; Pirlo et al. 1997; Waldo et al. 1998).

The data in Table 3.8 from some experiments suggests that high prepuberty LWG's have a detrimental effect when they are achieved during the critical period of 100 to 300 kg or the period from 3 to 9 months of age. However, the lack of effect in other experiments, especially those where genetically larger USA Holstein cows were used (Capuco et al. 1995; Gaynor et al. 1995; Waldo et al. 1998), might suggest that the presence or absence of the detrimental effect could be a function of the breed's (or strain's) genetic potential for growth. That is, animals with lighter mature weights may be at greater risk of developing 'fatty udders' and having lower milk yields when prepubertal LWG's are higher than 700 g/d. By contrast, heifers with genetically heavier mature weights may be able to support prepubertal LWG's as high as 1 kg/hd/d without showing any detrimental effect on their future lactation performance.

Table 3.8: Published data for the effect of prepubertal live-weight gain of dairy heifers on their subsequent lactation performance.

Source	LW interval (kg)		Age interval (mo.)		Prepuberty	First lactation:	
	Initial	Final	Initial	Final	LWG (kg/d)	Yield	Relative
Barash et al. 1994[4]	172.1	266.6	"	"	0.78	7478	(100)
(Israeli Holstein)	173.6	228.7	6.6	10.5	0.46	7344	(98)
Capuco et al. 1995[7]	175	325	7.3	--	0.786	21.7	(100)
(USA Holstein)	175	325	7.3	--	0.788	20.7	(95)
	175	325	7.3	--	0.992	19.6	(90)
	175	325	7.3	--	1.001	20.6	(95)
Gardner et al. 1977[3]	--	--	--	--	0.8	5415[e]	(100)
(USA Holstein)	--	--	--	--	1.1	4436[f]	(82)
Gaynor et al. 1995[7]	175	325	7.3	--	0.762	21.7	(100)
(USA Holstein)	175	325	7.3	--	0.811	20.6	(95)
	175	325	7.3	--	0.974	19.7	(91)
	175	325	7.3	--	0.996	19.9	(92)
Hohenboken et al. 1995[1]							
(Danish Jersey)	--	--	1.4	1stCvng	0.362	5125[g]	(100)
	--	--	1.4	1stCvng	0.487	4750[h]	(93)
	--	--	1.4	1stCvng	0.557	4125[i]	(80)
(Danish Red)	--	--	1.4	1stCvng	0.549	5675[g]	(100)
	--	--	1.4	1stCvng	0.718	4900[h]	(86)
	--	--	1.4	1stCvng	0.845	4700[i]	(82)
(Danish Friesian)	--	--	1.4	1stCvng	0.579	5425[g]	(100)
	--	--	1.4	1stCvng	0.731	5400[g]	(100)
	--	--	1.4	1stCvng	0.858	4900[h]	(90)
Little & Kay, 1979[5]	--	--	3.0	9.0	0.605	3863[g]	(100)
(British Friesian)	--	--	"	"	0.985	2450[h]	(63)
	--	--	"	"	1.095	1959[h]	(51)
Little and Harrison, 1981[5]	79.0	290.0	3.0	12.0	0.58	3550[e]	(100)
(British Friesian)	79.0	290.0	"	"	0.58	3120[e]	(88)
	79.0	310.0	"	"	0.68	3330[e]	(94)
	80.0	302.0	"	"	0.75	3400[e]	(96)
	81.0	343.0	"	"	0.82	3340[e]	(94)
	81.0	343.0	"	"	1.06	2950[f]	(83)
Peri et al. 1993[1]	169.4	244.0	5.7	9.6	0.625	7056[a]	(100)
(Israeli Holstein)	183.4	275.0	"	"	0.768	6070[b]	(86)
	172.8	304.2	"	"	1.10	5975[b]	(85)

Table 3.8: (Cont.).

Source	LW interval (kg) Initial	Final	Age interval (mo.) Initial	Final	Prepuberty LWG (kg/d)	First lactation: Yield	Relative
Pirlo et al. 1997[6]	89.6	301	3.0	14.5	0.601	22.7	(100)
(Italian Holstein)	87.1	301	3.0	13.8	0.653	22.2	(98)
	85.7	302	3.0	12.1	0.894	20.2	(89)
	86.4	302	3.0	11.5	0.906	21.8	(96)
Sandles et al. 1988[2]	137.0	213	7.0	11.0	0.00	13.9[c]	(100)
(Australian Holstein)	147.0	210	"	"	0.51	12.6[d]	(83)
Sejrsen, 1978[5]							
Red Danish	200	350	--	--	0.59	4900	(100)
Red Danish	"	"	--	--	0.64	5700	(116)
Red Danish	"	"	--	--	0.68	4800	(98)
Red Danish	"	"	--	--	0.69	4900	(100)
Red Danish	"	"	--	--	0.82	4600	(94)
Red Danish	"	"	--	--	0.89	3900	(80)
Black and White Danish	"	"	--	--	0.76	4200	(86)
Black and White Danish	"	"	--	--	1.06	4000	(82)
Valentine et al. 1987[6]	110.0	130.0	4.0	7.5	0.180	17.2[g]	(100)
(Australian Holstein)	110.0	175.1	4.0	7.5	0.620	15.2[g]	(88)
	110.0	209.0	4.0	7.5	0.940	13.1[h]	(76)
Waldo et al. 1998[7]	175	325	7.3	--	0.793	20.7	(100)
(USA Holstein)	175	325	7.3	--	0.992	19.8	(96)
	175	325	7.3	--	0.776	21.7	(105)
	175	325	7.3	--	0.997	20.9	(100)
Present experiment[8]							
Heavy	--	--	--	--	0.667	278	(100)
Light	--	--	--	--	0.636	277	(100)

Means within columns within reference differ significantly ([a,b] $P < 0.078$; [c,d] $P < 0.1$; [e,f] $P < 0.05$; [g,h] $P < 0.001$).

[1] Milk yield during the first 250 days of lactation (kg/cow).

[2] Milk yield during the first 250 days of lactation (kg/d).

[3] Milk yield during the first 100 days of lactation (kg/d).

[4] Milk yield during the first 300 days of lactation (kg/cow).

[5] 305-days 4% FCM yield (kg/cow).

[6] Milk yield during the first 10 weeks of lactation (kg/d).

[7] Yield of 4% FCM (kg/day).

[8] Milksolids yield (kg/cow/lactation).

Several studies (Sejrsen et al. 1982, 1983, 1986) have demonstrated the administration of growth hormone during the prepubertal period increased mammary parenchyma and decreased extraparenchymal tissue and weight of the mammary gland. This finding suggests that higher blood concentrations of somatotropin, either endogenous or achieved through exogenous administration, favour growth of mammary secretory tissue and counteract the detrimental effect of high prepuberty LWG's on mammary development. This mechanism of high endogenous somatotropin might have been operating in the above mentioned studies with the USA Holsteins, because there is evidence that the selection for high yield has changed the metabolic and endocrine profiles of the modern USA Holstein cow, so that blood concentrations of hormones favour lactation (Nebel and McGilliard, 1993). Moreover, there is also evidence from experimental herds in the USA (Bonzeck et al. 1988) that selection for high milk yield has caused a correlated increase in plasma somatotropin. Therefore, the effect of prepubertal LWG on subsequent lactation performance may be mediated by differences between different strains of Holstein in their genetically determined mature LW and their endogenous production of growth hormone.

Degree of maturity at puberty, at mating and at first calving

Hafez (1993) states that dairy heifers tend to attain puberty at a fixed proportion of their mature weight of around 30 to 40%. In the present experiment, LW at puberty of H and L heifers as a proportion of mature weight was slightly higher than the range given by Hafez (1993) at about 47%. Moreover, H heifers attained puberty at an older age but at the same degree of maturity in LW as L heifers. The older age at puberty of H heifers to achieve similar degree of maturity in LW as L heifers has important implications for the rearing of dairy replacements under the New Zealand seasonal system. That is, unless genetically heavier heifers are growing faster than genetically lighter ones, they will not be able achieve their 'target weights' (i.e. weights as proportion of mature weight) that enable them to become pubescent. Thus, low daily LWG's during the rearing period are expected to have a more detrimental effect on replacements with the genetic potential to grow to a heavier mature LW.

According to Penno (1995b and 1997), optimum fertility of New Zealand yearling heifers is achieved when they reach 60% of mature weight by the planned start of mating at 15 months of age. In the present experiment, H and L heifers were 14.2 and 14.4 months old at the start of mating and had achieved 57% and 58% of their mature weight, respectively, which closely agrees with the recommended target. By the end of the 12-weeks natural mating period, H and L heifers had achieved 76% and 77% of their mature weight, respectively. The fact that only one heifer did not become pregnant during the three years of the study indicates that the pattern of growth achieved by H and L heifers did not compromise their reproductive performance up to their first calving.

Heavy and light heifers calved for the first time at 24 months of age, and at that time they had achieved 82% and 83% of their mature weight, respectively. These figures are slightly lower than the 90% of mature weight at 22 months of age proposed by Penno (1997) to optimise milksolids production during the first lactation. Nevertheless H and L heifers achieved lactation yields of 278 and 277 kg milksolids respectively, which compares with the national average of 257 kg milksolids for first lactation cows during the 1996-1997 season (Livestock Improvement, 1997).

Weights at mating and at first calving

The mating and calving weights of the New Zealand heifer are low when compared to overseas standards (Penno, 1994). In the present experiments the LW's at mating and calving of H and L heifers were certainly lower than those reported for their North American counterparts (Heinrichs and Losinger, 1998). However, both reproductive performance and first lactation milksolids yield were satisfactory for heifers from the present experiments as referred to above. Moreover, the weights obtained at the start of mating (14 months of age) by the H (283 kg) and the L (273 kg) heifers are comparable to the 280 kg figure at 15 months of age given by Penno (1994) for New Zealand Holstein-Friesian heifers. Compared to overseas standards, these weights are certainly lower, but they are appropriate for the smaller mature LW New Zealand strain of Holstein-Friesian cow, and for the grass-fed and seasonal system of reproduction in which these animals have been evolving and spending the rest of their productive lives.

Calving difficulty

Calving difficulty was not different for H and L heifers either at their birth or when they gave birth to their first calf. These results agree with those of a much larger data set that included the adult cows and records of calving difficulty for 10 years (García-Muñiz et al. 1998a), which are also presented in Chapter 6. Although the small sample size prevented the differences from approaching significance, there are some interesting trends. At birth, heifer calves from the H line caused twice as much calving difficulty to their mothers than those from the L line (i.e. H = 6% and L = 3%). When these heifers became mothers and gave birth to their first calf, exactly the reverse happened: twice as many of the L heifers faced a difficult calving than did H heifers (i.e. H = 17% and L = 31%). Penno and Macdonald (1996) reported a higher incidence of difficult calvings for New Zealand Holstein-Friesian heifers that were mated at an average LW of 270 kg, compared to heifers with higher weight. Similarly, higher incidence of difficult deliveries (24%) has been reported for British Friesian heifers when they were mated at LW's lower than 260 kg (Drew, 1986). In the present experiment the weights at the start of mating for H and L heifers were 283 and 273 kg, respectively. Calving difficulty at the delivery of their first calf was 17% for the H and 31% for the L heifers. That is, a difference of 10 kg LW in favour of the H line at the start of mating translated into a difference of 14% less difficulty at calving.

Target weights

During the past eight years there has been increased interest for the definition of 'target weights' for the major breeds of dairy cattle in New Zealand (Bryant and McRobbie, 1991; Mackenzie and Brookes, 1994; Penno, 1994 and 1997; Penno and Macdonald, 1996). This has been mainly motivated by the introduction of schemes that encourage a better rearing of the replacement heifer through performance-based payment contracts. The concept of 'target weights' of dairy cattle under New Zealand conditions was first addressed by McMeekan more than 40 years ago, who summarised data from 10 years of research on growth from birth to first calving (McMeekan, 1954). His work was conducted with Jersey cattle with a genetic merit typical of cows of the 1940's. The current research directed to re-define target weights for Jerseys and

Friesians is well justified, since the genetic merit of the New Zealand cow has increased steadily since the 1950's (Livestock Improvement, 1997). In addition, the introduction of foreign bloodlines through the use of international genetics, particularly the USA Holsteins, might have caused an increase in the average size of the New Zealand cow (García-Muñiz et al. 1998b).

Table 3.9 summarises current recommended standards of LW at a given age for different strains of Holstein cattle. From these weights and ages the average LWG required to achieve those weights has been calculated. The weights obtained in the present experiments are also given for comparison. The pattern of growth for the H and L heifers obtained in the present experiment is plotted again in Figure 3.7, and compared to those derived from the average values given in Table 3.9 for British Friesians (Lawrence and Fowler, 1997) and New Zealand Holstein-Friesians (Penno, 1994). Data from a recent major survey on heifer growth of USA Holsteins (Heinrichs and Losinger, 1998) were used to construct the plot for this strain. However, this data set for the USA Holstein only predicts weights up to 23.5 months of age, and there is evidence that age at first calving for the USA Holstein is around 24 to 26 months, at a calving weight of 560 to 580 kg (Heinrichs, 1993; Kertz et al. 1998). Thus, the final weights for this plot do not represent calving weight, whereas for the other plots the final weight is the assumed (Lawrence and Fowler, 1997; Penno, 1994) or that actually measured (García-Muñiz et al. 1998b).

Table 3.9: Recommended live weights at different stages of growth for Holstein cattle from different strains, and calculated daily liveweight gains required to achieve these weights.

	Live weight (kg) and age (mo.) in brackets at:					Daily live-weight gain (kg/d) required from birth to:			
	Birth	Weaning	Puberty	First Service	First calving	Weaning	Puberty	1st service	1st calving
USA Holstein[1]	40				580 (24)		0.650		
British Friesian[2]	40		200 (8.5)	325 (15)	530 (24)		0.619	0.623	0.669
NZ Holstein-Friesian[3]	32	90 (2)	220 (10)	280 (15)	420 (24)	0.950	0.618	0.542	0.530
Present experiment[4]									
Heavy line	38	95 (2.5)	241 (10.6)	283 (14.2)	411 (24)	0.698	0.667	0.565	0.512
Light line	34	92 (2.7)	221 (9.8)	273 (14.4)	386 (24)	0.726	0.636	0.545	0.481

1 Adapted from: Heinrichs (1993), Heinrichs and Losinger (1998), Kertz et al. (1998), and Waldo et al. (1989).
2 Adapted from Lawrence and Fowler (1997).
3 Adapted from Penno (1994).
4 Actual live weights and ages recorded during the present experiment.

The weights obtained in the present experiment for H and L heifers closely match those given by Penno (1994) for New Zealand Holstein-Friesian, and as expected they are much lower than those recommended for the European and North American strains. Furthermore, the average daily LWG's required to achieve these target weights, as derived from Table 3.9, are within the range of LWG's attainable by pasture-fed animals (Penno, 1994; Penno and Macdonald, 1996).

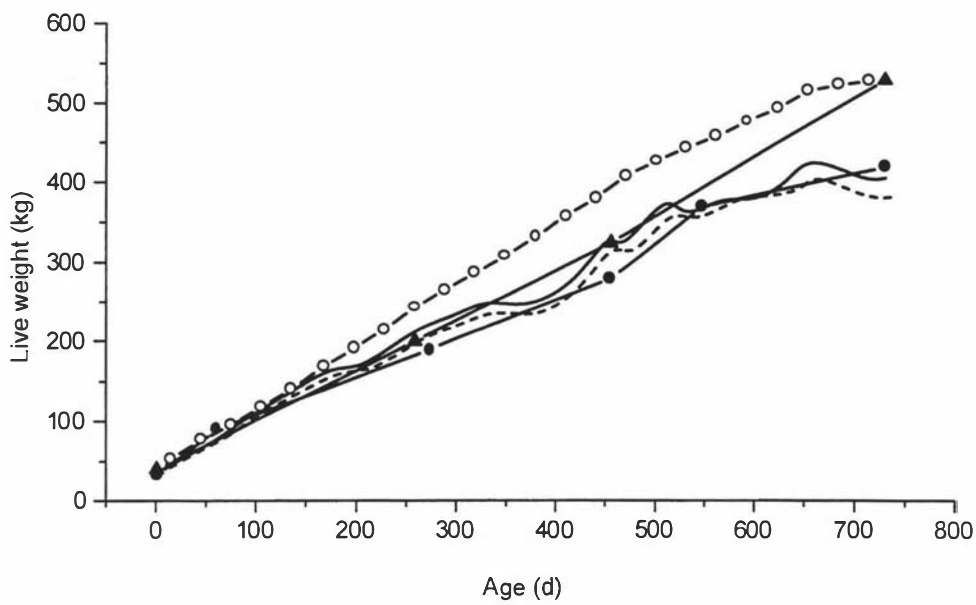

Figure 3.7: Growth pattern from birth to first calving of heifers from different strains of Holstein (—o—o— USA Holstein, Heinrichs and Losinger, 1998; —▲— British Friesian, Lawrence and Fowler, 1997; —●— New Zealand Holstein-Friesian, Penno, 1994; —NZ Holstein-Friesian heavy line; — NZ Holstein-Friesian light line, present experiment).

Conclusions

Heifers from the H line reached puberty at an older age and heavier weight than heifers from the L line. Despite their later puberty, heifers from the heavy line conceived within the 12-weeks breeding season and calved at the same date and similar age and degree of maturity as heifers from the light line. There was no difference between genetic lines in the incidence of calving difficulty either when the heifer was born or when she gave birth to her first calf (i.e. the heifer as a mother). H heifers were significantly heavier at first calving and at maturity than L heifers. Despite their heavier weight, H heifers produced similar amounts of milk and milk components as heifers from the light mature LW selection line.

Implications

Under the conditions of the seasonal system of reproduction in New Zealand, genetically heavier heifers showed a delayed onset of puberty. This has been achieved even though most of the animals from the project are from only the first and second generations of breeding to H sires. Due to the restrictive nature of the seasonal system of reproduction (i.e. grazed pasture with no supplements, short breeding season, competition for grass with other stock), further generations of breeding are likely to produce larger differences in mature LW and in age and LW at puberty. Eventually it is possible that the H heifers may be at a higher risk of not becoming pregnant during the restricted period of natural mating.

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CHAPTER 4

Herbage intake, grazing behaviour, milksolids yield and feed conversion efficiency of lactating cows offered high herbage allowances during early and mid-lactation

Abstract

The purpose of this experiment was to measure the herbage intake, herbage digestibility, yield of milksolids, grazing behaviour and feed conversion efficiency of lactating cows from the heavy (H) and the light (L) mature LW selection lines at Massey University, New Zealand. Forty-two mixed-age cows (21 H and 21L) in early lactation (EXP1) and 60 mixed-age cows (30 H and 30 L) in mid-lactation (EXP2) were fitted with slow release alkane capsules and used during the spring of 1996 in two short-term grazing experiments. Averaged across experiments, cows from the H line were heavier (489 *vs.* 415 kg; s.e.d = 15; $P < 0.001$), had higher body condition scores (4.49 *vs.* 4.35 units; s.e.d = 0.06; $P < 0.05$), produced higher daily milksolids yields (1.85 *vs.* 1.64 kg/day; s.e.d = 0.07; $P < 0.05$) and had slightly broader incisor arcade breadth (8.4 *vs.* 7.9 cm; s.e.d = 0.18; $P < 0.10$) than L cows. The H cows ate more herbage DM (13.7 *vs.* 12.4 kg; s.e.d = 0.49; $P < 0.05$) but selected herbage of lower DM digestibility (69.3 *vs.* 72.0%; s.e.d = 0.58; $P < 0.01$) than the L cows. Cows from the L line showed faster rates of biting (58 *vs.* 52 bites/min; s.e.d = 1.5; $P < 0.001$), shorter rumination times (471 *vs.* 572 min/d; s.e.d. = 11.8; $P < 0.001$), slightly longer grazing times (520 *vs.* 499 min/d; s.e.d = 7.2; $P < 0.10$), a higher number of total bites per day (31053 *vs.* 25046; s.e.d = 825; $P < 0.001$), and lower bite weights (408 *vs.* 528 mg DM/bite; s.e.d = 22.5; $P < 0.01$) than cows from the H line. Despite these differences in LW, herbage intake, milksolids yield and grazing behaviour, H and L cows achieved similar intake rates of herbage DM (H: 26 *vs.* L: 24 g DM/min; s.e.d = 0.97; $P = 0.8$) and similar gross feed conversion efficiencies (H: 135 *vs.* L: 134 g milksolids/kg DM eaten; s.e.d = 1.5; $P = 0.9$). Under the conditions of the present experiment, genetic differences in mature LW were associated with differences in the pattern of grazing behaviour of lactating cows but had no effect on the gross feed conversion efficiency of H and L cows when they were managed on generous herbage allowances.

Introduction

In pasture-based dairying systems herbage intake by the grazing cow is affected by bite size, biting rate and grazing time, and a study of these components of intake can show how variations in sward and animal characteristics influence daily herbage intake by dairy cows at pasture. The effect of sward characteristics on herbage intake and grazing behaviour of sheep and cattle has been amply researched (Forbes, 1988; Forbes and Hodgson, 1985; Hodgson, 1985; Hodgson and Jamieson, 1981; Jamieson and Hodgson, 1979; Laca et al. 1992; Rook et al. 1994; Ungar et al. 1991). The general conclusion drawn from these experiments is that bite size is the major determinant of daily herbage intake and that it is influenced by sward structure (mainly sward height and bulk density) and by pasture quality.

The effect of animal size on herbage intake and grazing behaviour, however, has scarcely been researched. From theoretical calculations, Illius and Gordon (1987) argued that across species, small-sized animals have an advantage over large-sized ones in dealing with short vegetation or more sparse pasture. Results from Allden and Whittaker (1970) with sheep supported this hypothesis with animals differing in weight due to differences in age. More recently, Ferrer Cazcarra et al. (1995) have also demonstrated this advantage with beef cattle differing in weight due to differences in age (i.e. mature cows, heifers and calves of the Charolais breed) and strip-grazed on short (7.5 cm), medium (10.2 cm) or tall (21.1 cm) cocksfoot (*Dactylis glomerata*) swards. In this experiment, herbage intake was limited by sward heights below 8 cm for mature cows and heifers, but not for calves.

Lazo and Soriguer (1993) reported that small- and medium-sized animals (Juveniles, sub-adults and adult females) from a population of Spanish feral cattle were more selective in their diet than larger animals (adult males). Smaller animals changed their behaviour according to the level of food abundance to maintain intakes of preferred food: when food was scarce these animals took a higher number of steps per minute than when food was plentiful. Similarly, Erlinger et al. (1990) showed that beef heifers of heavier mature weight (from the Charolais and Chianina breeds) took larger bites and grazed for longer than heifers of similar age but lighter mature LW (Angus, Hereford and Red Poll).

In all the above mentioned experiments, differences in size (LW) have been obtained by using different species (i.e. sheep and cattle), breeds that differ in mature weight, or animals within the same species differing in age and degree of maturity. Therefore it is not clear if the differences observed in herbage intake and grazing behaviour are a function of size *per se* or any of the other confounding factors.

To what extent genetic differences in mature LW of grazing cows of similar age affect their herbage intake, feed conversion efficiency and pattern of grazing behaviour have not been investigated. The effects of genetic differences in the mature LW of Holstein-Friesian cows at pasture are being studied in an ongoing research programme at Massey University and some results have already been published (García-Muñiz et al. 1998a and 1998b; Laborde et al. 1998a and 1998b). This Chapter reports the results of two experiments carried out during early (EXP1) and mid-lactation (EXP2) which were intended to measure the effect of genetic differences in mature LW on herbage intake, grazing behaviour and feed conversion efficiency of H and L cows when offered high herbage allowances.

Materials and methods

Animals, pastures and experimental design

Animals and management

Lactating Holstein-Friesian cows from the heavy (H) and light (L) mature LW selection lines at Massey University, New Zealand, were used for these experiments. Details of the formation of the lines have been given by García-Muñiz et al. (1998a and 1998b), and are also given in Chapter 1. Average mature LW estimated from growth curve analysis was 516 and 470 kg for the H and L cows respectively (García-Muñiz et al. 1998b; Chapter 8). For the present two experiments, cows from the H and L lines, balanced by age, parity, days in milk and yield of milksolids were used in two short-term grazing trials during early (September-October 1996) and mid lactation (November 1996). During early lactation (EXP1) 21 H and 21 L cows were used, and during mid lactation (EXP2) 30 H and 30 L cows were used. Each trial lasted four weeks, and 38 cows out of the 42 cows used in EXP1 were used again in EXP2. During the grazing trials, the experimental cows were separated from the main herd and rotationally grazed as a single group. In each experiment, H and L cows were offered a generous daily herbage allowance of about 45 to 50 kg DM/cow as assessed by a rising plate meter (Ashgrove Pastoral Products, Palmerston North, New Zealand), calibrated with quadrat cut samples (Earle and McGowan, 1979; Holmes, 1974; Stockdale, 1984). Cows were offered their daily herbage allowance as a new strip of pasture twice a day after each milking.

Pastures

Cows were grazing perennial ryegrass-white clover pastures all year round. In both experiments the group's level of feeding was assessed indirectly by recording 40 pre-grazing and 40 post-grazing readings of compressed sward height with the rising plate meter, and the daily area allocated for grazing. Additionally, during EXP2, fifty pre-grazing and 50 post-grazing sward height readings were recorded daily with the HFRO sward stick (Barthram, 1986) to assess pre-grazing and post-grazing sward height. Daily herbage allowance was calculated from the expression given by Milligan et al. (1987) as:

$$\text{Herbage allowance}\left(\text{kg DM/cow/day}\right) = \frac{\left[\text{Pre}-\text{grazing pasture mass (kg DM/ha)}\right] \text{x Area grazed per 24 hours}}{\text{Number of cows}} \qquad [4.1]$$

Pre-grazing and post-grazing pasture mass (kg DM/ha) were estimated from calibration equations (one for pre- and one for post-grazing herbage mass) in each experiment, relating kg DM/ha to compressed sward height. During the course of the two trials, 60 (EXP1) or 80 (EXP2) pre-grazing and post-grazing compressed sward heights were recorded within quadrat samples (0.3 x 0.3 m) using the rising plate meter (Ashgrove Pastoral Products, Palmerston North, New Zealand) and then cut to ground level. The grass samples were washed and dried at 100 °C for 24 hours, and their dry weight was used to obtain a calibration equation for the raising plate meter (Earle and McGowan, 1979; Holmes, 1974; Stockdale 1984).

Measurements recorded

Live weight, condition score and incisor arcade breadth

Cows were weighed after the morning milking and then body condition scored independently by three scorers during two consecutive days at the beginning, at the end, and weekly during the 4-week experimental period in each trial. Incisor arcade breadth and LW of 38 cows (17 H and 21 L) which had been used in EXP1 or EXP2 were recorded retrospectively in March 1998, after the morning milking. LW was recorded using electronic scales (Tru Test, NZ Ltd), and incisor arcade breadth was measured at the base of the incisors (where they emerged from the jawbone) to the nearest half a millimetre using callipers (Taylor et al. 1987).

Yield of milk and milk components

Cows were milked twice daily at approximately 0.600 and 15.00 h New Zealand time. Milk volume was recorded daily for each individual cow by an automated milking system (Westfalia Limited). In three of the 4 weeks of the experimental period of each trial, aliquots of milk samples were collected from each cow on two consecutive milkings, and the samples were analysed for fat, protein and lactose content using a Milkoscan 104 infrared analyser (Foss Electric, Denmark). The average of the three herd tests for each cow was used to calculate their average daily yield of milksolids during both 5-day sub-periods of intake determination.

Herbage intake

In both experiments, herbage intake of individual cows was assessed using the *n*-alkanes technique (Dove and Mayes, 1991). Cows were fitted with controlled release alkane capsules (CRC; Captec (NZ) LTD, Auckland) with release rates, as given by the manufacturer, of 355 mg/day for both *n*-Dotriacontane (C_{32}) and *n*-Hexatriacontane (C_{36}). Faecal and grass samples were collected for 10 days after a 6-day stabilisation period. Faecal samples (50 g wet weight) were collected on the paddock from cows immediately after defecation, or by sampling from the rectum at the milking parlour during the morning milking. During the 10-day periods of faecal collection, grass samples (150 g wet weight) were plucked manually from within five exclosure cages randomly located in the area to be grazed each day. The five grass samples were pooled within day, sub-sampled and stored at -20 °C until freeze-dried. Faeces were oven (EXP1) or freeze (EXP2) dried and pooled within 5-day sub-periods in each 10-day faeces collection period. The faeces and grass samples were submitted for *n*-alkanes analysis using the analytical procedure described by Mayes et al. (1986), at the Dairying Research Corporation, Hamilton, NZ. Herbage intake was estimated from the concentrations of C_{33} (natural odd-chain) and C_{32} (dosed even-chain) alkanes in the pasture and faeces using the following equation (Dove and Mayes, 1991):

$$\text{Daily dry matter intake (kg/cow)} = \frac{(F_i/F_j) x D_j}{H_i - (F_i/F_j) x H_j} \qquad [4.2]$$

Where,

D_j is the daily dose, or average release rate (mg/day) from the CRC device, of the synthetic even-chain alkane (C_{32});

H_j and F_j are, respectively, the herbage and faecal concentrations (mg/kg DM) of the natural even-chain alkane (C_{32}), and,

H_i and F_i are, respectively, the herbage and faecal concentrations (mg/kg DM) of the natural odd-chain alkane (C_{33}).

Herbage digestibility

Herbage dry matter digestibility (DMD, %) was estimated in two ways: firstly *in vitro* analyses were carried out on the pooled grass samples, and secondly, for individual cows, from the concentrations of *n*-alkanes in herbage and faeces. The pooled grass samples were analysed for nitrogen (N) content by the Kjeldahl technique and for *in vitro* dry matter digestibility (DMD) and digestible organic matter in the dry matter (DOMD) by the method of Roughan and Holland (1977). From these results, the metabolisable energy (ME) content of the pasture (MJ/kg DM) was estimated as 0.16 x DOMD (Geenty and Rattray, 1987).

Herbage DMD for each cow was calculated from the ratio of herbage and faecal concentrations of the natural odd-chain alkane C_{33} using the expression given by Robaina et al. (1993)

$$\text{DMD (\%)} = 1 - \left[\frac{H_i \times (\text{Recovery rate})}{F_i} \right] \qquad [4.3]$$

Where H_i and F_i are as defined in equation [4.2]. The recovery rate was assumed to be 0.8715, the average of recovery rates of 0.86 and 0.883 obtained by Stakelum and Dillon (1990) and Dillon and Stakelum (1989), respectively for C_{33}, with stall-fed Friesian cows fed on fresh cut herbage.

Grazing behaviour

Grazing behaviour was monitored on two separate periods of 24 hours in each experiment, one in each 5-day sub-period of intake determination. Observers were trained prior to the recording of the information, and allocated working shifts of three hours to avoid fatigue. Nocturnal observations were aided by using a spotlight, and by painting the cow's identification number on the flanks and rumps using fluorescent paint. The animals were accustomed to the presence of observers, and only minor disturbances in their pattern of grazing behaviour were expected. During EXP2, grazing, ruminating, and idling times were estimated by recording the grazing activity of individual cows every ten minutes during 24 hours (Hodgson, 1982). During EXP1, only grazing time and biting rate were recorded. Animals were considered to be grazing when their heads were down to the ground, and they were biting, searching or chewing (Ferrer Cazcarra and Petit, 1995). Grazing activities were recorded by letter (Inwood et al. 1992) using the recording sheet given in Appendix 4.1.

During the period of faeces collection, biting rate was measured on two occasions in 12 (EXP1) and 15 (EXP2) randomly selected cows per genetic line. Biting rates were recorded three times per day at peak grazing hours in the morning (8:00-9:00 a.m.), at noon (12:00-13:00 p.m.), and in the afternoon (17:00-18:00 p.m.). Within each two-hour observational period, two consecutive records of biting rate were obtained from each cow by counting the number of bites taken in two minutes (Hodgson, 1982). Biting rates (number of bites/min) for each hour of the day were calculated for each cow from the average of the two consecutive records. A bite was defined by sound and movement of the head when cutting grass, and records were discarded if the animal failed to graze for more than one minute as defined above (Ferrer Cazcarra and Petit, 1995).

Derived variables

Feed conversion efficiency

Feed conversion efficiency was calculated as g of milksolids per kg of herbage dry matter eaten and as g milksolids per MJME eaten.

Bite weight and rate of intake

For each five-day period of intake determination, bite weight (mg DM/bite), and rate of intake (mg DM eaten/minute) were calculated for each cow with available records of biting rate using the following equation (Hodgson, 1982):

$$DMI = GT \times BR \times BS \qquad [4.4]$$

Where DMI is the dry matter intake (kg/cow/day) as assessed by the *n*-alkanes technique; GT is the total grazing time (minutes/day) recorded during the 24-hour grazing behaviour observational periods; BR is the average of the biting rate records taken during the day, and BS is bite size (g DM/bite). From equation [4.4], mean individual bite weight was calculated from DMI divided by the total number of daily bites, estimated as the product of grazing time and biting rate. Intake rate was estimated as daily intake divided by daily grazing time (Hodgson, 1982). Additionally, the number of bites taken per kg of DM or per MJME eaten were calculated from the total number of daily bites, daily herbage DM intake and the calculated herbage dry matter digestibility of individual cows.

Statistical analyses

Data were analysed by least squares analysis of variance using PROC GLM (SAS, 1989). Data for LW, condition score, milksolids yield, and the parameters of grazing behaviour (grazing time, ruminating, time, idling time, biting rate, total bites per day, bite weight and rate of intake) were analysed with a model that included the main effects of experiment, genetic line, cow nested within genetic line, and the interaction genetic line by experiment. Cow was considered a random effect, and differences between genetic lines were tested using the mean square (MS) of cow nested within genetic line as the error term. Ruminating and idling time were recorded only during EXP2, and these variables were analysed with a model that included genetic line and cow nested within genetic line, and differences between genetic lines were tested using the MS of cow nested within genetic line as the error term. Milksolids yield was included as a covariate for the analyses of all the parameters of grazing behaviour.

Incisor arcade breadth (IAB) was related to LW using the allometric equation IAB = $a\text{LW}^b$ (Huxley, 1932), where a and b are parameters to be estimated. Linear regression (both the dependent and the independent variables as natural logarithms) or non-linear regression analyses (both dependent and independent in the original scale) were carried out using PROC REG and PROC NLIN (SAS, 1989), respectively. Additionally, the regression coefficient corresponding to the exponent relating IAB to LW was compared to its expected value of 0.33 (Taylor et al. 1987; Gordon and Illius, 1988) by a *t*-test.

Results

Three cows in EXP1 (all from the L line) and five cows in EXP2 (three from the L and two the H line) yielded very high values (μ+3 standard deviations) of herbage dry matter intake. This might have happened because the slow release capsule was faulty, or was damaged during insertion, since no regurgitated capsules were found during the daily inspection of the grazed areas. The data from these cows for dry matter intake and derived variables were deleted from the respective analyses.

Sward variables

The average sward conditions during EXP1 and EXP2 as well as the results of the *in vitro* analyses of the pasture are summarised in Table 4.1. No statistical analysis was performed on these variables, as they were repeated measures obtained from the two genetic lines managed as a single group. Results are summarised as means and standard deviations for the sward variables and as single values for the grass nutritive value. Figure 4.1 also shows the average sward heights recorded during the course of EXP2.

Table 4.1: Means and standard deviations for pasture variables recorded during EXP1 and EXP2.

Variable	EXP1	EXP2
Herbage mass (kg DM/ha)		
Pre-grazing	2762 ± 283	3239 ± 399
Post-grazing	1717 ± 189	2508 ± 280
Sward height (cm)		
Pre-grazing	-------	18.2 ± 4.1
Post-grazing	-------	11.9 ± 3.4
Daily herbage allowance		
kg DM/cow	43.5 ± 12.1	51.9 ± 13.9
Herbage disappearance rate (kg/cow/day)	17.5 ± 1.9	14.2 ± 3.8
Digestibility (%)		
Dry matter	76.7	71.0
Organic matter	77.3	72.0
Crude protein (%)	20.8	19.2
Ash (%)	11.1	9.5

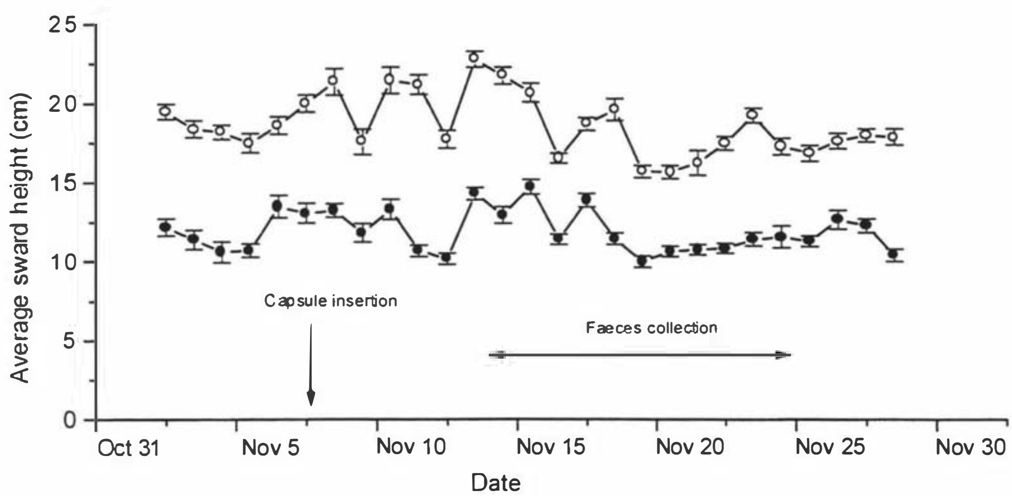

Figure 4.1: Means (±SE) for pre-grazing (–○–) and post-grazing (–●–) sward surface height recorded during EXP2.

Variables measured at the beginning of the experimental periods

By design, there were no differences between the two genetic lines in age, parity, and days in milk at the beginning of the experimental periods, in both EXP1 and EXP2. In EXP1 there were 20 sires represented (10 H and 10 L) and 22 (12 H and 10 L) in EXP2. Cows from the H line used in both experiments were the offspring of sires with significantly higher BV for LW, as planned, but also for milk volume, fat and protein yield. Overall, however, there was no difference in the breeding worth (an estimate of economic feed conversion efficiency) of the sires of H or L cows used in the two experiments (Table 4.2).

Table 4.2: Least squares means for age, lactation number, days in milk, and sire of cow BV's for LW, milk yield, milkfat yield, protein yield and breeding worth of genetically heavy or light Holstein-Friesian cows used in Experiment 1 (21 H- and 21 L-cows) and Experiment 2 (30 H- and 30 L-cows).

	Experiment 1				Experiment 2			
	Heavy	Light	s.e.d[1]	Significance	Heavy	Light	s.e.d[1]	Significance
Age (years)	3.7	3.5	0.48	NS	4.1	3.8	0.38	NS
Lactation number	2.5	2.4	0.48	NS	2.8	2.5	0.37	NS
Days in milk	44.0	47.0	3.7	NS	82.0	88.0	4.3	NS
Sire of cow breeding value for:								
Live weight (kg)	94.2	29.0	4.8	***	94.0	24.5	4.3	***
Milk yield (*l*)	1010.5	691.0	92.4	**	1062.0	649.3	79.4	***
Milkfat yield (kg)	30.0	24.7	1.9	**	31.0	25.4	1.5	**
Milk protein yield (kg)	28.5	19.6	2.0	***	29.6	18.5	1.9	***
Breeding worth ($)	37.0	44.0	5.1	NS	39.0	44.0	4.7	NS

[1] s.e.d = standard error of the difference.

Live weight, condition score and milksolids yield

Cows from the H line were, as expected, heavier (Figure 4.2a), had higher body condition scores (Figure 4.2b) and higher milksolids yields than L cows during the course of the 4-weeks experimental periods (Table 4.3).

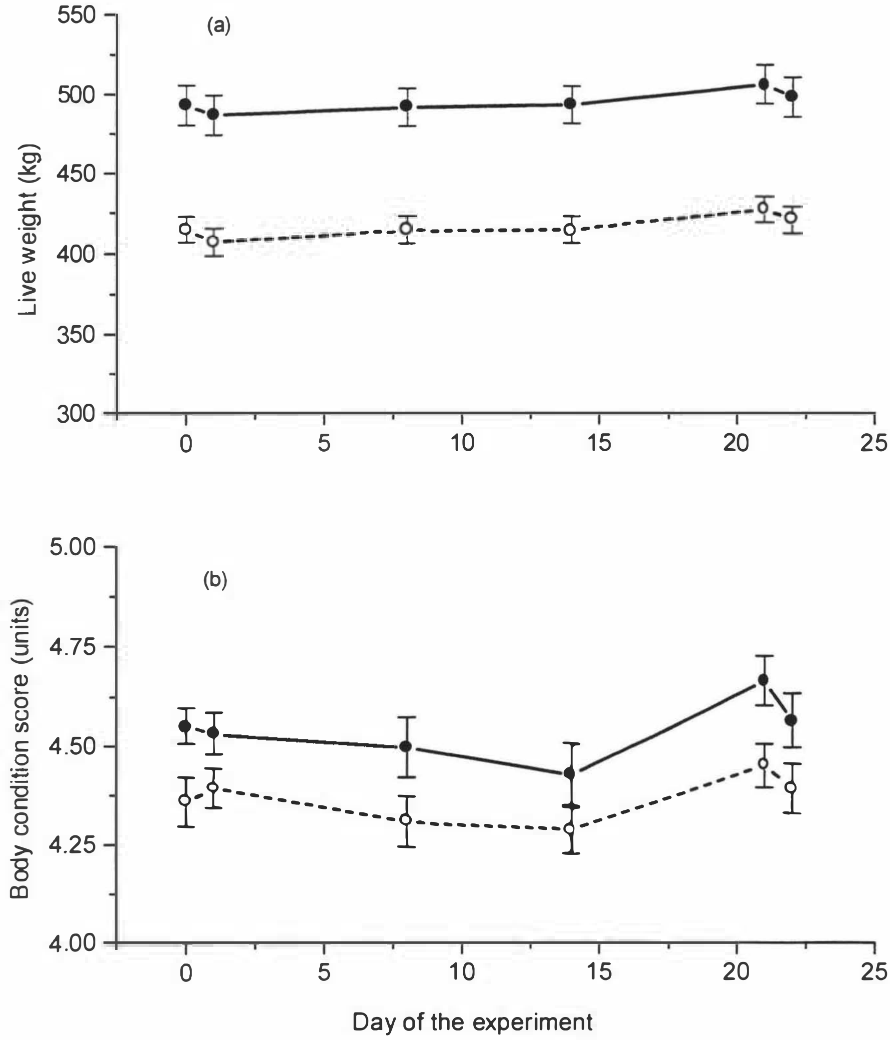

Figure 4.2: Live weight (a) and condition score (b) of genetically heavy (—●—) or light (-- ○--) Holstein-Friesian cows offered generous herbage allowances during early lactation. Means and standard errors calculated for the pooled data on EXP1 and EXP2

Live weight and incisor arcade breadth

Cows from the H line had slightly wider incisor arcade breadth (IAB) than L cows (Table 4.3). Figure 4.3 shows the relationship between $\log_e$ incisor arcade breadth and $\log_e$ LW. Both measurements were recorded on the same date during 1998 and retrospectively to the herbage intake and grazing behaviour records. The resulting pooled regression equation was:

$$\log_e(IAB) = 0.123 + 0.320(\pm 0.081)*\log_e(LW) \quad [4.5]$$

$R^2 = 31\%$; RSD = 0.065; CV = 3.1; n = 37.

When estimated through non-linear regression the corresponding regression equation was:

$$IAB = 1.1(LW)^{0.325(\pm 0.077)} \quad [4.6]$$

The exponent, 0.32, obtained for LW did not differ significantly from 0.33.

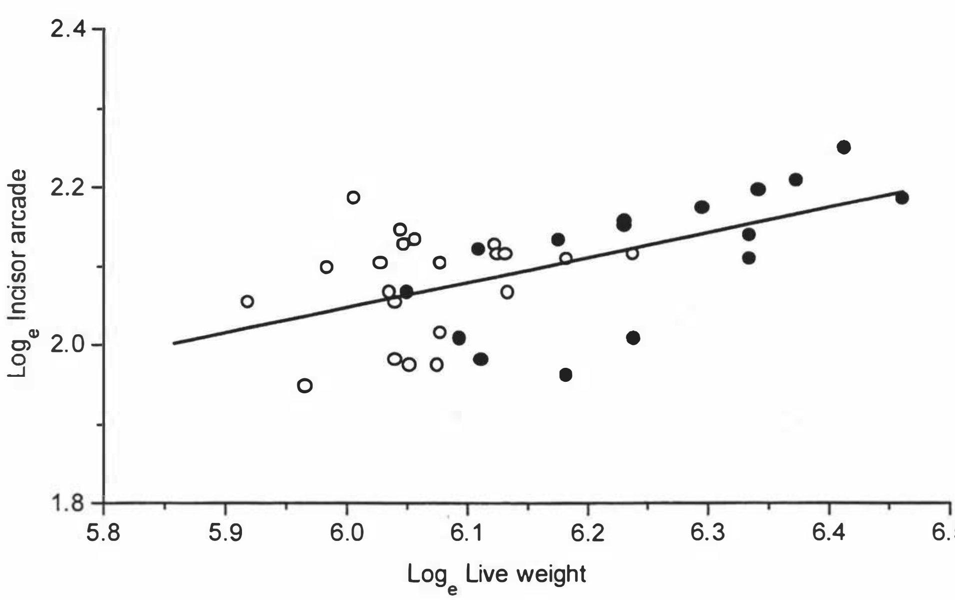

Figure 4.3: Relationship between $\log_e$ incisor arcade breadth and $\log_e$ live weight of genetically heavy (●) or light (○) Holstein-Friesian cows.

Herbage intake and herbage digestibility using *n*-alkanes

In both experiments the daily herbage dry matter intake (DMI) was higher for H than for L cows, in association with their heavier LW and higher milksolids yield. However, after adjusting for differences in milksolids yield, herbage dry matter intake was similar for H and L cows. In addition, daily herbage DMI in EXP2 was about 7% lower than the DMI measured in EXP1. Cows from the L line had higher DMI per kg of LW than H cows, but not different to H cows when scaled by $LW^{0.75}$. Cows from the L line showed calculated digestibility values higher by 3.9% than H cows. Also the calculated herbage DM digestibility was higher in EXP1 than in EXP2 (Table 4.3). The digestibility values obtained from the *n*-alkane data (Table 4.3) are comparable to those obtained for the pooled grass samples by the *in vitro* analyses, which were 76.7% (EXP1) and 71.0% (EXP2).

Feed conversion efficiency

Feed conversion efficiency of H and L cows was not significantly different between H and L cows whether expressed as g of milksolids per kg DM eaten or as g milksolids per MJME eaten (Table 4.3).

Table 4.3: Least squares means for LW, CS, milksolids yield, incisor arcade breadth, daily herbage intake and herbage dry matter digestibility of genetically heavy or light Holstein-Friesian cows.

		Genetic line			
Item	n	Heavy	Light	s.e.d.[1]	Significance[2]
Live weight (kg)	102	489	415	15.0	***
Condition score (units)[3]	100	4.49	4.35	0.06	*
Milksolids yield (kg)	102	1.85	1.64	0.07	**
Incisor arcade breadth (cm)	37	8.4	7.9	0.18	†
Daily herbage dry matter intake					
kg/cow	190	13.7	12.4	0.490	*
g DM/kg LW	190	27.5	30.5	0.795	*
g DM/kg $LW^{0.75}$	190	128.6	137.4	3.407	NS
Herbage DM digestibility (%)[4]	197	69.3	72.0	0.587	**
Feed conversion efficiency					
g milksolids/kg DM eaten	190	135.3	133.6	1.5	NS
g milksolids/MJ ME eaten	190	13.0	12.7	0.4	NS

[1] s.e.d. = Standard error of the difference.
[2] NS = not significant; † $P < 0.1$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.
[3] Scale: 1 = emaciated, 10 = obese (Holmes and Wilson, 1987).
[4] Calculated using Equation [4.3] and the concentration of the C_{33} alkane.

Grazing behaviour

Grazing time, ruminating time and idling time

The distribution of grazing time during the two 24-hour periods of recording is given in Figures 4.4 and 4.5 for EXP1 and EXP2, respectively. In EXP1 about 74% (H cows) and 73% (L cows) of the grazing activity occurred during the 13-hours daylight. Corresponding values for EXP2 (15-hours daylight) were 68% (H cows) and 67% (L cows). The pattern of grazing was very similar in both experiments with distinctive peaks of grazing activity just after the morning and afternoon milkings, and a distinctive large evening grazing bout (meal) especially during EXP1 (Figure 4.4).

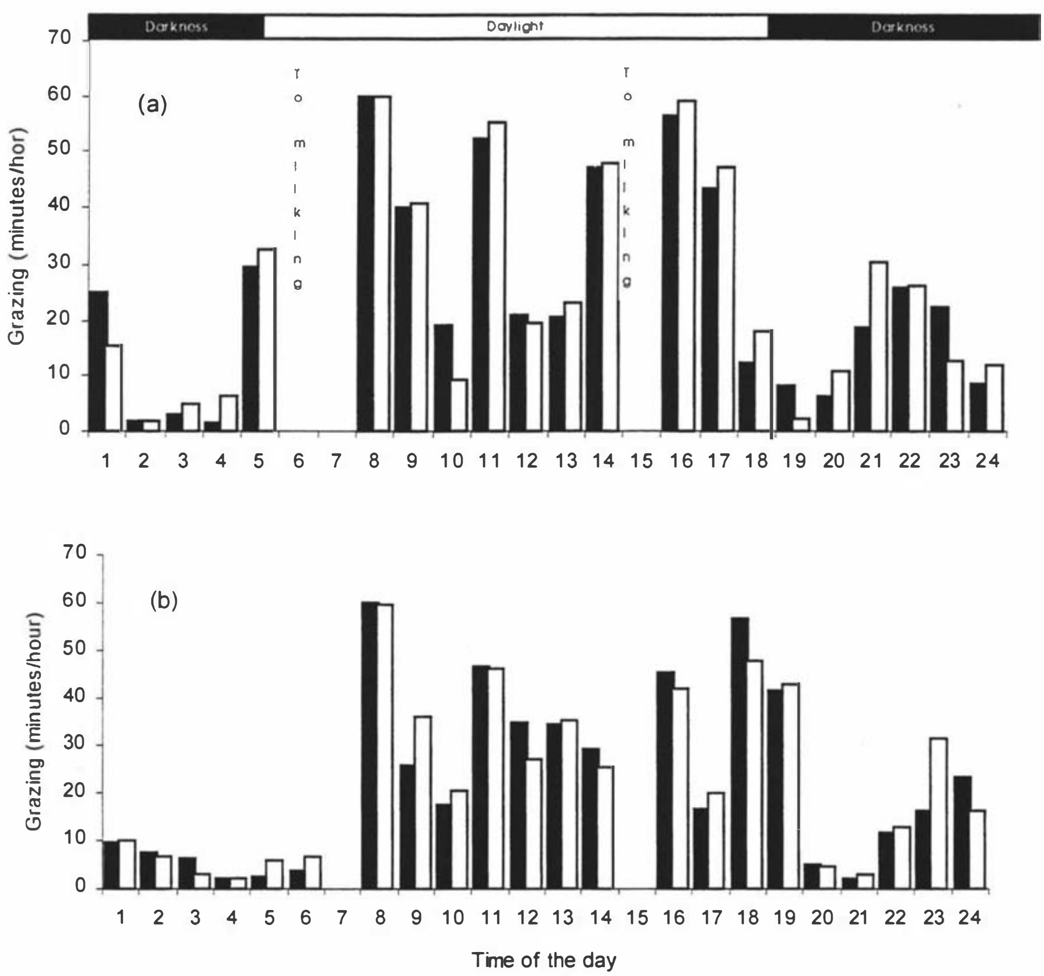

Figure 4.4: Mean time grazing in each hour of day for 1st (a) and 2nd period (b) during Experiment 1 for genetically heavy (■) or light (□) Holstein-Friesian cows

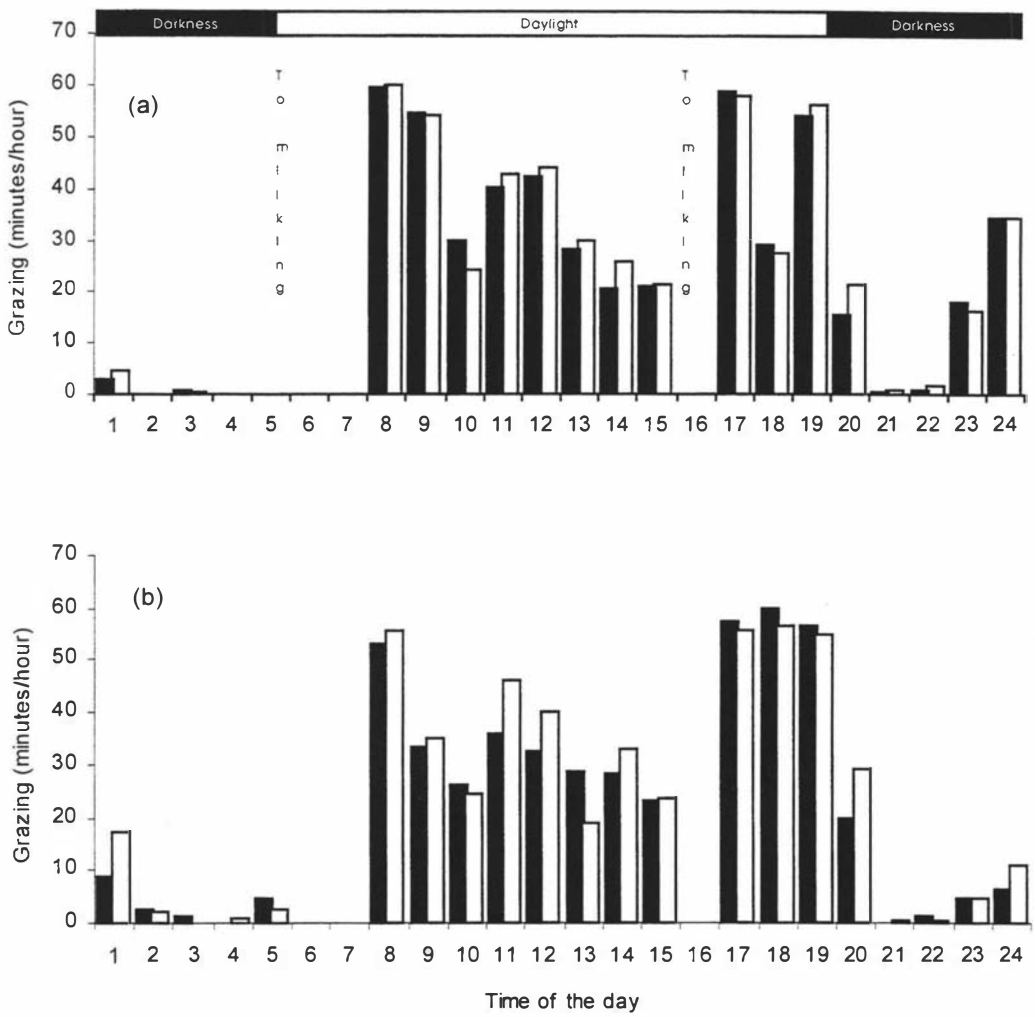

Figure 4.5: Mean time grazing in each hour of day for 1st (a) and 2nd period (b) during Experiment 2 for genetically heavy (■) or light (□) Holstein-Friesian cows

Results from the analysis of the grazing, ruminating and idling times (night, day and total) are given in Table 4.4. The L cows had slightly longer total grazing times than the H cows but the difference only approached significance ($P < 0.10$). In EXP2, the H cows had longer total ruminating times than L cows, and this difference was mainly due to their longer ruminating time during the night than L cows.

Biting rate and total bites

Cows from the L line showed significantly faster rates of biting than H cows, and due to their slightly longer grazing time, they also showed significantly higher number of total bites per day than the H cows. Cows from the L line also took significantly more bites per kg of DM eaten than H cows, but approximately the same number per MJME eaten (Table 4.4).

Bite weight and intake rate

Cows from the H line took significantly heavier bites that L cows, but bite weight per kg of LW or $LW^{0.75}$ was similar for H and L cows. Despite this difference in bite weight in favour of the H cows, H and L cows achieved similar intake rates of herbage dry matter (Table 4.4).

Table 4.4: Least squares means for grazing time, ruminating time, idling time, biting rate, bites per day, number of bites per kg of dry matter or MJME eaten, bite weight and rate of intake of genetically heavy or light Holstein-Friesian cows offered generous herbage allowances during early and mid-lactation.

Item[a]	n	Genetic line: Heavy	Light	s.e.d.[1]	Significance[2]
Grazing time (min./day)					
Day	204	355	364	6.1	NS
Night	204	146	156	6.7	NS
Total	204	499	520	7.2	†
Ruminating time (min./day)[3]					
Day	120	218	194	6.5	†
Night	120	354	277	8.4	***
Total	120	572	471	11.8	***
Idling time (min./day)[3]					
Day	120	57	35	4.6	*
Night	120	128	119	8.3	NS
Total	120	185	154	8.6	NS
Biting rate (bites/min.)	324	52	58	1.5	***
Total bites (bites/day)	104	25046	31053	825.0	***
Number of bites per					
kg of DM eaten	104	2026	2488	98.0	**
MJ ME eaten	102	200	229	14.0	NS
Bite weight					
mg DM/bite	103	528	408	22.50	**
mg DM/kg LW	103	1.07	1.02	0.05	NS
mg DM/kg $LW^{0.75}$	103	5.0	4.6	0.22	NS
Intake rate					
g DM/min.	103	26	24	0.97	NS
mg DM/kg LW/min.	103	53	59	1.78	NS
mg DM/kg $LW^{0.75}$/min.	103	252	265	7.80	NS

[a] Sunrise: 5:46 a.m. for EXP1 and 4:50 a.m. for EXP2; Sunset: 18:26 p.m. for EXP1 and 19:20 p.m. for EXP2.

[1] s.e.d = Standard error of the difference.

[2] NS = not significant; † = $P < 0.1$; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

[3] Recorded only during EXP2.

Discussion

Live weight, milksolids yield, FCE and breeding values of sires

The differences in LW and milksolids yield in favour of the H cows were expected, since they were the offspring of sires with significantly higher breeding value for LW, milk volume, milkfat and milk protein yield. Despite these differences in LW, herbage DM intake and milksolids yield, cows from the H and L lines were expected to be equally efficient since their sires had similar genetic merit for farm profitability (i.e. similar breeding worth). The results from the present short-term grazing experiments suggest that this was indeed the case, since FCE was similar for H and L cows. The higher yields by H cows compensated their higher herbage intakes and allowed them to achieve similar FCE as L cows. Similar results were obtained with growing heifers (Chapter 2) and when FCE was calculated over multiple lactations using LW predicted from individual growth curves and yields per lactation of milk and its components (García-Muñiz et al. 1998b; Chapter 8).

Herbage intake and digestibility

Herbage intake per cow was higher for cows from the H line as would be expected from their heavier LW and higher milksolids production. Similar results were found for phenotypically heavier Holstein-Friesian cows grazing ryegrass/white clover pastures or fed indoors on fresh cut pasture (Holmes et al. 1993), and for heavier Holstein-Friesian cows fed indoors on fresh cut pasture (Stakelum and Connolly, 1987). In the present experiments, however, when dry matter intake was adjusted for differences in milksolids yield, or scaled by $LW^{0.75}$, cows from the H and L lines had similar dry matter intakes.

When compared to the average herbage DM digestibility calculated from the concentration of the C_{33} alkane of individual cows, herbage digestibility calculated by the *in vitro* analyses of the pooled grass samples was only slightly higher for EXP1 (i.e. *in vitro*: 76.7%, alkane C_{33}: 72.3%) and very similar during EXP2 (i.e. *in vitro*: 71.0%, alkane C_{33}: 69%). Herbage DM digestibility calculated from the concentration of the C_{33} alkane in herbage and faeces was higher for cows from the L line, indicating that they were eating pasture that was more digestible. Relative to other plant parts, higher concentrations of the C_{33} alkane have been found in the leaf lamina of perennial ryegrass (Dove et al. 1996), which constitutes the most digestible part of the plant. Direct observations of grazing behaviour during the recording of biting rate indicated that cows from the L line appeared to graze closer to the top of the sward.

The significantly shorter ruminating time (see discussion below on grazing behaviour) of L cows may also indicate that they were eating more digestible herbage that required less processing time, perhaps because of lower fibre content (Phillips and Leaver, 1986) or smaller particle size (McGilloway and Mayne, 1996) or both. Grazing selectivity decreases with increased animal size when sheep and cattle have been used to provide the differences in body size (Forbes and Hodgson, 1985; Hodgson et al. 1991). Selectivity of larger cattle also decreased when beef and dairy cattle of different ages and degrees of maturity have been used to achieve differences in body size (Ferrer Cazcarra and Petit, 1995; Ferrer Cazcarra et al. 1995; Hodgson and Jamieson, 1981; Zoby and Holmes, 1983). The higher digestibility of extrusa collections, the higher faecal nitrogen concentration or the higher concentration of the C_{33} alkane for smaller or younger cattle in these experiments has been taken as evidence of higher digestibility due to higher selectivity of their diets while grazing. Hodgson and Jamieson (1981) found higher herbage digestibility of extrusa collected from fistulated calves than that of adult cattle (lactating cows and steers) when strip-grazed on perennial ryegrass (*Lolium perenne*) swards ranging in herbage mass from 2580 kg DM/ha to 5000 kg DM/ha, and *in vitro* OM digestibility from 60% to 70%.

Hodgson (1977) suggested that differences in digestibility between different animal classes might simply reflect the existence of digestibility gradients within the swards rather than the deliberate exercise of choice by the grazing animal between different components of the sward. Thus cattle feeding predominantly on the upper layer of the sward (i.e. shallow grazers) because of limitations due to the shape and size of their buccal apparatus are expected to harvest more digestible herbage on each bite taken. Clutton-Brock and Harvey (1983) suggested that the size of the mouth is likely to determine the degree of selectivity the grazing animal can exercise over the plant material that it consumes.

Illius and Gordon (1987) have shown that the breadth of the incisor arcade is an important determinant of the rate of food intake in grazing ruminants, and that its relationship with body weight is isometric, scaling with an exponent of about 0.33.

Gordon and Illius (1988) suggest that such a relationship between LW and incisor arcade breadth implies that larger-sized animals are less able to be selective while foraging than are smaller ones. In the present study incisor arcade breadth was slightly wider for H than for L cows, and scaled with $LW^{0.325}$, an exponent not significantly different from the expected value of 0.33 (Taylor et al. 1987).

The results from the present experiments suggest that for H and L cows managed as a single group and rotationally grazed at high herbage allowances, there may not be a 'purposeful' diet selection by the grazing cow. Instead, it is likely that the differences in incisor arcade breadth between the H and L cows enabled them to graze either less deeply and cover less area (for the L cows) or more deeply into the sward and cover more area with each bite (for the H cows) thereby enabling them to take smaller, more digestible bites or larger and less digestible bites, respectively.

Grazing behaviour

In association with their wider incisor arcade breadth, cows from the H line took larger bites than L cows. The relatively high herbage allowances, the presentation of fresh herbage as a new strip of pasture twice a day, and the high pre- and post-grazing sward heights during these experiments allowed large bites to be taken and hence the differences between genotypes in bite weight to be observed. Larger bite sizes have been observed for contemporary beef heifers from breeds with larger mature weight or slower maturation rate (Erlinger et al. 1990) and for dairy cattle (Zoby and Holmes, 1983) and beef cattle (Ferrer Cazcarra and Petit, 1995) differing in size due to differences in age. In the present experiments cows were of similar age and were at a similar degree of maturity in body weight. Thus the lower bite weights of the L line cows probably were a direct reflection of their smaller mouths.

The diurnal pattern of grazing behaviour was very similar for cows from the H and L lines during the two recording days in each experiment. About 73% and 68% of the grazing activity took place during daylight for EXP1 and EXP2, respectively, with distinctive peaks of grazing activity just after the morning and afternoon milkings, and a large evening grazing bout, especially in EXP1. Rook et al. (1994) suggested that the occurrence of greater grazing activity during the morning and afternoon could be a short-term fasting effect following milking. They have also shown that dairy cows exhibit a nycterohemeral pattern of grazing behaviour with more grazing occurring during darkness as daylength declines. Thus the shorter daylength during EXP1 (13 *vs.* 15 hours) may have been responsible for the large evening bout observed on cows from both genetic lines. Mean daily grazing times of L cows were slightly longer than those of H cows (8.67 *vs.* 8.31 hours) and this difference was reinforced by L cows having more grazing activity at night than H cows. These grazing times are typical of fully fed spring calving Holstein-Friesian cows and daylight hours at this time of the year, and fell within the range of other estimates reported in the literature (Gibb et al. 1997; Hodgson and Jamieson, 1981; Phillips and Denne, 1988; Phillips and Leaver, 1986; Rook and Huckle, 1997).

Cows from the L line also showed significantly faster rates of biting, higher total number of daily bites and therefore required more bites per kg of DM eaten than H cows. Faster rates of biting and less mastication and rumination have been observed for lactating dairy cows grazing perennial ryegrass (*Lolium perenne*) white clover (*Trifolium repens*) swards, when they are forced to graze down to a sward surface height of 4 cm compared to 8 cm (Rook et al. 1994). This increase in biting rate is regarded as a compensatory mechanism triggered by a lower bite weight, and displayed in order to maintain total daily intake when sward conditions, especially height (Phillips, 1993), or mouth size, i.e. a narrower incisor arcade breadth, (Illius and Gordon, 1987) become limiting. Hodgson (1986) argues that variations in biting rate are better thought of as a direct response of the grazing animal to variations in sward conditions, rather than as an attempt to compensate for reduction in intake per bite. In the present experiments, the grazing conditions ensured both a high pre-grazing (18.2 ± 4.1 cm) and a high post-grazing (12.0 ± 3.4 cm) (mean ± SD) sward height and an easily prehended pasture presented as a new strip of fresh pasture in the morning and in the afternoon. These management conditions were such that it was unlikely to create sward conditions that would limit intake per bite and therefore trigger an increase in biting rate, grazing time and hence total number of bites (McGilloway and Mayne, 1996). Therefore, the data suggests that lighter mature LW lactating Holstein-Friesian cows have a higher biting rate possibly because of their smaller mouths, their mainly New Zealand ancestry (Chapter 1), or both.

Rook and Huckle (1996) have suggested that differences in grazing behaviour between animals may be an evolutionary adaptation to the seasonal availability of food under natural conditions. Similarly, Simm et al. (1996) have suggested that differences in grazing behaviour between and within breeds may indicate that breeds or individuals within breeds are better adapted to more extensive systems of production. Cows from the L line used in the present two experiments were the descendants from sires with mainly New Zealand ancestry in their pedigrees. Contrary to this, sires contributing to the formation of the H line had a higher proportion of USA Holstein genetics in their ancestry (Chapter 1). New Zealand dairy sires are nationally progeny tested across-breeds in commercial herds which are managed on a seasonal system of milk production based almost entirely on grazed pasture (Livestock Improvement, 1997). Thus, their daughters might be expected to display a more competitive pattern of grazing behaviour like the one displayed by cows from the L line in the present experiments.

Conclusions

Cows from the H line ate more herbage DM and produced more milksolids than L cows. There were differences in the pattern of grazing behaviour of cows from the two genetic lines. Cows from the L line showed faster rates of biting, higher number of total bites, longer grazing times and shorter rumination times than H cows. Despite the differences in milksolids yield, grazing behaviour and herbage intake cows from the H and L lines achieved similar rates of herbage intake and similar feed conversion efficiency under the conditions of the present experiments.

Implications

Genetically heavier or lighter Holstein-Friesian cows achieved similar rates of herbage intake and similar feed conversion efficiency when they were presented with abundant and easily prehended pasture. However, with grazing management practices aimed at harvesting as much as possible of the grass grown on the farm, it is likely that genetically heavier cows with their larger mouths will be less able to harvest shorter herbage compared to genetically lighter cows with smaller mouths. Therefore, these differences in grazing behaviour may be an advantage for the L cows when faced with less favourable grazing conditions, such as those experienced at high stocking rates with little or no use of supplementary feeds.

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CHAPTER 5

Herbage intake, yield of milksolids and feed conversion efficiency of cows grazed at high or low herbage allowances during mid-lactation

Abstract

The purpose of this experiment was to measure herbage intake, milk yield and feed conversion efficiency (FCE) of Holstein-Friesian cows from the heavy (H) and the light (L) mature live weight (LW) selection lines at Massey University, New Zealand, when offered generous (G) or restricted (R) herbage allowances during mid-lactation. The experiment was designed to test for the existence of an interaction between genetic line and herbage allowance. Thirty cows from each genetic line were used in the short-term grazing experiment during mid-lactation. Fifteen cows from each line were allocated to either a high (60 kg DM $cow^{-1}day^{-1}$) or a low (30 kg DM $cow^{-1}day^{-1}$) herbage allowance during three weeks in a 2 x 2 factorial design. Faecal output from individual cows, measured by controlled release chromium capsules, *in vitro* digestibility of grass samples and yields of milk and milk components were used to measure individual herbage DM (OM) intake and FCE. There were no significant interactions between genetic line and herbage allowance for any of the variables analysed. Across genetic lines, cows on the generous herbage allowance achieved higher body condition scores at the end of the experimental period (4.63 *vs.* 4.45; $P < 0.001$) and produced more milksolids (1.60 *vs.* 1.44 kg/cow/d; $P < 0.01$) than cows on the restricted herbage allowance. Averaged across herbage allowance treatments, H cows were heavier (500 *vs.* 421 kg; s.e.d = 14.7; $P < 0.001$), had higher body condition scores (4.60 *vs.* 4.45 units; s.e.d = 0.068; $P < 0.05$), and produced higher daily yields of milksolids (1.6 *vs.* 1.45 kg; s.e.d = 0.064; $P < 0.001$) than the L cows. Cows from the H line ate more herbage DM than L cows, whether herbage intake was expressed as kg DM per cow per day (19.8 *vs.* 16.2; s.e.d = 0.68; $P < 0.001$) or as g DM per kg of $LW^{0.75}$ per day (190.2 *vs.* 173.6; s.e.d = 5.4; $P < 0.01$). Despite the higher yields by H cows, the FCE of herbage DM into milksolids was higher for the L cows (91.0 *vs.* 81.8 g/kg DM; s.e.d = 3.0; $P < 0.01$). Under the conditions of the present experiment, Holstein-Friesian cows of lighter mature LW were more efficient converters of herbage into milksolids than heavier mature LW Holstein-Friesian cows. The implications of these results are discussed in relation to the genetic evaluation system of dairy animals in New Zealand.

Introduction

The genetic evaluation system of dairy animals in New Zealand ranks animals for breeding according to an index of farm profitability, known as breeding worth. The index represents the expected net income per unit of feed (i.e. 4.5 tonnes of dry matter) an animal is expected to generate through breeding replacements that are efficient converters of feed into profit (Harris, 1998). The index is made up of the breeding values (BV) for milk volume (*l*), milkfat (kg), milk protein (kg), LW (kg), and survival (%). Both milk volume and LW receive negative relative economic values in the index. For milk volume this is done mainly to account for its effects on the extra costs of transportation and processing of milk with more water. The negative economic value on LW is to account for the disadvantage of the extra dietary energy requirements for maintenance and growth being larger than the benefits from selling heavier culled animals (Dempfle, 1986; Spelman and Garrick, 1997; Visscher et al. 1994).

Under feedlot conditions, higher yields of milksolids per cow have shown to cause increases in gross feed conversion efficiency but often at the expense of body tissue mobilisation (Gordon et al. 1995; Korver, 1988). Additionally, selection for higher milk yield has also produced heavier cows (Lin et al. 1985; Mahoney et al. 1986), and body weight is negatively correlated with feed conversion efficiency of cows managed under feedlot conditions (Lee et al. 1992; Persaud et al. 1991; Sieber et al. 1988). However, experimental information on the effect of cow body size on the feed conversion efficiency of grazing dairy cows is scarce, and no data have been published comparing the milk production efficiency of genetically lighter or genetically heavier Holstein-Friesian cows under grazing conditions.

To fully document and justify the assumptions underlying the inclusion of cow live weight in the selection index of New Zealand dairy cattle, a project was set up at Massey University to generate two lines of high genetic merit Holstein-Friesian cows differing in mature live weight (see Chapter 1 for details). The results on lifetime live weight, yield, and estimated feed requirements, indicate that the H cows are heavier all the way through from birth to maturity, they produced more milk and milk components and had higher estimated total feed requirements than the L cows (Chapter 8). Under the New Zealand pasture-based dairying system, the combination of high mature live weight and high yield of milksolids may present some challenges to both the cows that must harvest their own food and herd managers that aim at fully feeding them, while at the same time harvesting as much grass grown on the farm as possible through the grazing cow. With the present difference in mature live weight and yield of milk solids between the H and L cows (e.g. Chapter 8) the possibility of the existence of a genotype by level of feeding interaction could be explored. Oldham et al. (1996) suggest that with present day genotypes there are sound reasons to expect genotype by nutrition interaction, especially in systems that emphasise the use of forage. Similarly, Mayne (1998) suggests that in dairying systems where grazed pasture is the main source of feed, high genetic merit cows may not be able to eat enough of a high forage diet to 'fuel' their potential extra yield. Thus, the objectives of the present experiment were to measure herbage intake and feed conversion efficiency of Holstein-Friesian cows from the heavy and the light mature LW selection lines when offered generous or restricted herbage allowances during mid-lactation. The design of the experiment enabled the possible existence of a genotype by level of feeding interaction to be tested.

Materials and methods

Animals, experimental design and grazing management

Animals

Sixty lactating Holstein-Friesian cows (16 primiparous and 44 multiparous) from the heavy (H) and the light (L) mature LW selection lines at the Dairy Cattle Research Unit, Massey University, New Zealand, were used in a 3-weeks grazing experiment. Thirty cows from each genetic line balanced by age, parity and calving date were used from 1st to 21st December 1996 to measure herbage intake and feed conversion efficiency when offered high or low herbage allowances. Some of these cows had been used in two previous experiments (See Chapter 4) to measure herbage intake, feed conversion efficiency and grazing behaviour parameters when offered high herbage allowances. The H cows were the offspring of 12 bulls whereas 10 bulls sired the L cows. Table 5.1 summarises the information about the H and L cows and their sires used in the present experiment. Although an effort was made to balance the cows in each treatment group before the start of the experiment, H cows were producing higher yields of milk and milk components than L cows, which in fact reflected the higher BV's for milk, milkfat and protein of the H sires. However, sires-of-cows from the H line had lower Breeding Worth than sires-of-cows from the L line (Table 5.1).

Experimental design

Fifteen cows from both genetic lines were randomly allocated to a high (nominally 60 kg DM/cow/day) or to a low (nominally 30 kg DM/cow/day) herbage allowance for three weeks in a 2 x 2 factorial design. The final actual daily herbage allowance for both genetic lines on the high allowance treatment was calculated to give 13 kg DM/100 kg LW, which was equivalent to 64 and 54 kg DM/cow/d for the H and L lines, respectively. The corresponding figure for the low allowance treatment was 8 kg DM/100 kg LW to both genetic lines, which was equivalent to 39 and 33 kg DM/cow/d for the H and L lines, respectively (Table 5.3).

Table 5.1: Means and standard deviations (in parenthesis) for breeding values of sires of H and L cows and variables recorded in cows from the heavy and the light mature live weight selection lines when offered high or low herbage allowances during mid-lactation

		Genetic line			
		Heavy		Light	
Item	Units	High allowance	Low allowance	High allowance	Low allowance
Information on cows					
Number of cows	n	15	15	15	15
Parity	n	3.0 (1.4)	2.7 (1.4)	2.6 (1.6)	2.3 (1.4)
Live weight	kg	502.0 (68)	502.0 (73)	422.0 (36)	417.4 (45)
Condition score[1]	units	4.74 (0.3)	4.48 (0.4)	4.34 (0.4)	4.40 (0.2)
Days in milk	n	102.0 (22)	109.0 (17)	106.0 (20)	114.0 (7.0)
Milk yield	*l*/d	21.4 (3.0)	21.0 (4.4)	18.5 (2.4)	17.8 (3.4)
Milksolids yield	kg/d	1.63 (0.3)	1.58 (0.3)	1.52 (0.3)	1.36 (0.2)
Fat content	g/kg	44.0 (5.8)	43.9 (6.1)	48.6 (8.5)	44.3 (5.5)
Protein content	g/kg	32.4 (3.6)	32.2 (3.4)	34.1 (3.3)	32.4 (2.2)
Breeding values of sires					
Milk	*l*	1102.3 (294)	1021.3 (285)	666.0 (327)	667.0 (313)
Milkfat	kg	30.9 (3.4)	31.4 (5.8)	26.0 (7.0)	25.4 (6.9)
Milk protein	kg	29.9 (9.3)	29.3 (7.8)	19.0 (5.8)	18.6 (6.0)
Fat percentage	%	4.32 (0.3)	4.41 (0.3)	4.68 (0.4)	4.66 (0.4)
Protein percentage	%	3.46 (0.1)	3.50 (0.1)	3.60 (0.2)	3.54 (0.2)
Live weight	kg	93.6 (16)	94.5 (13)	24.0 (19)	26.0 (18)
Survival	%	0.08 (1.5)	-0.18 (1.2)	0.36 (1.3)	0.16 (1.4)
Breeding worth	$	38.8 (25)	39.7 (25)	45.3 (8.0)	42.7 (9.1)

[1]Scale: 1 = emaciated, 10 = obese (Holmes and Wilson, 1987)

Grazing management

Cows from each treatment group were rotationally grazed and provided with a new strip of pasture every day. Cows from the four treatment groups grazed as four separate groups in the same paddock or adjacent paddocks and the allowance treatments were achieved by reducing or increasing the area of pasture allocated using temporary electric fences.

Daily area of pasture allocated

The daily area of pasture allocated to each treatment group was calculated by triangulating the rectangular strips of pasture grazed by the cows. Whenever possible, square or rectangular breaks of pasture were allocated to the cows. Rectangles were divided into triangles, and their areas were calculated using the following formula (Spencer, 1977):

$$\text{Area}_i = \sqrt{S_i(S_i - A_i)(S_i - B_i)(S_i - C_i)} \qquad [5.1]$$

Where:

$$S_i = \frac{(A_i + B_i + C_i)}{2}$$

Area_i = area (m^2) of the i^{th} triangle, and

A_i, B_i, and C_i are each side of the i^{th} triangle.

Sward measurements

Herbage mass, compressed grass height and herbage allowance

One hundred and twenty pre-grazing and 120 post-grazing, grass quadrat samples (0.3 x 0.3 m) were cut to ground level during the course of the experimental period. Before cutting, compressed sward height was recorded within each quadrat using a rising plate meter (Ashgrove plate meter, Ashgrove Pastoral Products, Palmerston North, New Zealand). The grass samples were washed and dried at 100 °C for 24 hours, and their dry matter content was used to obtain a calibration equation for the raising plate meter (Earle and McGowan, 1979; Holmes, 1974; Stockdale, 1984).

On the area allocated to each treatment group, thirty pre-grazing and 30 post-grazing compressed sward height readings were recorded every day using the rising plate meter. These pre-grazing and post-grazing plate meter readings were used in conjunction with the corresponding calibration equation for the plate meter to estimate pre-grazing and post-grazing herbage mass (kg DM/ha) and consequently herbage allowance (kg DM/cow/day) for each treatment group.

Grass height and frequency of grazing

Forty pre-grazing and forty post-grazing sward height readings were recorded daily in the areas allocated to each treatment group using the HFRO (Hill Farming Research Organisation) sward stick (Barthram, 1986). In the present experiment, the HFRO sward stick was fitted with a circle of wire, 15 cm in diameter, with readings taken every five paces following a "W" pattern. At each reading point the sward within the wire circle was scored as frequently (where more than 50% of the grass had been defoliated) or infrequently grazed (Gibb and Ridout, 1988).

Chemical composition of grass samples

Each day during the period of faeces collection, two exclosure cages per break were randomly located within the area to be grazed by each treatment group. Hand plucked samples (one from within each exclosure cage and sampled at a residual sward height similar to that outside the cage) were collected for each day, pooled within day and treatment group, sub-sampled, and stored at -20 °C until freeze-dried. Dried grass samples were pooled within treatment group, ground and analysed for nitrogen (N) content by the Kjeldahl technique and for *in vitro* dry matter digestibility (DMD) and digestible organic matter in the dry matter (DOMD) by the method of Roughan and Holland (1977). Metabolisable energy concentration of the pasture (MJ/kg DM) was estimated from the results of the *in vitro* digestibility of the pooled grass samples as 0.16 x DOMD (Geenty and Rattray 1987). The average values for the laboratory analyses of grass samples are summarised in Table 5.2.

Table 5.2: Characteristics of the swards (measured on samples taken from exclosure cages) used with genetically heavy or light cows offered high or low herbage allowances during mid-lactation (means ± SE)

	Genetic line			
	Heavy		Light	
Item	High allowance	Low allowance	High allowance	Low allowance
In vitro digestibility (%)				
DMD[1]	81.7 ± 2.5	79.4 ± 2.0	78.2 ± 1.08	77.6 ± 1.77
OMD[2]	82.1 ± 2.7	79.7 ± 2.2	78.5 ± 1.05	77.9 ± 1.70
DOMD[3]	72.6 ± 2.6	70.5 ± 2.1	69.3 ± 0.64	68.9 ± 0.97
Nitrogen content (%)	3.7 ± 0.07	3.4 ± 0.24	3.6 ± 0.38	3.0 ± 0.08
Crude protein content (%)	23.0 ± 0.04	21.5 ± 1.5	22.3 ± 2.40	18.8 ± 0.52
ME (MJ/kg DM)[4]	11.4 ± 0.14	11.3 ± 0.34	11.2 ± 0.02	11.0 ± 0.15
Ash (%)	10.4 ± 0.38	10.5 ± 0.37	10.6 ± 0.42	10.4 ± 0.80

[1]DMD = Dry matter digestibility.
[2]OMD = Organic matter digestibility.
[3]DMOD = Digestible organic matter in the dry matter.
[4]ME = 0.16 x DOMD (Geenty and Rattray, 1987).

Animal measurements

Live weight and condition score

Cows were weighed after the morning milking and body condition scored independently by three observers using a 10-point scale, where 1 represented an emaciated cow and 10 an obese cow (Holmes and Wilson, 1987). The average for CS from the three observers was used in further analyses. LW and CS were recorded during two consecutive days at the beginning, two consecutive days at the end and weekly during the 3-week experimental period. Changes in live weight and condition score by individual cows during the experimental period were calculated as the difference between the average of the first two and the last two consecutive records for LW or CS divided by the number of days.

Milk yield and composition

Cows were milked twice a day starting at 5.30 h in the morning and at 14.30 h in the afternoon. Samples of milk to determine milk composition of individual cows were collected during two consecutive milkings in the morning and in the afternoon each week. The milk samples were analysed for fat, protein and lactose content using a Milkoscan 133B (Foss Electric, Denmark). Milk volume was recorded daily for each individual cow by an automated milking system (Westfalia separator). For each herd test date, daily yield of 4% fat corrected milk (FCM), milkfat, milk protein, lactose, and milksolids (fat plus protein) were calculated from the milk volume and composition data. Milksolids yield was calculated as the sum of the yields of fat plus protein, and 4% FCM was calculated using the following formula (Gaines and Davidson, 1923):

$$\text{FCM (kg)} = \text{milk yield (kg)} * (0.4 + 0.15 * \text{fat\%}) \qquad [5.2]$$

Faecal output and herbage intake

Herbage intake by individual cows was estimated from faecal output (FO) data derived using chromium oxide (Cr_2O_3) as the indigestible marker. On 2nd December each cow was fitted with an intra-ruminal Controlled Release Chromium Capsule (CRC, 4.06 cm core, 65% Cr_2O_3, average release rate 640.4 mg of Cr_2O_3/day, multi-orifice end plate, Captec (NZ) Ltd, Auckland, New Zealand) to assess individual cow daily FO. Capsules were individually numbered using a sharp heated screwdriver and this number was recorded along with the cow's identification number at the time of capsule insertion. A modified flexible drenching applicator was used to put the capsules on the distal part of the tongue; capsules were generally swallowed immediately. After capsule insertion, the cows were kept on concrete yards and observed for one hour to detect capsule regurgitation. No capsules were regurgitated.

Faeces collection (200 g wet weight) did not begin until six days after CRC insertion, to allow the Cr_2O_3 to reach stable concentrations in faeces, and then continued for 10 days. Faecal samples were collected on the paddock from cows observed defecating or at the milking shed during the morning milking. Individual cow samples were pooled within each 5-day sub-period of the 10-day period of faeces collection; oven dried at

100 °C for 48 hours and analysed for chromium concentration by atomic absorption spectrophotometry as described by Parker et al. (1989). See also Chapter 2 for details.

Derived variables

Feed conversion efficiency

The estimated herbage intake and the measured yield of milk and milk composition were used to derive indicators of feed conversion efficiency. Feed conversion efficiency was calculated as kg of milk or grams of milksolids per kg of DM or OM eaten. There were two records of feed conversion efficiency for each cow, one for each 5-day sub-period of faecal collection.

Daily stocking rate

The number of cows and the area allocated in each daily break of pasture were used to calculate the daily stocking rate for each treatment group

Statistical analyses

Frequency of grazing

Frequency of grazing, as assessed by the sward stick readings, was compared separately for allowance treatment and for genetic line using a chi-square test using PROC FREQ (SAS, 1989).

Daily yield of milk, live weight, condition score, herbage intake and feed conversion efficiency

Daily yield of milk, the weekly records of LW and condition score, and the herbage intake and feed conversion efficiency measures (i.e. repeated measures) were analysed using PROC MIXED (SAS, 1996). The following univariate mixed linear model was fitted to test for the fixed effects of genetic line, herbage allowance, day of the experiment (or period of intake determination for herbage intake and FCE) and their interactions:

$$Y_{ijkl} = \mu + L_i + A_j + C_{ijk} + T_l + LA_{ij} + LT_{il} + AT_{jl} + bX_{ijkl} + e_{ijkl} \qquad [5.3]$$

Where:

Y_{ijkl} = observation on day l from animal k offered herbage allowance j from genetic line i;

μ = general mean,

L_i = fixed effect of genetic line i, $i = 1, 2$;

A_j = fixed effect of herbage allowance j, $j = 1, 2$;

C_{ijk} = random effect of cow k from genetic line i offered herbage allowance j, $k = 1, 60$;

T_l = fixed effect of day (or period) l of the experiment, $l = 1, 2$;

LA_{ij} = fixed interaction effect of genetic line i and herbage allowance j;

LT_{il} = fixed interaction effect of genetic line i and day l;

AT_{jl} = fixed interaction effect of herbage allowance j and day l;

X_{ijkl} = number of days since calving at the beginning of the experiment for observation of day l from cow k, on genetic line i and herbage allowance j,

b = regression of Y on days since calving at the beginning of the experiment;

e_{ijk} = error term.

An approach suggested by Littell et al. (1998) was followed to model the covariance structure of the data and to obtain the final model using the REPEATED and SUBJECT options in PROC MIXED (SAS, 1996). Results are given as least square means and the standard error of the difference between means for the contrasts H *vs.* L for genetic lines and the contrast high *vs.* low for herbage allowance. Least squares means were separated using Scheffe's multiple comparison test available in PROC MIXED (SAS, 1996).

Herbage mass, sward height, herbage allowance and stocking rate

Pre-grazing and post-grazing herbage mass calculated from the cut quadrats, the pre- and post-grazing sward height recorded with the HFRO sward stick (Barthram, 1986), the derived daily herbage allowance, the daily area offered to each treatment group and the derived stocking rate were analysed by fitting the following fixed effects linear model using GLM (SAS, 1989):

$$Y_{ijk} = \mu + P_i + L_j + A_k + LA_{jk} + e_{ijk} \qquad [5.4]$$

Where Y_{ijk} is any of the response variables being analysed (herbage mass, sward height, herbage allowance or stocking rate), P_i is the effect of the *ith* paddock used during the experimental period (i = 1, 15), and L_j, A_k, LA_{jk} and e_{ijk} are as defined for equation [5.3].

Results

There were no significant interactions between genetic line and herbage allowance for any of the variables analysed. The reasons for this could have been the short period of time for which the H and L cows were subjected to the herbage allowance treatments. Therefore in the following section only main effects are presented in the corresponding tables.

Area allocated and stocking density

The daily herbage allowances were allocated in such a way as to offer cows of the two lines similar allowances per kg LW. Therefore, cows from the H line were offered daily 16% more area of pasture per cow per day (142.0 m^2 *vs.* 121.4 m^2; $P < 0.05$), with a lower daily stocking rate (80.5 *vs.* 94.7 cows $ha^{-1}day^{-1}$; $P < 0.01$). As expected, the area offered daily to cows on the high herbage allowance was about twice the area allocated to cows on the restricted herbage allowance. Consequently, cows on the lower herbage allowance were grazed at a higher daily stocking rate than cows on the higher herbage allowance (expressed either as cows/ha, kg LW/ha or kg $LW^{0.75}$/ha) (Table 5.3).

Herbage mass, herbage allowance and sward height

There were no differences between genetic lines in pre-grazing or post-grazing herbage mass or sward height. Similarly, pre-grazing herbage mass or pre-grazing sward height did not differ between herbage allowance treatments. However, as was expected from the treatments applied, post-grazing herbage mass was significantly lower and post-grazing sward height was significantly shorter for the low herbage allowance treatment. Herbage allowance did not differ between the two lines of cows whether expressed as kg DM/cow/day, kg DM/100 kg LW/ day or as g DM/kg $LW^{0.75}$. As expected, the effect of herbage allowance treatment was highly significant for all the variables, except for pre-grazing herbage mass and sward height (Table 5.3).

Table 5.3: Least squares means for pasture variables recorded during the experimental period for heavy and light Holstein-Friesian cows offered a high or a low herbage allowance during mid-lactation

	Genetic line				Herbage allowance			
Variable	Heavy	Light	s.e.d[1]	*P*	High	Low	s.e.d[1]	*P*
Area per cow, m^2/day	142.0	121.4	9.5	< 0.05	169.0	94.3	9.5	< 0.0001
Stocking density								
Cows/ha/day, number	80.5	94.7	4.7	< 0.01	63.4	112.0	4.7	< 0.0001
Live weight/ha/day, kg	39446.0	39083.0	2073.5	NS	28890.0	49639.0	2073.5	< 0.0001
$LW^{0.75}$/ha/day, kg	2767.0	2750.0	111.5	NS	2205.0	3312.3	111.5	< 0.0001
Herbage mass, kg/DM/ha								
Pre-grazing	3542.4	3577.0	83.1	NS	3558.5	3561.0	83.1	NS
Post-grazing	2726.0	2719.0	72.0	NS	2878.0	2567.0	72.0	< 0.0001
Sward height, cm								
Pre-grazing	20.0	19.6	0.57	NS	20.4	19.3	0.57	NS
Post-grazing	9.7	9.5	0.16	NS	11.0	8.0	0.16	< 0.0001
Herbage allowance								
kg DM/cow/day	50.0	43.5	3.4	NS	60.0	33.5	3.4	< 0.0001
kg DM/100 kg LW/day	10.3	10.4	0.76	NS	13.1	7.5	0.76	< 0.0001
g DM/kg $LW^{0.75}$	99.0	112.0	8.0	NS	133.2	77.6	8.0	< 0.0001

[1] s.e.d = standard error of the difference.

Figure 5.1 summarises the average pre-grazing and post-grazing sward heights recorded during the experimental period. Daily means (± SE) are indicated along with the dates of CRC's insertion and periods of faeces collection. Pre-grazing sward heights were higher for the second period of faeces collection for the cows offered the high herbage allowance treatment (Figure 5.1a). The post-grazing sward heights were as expected, with cows offered the higher allowance leaving higher residuals than the cows on the restricted herbage allowance treatment (Figure 5.1b).

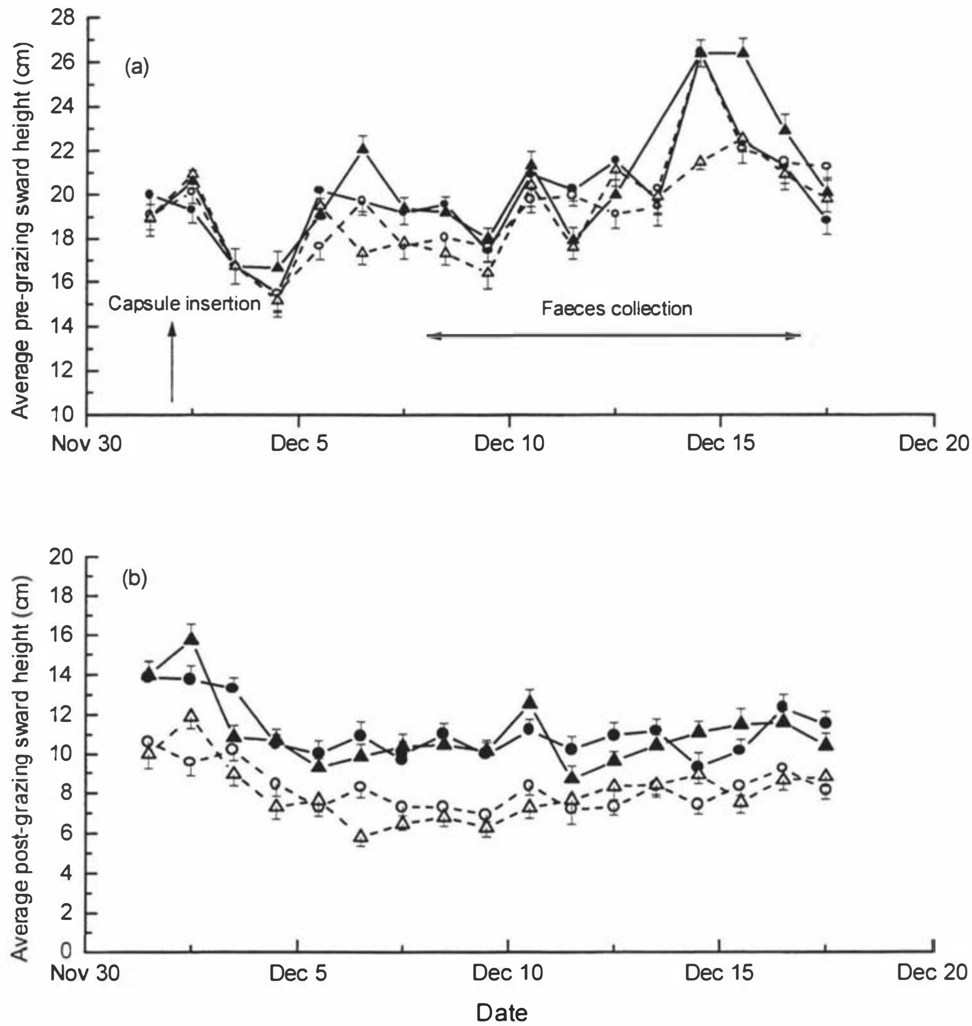

Figure 5.0: Average pre-grazing (a) and post-grazing (b) sward height of pastures grazed by genetically heavy or light Holstein-Friesian cows offered a high (Heavy cows: —●—; Light cows: —▲—) or a low herbage allowance (Heavy cows: —O—; Light cows:—Δ—).

Efficiency of grazing

As expected, there was a significant effect (χ^2 = 80.5; P < 0.001) of herbage allowance treatment on the proportion of frequently or infrequently grazed areas of pasture. Averaged over genetic lines, the proportion of reading points rated as frequently grazed was 66.2% and 83.2% for the high and the low herbage allowance treatments, respectively. There was, however, no difference for this parameter between genetic lines. Pooled over herbage allowance treatments the proportion of frequently (H: 74.5% *vs.* L: 72.5%) and infrequently (H: 25.5% *vs.* L: 27.5%) grazed areas were very similar for both genetic lines (Table 5.2). Frequency distributions for post-grazing sward heights by treatment group for frequently and infrequently grazed areas are depicted in Figure 5.2, and their corresponding means and standard deviations are given in Table 5.4.

Table 5.4: Frequency of grazing and average sward height as assessed with the HFRO sward stick for heavy or light Holstein-Friesian cows offered high or low herbage allowances during mid-lactation

		Percentage of reading points with the sward stick rated as being grazed:		Sward height (mean ± SD) for areas of pasture grazed:	
Genetic line	Herbage allowance	Frequently	Infrequently	Frequently	Infrequently
Heavy	High	67.1	32.9	9.2 ± 2.6	15.0 ± 3.9
	Low	84.7	15.3	7.5 ± 2.1	12.6 ± 2.8
Light	High	65.3	34.7	8.9 ± 2.7	14.7 ± 3.4
	Low	81.7	18.3	7.0 ± 2.3	12.4 ± 3.4

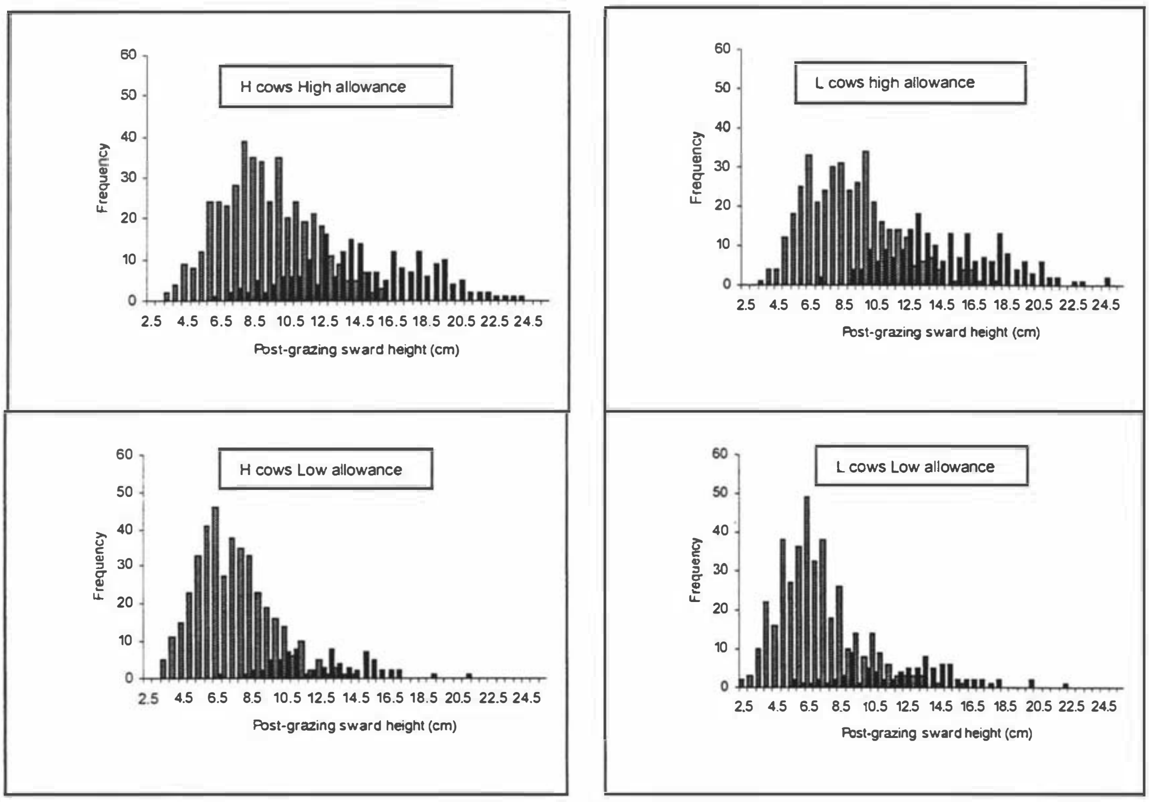

Figure 5.2: Frequency distributions for post-grazing sward height of frequently grazed (hatched bars) and infrequently grazed (filled bars) areas of pasture by genetically heavy or light Holstein-Friesian cows offered a high or a low herbage allowance.

Herbage intake

Data for herbage intake of three cows (2 L and 1 H) were discarded because of very low chromium contents in faeces. This could have been due to capsule damage since no regurgitated capsules were found during the daily inspections of the areas grazed. Cows from the heavy line ate more herbage DM (OM) than L cows, whether herbage intake was expressed as kg of DM (OM) per cow per day or as g DM (OM) per kg of $LW^{0.75}$ per day (Table 5.5).

Table 5.5: Least squares means for intake of daily herbage dry matter (DM) or organic matter (OM) expressed per cow or per kg $LW^{0.75}$ for genetically heavy or light Holstein-Friesian cows offered high or low herbage allowances during mid-lactation.

	Genetic line				Herbage allowance			
Variable	Heavy	Light	s.e.d[1]	Significance[2]	High	Low	s.e.d[1]	Significance[2]
Daily herbage DM intake								
kg/cow	19.0	15.9	0.68	***	19.2	15.9	0.66	***
g DM/kg $LW^{0.75}$	183.2	171.8	5.2	*	191.5	163.4	5.0	*
Daily herbage OM intake								
kg/cow	17.9	14.9	0.63	***	17.8	14.8	0.61	***
g DM/kg $LW^{0.75}$	170.6	160.2	4.6	*	178.0	153.0	4.4	***

[1] s.e.d =standard error of the difference.

Daily yield of milk and composition

Cows from the H line had higher daily yields of milk and milk components than L cows. Cows on the high herbage allowance had higher ($P < 0.05$) yields of 4% FCM, milkfat and milk protein than the cows on the low herbage allowance. The interaction between genetic line and herbage allowance was not significant for any of the yield or composition variables analysed (Table 5.6). For milk yield, however, there were significant interactions between time and herbage allowance ($P < 0.01$) and between time and genetic line ($P < 0.001$) (Figure 5.3).

Table 5.6: Least squares means for daily yield and composition of milk for genetically heavy or light Holstein-Friesian cows offered high or low herbage allowances during mid-lactation.

Variable	Genetic line: Heavy	Light	s.e.d[1]	Significance[2]	Herbage allowance: High	Low	s.e.d[1]	Significance[2]
Yield (kg/day)								
Milk[3]	20.6	17.6	0.751	***	19.9	18.5	0.763	NS
4% FCM[4]	22.0	19.8	0.850	**	22.0	20.0	0.864	*
Milkfat[4]	0.918	0.840	0.036	*	0.922	0.836	0.034	*
Milk Protein[4]	0.678	0.613	0.026	**	0.684	0.607	0.027	***
Lactose[4]	1.03	0.875	0.038	***	0.988	0.917	0.039	NS
Milksolids[4]	1.60	1.45	0.064	*	1.60	1.44	0.065	**
Composition (g/kg)								
Milkfat[4]	44.3	47.0	1.40	NS	45.8	45.5	1.42	NS
Milk Protein[4]	32.7	34.1	0.674	*	34.0	32.8	0.683	NS
Lactose[4]	49.6	48.7	0.444	NS	49.0	49.3	0.450	NS

[1] s.e.d =standard error of the difference.
[2] NS = not significant; * = P < 0.05; ** = P < 0.01; *** = P < 0.001.
[3] Lest squares means calculated from the daily yields recorded during the 21-days experimental period.
[4] Lest squares means calculated from the three herd tests carried out during the 21-days experimental period.

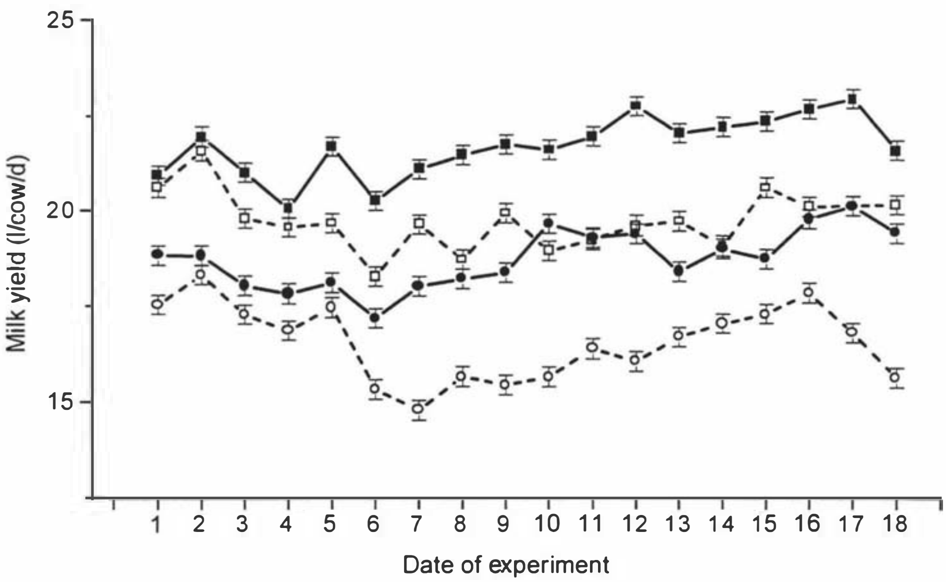

Figure 5.3: Daily milk yield (kg/cow/day) of genetically heavy or light Holstein-Friesian cows offered a high (heavy cows: —■—; Light cows: —●—) or low (heavy cows: ---□--- Light cows: ---○---) herbage allowances during mid-lactation.

Live weight and body condition score

As expected, cows from the H line were significantly heavier in LW than L cows at each weighing time and throughout the course of the experiment (Figure 5.4). On average, cows from the heavy line were 79 kg heavier than cows from the L line (500 kg *vs.* 421 kg; P < 0.001). Similarly, heavy cows had higher body condition scores than

L cows during the experimental period (4.60 units *vs.* 4.45 units; P < 0.05) (Figure 5.5). Herbage allowance had no effect on average LW, but it had a significant effect on body condition score, since cows on the generous herbage allowance had higher average body condition scores than those on the restricted treatment (4.61 units *vs.* 4.44 units; P < 0.05). The interaction between genetic line and herbage allowance was not significant for either LW or body condition score. However, there were significant interactions between genetic line and day of the experiment and between herbage allowance and day of the experiment for body condition score (Figure 5.5). For LW the only significant interaction was that between herbage allowance and day of the experiment.

Least squares means for initial and final LW and CS, and for changes in LW and CS (the difference between the average of the first two consecutive LW or CS records and the last two consecutive LW or CS records) are also given in Table 5.7. Cows from the L line gained only slightly more LW (P < 0.10) but gained significantly more CS than H cows, and, as expected, cows on the low herbage allowance treatment lost significantly more LW and gained less CS than those on the high herbage allowance treatment. There were no significant interactions between genetic line and herbage allowance for changes in LW or CS (Table 5.7).

Table 5.7: Least squares means for live weight, body condition score, and for changes in live weight and body condition score of genetically heavy or light Holstein-Friesian cows offered high or low herbage allowances during mid-lactation

	Genetic line				Herbage allowance			
Variable	Heavy	Light	s.e.d[1]	*P*	High	Low	s.e.d[1]	*P*
Live weight (kg)								
Average[2]	499.7	420.7	14.7	< 0.0001	462.3	458.2	14.9	NS
Initial	502.0	419.5	10.3	< 0.0001	462.0	459.7	10.3	NS
Final	501.8	424.8	10.4	< 0.0001	469.2	457.4	10.4	NS
Gain[3]	-0.217	5.3	2.78	< 0.10	7.33	-2.28	2.78	NS
Body condition score (units)[4]								
Average[2]	4.60	4.45	0.068	< 0.05	4.61	4.44	0.069	< 0.05
Initial	4.61	4.38	0.053	< 0.0001	4.54	4.44	0.053	NS
Final	4.57	4.51	0.050	NS	4.63	4.45	0.050	< 0.001
Gain[5]	-0.043	0.139	0.028	< 0.0001	0.087	0.009	0.028	< 0.01

[1] s.e.d =standard error of the difference.

[2] Average of all the records calculated using model equation [5.3].

[3] Kilograms gained (or lost) during 18 days.

[4] 1= emaciated, 10 = obese.

[5] Units gained (or lost) during 18 days.

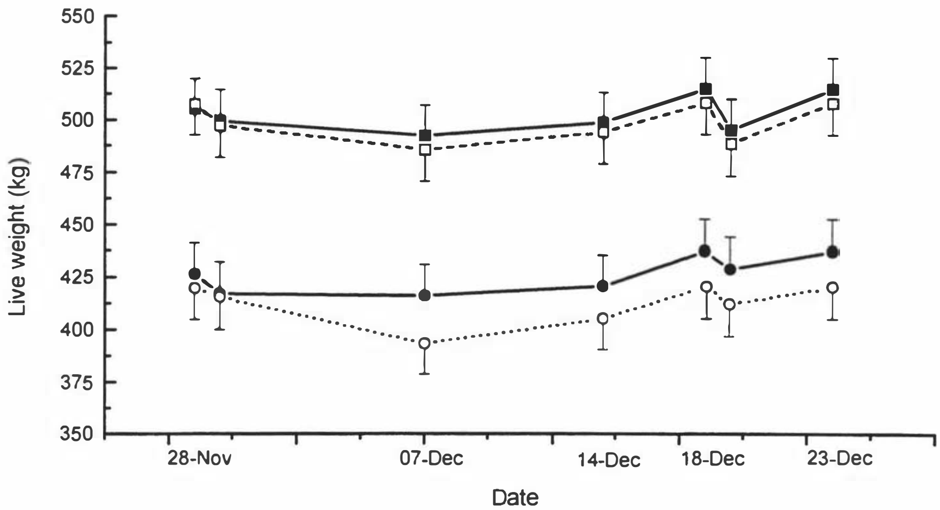

Figure 5.4: Live weight at each recording date during the experimental period for genetically heavy or light Holstein-Friesian cows offered a high (heavy cows: —■—; Light cows: —●—) or a low (heavy cows: ---□---Light cows: ---○--) herbage allowance during mid-lactation.

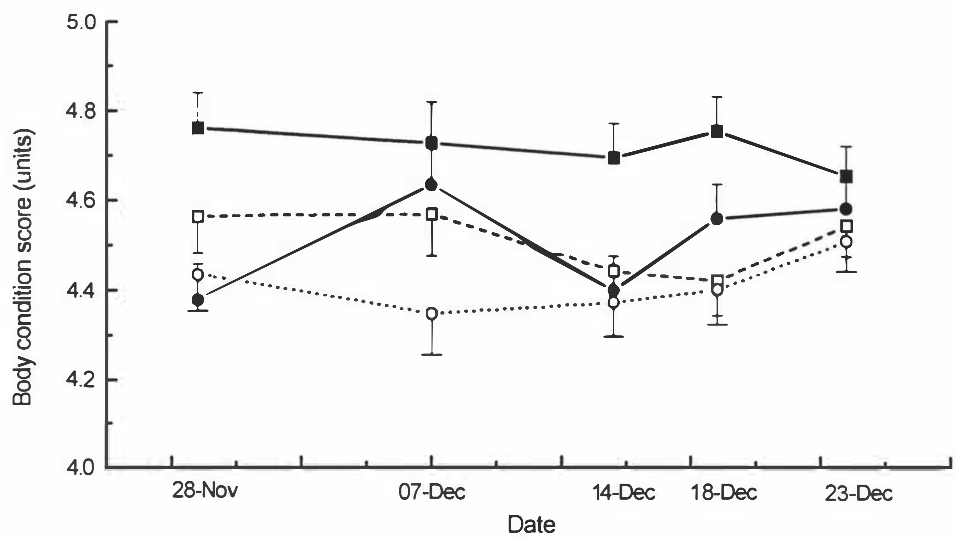

Figure 5.5: Body condition score at each recording date during the experimental period for genetically heavy or light Holstein-Friesian cows offered a high (heavy cows: —■—; Light cows: —●—) or a low (heavy cows: ---□--- Light cows: ---○--) herbage allowance.

Feed conversion efficiency

H and L cows were equally efficient at converting herbage DM (OM) into milk. However, L cows were more efficient at converting DM (OM) into milksolids than H cows. There were no significant differences between the high and the low herbage allowance nor was the interaction between genetic line and herbage allowance significant for any of the feed conversion efficiency variables derived (Table 5.8).

Table 5.8: Least squares means for efficiency parameters for genetically heavy or light Holstein-Friesian cows offered high or low herbage allowances during mid-lactation.

	Genetic line				Herbage allowance			
Variable	Heavy	Light	s.e.d	P	High	Low	s.e.d	P
Milk								
kg/kg DM	1.08	1.12	0.038	NS	1.08	1.11	0.038	NS
kg/kg OM	1.16	1.20	0.040	NS	1.16	1.20	0.040	NS
Milksolids								
g/kg DM	81.8	91.0	3.09	< 0.01	85.9	86.8	3.08	NS
g/kg OM	87.6	97.3	3.28	< 0.01	92.2	92.7	3.27	NS

Discussion

The present experiment was designed to measure the herbage intake, yield of milk and milk components and the feed conversion efficiency of cows from the H and L lines when they were offered high or low herbage allowances during mid-lactation. The aim of the experiment was also to test for an interaction between the effects of genetic line and herbage allowance. The results of the present experiment indicated no significant interactions between genetic line and herbage allowance for any of the variables analysed. Therefore, only the main effects of genetic line and herbage allowance are discussed in the following section.

It is recognised that the short duration of the present experiment (three weeks) probably reduced the chances of detecting a possible genotype by environment interaction. It may also be the case that the differences between the H and L lines for mature live weight and milk yield are not as great as it would be needed to cause the H cows to have measurably greater difficulty in meeting their higher requirements of ME from a restricted herbage allowance.

The average difference in live weight for the H and L cows used in the present experiment was 82.0 kg (i.e. 502 *vs.* 420 kg), and the H cows were producing only 3 kg milk per day more than the L cows (i.e. 21.2 *vs.* 18.0 kg/d). Thus, using standard feed requirements (AFRC, 1993), and assuming zero liveweight change, the H cows would have had an extra requirement of approximately 22 MJME/d or about 2 kg herbage DM/d, for the pasture grazed during the experimental period. With these differences in feed requirements, it was hypothesised that the H cows would be at a disadvantage compared to L cows when both are offered restricted herbage allowances.

The results from the present experiment indicate that the H cows counteracted the restriction by mobilising more live weight and CS than the L cows. This 'buffering' capacity of the dairy cow has been observed in other studies comparing high and low genetic merit cows on a high and low input feeding system (Veerkamp and Emmans, 1995; Veerkamp et al. 1994). The use of these reserves during the lactation might buffer high genetic merit animals against nutritional adversity and so diminish interactions in the short-term (Veerkamp et al. 1994).

Oldham et al. (1996) suggested that the high rates of genetic gain achieved for dairy cattle populations around the world have begun to outstrip the capacity of cows to eat sufficient nutrients and to remain in good health on all feeding systems that are used in practice. Thus, with present day genotypes there are sound reasons to expect genotype by nutrition interaction, especially in systems that emphasise the use of forage. In dairying systems where grazed pasture is the main source of feed, high genetic merit cows may not be able to eat enough of a high forage diet to 'fuel' their potential extra yield (Mayne, 1998). Recent evidence from experiments with high yielding (> 44 kg milk/d; 603 kg LW) USA Holstein cows have shown that those fed solely on grazed pasture achieved intakes of herbage dry matter that were only 80% of those achieved by the cows fed a total mixed ration (TMR) (i.e. 19.0 *vs.* 23.4 kg DM/d). Milk yield of the pasture-fed cows was only 67% of the yield by the cows on the TMR (i.e. 29.6 *vs.* 44.1 kg/cow/d), and they lost more live weight (562 *vs.* 597 kg) and body condition score (2.0 *vs.* 2.5) than the cows on the TMR treatment (Kolver et al. 1998).

In the present experiment differences between genotypes for feed requirements have been created by differences in mature live weight, and an associated difference in yield of milk and milk components of cows from the H and L lines. The fact that the H and L cows were subjected to the two herbage allowance treatments for a short period of time might have prevented the observation of a genetic line by herbage allowance interaction. Alternatively, it may be the case that the differences between the H and L cows used in the present experiment are not sufficiently large to produce a genotype by environment interaction.

Effects of herbage allowance

The purpose of the experiment was to provide cows from the two genetic lines with contrasting levels of feeding given by the low and the high herbage allowance treatments. The generous herbage allowance aimed to fully feed the H and L cows, whereas the restricted herbage allowance was designed to provide the cows with 70% of the intake achieved by the cows on the generous herbage allowance. Grazing dairy cows achieve maximum herbage intake when they are offered 10-12% of their body weight (Hodgson, 1990) or when they have access to about 50% more herbage than they are eating (Greenhalgh, 1966).

In New Zealand studies with Jersey x Friesian cows grazing ryegrass/white clover pastures in early lactation (Glassey et al. 1980), and in early, mid- and late lactation (Bryant, 1980), maximum herbage intakes were achieved at herbage allowances of 50 to 54 kg OM/cow/day or about 13 to 15% of body weight. In the present experiment cows on the generous herbage allowance were offered 60 kg herbage DM/cow/d, which was equivalent to 13% of live weight or about 133 g DM/kg $LW^{0.75}$.

The measured herbage intake by cows on the high herbage allowance treatment was 19.2 kg DM/day, which was less than a 35% of the 60 kg that was offered, and therefore can be presumed to be close to maximum intake. In contrast, the cows on the restricted herbage allowance were offered only 33.5 kg herbage DM or 7.5% of their body weight, and they achieved daily herbage intakes of 16.0 kg DM/cow or about 83% of the intake of the cows on the generous herbage allowance treatment. Thus, even though cows on the restricted herbage allowance were offered only half the allowance offered to the fully fed cows, the level of feed intake restriction originally planned (x 0.7) was not achieved. Nevertheless, the difference in herbage allowance, and the resultant restriction in herbage intake was sufficient to affect the residual herbage mass post-grazing, the post-grazing sward height and the efficiency of grazing assessed by the proportion of frequently or infrequently grazed areas of pasture.

The effect of the reduced herbage allowance was to significantly reduce the daily yield of FCM, milkfat, milk protein and milksolids but not the yield of milk or lactose, and it had no effect on milk composition. As expected, cows on the higher herbage allowance achieved higher daily live weight gains and higher body condition score changes during the 3-weeks experimental period, although the difference for live weight was not significant. In general, the effects of the difference in herbage allowance were as expected from previous studies with New Zealand dairy cattle (Bryant, 1980; Glassey et al. 1980).

Effects of genetic line

In the present study, cows from the H line were the offspring of sires with higher BV's for live weight and yield of milk, fat and protein, and in fact they were heavier, ate more herbage dry matter, and produced significantly more milk and milk components than L cows.

Cows from the H line were on average 18% heavier than the L cows, with a difference of about 80 kg LW, which is similar to the 70 kg difference in mature live weight predicted from the BV's for LW of their sires (e.g. Table 5.1). These differences are larger than those in other experiments reported in this thesis (e.g. Chapter 8) because the more extreme cows for LW from each genetic line were selected to form the experimental groups in the present experiment.

The daily intake of ME calculated from the measured herbage intake derived from the FO data, the milk energy output, and the corresponding theoretically calculated ME requirements for maintenance, lactation and liveweight change are summarised in Table 5.9. In the present experiment cows from the H line achieved higher intakes of ME than the L cows even after scaling by $LW^{0.75}$. Cows from the H line produced more milk energy per day than L cows, but similar milk energy output per kg of metabolic weight.

Because of their heavier LW, cows from the H line were calculated to have higher maintenance requirements than L cows. Cows from the H line lost more live weight than the L cows (although this difference was not significant) and because of the higher body tissue mobilisation by the H cows, the calculated total dietary ME requirement was similar for H and L cows. The calculated ME intakes derived from the FO data were higher than the theoretical requirements for these cows, according to the feeding requirements of AFRC (1993), with the difference being larger for the H cows (+ 28%)

than for the L cows (+ 7%) (Table 5.9). This apparent discrepancy must be kept in mind when assessing the differences in efficiency between the lines.

Table 5.9: Least squares means for ME intake by heavy and light Holstein-Friesian cows either theoretically required (calculated from AFRC, 1993) or measured from faecal output data, when grazing high or low herbage allowances during mid-lactation[1]

	Genetic line				Herbage allowance			
Variable	Heavy	Light	s.e.d[2]	*P*	High	Low	s.e.d[2]	*P*
Calculated								
Milk energy[4]								
MJ/d	67.6	60.7	2.42	**	68.0	60.5	2.45	**
MJ/kg $LW^{0.75}$/day	0.64	0.65	0.017	NS	0.68	0.61	0.018	***
ME for milk production[5]								
MJ/d	111.4	100.9	4.0	**	112.0	100.3	4.1	**
ME for maintenance[6]								
MJ/d	61.3	54.5	1.36	***	58.0	57.8	1.38	NS
ME for LW change[7]								
MJ/d	-0.96	9.4	6.7	NS	11.2	-2.8	6.8	*
Total ME intake								
MJ/d	171.6	164.7	8.2	NS	181.0	155.4	8.3	**
Efficiency								
Milk energy (MJ/d)/Total MEI (MJ/d)	0.40	0.38	0.02	NS	0.38	0.40	0.02	NS
Measured								
Total ME intake[3]								
MJ/cow/day	219.2	177.0	7.68	***	217.5	178.5	7.42	***
MJ/kg $LW^{0.75}$/day	2.2	2.0	0.06	*	2.26	1.92	0.06	***
Efficiency								
Milk energy (MJ/d)/Total MEI (MJ/d)	0.30	0.35	0.01	**	0.32	0.33	0.01	NS

[1] Milk yield and milk composition were taken from Table 5.5; Live weight and liveweight gain taken from Table 5.7; Herbage DM intake (taken from Table 5.5).

[2] s.e.d = Standard error of the difference.

[3] Calculated from faecal output data and *in vitro* digestibility of the herbage dry matter.

[4] Milk energy = 0.0384 [fat] + 0.0223 [protein] + 0.0199 [lactose] – 0.108 (Tyrell and Reid, 1965).

[5] ME for milk production = $\frac{\text{Milk energy (MJ/kg)}}{k_l}$. With k_l = 0.35 x (ME/18.4) + 0.420 (AFRC, 1993).

[6] ME for maintenance = $\frac{0.53\,(LW/1.08)^{0.67} + 0.0095LW}{k_m}$. With k_m = 0.35 x (ME/18.4) + 0.503 (AFRC, 1993).

[7] ME for LW change = $\frac{\text{Energy in LW (MJ/kg)}}{k_g}$. With k_g = 0.95k_l, and 19 MJ/kg liveweight change (AFRC, 1993).

At both herbage allowances the cows from the L line converted DM (OM) into milksolids more efficiently (+ 11%) than H cows, in close agreement with the difference in Breeding Worth (11%) between the sires of H and L cows. This result agrees with the findings presented in Chapters 2 with growing heifers, and Chapter 4, and Chapter 8 with lactating cows, in which the differences in Breeding Worth of sires of H and L cows were similar to the differences in feed conversion efficiency of their daughters. It can be concluded that for the H and L cows, offered either high or low herbage allowances, the breeding values of the sires are reliable predictors of their daughters actual performance, and that the estimate of the sire's Breeding Worth is closely related to the cow's feed conversion efficiency. However, the discrepancy between measured intakes (from faecal output) and theoretical requirements must be remembered. If the theoretical requirements are used to calculate efficiency, the H and L cows are calculated to have similar feed conversion efficiencies under the conditions of the present experiment.

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CHAPTER 6

Calving difficulty and calf mortality of cows and first calving heifers

Abstract

Calving difficulty records (0 = no difficulty, 1 = difficult calving) and records on calf mortality (0 = calf alive, 1 = calf dead) were collected from 1987 to 1997 from the Massey University dairy herd used to develop the heavy (H) and the light (L) mature live weight (LW) selection lines of Holstein-Friesian cows. Cows from the base herd (B, n = 157), the heavy (H, n = 65), and light (L, n = 63) LW selection lines provided 806, 172, and 163 calving records, respectively. Nationally evaluated across breeds, the average breeding values (BV's) for LW were 41.3 kg (B), 18.5 kg (L), and 92.5 kg (H), for maternal grand sires (MGS), and 47.4 kg (B), 32.1 kg (L), and 87.3 kg (H) for sires. Stepwise logistic regression analyses was used for variable selection and to estimate the regression coefficients and odds ratio (OR) of variables related to calving difficulty or calf mortality. Variables considered were calf sex, parity, age, genetic line, sire of calf breed, an index for farm profitability termed "Breeding Worth", and the BV's for production traits and traits other than production (TOP) for sires and MGS. For calf mortality, type of calving (induced or normal) and calving difficulty were also included as independent variables in the regression analyses. Primiparous (n = 255 calvings) and multiparous (n = 564 calvings) cows were analysed separately. There was no effect of genetic line (H or L) on calving difficulty of primiparous or multiparous cows. For primiparous cows (both lines mated to the same bulls), calves were more difficult to deliver if i) sired by Friesian rather than by Jersey bulls (OR = 2.3; $P < 0.05$), ii) if they were males (OR = 2.7; $P < 0.005$), or iii) if primiparous cows had a sire with a BV for rump angle one standard deviation (SD) below average (OR = 1.5; $P < 0.005$). For multiparous cows (H cows mated to H bulls; L cows mated to L bulls), calves were more difficult to deliver if i) calved by younger cows (OR = 1.6; $P < 0.005$), ii) if they were males (OR = 1.7; $P< 0.05$), or iii) if sired by bulls with BV for rump width one SD above average (OR = 1.4; $P < 0.01$). There was also no effect of genetic line (H or L) on calf mortality of primiparous or multiparous cows. However, calves were more likely to die or undertake an emergency slaughter if they were from an induced calving (OR = 13.6; $P < 0.0001$), from a difficult calving (OR = 3.54; $P < 0.0001$), or from younger cows. Up to this point of the selection experiment, selection for heavier or lighter mature live weight has had no effect on calving difficulty or calf mortality of grazing Holstein-Friesian cows.

Introduction

Simulation studies have shown that heavier LW affects dairy farm profitability through its effects on extra dietary energy requirements for maintenance and growth and extra income from culled cattle (Dempfle, 1986; Visscher et al. 1994); therefore LW is included with a negative economic value in the breeding objective of New Zealand dairy cattle (Spelman and Garrick, 1997). Cows on commercial farms and bulls used for artificial breeding are evaluated on an index for net farm income termed 'Breeding Worth'. The index represents the expected net income per unit of feed (i.e. dollars per 4.5 tonnes of dry matter) that cows and bulls are likely to generate through breeding replacements that are efficient converters of feed into profit (Harris, 1998).

Experimental evidence is scarce regarding the effect that selection for lighter or heavier mature LW has on the incidence of difficult calvings, calf birth weight and calf mortality of New Zealand Holstein-Friesian cows. Calving difficulty is particularly important due to its effects on calf mortality, subsequent cow reproductive performance, and extra labour required from the farmer and veterinary assistance (Philipsson, 1976e; Meijering, 1984). The objectives of the present chapter are to evaluate the effect of using bulls with high or low breeding value for live weight on the incidence of calving difficulty, calf mortality and change in calf birth weight of primiparous and multiparous cows from the base herd and the heavy and light mature live weight selection lines at Massey University, New Zealand. This chapter also aims to identify risk factors associated with calving difficulty and calf mortality of primiparous and multiparous cows from this population.

Materials and methods

Source of data

The data consisted of calving records for 11 years from 1987 to 1997, of the Holstein-Friesian herd at the Dairy Cattle Research Unit, Massey University, New Zealand. For each mating season, semen of Holstein-Friesian bulls was sourced by the New Zealand Livestock Improvement Corporation to inseminate the herd. During the first three years from 1987 to 1989 inclusive, calves born from artificial breeding were sired by bulls which were selected on the basis of an index (Total Breeding Index) combining milkfat (kg), milk protein (kg), and milk volume (*l*), and there was no selection emphasis on live weight. For the following eight years from 1990 to 1997, bulls with breeding value (BV) for live weight greater than 60 kg (H) or lower than 60 kg (L) were used in a research programme with the objective of generating two lines of Holstein-Friesian cows which differed genetically in their mature live weight. Details of the mating strategy to develop the H and L lines are given in Chapter 1.

Animals and management

Multiparous cows

For each mating season, multiparous cows were submitted to artificial insemination (AI) for a period of seven weeks during October to December, followed by four weeks of natural mating with Holstein-Friesian or Jersey bulls during December to January. Cows detected in oestrus were inseminated in the morning, and cows still in oestrus 24 hours from the first observed oestrus were inseminated a second time using semen from the same bull; both AI were counted as one service.

For the years 1989 to 1997 inclusive, high genetic merit Holstein-Friesian cows from the base herd were used to develop the two genetic lines differing in mature live weight. Each year before the start of mating, cows were blocked by age, live weight and milksolids yield; within block heavier cows were allocated to H bulls and lighter cows to L bulls, respectively. During the first three years, cows were allocated to either a group of two H or two L bulls, and to a group of three H or three L bulls during the remaining six years. Cows from the herd not taking part in the development of the two genetic lines were inseminated with sires from the Premiere Sires team sourced by the New Zealand Livestock Improvement Corporation.

Replacement heifers

Every year all heifer calves sired by an H or L bull were reared in one group as replacements off the home farm, and naturally mated as yearlings to Holstein-Friesian (years 1987-89, and 1993-97) or Jersey (years 1990-92) bulls, during a 90-day breeding season starting two weeks before that of the adult cows. They were then brought back to the home farm in June two months before the start of calving, and grazed along with the rest of the herd. After calving and during the following mating season, first calving heifers and multiparous cows with an H or L bull as sire were mated back to an H or L bull in the subsequent years.

New born calves

Each year, calves were born during July to October, with a peak in August, in a calving season of about 90 days. After calving, which took place in the paddock, calves were identified to their mothers, their live weight was recorded and they were allowed to suck colostrum during the first 24 hours; they were then put in a calf shed and group-penned according to age. Male calves and surplus females were sold as bobby calves during their first week of age. Female calves kept for replacement purposes were bucket fed for one or two weeks and allowed learning to suckle from a calfteria system. After two weeks of age they were taken out to a paddock, rotated around the farm ahead of the adult cows, offered concentrate pellets *ad libitum* and group-fed using the calfeteria system until weaning, which took place at about 12 weeks of age. Details of feeding and management of growing cattle are presented in Chapters 2 and 3.

Information recorded

Information on sires of cows

Sires of all the cows in the herd (B, H, and L) were from the artificial breeding team of progeny tested sires sourced by the New Zealand Livestock Improvement Corporation. Sires of cows had information on an index for farm profitability ($) termed Breeding Worth (BW), and on their breeding values (BV's) for production traits and traits other than production (TOP). The BV's represented the genetic merit of an animal for individual traits relative to a base of zero (i.e. a cow born in 1985). For production traits, their BV's were given in the unit of measurement of the particular trait. They included live weight (kg), milkfat (kg), milk protein (kg), milk volume (*l*), fat (%), protein (%) and survival (%).

The BV's for TOP are given in units corresponding to a scale from 1 to 9, where 1 and 9 represent the biological extremes. TOP included were adaptability to milking, shed temperament, milking speed, overall opinion, stature, capacity, rump angle, legs, udder support, front udder, rear udder, front teat placement, rear teat placement, udder overall, and dairy conformation. The first four traits are scored by the farmer while the remaining 12 are scored by an official inspector. The description of these 16 TOP has been given elsewhere (Cue et al. 1996; Livestock Improvement, 1997) and are given in Appendix 1.1. Means and standard deviations for the BV's of sires of cows from the base herd and the H and L lines are presented in Table 6.1. In total 129 cows from the base herd, daughters of 35 sires, and 50 cows from the H and 50 from the L line, daughters of 12 H and 12 L sires respectively, had calving records during the 11 years considered in the present study.

Information on sires of calves

Sires of calves born to an artificial breeding service also had information on their BV's for production traits and TOP. Sires of calves born to a natural mating (i.e. those from first calving cows and those from multiparous cows pregnant to a bull by natural mating) were categorised by breed only as no other information was available. Table 6.2 gives the means and standard deviations for the BV's of sires of calves born to the H and L lines. In total 22 H and 22 L sires were used to sire the calves from the H and L lines during the years 1990 to 1997.

Table 6.1: Summary statistics for the breeding values for production traits and traits other than production of sires of cows from the base herd, the heavy and the light live weight selection lines calving in the years 1987 to 1997.

		Cow genetic line					
		Base (n = 129 cows)		Heavy (n = 50 cows)		Light (n = 50 cows)	
Item	Units	Mean	SD	Mean	SD	Mean	SD
Number of sires	n	35		12		12	
BV's for production traits:							
Milk	*l*	453.2	362	1015.2	306	655.0	318
Milkfat	kg	11.9	16	30.8	5	25.4	6
Protein	kg	9.2	12	28.4	9	18.5	6
Fat percent	%	4.5	0.3	4.4	0.3	4.7	0.4
Protein percent	%	3.5	0.13	3.5	0.14	3.6	0.16
Survival	%	0.6	2.6	0.13	1.4	0.33	1.3
Live weight	kg	42.5	14	92.4	15	26.0	19
Breeding worth	$	2.0	38	37.5	24	43.2	9
Sire of cow BV's for TOP:							
a) Evaluated by the farmer							
Adaptability to milking	units	0.0130	0.18	-0.0416	0.32	-0.0525	0.19
Shed temperament	units	0.0197	0.20	-0.0326	0.37	-0.0386	0.22
Milking speed	units	0.1034	0.22	-0.1391	0.35	0.1405	0.16
Overall opinion	units	0.0754	0.15	0.0781	0.27	0.0121	0.16
a) Evaluated by the inspector							
Stature	units	0.2977	0.32	1.2914	0.27	0.0511	0.25
Capacity	units	0.0160	0.25	0.5438	0.30	-0.1470	0.19
Rump angle	units	0.0054	0.25	-0.1277	0.21	0.0438	0.29
Rump width	units	0.1091	0.29	0.4497	0.21	-0.0161	0.25
Legs	units	0.0037	0.08	-0.0586	0.09	0.0438	0.09
Udder support	units	-0.0817	0.34	-0.0273	0.40	-0.3244	0.30
Front udder	units	-0.1075	0.32	-0.0705	0.32	-0.2738	0.31
Rear udder	units	-0.1593	0.34	0.0833	0.34	-0.2669	0.16
Front teat placement	units	-0.1003	0.23	0.0104	0.27	-0.2353	0.14
Rear teat placement	units	0.0100	0.39	-0.0842	0.44	-0.0653	0.19
Udder overall	units	-0.1649	0.36	-0.0049	0.36	-0.4015	0.30
Dairy conformation	units	-0.0415	0.25	0.4319	0.18	-0.2436	0.22

Table 6.2: Summary statistics for the breeding values for production traits and traits other than production of sires of calves born to the heavy or to the light live weight selection lines during the years 1990 to 1997.

		Calf genetic line			
		Heavy (n = 216)		Light (n = 235)	
Item	Units	Mean	SD	Mean	SD
Number of sires	n	22		22	
Sire of calf BV for production traits:					
Milk	*l*	1074.0	292	783.6	338
Milkfat	kg	33.7	6	29.5	8
Protein	kg	33.0	9	23.5	9
Fat percent	%	4.4	0.3	4.6	0.3
Protein percent	%	3.5	0.14	3.6	0.17
Survival	%	0.53	1.6	0.73	1.25
Live weight	kg	85.2	17	34.0	17
Breeding worth	$	58.0	29	56.0	21
Sire of calf BV for TOP:					
a) Evaluated by the farmer					
Adaptability to milking	units	0.0434	0.34	-0.0207	0.25
Shed temperament	units	0.0343	0.33	-0.0188	0.21
Milking speed	units	0.0166	0.31	0.1031	0.19
Overall opinion	units	0.1746	0.28	0.0586	0.22
a) Evaluated by the inspector					
Stature	units	1.2135	0.34	0.1808	0.28
Capacity	units	0.3741	0.32	-0.0204	0.27
Rump angle	units	-0.0975	0.22	-0.0043	0.23
Rump width	units	0.3588	0.30	0.0855	0.25
Legs	units	-0.0146	0.09	0.0182	0.09
Udder support	units	0.0489	0.35	-0.2306	0.27
Front udder	units	0.0136	0.26	-0.1675	0.29
Rear udder	units	0.1467	0.35	-0.2040	0.22
Front teat placement	units	0.0427	0.31	-0.2335	0.17
Rear teat placement	units	-0.0246	0.50	-0.1041	0.25
Udder overall	units	0.0893	0.37	-0.2773	0.31
Dairy conformation	units	0.3770	0.21	-0.0787	0.32

Information on cows

Each cow had pedigree records, age of the cow's dam at the time of her birth, date of birth, sex of the calf at each calving (males, females, and twins), dates of insemination and calving, and drying off dates, a variable coding for type of calving (normal, abortion, or induced), and a variable coding for calf presentation at calving. Calving was judged to occur with normal presentation when the calf exited the birth canal with his/her front legs forward with the head between them; abnormal presentation was given by any of the following situations: head back, one (or two) front leg (s) back, rear legs forward, and breach.

Calf birth weight, gestation length and dates of calving

Birth weights were recorded for 188 bull calves (86 B, 55 H, and 47 L) and 184 heifer calves (126 B, 46 H and 53 L) during the 11 years examined. Gestation length was calculated from the latest insemination or natural mating recorded and the subsequent calving date. There were only a few records of gestation length for first calving cows that were reared at the home farm, since no records of individual mating dates were available for maiden heifers in any of the 11 years examined. Table 6.3 summarises the information available for calf birth weight and gestation length (males and females pooled) for each genetic line during the 11 years considered in the analyses.

Table 6.3: Number of records, number of sires, cows and first calving heifers, and mean ± SD of calf birth weight and gestation length within genetic line for data recorded during the years 1987 to 1997.

	Number of:			Records on:			Mean ± SD		
Genetic line	Sires	Cows	Heifers	Cows	Heifers	Total	Cows	Heifers	Total
				Calf birth weight (kg)					
Base	41	157	157	209	3	212	39.0 ± 6.0	37.5 ± 4.1	39.0 ± 6.0
Heavy	12	65	65	72	29	101	40.8 ± 5.0	36.6 ± 5.1	39.6 ± 5.4
Light	12	63	63	71	29	100	35.9 ± 4.5	34.5 ± 3.1	35.5 ± 4.2
Total	65	285	285	352	61	413	38.7 ± 5.8	35.6 ± 4.3	38.3 ± 5.7
				Gestation length (days)					
Base	62	177	177	643	4	647	278.5 ± 10.7	277.3 ± 6.4	278.5 ± 10.7
Heavy	12	45	45	105	6	111	279.8 ± 10.5	280.0 ± 0.1	279.8 ± 10.2
Light	12	41	41	96	1	97	279.1 ± 7.2	285.0 ± 0.0	279.2 ± 7.2
Total	86	263	263	844	11	855	278.7 ± 10.3	279.5 ± 4.2	278.7 ± 10.3

Calving difficulty, induction, and calf mortality

Cows calved outdoors, and diagnosis of calving difficulty and determination of need for assistance was at the discretion of the herd manager. Calvings were observed and given a numerical score where 1 represented an assisted calving (from slight manual assistance to veterinary assistance) and zero represented no difficulty or assistance required.

Calvings were categorised as abortions, normal deliveries or inductions. A calving was considered an abortion when the calf was delivered at less than 250 days of gestation; a normal calving was the delivery of a full term calf (> 276 days) (Macmillan and Curnow, 1976; Moller, 1967; Philipsson, 1976a), and an induced calving was any calving in which the cow had a recorded treatment for induction. Additionally, records were available for the calves' fate at each calving. Calves were categorised as being reared for replacement, sold as bobby calves, or dead at birth or soon after. All causes of death (i.e. because of a difficult calving, an emergency slaughter because of induction, or dead within the first two weeks of rearing for any other reasons) were grouped under the category of dead calves. The number of sires, adult cows and first calving heifers, and the percentage of difficult calvings and calf deaths within genetic line are given in Table 6.4.

Table 6.4: Number of sires, cows and first calving heifers, and percentage of difficult calvings or calf deaths within genetic line for data recorded during the years 1987 to 1997.

Genetic line	Number of: Sires	Cows	Heifers	Records on: Cows	Heifers	Total	Percentage of difficult calvings, Induced calvings or dead calves: Cows	Heifers	Total
				Calving difficulty					
Base	68	157	157	649	157	806	8.8	18.5	10.7
Heavy	14	65	65	107	65	172	7.5	16.9	11.0
Light	14	63	63	100	63	163	6.0	27.0	14.1
Total	96	285	285	856	285	1141	8.3	20.0	11.2
				Induced calvings					
Base	68	157	157	649	157	806	10.8	2.6	9.2
Heavy	14	64	64	107	64	171	15.0	1.6	10.0
Light	14	62	62	100	62	162	8.0	0.0	4.9
Total	96	283	283	856	283	1139	11.0	1.8	8.7
				Calf mortality					
Base	68	157	157	649	157	806	9.2	6.4	8.7
Heavy	14	64	64	107	64	171	9.4	6.3	8.2
Light	14	62	62	100	62	162	5.0	6.5	5.6
Total	96	283	283	856	283	1139	8.8	6.4	8.2

Statistical analyses

Gestation length and calf birth weight

Differences between genetic lines for calf birth weight and gestation length were tested by least squares analysis of variance using PROC GLM (SAS, 1989). The model included the effects of genetic line, sire of cow nested within genetic line, cow age-group (i.e. primiparous or multiparous), calf sex, year of calving (1987 to 1997), month of calving (July, August and September), induced calving (yes or no), and all the two way interactions between main effects. Interactions not contributing to the reduction in sums of squares of residuals were dropped from the model and the reduced model was refitted. Sires of cows were regarded as random, and differences between genetic lines were tested using the mean square (MS) of sire of cow nested within genetic line as the error term. All other tests of significance used the error MS in the denominator of the corresponding F-test. Additionally, the relationship between calf birth weight and the sire of calf BV for LW was assessed by linear regression. Heterogeneity of regression lines due to sex of calf was tested as described by Snedecor and Cochran (1980).

Calving difficulty and calf mortality

The categorical dependent variables (y) calving difficulty (i.e. 0 = no difficulty, 1 = difficult calving) and calf mortality (i.e. 0 = calf alive, 1 = calf dead at birth or soon after) were assumed to follow the binomial distribution, with the probability of a cow having a difficult calving or a calf dying at birth or soon after (P_i) given a set of independent quantitative variables or covariates (xi's) being modelled using a linear logistic regression model (SAS, 1995). The probability of calving difficulty or calf mortality was assumed to be

$$\text{Prob}\left(y_i = y_1 | x_1,\ldots,x_k\right) = P_i \quad = \frac{1}{1+\exp\left[-\left(\beta_0 + \sum_{i=1}^{k}\beta_i x_i\right)\right]} \qquad [6.1]$$

and the probability of a cow not having a difficult calving or a calf not dying at birth or soon after being modelled as

$$\text{Prob}\ \left(y_i = y_0 \mid x_1,\ldots,x_k\right) = Q_i = (1 - P_i) = \frac{\exp\left[-\left(\beta_0 + \sum_{i=1}^{k}\beta_i x_i\right)\right]}{1 + \exp\left[-\left(\beta_0 + \sum_{i=1}^{k}\beta_i x_i\right)\right]} \qquad [6.2]$$

The ratio of these probabilities is equal to

$$\left(\frac{P_i}{1 - P_i}\right) = \frac{1}{\exp\left[-\left(\beta_0 + \sum_{i=1}^{k}\beta_i x_i\right)\right]} \qquad [6.3]$$

The natural logarithm of this ratio, or the logit transformation of the ith individual's event probability, P_i, turns out to be a simple linear function of the independent covariates, x_i's, (SAS, 1995),

$$\text{logit}\ (P_i) = \ln\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \sum_{i=1}^{k} \beta_i x_i \qquad [6.4]$$

Where:

$P_i = Prob\ (y_i = y_1 \mid x_i)$	is the response probability to be modelled, and y_1 is the first ordered level of the response variable, y [i.e. $y = 0$ for no difficulty (or calf alive) and $y = 1$ for a difficult calving (or a dead calf) for calving difficulty and calf mortality, respectively].
β_0	is the intercept parameter (i.e. a background log-odds), and
β_i's	are the regression coefficients associated with individual or combinations of regressor variables (x_i).

Once the regression coefficients of the independent variables have been estimated, the probability of a cow having a difficult calving (or a calf dying at birth or soon after), P_i, can then be calculated from equation [6.1] as

$$\text{Prob}\ (y_i = y_1 \mid x_i, \ldots, X_k) = P_i = \frac{1}{1 + \exp\left(\hat{\beta}_0 + \sum_{i=1}^{k} \hat{\beta}_i x_i\right)} \qquad [6.5]$$

Additionally, for each independent variable included in the final multiple logistic regression equation, odds ratios were calculated by raising the base of the natural logarithms, *e*, (i.e. 2.718) to the respective estimated regression coefficients, i.e.

$e^{\hat{\beta}_i}$ for dichotomous variables, and as

$e^{c\hat{\beta}_i}$ for continuous variables, where c is a constant.

Odds ratios are a statistical measure that indicates how likely or unlikely it is for individuals exposed to a risk factor to show the outcome of interest (Hosmer and Lemeshow, 1989). Moreover, an odds ratio of one indicates no association between the risk factor and the probability of occurrence of the outcome being modelled. In the context of the present experiment, for example, if calving difficulty (0 = no difficulty, 1 = difficult calving) is the outcome of interest, and sex of calf (0 = female, 1 = male) is the risk factor thought to be associated with calving difficulty, an odds ratio of 2 will indicate that cows delivering male calves are two times more likely to face a difficult calving than those delivering female calves. For a continuous independent variable it is sometimes more informative to calculate odds ratios for a standard deviation of change, or some other meaningful constant. Thus, in the present experiment odds ratios of continuous independent variables are given for one standard deviation of change.

Logistic regression on calving difficulty and calf mortality

An approach similar to that suggested by Hosmer & Lemeshow (1989) was used to select individual independent variables (categorical or continuous) to build a multiple logistic regression model for calving difficulty and for calf mortality. For categorical independent variables, a χ^2 test using PROC FREQ (SAS, 1989) was used to test the null hypothesis of no relationship between the categorical independent variable and calving difficulty or calf mortality outcome (Losinger & Heinrichs, 1997).

For continuous independent variables, the contribution of individual regressor variables to calving difficulty or calf mortality was evaluated by fitting their linear, quadratic and cubic effect. The better of the three models for each regressor variable was deemed to be the one (linear, linear plus quadratic, or linear plus quadratic and cubic) for which the statistical significance associated with all terms in the model was highest (Bergmann and Hohenboken, 1992). Only those variables whose univariate test had a P-value < 0.25 were considered for the multiple logistic regression model. Stepwise variable selection was employed to develop the final model. Significance levels of $P < 0.25$ and $P < 0.05$ were required for variables to enter and to remain in the model, respectively. Two-way interactions between all main effects were investigated in the stepwise procedures and a significance level of 5% was used. The LOGISTIC procedure (SAS, 1995) was used to obtain maximum likelihood estimates of the regression coefficients. Ninety five percent confidence intervals and odds ratios were calculated by specifying the appropriate options in the model statement. Odds ratios for continuous independent variables were calculated for one standard deviation of change.

For calving difficulty, analyses were done separately for primiparous and for multiparous cows. For primiparous cows the probability of calving difficulty was modelled by including in the stepwise procedure their sire's BV for production and

TOP, age at first calving (days), calf sex, sire of calf breed, and genetic line. For multiparous cows, the probability of calving difficulty was modelled by including BV's for production traits and TOP from both the sire of calf and the sire of cow, parity, calf sex, and genetic line. In both cases, genetic line and sex of calf were first forced into the model to avoid variables entering the model merely because of differences in cow genetic line or calf sex (Losinger & Heinrichs, 1997). Twins, deformed calves, and calves from multiparous cows pregnant to a NM bull were excluded from the analyses. In total 255 and 564 calving records from primiparous and multiparous cows, respectively, met the criteria for the multiple logistic regression analyses on calving difficulty.

The probability of calf mortality was modelled similarly to calving difficulty with only a few variations. Preliminary analyses showed no difference between genetic lines for calf mortality of primiparous cows, and none of the independent variables proved to be significantly related to calf mortality. Therefore, results from the analyses on calf mortality refer only to data on multiparous cows. Additionally, calving difficulty outcome (difficult or free) and type of calving (induced or normal) were also included in the stepwise variable selection as independent variables thought to be associated with calf mortality. In total, there were 943 recorded births with the calf's fate specified. Genetic line was the only variable forced into the model, and odds ratios were calculated setting to zero the coefficient for cows from the light line (i.e. the reference group) since they were the group with the lowest number of dead calves.

The effect of gestation length on calf mortality was also assessed separately. For this purpose, all calvings with a calculated gestation length and a record of calf survival or death were included (i.e. abortions, premature calvings, full term calvings, induced calvings). The linear, quadratic and cubic effects of gestation length were fitted to the log odds of calf mortality using logistic regression. A preliminary fit including a design variable to distinguish between genetic lines showed no effect of genetic line, and the model was therefore refitted to the pooled data of B, H and L cows. In total, 786 calvings met the criteria.

Results

Gestation length and calf birth weight

Results from the analyses of variance for calf birth weight and gestation length are summarised in Table 6.5. The least-squares models for birth weight and gestation length accounted for 57% and 30% of the total variation, respectively. Detailed results for each trait are given below.

Table 6.5: Analysis of variance for birth weight and gestation length of cows from the base herd, the heavy and the light live weight selection lines. F- values for the main effect of line were tested against the error mean square of sire of cow nested within genetic line.

Effect of:	d.f	Birth weight (kg)		Gestation length (d)	
Genetic line	2	12.8	***	2.0	NS
Sire of cow nested within line[1]	93	1.9	***	0.98	NS
Cow age-group	1	4.4	*	0.74	NS
Calf sex	1	30.4	***	2.7	†
Year of calving[2]	10	15.4	***	4.2	***
Month of calving	2	0.25	NS	18.5	***
Induction[3]	1	2.5	NS	23.0	***
Calving difficulty	1	1.2	NS	2.5	NS
Line*Induction	2	---		7.7	***
R^2 (%)		57.0		29.8	

[1] Degrees of freedom for: Calf birth weight = 69; Gestation length = 83.
[2] Degrees of freedom for: Calf birth weight = 9.
[3] Induction (i.e. yes or no).

Calf birth weight

The major sources of variation for calf birth weight were the sex of the calf, the year of calving and the cow's genetic line. Male calves were heavier at birth than female calves (43.2 *vs.* 40.6 kg; s.e.d = 0.47; P < 0.001). Calves born to cows from the base herd and the heavy line had similar birth weight, but heavier than that of calves born to cows from the L line (B: 42.6; H: 43.4; and L: 39.7 kg; s.e.d = 1.1; P < 0.001). Calves from primiparous cows were lighter than those from multiparous cows (41.0 kg *vs.* 43.2

kg; s.e.d = 0.92; P < 0.05). However, there was no difference in the birth weight of calves from an induced or a normal calving or from a difficult or a free calving. The effect of using bulls with high or low breeding value for live weight to generate the H and L lines brought about a linear increase in the birth weight of both female and male calves, with increased sire of calf BV for LW. Figure 6.1 shows the scatter plot with the respective regression lines fitted to the data. The best fit was obtained by the following parallel regression lines model:

$$\text{Birth weight (kg)} = \left\{ \begin{array}{ll} \text{Females} & 33.1\ (\pm 0.72) \\ \text{Males} & 35.5\ (\pm 0.76) \end{array} \right\} + 0.082(\pm 0.01)\text{*Sire of calf BV for LW}$$

R^2 = 19.0%; RSD = 5.2; CV = 13.3%; n = 335.

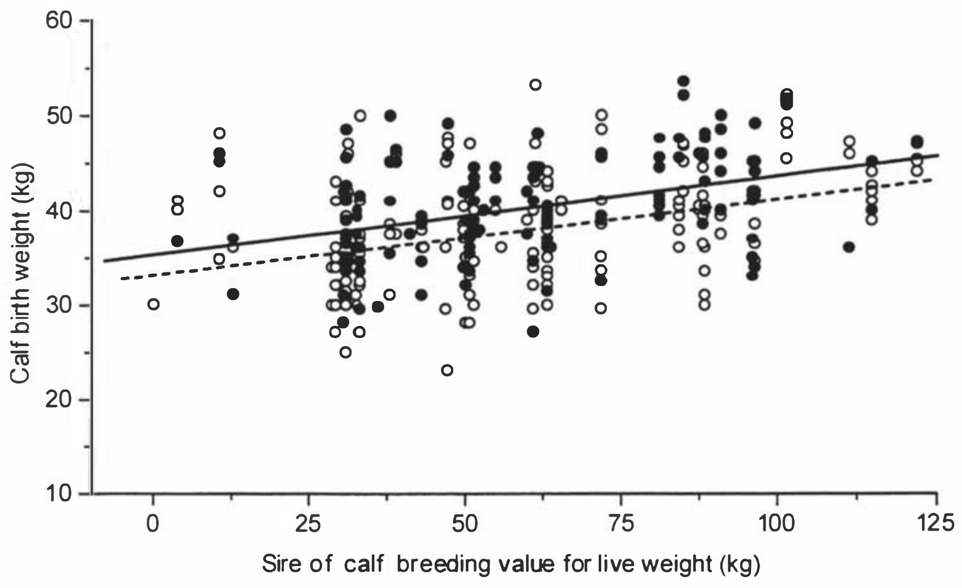

Figure 6.1: Relationship between sire of calf breeding value for live weight and birth weight of female (–o–) and male (—●—) calves.

Thus, male calves were heavier at birth, but they increased in birth weight at the same rate as female calves with each increase of their sires' BV for LW. On average, a difference in sire of calf BV for LW of 100 kg was expected to increase birth weight by 8.2 kg for both male and female calves.

Gestation length

The major sources of variation for gestation length were the use or not of induction and the month of calving, and there were significant effects of year of calving and an interaction of genetic line by induction. Male calves had only slightly longer gestation lengths than female calves (males: 277 *vs.* females: 276 days; s.e.d = 0.7; P < 0.10). Compared to gestation lengths of cows calving in August, shorter or longer gestation lengths occurred for cows calving during July and September, respectively (i.e. July: 269.8 days; August: 278.0 days and September: 281.5 days). Most of the differences in gestation length were due to year to year variation caused by the differential use of induction. Induced cows had an average gestation length 9 days shorter than non-induced cows (induced: 272.0 *vs.* non-induced: 280.8 days; s.e.d = 1.8; P < 0.001). The interaction between genetic line and induction showed how induction caused shorter gestation lengths but only for the cows from the base herd and those from the heavy line (Figure 6.2). This interaction reflected the lower induction rate undertaken with cows from the L line compared to that recorded for cows from both the base herd and the H line.

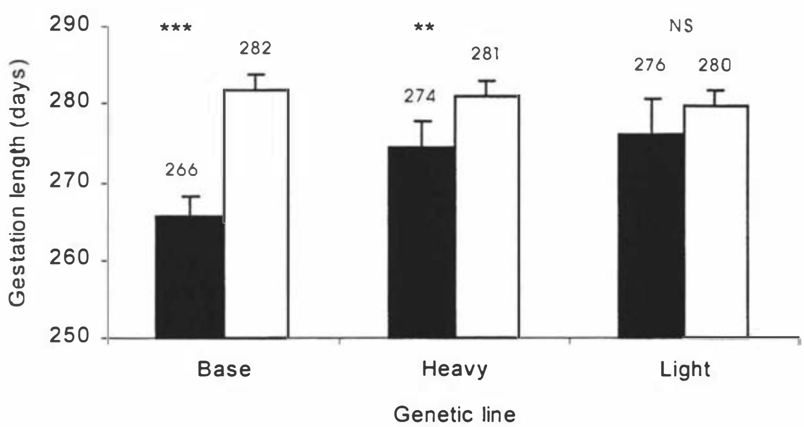

Figure 6.2: Gestation length of induced (filled bars) and non-induced (open bars) cows from the base herd, the heavy and the light mature live weight selection lines.

Analysis of categorical variables using logistic regression

Calving difficulty

Tables 6.6 and 6.7 show the parameter estimates and odds ratios with their respective 95% confidence intervals for the stepwise logistic regression of primiparous and multiparous cows, respectively. Average calving difficulty was higher (P < 0.001) at 22.2% for primiparous compared to 8.6% for multiparous cows.

Primiparous cows

Although primiparous cows from the light line showed a higher incidence of difficult calvings, there was no effect of genetic line on the probability of calving difficulty. However, calves were more difficult to deliver if sired by Holstein-Friesian than by Jersey bulls (P < 0.05; OR = 2.1), and if they were males (P < 0.01; OR = 2.43). Additionally, primiparous cows whose sire had a BV for rump angle one SD below average were more likely to face a difficult calving (P < 0.001; OR = 1.7). Thus, primiparous cows with high pin bones appeared to be more likely to face calving difficulty than those with low pin bones; this difference was apparent regardless of the sex and genotype of their calves.

Table 6.6: Regression coefficients estimates, standard deviations (SD) for continuous variables, odds ratios and 95% confidence intervals (CI) for the odds ratios, and probability levels from stepwise logistic regression analysis of primiparous cows (n = 255 calvings).

Variable	Regression coefficient	SD	Odds ratio Discrete	Odds ratio Continuous	95% CI	*P*
Genetic line						
Base	0.6602		1.94		0.85-4.69	0.127
Light	0.6762		1.97		0.81-4.94	0.140
Heavy	0.0		1.0			
Calf sex						
Male	0.8879		2.43		1.28-4.74	0.008
Female	0.0		1.0			
Sire of calf breed						
Holstein-Friesian	0.737		2.1		1.20-4.80	0.050
Jersey	0.0		1.0			
Sire of cow BV for rump angle, *units*	-2.1096	0.250		1.7	1.22-2.40	0.001

[1] Odds ratios for continuous independent variables were calculated for one standard deviation of change.

Multiparous cows

For multiparous cows there was also no effect of genetic line on the probability of calving difficulty. However, male calves were almost two times more difficult to deliver than female calves. In addition, calves were more difficult to deliver if delivered by younger cows. Calves were also more difficult to deliver when they were sired by bulls with an BV for rump width one SD above average (Table 6.7).

Table 6.7: Regression coefficients estimates, standard deviations (SD) for continuous variables, odds ratios and 95% confidence intervals (CI) for the odds ratios, and probability levels from stepwise logistic regression analysis of multiparous cows (n = 564 calvings).

	Regression		Odds ratio			
Variable	coefficient	S.D	Discrete	Continuous	95% CI	P
Genetic line						
Base	0.6897		1.99		0.79-6.1	0.176
Heavy	0.1288		1.14		0.34-4.1	0.836
Light	0.0		1.0			
Calf sex						
Male	0.6384		1.89		1.02-3.6	0.045
Female	0.0		1.0			
Parity, *number*	-0.3932		0.68		1.17-2.0	0.002
Sire of calf BV for rump width, *units*	1.5368	0.31		1.6	1.18-2.2	0.003

[1] Odds ratios for continuous independent variables were calculated for one standard deviation of change.

Calf mortality

Primiparous cows

There was no effect of genetic line on calf mortality of primiparous cows, and none of the independent variables considered in the multiple logistic regression were significantly associated with calf mortality of this age-group.

Multiparous cows

The results of the multiple logistic regression for multiparous cows are summarised in Table 6.8. The chances of death for calves from the heavy line were higher but not significantly different from those from the light live weight selection line (i.e. OR = 1.42; P > 0.3). However, calves from the base herd were almost two times more likely to die or undertake an emergency slaughter (i.e. OR = 1.97; P < 0.05) than calves from the light line. Similarly, calves from an induced calving were almost 14 times more likely to die or undertake an emergency slaughter than non-induced calves. Calves born to a difficult calving were over three and a half times more likely to die than calves born to normal deliveries. Finally, the risk of death was lower for calves delivered by older cows (i.e. OR = 0.82). That is, in the range from parity 2 to parity 5, the chances of a calf dying at birth (or undertaking an emergency slaughter) at any particular parity after the first one, were only 82% those of a calf from a previous parity.

Table 6.8: Regression coefficient estimates and standard errors (SE), odds ratios and 95% confidence intervals (CI) for the odds ratios, and probability levels from stepwise logistic regression analysis on calf mortality of primiparous and multiparous cows from the base herd and the heavy and light live weight selection lines (n = 943 calvings).

Variable	Regression coefficient	S.E	Odds ratio	95% CI	P
Genetic line					
Base	0.6778	0.308	1.97	1.10-3.7	0.028
Heavy	0.3513	0.363	1.42	0.70-2.9	0.332
Light	0.0		1.0		
Induction					
Yes	2.6095	0.224	13.6	8.77-21.0	0.0001
No	0.0		1.0		
Calving difficulty					
Yes	1.2654	0.245	3.54	2.17-5.70	0.0001
No	0.0		1.0		
Parity number[1]	-0.1990	0.057	0.82	0.73-0.91	0.0001

[1] Parity from 2 to 5, with the last category grouping parities from 5 onwards.

Gestation length and calf mortality

The linear, quadratic and cubic effects of gestation length on calf mortality were all significantly different from zero ($P < 0.05$). Thus, both calves delivered earlier (i.e. abortions, premature calvings or inductions six weeks before the planned start of calving) and calves that were overdue had a higher risk of mortality than calves delivered at the expected gestation length of 282 days (Figure 6.3).

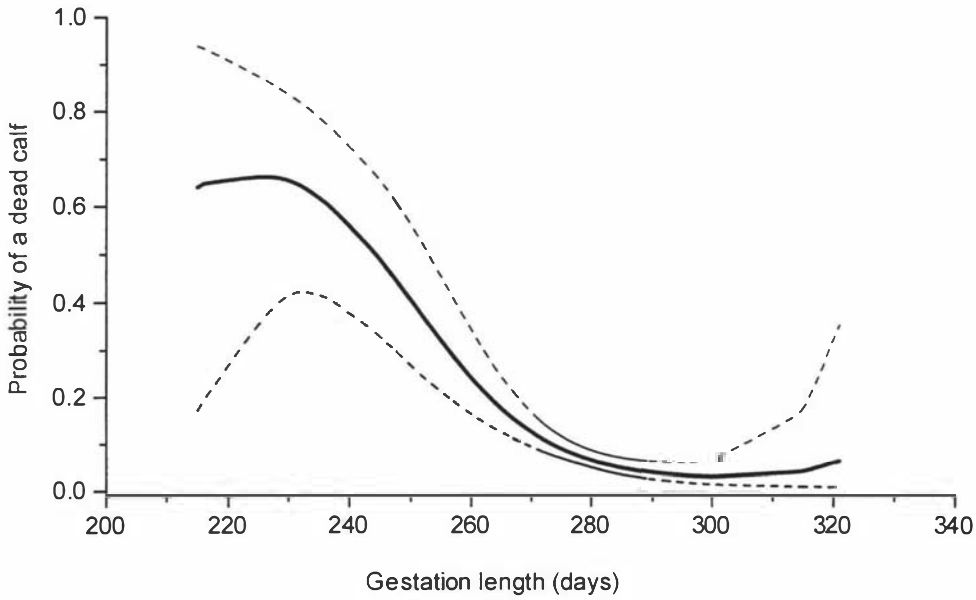

Figure 6.3: Relationship between gestation length (GL) and the probability of death of calves for the pooled data of Holstein-Friesian cows from the base herd, the heavy and the light live weight selection lines. Dashed lines represent the 95% confidence limits. The regression equation obtained was: logit (calf mortality) = $-289.7 + 3.45*GL - 0.0134*(GL)^2 + 0.000017*(GL)^3$; $P < 0.05$.

Discussion

Calf birth weight

In line with the lower breeding value for live weight of their sires, calves from the L line were significantly lighter than those from the base herd and the H line. Calf birth weight showed a linear response to increases in their sire's BV for live weight, with males and females increasing at the same rate of about 0.08 kg per kg of sire of calf BV for LW. Breeding values for LW of progeny tested bulls in New Zealand are calculated from live weights on daughters once they calve for the first time, and with regular weights at each lactation throughout their lives until they leave the herd (Harris, 1998). Thus, the bull's estimated BV for live weight is effectively an estimate of how heavy or light his daughters will be at maturity. The increase in calf birth weight with increased sire of calf BV for live weight agrees with moderate to high positive genetic correlation between mature weight and weights at early ages in beef cattle (Meyer, 1995) and dairy cattle (Koenen and Groen, 1996). Despite the high variation observed ($R^2 = 0.19$), the regression of birth weight on sire of calf BV for live weight was highly significant.

Gestation length

There was no difference between genetic lines for gestation length, and differences were mainly caused by the differential use of induction in each genetic line. Average gestation length for non-induced cows was 282 days, which is virtually the same as that of 281.9 days calculated by Macmillan and Curnow (176) for a large data set (> 13000 records) of New Zealand dairy cows conceiving to their first insemination, and excluding abnormally short (i.e. < 272 days) and abnormally long (i.e. > 293 days) gestation length records. The curvilinear relationship between gestation length and calf mortality observed in the present study has also been observed for European Friesians, in which calf mortality increases after long (> 278 days) as well as short (< 267 days) gestation periods (Philipsson, 1976c). In the present experiment the higher mortality of calves with shorter gestation lengths was due to abortions, premature calvings without induction and induced calvings, whereas the increased mortality for longer gestations was probably due to difficult calving caused by an oversized calf.

Calving difficulty

Calving difficulty of primiparous cows was high at 20% compared to only 8.3% for multiparous cows. The average calving difficulty for multiparous cows is in agreement with the 9.5% reported by Elliot (1992) for New Zealand Holstein-Friesian cows. The high incidence of difficult calvings for primiparous cows agrees with other reports from the literature (McGuirk et al. 1998; Philipsson 1976b), but is considerably higher than the relatively low estimate of 5.9% reported by Ahlborn-Breier (1989) for New Zealand Holstein-Friesian heifers mated to Holstein-Friesian bulls.

Although the differences were not significant, calving difficulty for primiparous cows from the L line was higher (27%) compared to that shown by cows from the base herd (18.5%) and the H line (16.9%). For every year in the study, maiden heifers were mated to bulls by natural mating, from which nothing was known but their breed. In three years (1990 to 1992) out of the 11 years analysed in the present experiment, Jersey bulls were used to mate the maiden heifers. The net effect of using Jersey bulls was a reduction in the probability of difficult calvings by Jersey crossbred calves compared to that of calves sired by NM Holstein-Friesian bulls. Unfortunately, there were no records of birth weight for these crossbred calves, but their likely lower birth weight might have been an important factor in reducing the probability of calving difficulty of primiparous cows in the present experiment. From the birth weight data available, lower birth weights were calculated for primiparous than for multiparous cows. Despite their lower birth weight, calving difficulty was more than twice higher for primiparous cows than for multiparous cows. In agreement with other studies, male calves were heavier at birth and more difficult to deliver than female calves (McGuirk et al. 1998; Philipsson, 1976b).

The sire of cow breeding value for rump angle showed the highest association with the probability of calving difficulty of primiparous cows. Thus, primiparous cows with genetically sloping pelvises were less likely to face a difficult calving. In line with this finding, results from European studies with Friesian heifers (Philipsson, 1976d) have shown that higher calving difficulty is experienced by first calving heifers with smaller pelvic inlet dimensions before or after parturition. Pelvic inlet is commonly measured as pelvic height (= perpendicular distance from the cranial end of the symphysis pubis to the ventral surface of the midsacrum), pelvic width (largest distance between the shafts of the ilia) and pelvic area (height x width), and can be easily measured in the live animal with reasonable accuracy (Meijering, 1984).

The effective dimensions of the pelvic inlet are also influenced by hormonal changes around parturition (Meijering, 1984) and may be affected by the external shape of the rump. The lower probability of calving difficulty of primiparous cows sired by bulls with above average breeding value for rump angle suggests that primiparous cows with sloping pelvises may be more likely to have larger pelvic inlet dimensions or may be more likely to relax muscles and joints around the pelvis before and during parturition, or both (De Jong, 1998). Thus, the results from the present experiment indicate that the external shape of the rump (given in this case by rump angle) may be used as a rough guide to score for difficult calvings of primiparous cows.

For multiparous cows, there was also no effect of cow genetic line on the probability of calving difficulty, and, as for primiparous cows, male calves were more likely to cause difficult calvings. In the range from parity 2 to 5, parity number was negatively associated with the probability of calving difficulty, i.e. older cows were less likely to face difficult calvings, which agrees with reports from the literature where decreasing incidence of difficult calvings in beef cattle has been observed up to the third or fourth parturition (Brinks et al. 1973; Burfening et al. 1978). The sire of calf breeding value for rump width was positively associated with the probability of calving difficulty, i.e. calves sired by bulls that were superior by one standard deviation in BV for rump width were over 1.6 times more likely to cause difficult calvings. Thus, calves with wider pelvises at birth are expected to be more difficult to deliver than calves with narrower pelvises.

Calf mortality

Across genetic lines, calves born to a difficult calving were over three and a half times more likely to die or be subjected to an emergency slaughter than calves born to a free calving. By far the main cause of death or emergency slaughter among new born calves was the use of induction, since induced calves were over 14 times more at risk of death than their non-induced counterparts. This negative effect of induction on calf mortality is well documented for New Zealand dairy cows (Armer et al. 1993; MacDiarmid and Moller, 1981; McGowan et al. 1975; Merral, 1972; Welch and Kaltenbach, 1977). In these studies, calf mortality of induced cows ranged from 15% to 30%, compared to 2 to 8% dead calves for non-induced cows. The higher calf mortality rate for induced calvings may be due to a lower vitality of calves born after a relatively short gestation period (Meijering, 1984).

In the present experiment, gestation length of cows induced to calve was significantly shorter by 9 days compared to that of non-induced cows. The interaction genetic line by type of calving (i.e. induced or non-induced) for gestation length indicated that, within genetic line, significantly shorter gestation lengths were recorded for induced compared to non-induced calvings, especially for cows from the base herd (induced: 266.0 days *v.* non-induced: 282.0 days) and cows from the H line (induced: 274.5 days *v.* non-induced: 281.0 days), but not for cows from the L line (induced: 276.0 days; non-induced: 281.0 days). Thus, the lower risk of calf mortality for cows from the L line compared to that of H and B cows was greatly influenced by their lower induction rate and consequently gestation lengths close to the average (282 days in this case for non-induced cows). The significant quadratic and cubic effects of gestation length on calf mortality certainly suggest lower calf mortality for gestation lengths close to the average of 282 days. Analyses of the reproductive data of cows from the H and L lines generated from 1991 to 1997 also indicates cows from the L line have a higher conception rate to the first service, a more compact calving pattern, and therefore are less prone to induction than H cows. These analyses have also shown that as a consequence of the lower conception rate to the first service, higher induction rate and higher calf mortality, cows from the H line produced a lower proportion of AI female calves suitable as replacements than cows from the L line (See Chapter 7).

Conclusions

Calving difficulty and induction had a major effect (especially induction) on calf survival regardless of genetic line. Induction affected calf survival mainly through shorter gestation lengths. Higher induction rates were experienced by cows from the base herd and the H line compared to cows from the L line, and thus their calves were more at risk of death than those delivered by cows from the L line. Up to this point, selection for heavier or lighter mature LW has had no effect on calving difficulty of grazing Holstein-Friesian cows. However, the lower induction rate and consequent lower risk of calf mortality by cows from the L line suggest that it is advantageous to farm smaller mature live weight cows under the conditions of the present experiment.

Implications

Due to the overriding effect of induction on calf mortality, it is likely that calves from cows more prone to induction will face a greater risk of death than those from cows having a non-induced calving. The available data shows that cows from the L line are less likely to undertake an induced calving and therefore their calves have greater chances of survival under the management practices of the seasonal system of milk production in New Zealand.

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CHAPTER 7

Reproductive performance of multiparous cows and first calving heifers

Abstract

The reproductive performance of Holstein-Friesian cows from the heavy (H) and the light (L) mature live weight (LW) selection lines at Massey University, New Zealand was evaluated from 1992 to 1997. Differences between genetic lines were evaluated for age at first calving (AFC), calving interval (CI) and the intervals from calving to first heat (CFH), calving to first service (CFS), first service to conception (FSCO), and calving to conception or days open (DO). Additionally, the proportion of induced calvings, calving dates, conception rate to the first service and two intervals unique to the New Zealand seasonal system of reproduction given by the start of mating to the first service (SMFS) and the start of mating to conception (SMCO) were also evaluated. Averaged across years, there were no differences between H and L cows for AFC, CI, CFH, CFS or DO. However, cows from the H line calved on average 6 days later during the calving season, and had both longer FSCO (17 *vs.* 13 d; $P < 0.05$) and longer SMCO (29 *vs.* 24 d; $P < 0.05$) intervals than L cows. Cows from the H line had a lower conception rate to the first service (54 *vs.* 65%; $P < 0.05$) and a higher percentage of induced calvings (10.5 *vs.* 4.2%; $P < 0.05$) than the L cows. The combination of later calving and lower conception rate at the first insemination extended the conception and calving pattern of H cows and increased their probability of an induced calving. Under the conditions of the present experiment, lighter mature LW cows had higher conception rates to the first service, achieved a more concentrated calving pattern and were less likely to be induced to calve than heavier mature live weight cows.

Introduction

The profitability of the New Zealand seasonal dairy enterprise is directly related to the amount of milksolids produced per hectare of grazed grass (Deane, 1993). High production per hectare when grazed grass is the main source of feed can only be achieved with high fertility high genetic merit cows that are capable of harvesting a high proportion of the grass grown on the farm and converting it efficiently into milksolids (McMeekan, 1960), and with the skills of herd managers that make the most from both dairy cows and pastures (Holmes, 1990). New Zealand dairy farmers address these components of their production system by artificially breeding their cows to sires with high genetic merit for farm profitability, which are proven under the environmental conditions in which their daughters are expected to perform (Harris, 1998). Additional strategies are the use of relatively high stocking rates during the milking season (Holmes, 1990), and the attainment of a highly concentrated calving pattern of their herds in late winter-early spring to match feed requirements with pasture growth (Macmillan, 1974 and 1979; Macmillan et al. 1984a and 1984b). Under this scenario, and because of the costs of meeting the cow's maintenance requirements, size of the lactating cow has been identified as a component affecting the final efficiency of the New Zealand dairy system (Ahlborn and Dempfle, 1992; Dempfle, 1986; Holmes et al. 1993). Therefore, live weight of the lactating cow is now given a negative weight in the new overall objective of increasing the value of milk solids produced per tonne of DM eaten (Livestock Improvement, 1997).

A highly concentrated calving pattern is fundamental for the efficiency of the seasonal system, and will depend on the herd's reproductive performance during the previous season, particularly on the achievement of both a high submission rate and a high conception rate to a single service (Macmillan, 1974; Xu and Burton, 1996). The detrimental effect of high genetic merit for milk yield on the reproductive performance of dairy cows is now well documented (Nebel and McGilliard, 1993), but experimental evidence about the effect of cow size on fertility is scarce. Markusfeld and Ezra (1993) reported lower pregnancy rates to the first service for heavier, taller compared to lighter, shorter Israeli Holstein-Friesian cows. After 20 years of divergent selection for live weight

(LW) in a research herd of USA Holsteins, Hansen et al. (1998) reported an increased number of services per conception required by cows from the heavy live weight selection line.

The effects of genetic differences in live weight (and milk yield) on the reproductive performance of cows under the New Zealand seasonal system of reproduction have not been investigated previously. Parameters to evaluate the reproductive performance of spring calving herds in New Zealand have been proposed by Grosshans et al. (1996), based on the cow's calving date and the planned start of mating (PSM) of the herd, (i.e. the date chosen by the farmer to start artificially breeding the cows). Thus, the objective of the present study was to compare the productive and reproductive performance of cows from the heavy (H) and light (L) mature live weight selection lines developed at Massey University, New Zealand. A preliminary analysis of the reproductive data has been given by Laborde et al. (1998).

Materials and methods

Animals and management

New-born calves

Each year calves were born during July to October, with a peak in August, in a calving season of about 90 days. Cows calved on the paddock and were monitored for identification of dam and calving difficulty. Calves were identified with their mothers within the first 24 hours after calving. Scoring for calving difficulty was at the discretion of the herd manager and assistance was provided when required. Results on calving difficulty of primiparous and multiparous cows from the project have been given by García-Muñiz et al. (1998a) and have been discussed in detail in Chapter 6.

First calving heifers

Every year all heifer calves with an H or L bull as sire were reared as replacements. The heifers spent their first year of age at the home-farm and then moved to graze on a neighbouring farm until about two months before their first calving. While grazing away the heifers were naturally mated at 14 to 15 months of age to Holstein-Friesian (1993-96) or Jersey (years 1990-92) bulls, during a 90-day breeding season starting about one week before that of the adult cows. They were then brought back to the home farm in June each year or about two months before the start of calving, and grazed with the rest of the herd. Dates when bulls joined the maiden heifers for NM and when they finished mating were recorded every year. After calving they were submitted to the same reproductive management as the rest of the adult herd (Figure 7.1).

Multiparous cows

Data were collected during the period 1992 to 1997 inclusive. The reproductive, grazing and feeding management of cows from the H and L lines is described in the following section.

Reproductive management

After calving, heats were recorded daily for all the cows by observation during the morning and afternoon milking and during the allocation of new areas of pasture to the milking herd. Primary (standing to be mounted and discharge of vaginal mucus) and secondary (including mounting, restlessness and increased vocalisation) signs of oestrous behaviour were used to determine if a cow was on heat. Additionally, about 26 days before the planned start of mating (PSM), heat detection was aided by the tail paint technique (Macmillan and Curnow, 1980; Macmillan et al. 1988). All calved cows were painted red regardless of their cycling status. Cows with signs of oestrus and/or signs of the paint having been rubbed off their tails within the first 21 days after tail painting were regarded as being cycling and were subsequently submitted to AI starting at the PSM. Cows which had not shown oestrus behaviour and/or tail paint removal 6 days prior to the PSM were regarded as anoestrus, examined by a veterinarian and prescribed a fertility treatment accordingly. Anoestrus cows were treated with Controlled Intravaginal Drug Release devices (EAZI-breed CIDR B™; InterAg, Hamilton, New Zealand) and cows with cystic ovaries were treated with prostaglandin $F_{2\alpha}$ (Lutalyse®, Upjohn NZ Ltd).

Prior to the PSM, cows from the H and L lines were allocated to the bulls to be used in the AI programme. For each mating season, multiparous cows were submitted to AI for a period of seven weeks during October to December, followed by five weeks of NM, during December to January with Holstein-Friesian bulls. Cows detected in oestrus were inseminated in the morning and cows, which were still in oestrus 24 hours later, were inseminated a second time using semen from the same bull. Both inseminations were counted as one service. Multiparous cows that did not conceive to an AI service were naturally mated to Holstein-Friesian bulls. Dates of bulls entering (i.e. end of the AI program and start of NM of cows returning to heat) and withdrawing from the milking herd (end of NM of multiparous cows returning to heat) were recorded every year.

After insemination, cows were tail-painted with a different colour (blue or green), and closely monitored for any signs of a repeated oestrus. After seven weeks of AI, 'clean up' bulls were run with the herd for another five weeks until the end of February, the following year to naturally mate cows that had not conceived to an AI service. All the cows were pregnancy tested by rectal palpation in April each year about 150 days after the PSM. Cows with a doubtful pregnancy diagnosis were rescheduled 20 days later for a second examination. Empty cows were culled in April-May each year. Cows were dried off in May-June each year after a lactation of about 250 days (Figure 7.1).

Milking and grazing management

Every year of the study, H and L cows were rotationally grazed as one group (except during experiments that required otherwise) on ryegrass/white clover pastures. The cows were offered generous herbage allowances during lactation according to the farm's feeding and management policy for lactating cows. Cows were milked twice a day for most of the milking season, which lasted from August to May each year. In some occasions, due to low pasture cover on the farm and lack of supplementary feeding, the herd was put on once-a-day milking as an aid to lower their feed requirements. Cows from both genetic lines were subjected to this management practice when needed.

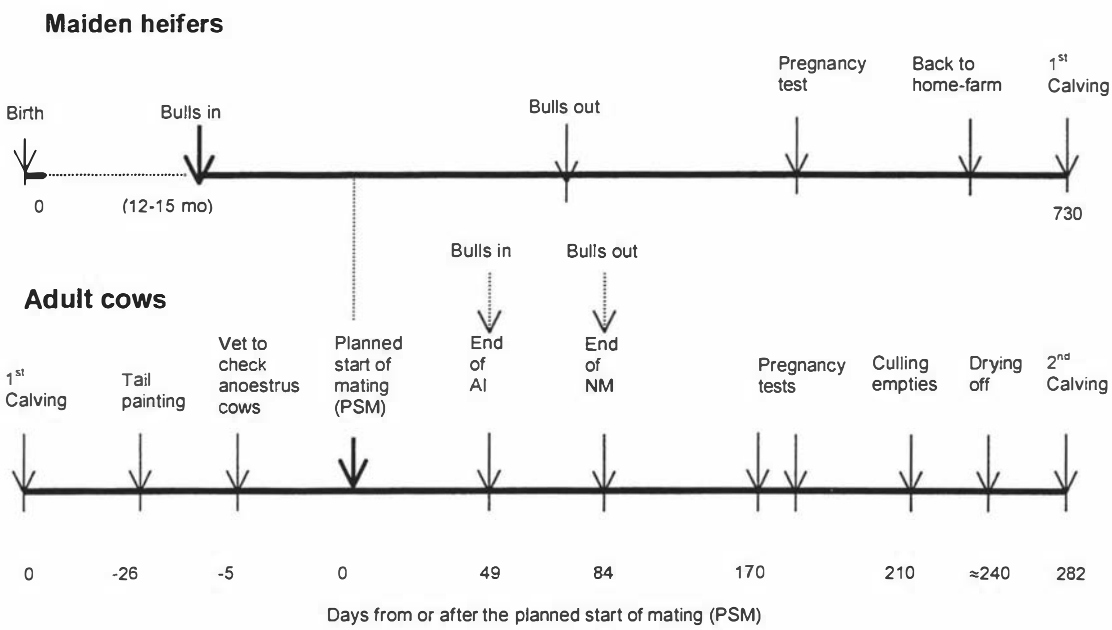

Figure 7.1: Reproductive management of Holstein-Friesian maiden heifers (top panel) and adult cows (bottom panel) from the heavy and light mature live weight selection lines under the seasonal system of milk production in New Zealand. For maiden heifers, the broken line from just after birth to when they are joined by the bulls, indicates a time span much larger than that suggested by the timeline for multiparous cows at the bottom.

Information on sires of calves

Bulls used to artificially inseminate the H and L cows had complete information on their BV's for production traits and TOP. Definitions and scales of measurements of production traits and TOP have been given elsewhere (Cue et al. 1996; Livestock Improvement, 1997) and are also given in Chapter 1. No attempt was made in this study to test for the effect of the insemination sire on the fertility of the cow.

Information on sires of cows

Percentage of USA Holstein

Three generation pedigrees were available for all the sires used to develop the H and L lines of HF cows. This information was used to calculate the proportion of USA Holstein genes in both sires and cows (See Chapter 1).

Breeding values for production traits and TOP

Sires of cows also had complete information on their breeding values for production traits and TOP (Chapter 1). Table 7.1 summarises the comparison of the BV's for production traits and TOP of sires of H and L cows. A table similar to this one is given in Chapter 6 (Table 6.1). However, Table 7.1 below also includes the reproductive and lactation performance of heifers born in 1995 that calved for the first time in 1997, which are not included in Table 6.1 in Chapter 6. In total there were 126 cows (62 H and 64 L) that provided records for analysis. These cows were sired by 13 H and 15 L bulls, respectively.

Information on cows

Each cow had information on percentage of USA Holstein genes (See Chapter 1), the sex of her calf at each calving (males, females, and twins), calf fate (reared for replacement, bobbied, and dead at birth or soon after), use of CIDR or hormones (if she was treated for anoestrus), parity number, dates of birth, calving dates, insemination and drying off dates, number of pre-mating heats recorded using the tail-paint technique, a variable coding for type of calving (normal, abortion, or induced) and a variable coding for calf presentation at calving (normal or abnormal), as described in Chapter 6. Each cow also had information on yields per lactation of milk (*l*), milkfat (kg), milk protein (kg) and milksolids (kg) obtained from herd test records carried out by Livestock Improvement Corporation personnel. Further traits considered were: 1) age at first calving; 2) number of services per conception; 3) total number of times the cow was mated during the mating season (including AI and NM services), with natural matings recorded using the Tail-paint technique (Macmillan and Curnow, 1980); 4) the cow's date of birth (Julian); 5) the number of lactations initiated in the herd; 6) the incidence of difficult calvings; 7) the percentage of cows requiring fertility treatment; 8) the percentage of calvings with abnormal presentation of the calf; 9) the proportion of cows inseminated at their first recorded heat after calving; 10) the proportion of cows (both those becoming pregnant and those failing to conceive) with at least one NM recorded during the mating season; 11) the percentage of female calves eligible as future replacements (i.e. born alive to an AI and not from a twin calving), and 12) the number of dead calves.

Derived variables

Calving pattern

The date of the planned start of calving (PSC) for maiden heifers and multiparous cows from the H and L lines was calculated as 282 days after the date on which the natural mating or AI program commenced, respectively. All calvings were recorded each year and used to construct frequency distributions to ascertain the calving pattern of H and L cows. Within genetic line, data on calving dates were pooled for the six calving years (1992 to 1997). Due to the skewed shape of the distribution of calvings during the calving season, the following intervals were calculated for each genetic line to describe their calving pattern (Macmillan et al. 1984a and 1984b):

1. the interval from PSC until 50% of the cows had calved (**PSC-to-median**),
2. the interval over which the next 25% of cows calved (**Median-to-75%**),
3. the interval over which the last 25% of cows calved (**75%-to-end-of-calving**),
4. the total **calving period** (i.e. from PSC to end of calving), and
5. the total **calving spread** (i.e. from the first to the last calving recorded)

These intervals are shown diagrammatically in Figure 7.2.

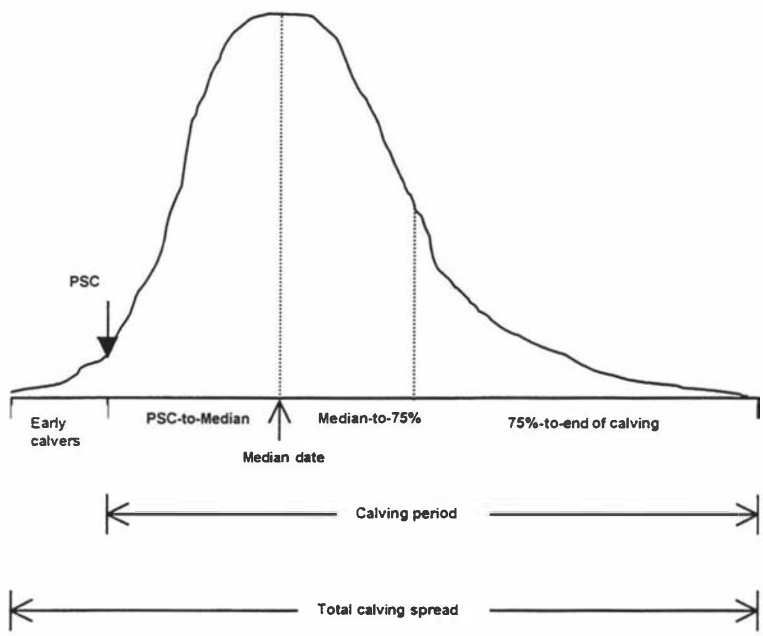

Figure 7.2: Intervals used to describe the calving patterns of genetically heavy or light Holstein-Friesian cows calving during spring (After Macmillan et al. 1984a).

It was also of interest to test whether there was a difference between genetic lines for the interval from the PSC to calving. In this instance the interval PSC to calving had negative values due to the fact that not all the cows had a 282-day gestation length, and due to the practice of inducing to calve late calving cows (Welch and Scott, 1979; Macmillan, 1993 and 1995). To overcome this problem, the date of calving (DTC) was calculated instead. DTC were calculated as the difference between the observed calving date and the calendar date corresponding to January the 1st of the year in which the cow calved. This new variable displayed exactly the same distribution as that observed for the variable PSC to calving, and was then used to test differences between genetic lines in their calving pattern.

Postpartum intervals

Following Grosshans et al. (1996), dates of calving, appearance of first heat, start of mating (or joining date for maiden heifers naturally mated), first and subsequent inseminations or NM (NM were not recorded for maiden heifers) were used to calculate the following intervals on multiparous cows:

1. Calving to first heat (CFH).
2. Calving to first service (CFS).
3. Calving to conception or days open (DO).
4. Calving interval (CI).
5. Gestation length (GL).
6. Planned start of mating to first service (SMFS).
7. First service to conception (FSCO).
8. Planned start of mating to conception (SMCO), and
9. Calving date (DTC).

For the New Zealand seasonal dairying system to make most efficient use of the seasonal supply of grass, each individual herd has to have a highly concentrated calving pattern (Macmillan, 1974). A highly concentrated calving pattern is achieved by mating as many cows as possible and having as many of them as possible in calf after the PSM, regardless of the number of days after calving. The variables SMFS and SMCO account for this fact (Grosshans et al. 1996). Therefore, these two parameters along with the conception rate to the first insemination (described later) and the calving pattern are the most relevant traits to assess fertility of dairy cows in New Zealand. The other reproductive variables were also analysed to compare the results from the present study with those reported in the literature. Figure 7.3, modified from Grosshans et al. (1996) summarises these intervals.

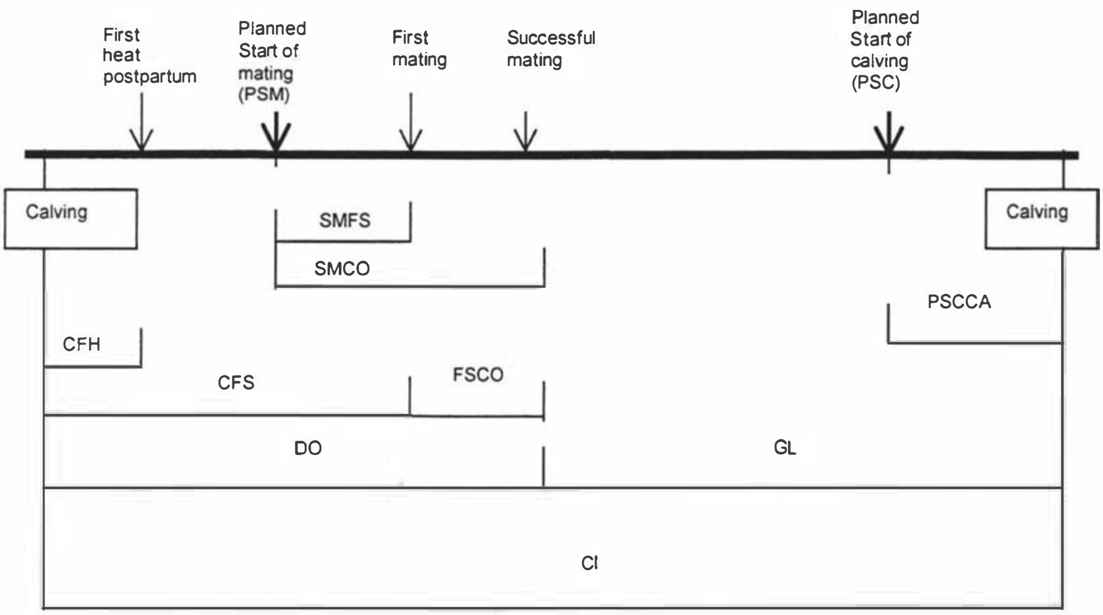

Figure 7.3: Graphic representation of the intervals derived from the reproductive data recorded in the present study. The abbreviations stand for the following fertility traits: i) CFH: Interval from calving to the first recorded postpartum heat; ii) SMFS: Interval from the planned start of mating to the first service; iii) SMCO: Interval from the planned start of mating to conception; iv) CFS: Interval from calving to first service; v) FSCO: Interval from first service to conception; vi) DO: Interval from calving to conception (days open); vii) GL: gestation length, viii) PSCCA: Interval planned start of calving to calving, and ix) CI: Interval between successive calvings. (Modified from Grosshans et al. 1996).

Submission rate, conception rate and herd in-calf rate

Definitions of these terms were those given by Macmillan (1974) and Macmillan and Watson (1973). Submission rate was defined as the percentage of cows from each genetic line, which were mated or inseminated at least once during the first four (SR28) or seven weeks (SR49) of mating. Conception rate was defined as the percentage of cows conceiving to the first insemination (CR1st). Herd in-calf rate was defined as the percentage of cows from each genetic line which conceived during the first four (HIR28) or seven weeks (HIR49) after the start of mating. Conception rate to the first service and its associated SR28 and HIR28 are important reproductive parameters for herds in which a concentrated calving is a major objective (Macmillan and Watson, 1973).

Statistical analyses

The categorical variables, induction rate, percentage of anoestrus cows, incidence of difficult calvings, percentage of cows calvings with abnormal presentation of the calf, percentage of female calves born to an AI service, percentage of dead calves and the percentage of cows registering at least one NM with the bull during the mating season were analysed by chi-square analysis using PROC FREQ (SAS, 1989). Odds ratios (OR) and their corresponding 95% confidence interval were calculated to test differences between genetic lines. For all the quantitative variables analysed, histograms and frequency distributions were produced to ascertain whether the data were normally distributed. The procedure UNIVARIATE (SAS, 1989) was used for this purpose. Continuous variables normally distributed were analysed using least-squares analysis of variance using GLM (SAS, 1989). Results are reported as least-squares means and the standard error of the difference (s.e.d) for the contrast H *vs.* L.

Cow birth date, age at first calving and number of lactations

Cow birth date (Julian), age at first calving (days) and number of lactations initiated in the herd were analysed with a model containing the effects of genetic line, sire nested within genetic line and cow nested within sire and genetic line. For age at first calving, the model also included the effect of the cow's date of birth as a linear covariate. Sire and cow were regarded as random effects and differences between genetic lines were tested using the mean square of sire nested within genetic line as the error term.

Gestation length, calving interval, services per conception and times mated

Gestation length, calving interval, services per conception and the total number of times the cow was mated during each lactation were analysed with a model that included the effects of genetic line, sire nested within genetic line, cow nested within sire and genetic line, parity number, calving type (normal or induced), year of calving (1990 to 1997), month of calving (July to October), and all possible two-way interactions. Interactions not contributing significantly to the reduction of sums of squares of the residuals were dropped from the model and the reduced model refitted. Differences between genetic lines were tested using the mean square of the random effect of sire nested within genetic line as the error term. All other tests of significance for fixed effects used the error MS in the denominator of the corresponding *F*-test.

Calving pattern

The calving pattern of H and L cows was described using the intervals proposed by Macmillan et al. (1984a) based on the PSC to allow comparisons with other New Zealand studies. Additionally, the variable DTC was analysed using survival analysis as described in the following section.

Postpartum intervals

For the postpartum intervals, only cows that were artificially inseminated or naturally mated at least once during the mating season were eligible for follow up. In total 326 lactations (collected during 1992-1997 and from 62 H and 64 L cows sired by 13 H and 15 L sires) met this criterion. Dates of calving, gestation lengths and calving intervals from a recorded abortion (only two records in total) were excluded from the respective analyses. Conception was assumed to have occurred when an AI or NM resulted in a live calf, an abortion or a cow checked pregnant by a veterinarian.

Univariate survival analyses on postpartum intervals

The reproductive information collected during the 6 years analysed was pooled and the intervals DO, FSCO and SMCO were subjected to univariate non-parametric survival analysis using PROC LIFETEST (SAS, 1989). Survival analysis is a regression technique for data analysis in which the outcome variable is timed to an event (Cox, 1972; Kalbfleisch and Prentice, 1980). Several studies have reported analysis of reproductive data of dairy cattle using this technique (Lee et al. 1989; Pankowski et al. 1995; Pursley et al. 1997a). Advantages of the technique include the use of censored records for which the event of interest was not observed. In the analysis of reproductive data, censoring occurs when a cow fails to conceive during the mating period. For an empty cow, the intervals

DO, FSCO and SMCO are regarded as being censored because only their lower bound is known. Data with censoring cannot be analysed ignoring the censored observations because, among other things, the less fertile individuals are generally more likely to be censored. The analysis methodology must correctly use the censored as well as the non-censored observations. Survival analysis addresses this problem by appropriately including the information contained in the censored records (SAS, 1989).

Submission rate, conception rate and herd in-calf rate

From the univariate survival analyses, survival curves for the intervals SMFS and SMCO were estimated using the Kaplan-Meier option available in PROC LIFETEST (SAS, 1989). Differences between genetic lines for the specified intervals were tested using the Log Rank test and the Wilcoxon test given as default options in PROC LIFETEST (SAS, 1989). Additionally, plots of the cumulative distribution function (CDF) obtained from the survival analyses are given for each of the postpartum intervals analysed. Additionally, for each genetic line, submission rates to the 4^{th} week, and conception rate to first service were calculated respectively from the CDF's of the intervals SMFS and FSCO. Additionally, HIR28 and HIR49 for H and L cows were calculated from the CDF of the interval SMCO.

Survival analyses of postpartum intervals using proportional hazards multiple regression

It was also of interest to explore the association of independent variables with the fertility variables represented by each of the above mentioned postpartum intervals. For this purpose, stepwise proportional hazards multiple regression analyses were performed using PROC PHREG (SAS, 1996). The following Cox proportional hazards (Cox, 1972) multiple regression model was fitted to the data on each interval:

$$\lambda_{ij}(t) = \lambda_{0j}(t)\exp\left(\sum_{i=1}^{n}\beta_i x_i\right) \qquad [7.1]$$

This analysis was stratified by year of calving, since number of submissions (for the interval SMFS) or number of pregnancies (for the interval SMCO) per time varied between years. Thus in equation [7.1], $\lambda_{ij}(t)$ is the probability that cow *i* calving in year *j* is submitted (for the interval SMFS) or becomes pregnant (for the interval SMCO) at *t* days after the start of mating (i.e. the hazard function). This probability depends on the covariates represented by the x's on the right hand side of equation [7.1], and a baseline hazard function, $\lambda_{0j}(t)$. The baseline hazard function represents the unknown baseline probability of submission or pregnancy when all the covariates are equal to zero. For each independent variable in the model, a hazard ratio (analogous to a relative risk) was estimated (Pankowski et al. 1995; Kristula and Bartholomew, 1998).

Categorical (coded as zeros or ones) and continuous variables were included as independent variables in model equation [7.1] to assess their association with the event of interest represented by each interval. Continuous variables included were the percentage of USA Holstein genes in cows from the H and L lines, the breeding values for production traits and TOP of the sires of cows, as described above; the cows' yield per lactation of milk, milkfat and protein; the cows' live weight at calving estimated from individual growth curves (García-Muñiz et al. 1998b), and dates of calving (Julian). Categorical variables included were genetic line (0 = light, 1 = heavy); parity number (0 = first parity, 1 = second and beyond); calving type (0 = normal, 1 = induced); sex of calf (0 = female, 1 = male or twins); anoestrus treatment (0 = no, 1 = yes), and calving difficulty (0 = no, 1 = yes). In all the models genetic line and percentage of USA Holstein genes in cows were first forced in the model. The stepwise model building option available in PROC PHREG (SAS, 1996) was used. Significance levels of 0.25 and 0.05 were required for independent variables to enter and to remain in the model, respectively.

Results

Breeding values of sires of cows

Production traits

As planned, sires contributing to the formation of the H line had higher BV for LW than those contributing to the formation of the L line. Heavy sires also had significantly higher BV's for yield of milk, milkfat, milk protein, and fat percentage and protein percentage. However, H and L sires had similar BV's for survival and breeding worth (Table 7.1).

Table 7.1: Least squares means for the breeding values for production traits of the bulls used to develop the heavy and light mature live weight selection lines of Holstein-Friesian cows.

		Genetic line			
Item	Units	Heavy	Light	s.e.d[1]	Significance[2]
Number of sires	n	13	15		
Number of cows	n	62	64		
Live weight BV	kg	88.0	29.4	3.2	***
Milk yield BV	*l*	1039.5	693.3	55.2	***
Fat yield BV	kg	32.2	26.9	1.2	***
Protein yield BV	kg	30.2	20.6	1.5	***
Fat percentage BV	%	4.41	4.68	0.06	***
Protein percentage BV	%	3.51	3.57	0.02	*
Survival BV	%	0.25	0.41	0.22	NS
Breeding worth	$	46.5	48.9	4.3	NS

[1] s.e.d = Standard error of the difference.
[2] NS = not significant; * = P < 0.05; *** = P < 0.001.

Traits other than production

Sires of H cows also had higher BV's for TOP related to body size such as stature, body capacity and rump width, and higher (i.e. desirable) BV's for udder conformation traits than L sires. Cows from the L line were also sired by bulls with higher BV for rump angle (i.e. more sloping pelvises) and higher BV for milking speed (Table 7.2).

Table 7.2: Least squares means for the breeding values for traits other than production (TOP) of the bulls used to develop the heavy and light mature live weight selection lines of Holstein-Friesian cows.

		Genetic line				Description and scale of measurement for Traits Other than Production		
Item	Units	Heavy	Light	SED	Significance[1]			
Number of sires	n	13	15					
Number of cows	n	62	64					
TOP scored by the farmer								
Adaptability to milking	units	-0.04	-0.02	0.05	NS	Slowly	1—5—9	Quickly
Farmer's overall opinion	units	0.10	0.03	0.04	NS	Undesirable	1—5—9	Desirable
Milking speed	units	-0.07	0.11	0.05	***	Slow	1—5—9	Fast
Shed temperament	units	-0.02	-0.03	0.05	NS	Vicious	1—5—9	Placid
TOP scored by the inspector								
Capacity	units	0.47	-0.08	0.05	***	Frail	1—5—9	Robust
Stature	units	1.25	0.09	0.05	***	Under 105	1—5—9	Over 140 cm
Dairy conformation	units	0.39	-0.18	0.04	***	Undesirable	1—5—9	Desirable
Front udders	units	-0.06	-0.25	0.05	***	Loose	1—5—9	Strong
Rear udders	units	0.12	-0.26	0.05	***	Low	1—5—9	High
Front teat placement	units	0.02	-0.25	0.04	***	Wide	1—5—9	Close
Rear teat placement	units	-0.02	-0.10	0.07	NS	Wide	1—5—9	Close
Udder support	units	0.004	-0.32	0.06	***	Weak	1—5—9	Strong
Udder overall	units	0.03	-0.39	0.06	***	Undesirable	1—5—9	Desirable
Rump angle	units	-0.10	0.00095	0.04	**	Pins high	1—5—9	Pins low
Rump width	units	0.36	0.00306	0.05	***	Narrow	1—5—9	Wide
Legs	units	-0.05	0.04	0.02	***	Strait	1—5—9	Sickled/curve

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

Birth date, age at first calving, gestation length, calving interval, services per conception, lactations initiated and lactation length

Cows from the H line tended to be born about four days later in their corresponding calving season than cows from the L line. They were also mated more times during the mating season than L cows. However, cows from the H and L lines did not differ for age at first calving, number of lactations initiated in the herd, services per conception, calving interval or gestation length. Gestation length was shorter than the expected value of 282 days, and this was due to the effect of induction. The effect of induction was to significantly shorten the gestation length for the induced cows (i.e. induced: 268 days *v.* non-induced: 282 days; P < 0.001). After adjusting for induction, parity number, sire and cow effects, gestation lengths were only slightly longer (P > 0.10) for cows from the H line. Cows from the H and L lines did not differ for the number of lactations initiated in the herd nor for the length of the lactation (Table 7.3).

Table 7.3: Least squares means for date of birth, age at first calving, gestation length, times mated per lactation, services per conception and calving interval of genetically heavy or light Holstein-Friesian cows calving during 1992 to 1997.

	Genetic line			
Trait	Heavy	Light	s.e.d	Significance
Date of birth (Julian days)[1]	231.0	227.0	1.8	†
Age at first calving (days)[1]	730.2	728.2	3.6	NS
Gestation length (days)[2]	276.2	274.0	0.98	NS
Times mated[3]	1.61	1.38	0.08	*
Services per conception[4]	1.45	1.32	0.09	NS
Calving interval (days)[5]	374.6	372.8	6.13	NS
Lactations initiated in the herd[6]	2.8	2.7	0.50	NS
Lactation length (days)[6]	246.0	252.0	4.2	NS

[1] 28 sires (13 H and 15 L); 126 cows (62 H and 64 L); 6 birth years (1990-1995); 6 calving years (1992-1997). Cow date of birth fitted as a covariate (slope = - 1.3 ± 0.02 d/d; P < 0.001).

[2] 24 sires (12 H and 12 L); 88 cows (44 H and 44 L); 5 calving years (1992-1996); 207 gestation lengths (107 H and 100 L).

[3] Includes both cows that were mated (AI or NM) and became pregnant and cows that were mated but failed to conceive. There were 28 sires (13 H and 15 L), 120 cows (59 H and 61 L); 6 mating years (1992-1997) and 328 lactations (165 H and 163 L).

[4] Includes only those cows that were mated (AI or NM) and became pregnant. There were 28 sires (13 H and 15 L), 114 cows (56 H and 58 L), 6 mating years (1992-1997) and 297 lactations (150 H and 147 L).

[5] 24 sires (12 H and 12 L); 89 cows (44 H and 45 L); 5 calving years (1992-1996); 212 calving intervals (110 H and 102 L).

[6] 28 Sires (13 H and 15 L); 126 cows (62 H and 64 L); 338 lactations (172 H: 62 1st, 44 2nd, 31 3rd, 35 ≥ 4th; and 166 L: 64 1st, 45 2nd, 27 3rd, 26 ≥ 4th); six birth years (1990-1995) and six calving years (1992-1997).

Induction, anoestrus, empty rate and difficult calvings

Cows from the H line were almost three times more likely to be induced to calve (OR = 2.6; P < 0.05) and almost six times more likely to face a breached calving (OR = 5.8; P < 0.05) than L cows. However, there was no difference between the H and L cows in the incidence of difficult calvings, anoestrus cows, and dead calves. The overall empty rate (including maiden heifers naturally mated) was similar for H and L cows at 7.0% and 7.5%, respectively (Table 7.4).

Table 7.4: Odds ratio and 95% confidence interval for the percentage of cows induced to calve, with difficult calvings, breached calvings, anoestrus, mated to the first observed oestrus, empty, naturally mated, and heifer calves born to an AI for genetically heavy or light Holstein-Friesian cows calving during 1992 to 1997.

Trait	n	Genetic line		Odds ratio	95% CI	Significance
		Heavy	Light			
Induced calvings	328	10.5	4.2	2.6	1.10-6.5	*
Breached calvings	328	3.5	0.6	5.8	0.99-37.0	*
Dead calves[1]	338	8.7	6.0	1.4	0.6-3.1	NS
Difficult calvings	328	12.2	13.4	0.66	0.35-1.2	NS
Anoestrum treatment[2]	329	14.0	11.0	1.25	0.70-2.2	NS
Cows mated at their first oestrus cycle	327	20.4	16.9	1.20	0.76-1.9	NS
Adult cows with at least one NM[3]	329	22.0	16.5	1.33	0.85-2.0	NS
Empty rate[4]	457	7.0	7.5	0.94	0.49-1.8	NS
Heifer calves as possible replacements[5]	338	22.0	26.5	0.83	0.57-1.2	NS

[1] Includes calves dead at birth or soon after as well as those with an emergency slaughter because of induction.
[2] Includes both cows that conceived and cows that were empty at the end of the mating season.
[3] Includes only those cows exposed to clean up bulls after the 7-weeks of AI.
[4] Includes both multiparous cows and maiden heifers naturally mated (n = 457).
[5] i.e. heifer calves born alive to an AI service.

Calving pattern

The intervals derived to describe the calving pattern of H and L cows are given in Table 7.5 and the frequency distributions are depicted in Figure 7.4. The average PSC date was August the 4th or day 216 of the year. However, by the PSC 12.8% of the H and 17% of the L cows had already calved. This meant that 50% of the cows from each genetic line had calved by the end of a period of 15 or 12 days from the date of the PSC for H and L cows, respectively. The next 25% calved over a period of 20 or 13 days for H and L cows respectively, and the last 25% calved over 52 days for H and 65 days for L cows. Consequently, the average duration of the calving period, starting from the PSC, was 86 days for the H and 90 days for L cows. The final calving spread was 106 and 131 days for the H and L cows, respectively. Thus, even with a lower proportion of induced calvings, cows from the L line had a more concentrated calving pattern than H cows (Figure 7.4b).

Table 7.5: Calving date, percentage of cows calving before the planned start of calving, and intervals from the planned start of calving used to describe the calving patterns of cows from the heavy and light mature live weight selection lines calving during 1992 to 1997.

Item	Genetic line	
	Heavy	Light
Planned start of calving (date)	4th August	4th August
Median calving date	19 August	15 August
Mean calving date	25 August	20 August
Cows calved before the PSC (%)	12.8	17.0
Interval PSC to median (days)	15.0	12.0
Interval median to 75% (days)	20.0	13.0
Interval 75% to end-of-calving (days)	52.0	65.0
Total calving period (days)	86.0	90.0
Total Calving spread (days)	106.0	131.0

Univariate survival analyses on postpartum intervals

Cows from the H and L lines had similar mean intervals for the variables CFH, DO, and SMFS. However, cows from the L line had slightly longer CFS intervals but significantly shorter SMCO and FSCO intervals than H cows. In addition, cows from the L line calved on average 6 days earlier than H cows (Table 7.6). The percentage of censoring in the data ranged from 7.9% to 10.6% for DO of L and H cows respectively. Pooled across postpartum intervals, average censoring was 8.7% and 10.5% for cows from the L and H lines, respectively (Table 7.6).

Table 7.6: Means (± SE), tests of significance for the survival curves, and percent of censored observations for the postpartum intervals and calving dates of genetically heavy or light Holstein-Friesian cows calving during 1992 to 1997.

		Genetic line							
		Heavy		Light		Significance tests		Censored (%)	
Trait[1]	Units	n	Mean ± SE	n	Mean ± SE	Log rank	Wilcoxon	Heavy	Light
CFH	Days	167	43.5 ± 1.8	160	42.4 ± 1.8	NS	NS	0	0
CFS	Days	163	78.0 ± 1.5	160	82.7 ± 1.5	†	†	0	0
DO	Days	163	93.5 ± 2.1	160	93.6 ± 2.0	NS	NS	10.6	7.9
SMFS	Days	164	11.7 ± 0.7	162	11.6 ± 0.8	NS	NS	0	0
FSCO	Days	164	17.2 ± 1.8	163	13.4 ± 1.8	†	*	10.4	9.1
SMCO	Days	164	28.5 ± 1.8	162	24.4 ± 1.9	†	*	10.4	9.1
DTC	Days	172	239.0 ± 1.9	165	233.0 ± 1.8	*	*	0	0

[1] CFH = Interval calving to first heat; CFS = Interval calving to first service; DO = Days open; SMFS = Interval start of mating to first service; FSCO = Interval first service to conception; SMCO = Interval start of mating to conception; DTC = Days to calving.

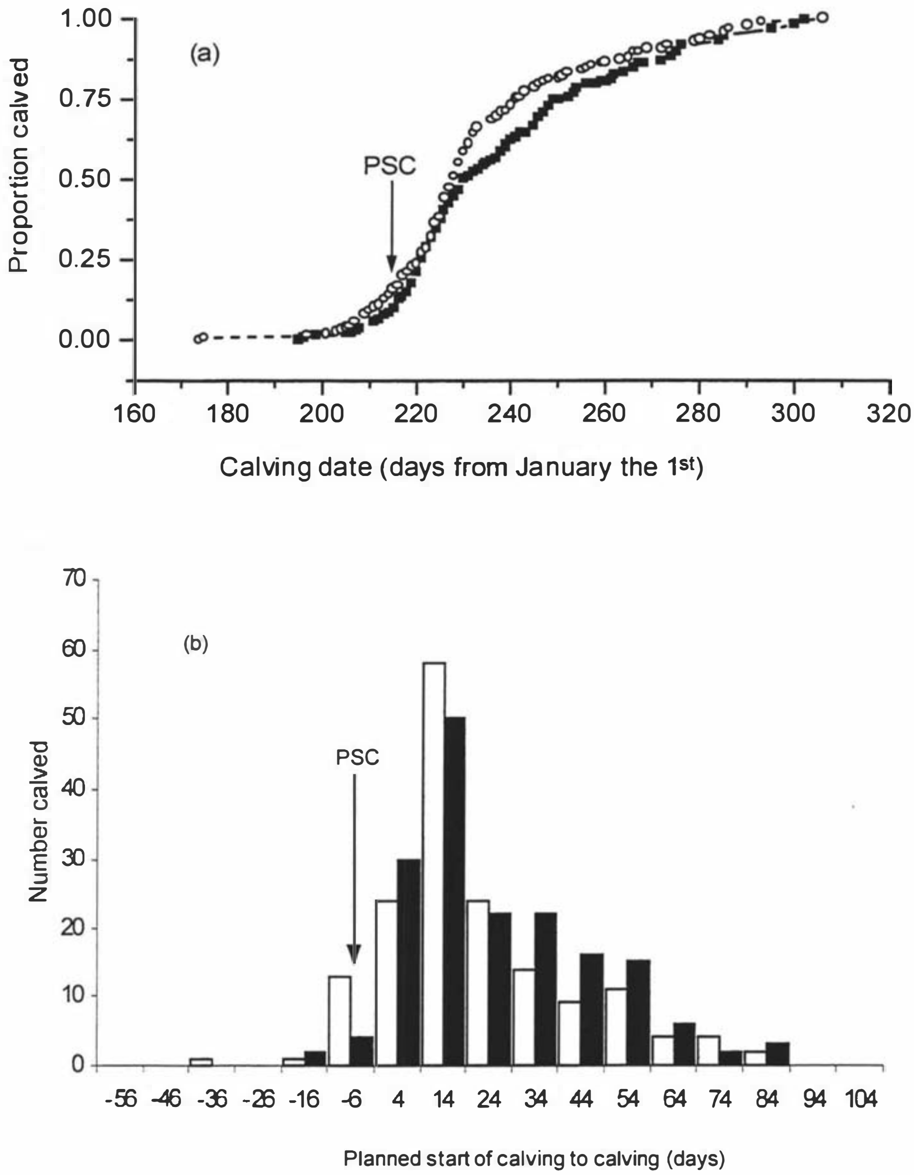

Figure 7.4: Cumulative distribution function (a) for calving date of genetically heavy (—●—) or light (- -○- -) and frequency distribution (b) for the planned start of calving to calving of genetically heavy (■) or light (□) Holstein-Friesian cows.

Submission rate, conception rate and herd in-calf rate

Submission, conception, herd in-calf rates and the percentage of cows calving in the first 21 days after the planned start of calving as calculated from their respective survival curves are summarised in Table 7.7. Three- and four-week submission rate calculated from the CDF of the interval SMFS (Figure 7.5a) were very high and not different for H and L cows. However, conception rate to the first service was higher for L cows at 64.5% compared to 53.7% for cows from the H line (Figure 5b). In addition, herd in-calf rates after 4-weeks of AI and at the end of the 7-weeks AI period, calculated from the CDF for the interval SMCO (Figure 7.5c), were higher for cows from the L line. The percentage of cows calving during the first 21-days after the PSC was higher for cows from the L line (Table 7.7).

Table 7.7: Submission rate, first service conception rate, herd in-calf rate and percentage of cows calving in the first 21 days after the planned start of calving.

	Genetic line		
Trait	Heavy	Light	Significance
First service submission rate (%)			
Three weeks	91.0	92.6	NS
Four-weeks	94.5	94.4	NS
First service conception rate (%)	53.7	64.5	*
Herd in-calf rate (%)			
Four-weeks	58.4	69.5	*
Seven-weeks	78.8	85.3	*
Cow calved from the PSC[1] to day 21 (%)	56.4	70.0	*

[1] PSC = Planned start of calving.

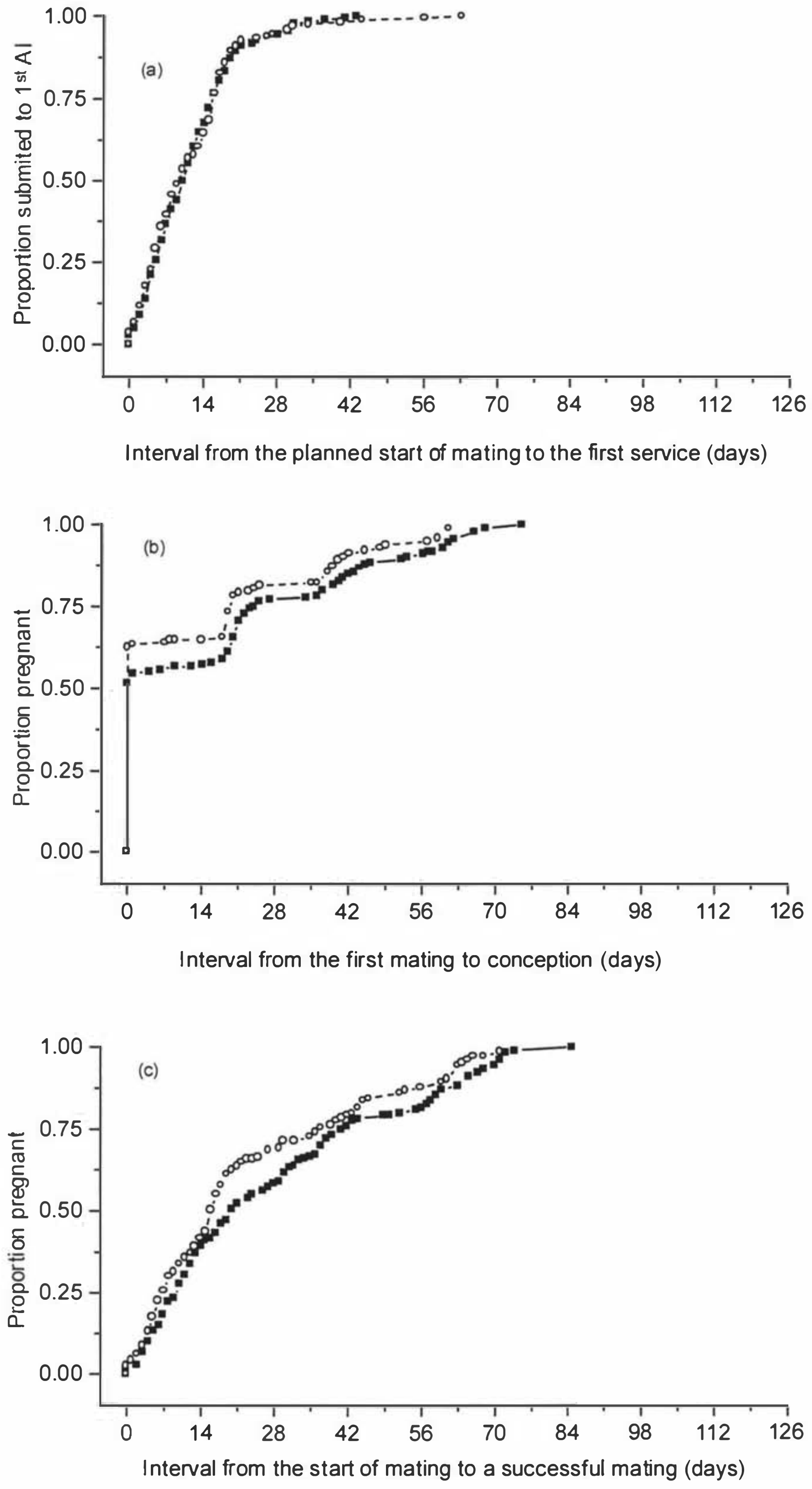

Figure 7.5: Cumulative distribution function for the intervals SMFS (a), FSCO (b) and SMCO (c) of genetically heavy (—●—) or light (—○—) Holstein-Friesian cows.

Results from the multiple regression analyses on the postpartum intervals

Only the intervals SMFS and SMCO showed significant associations with some of the independent variables analysed. The results of the multiple regression analyses are presented in the following section.

Interval start of mating to first service (i.e. submission rate)

Results from the stepwise multiple regression analysis for the interval SMFS are summarised in Table 7.8. Regression coefficients with corresponding standard errors (SE) and hazard ratios (HR) with their 95% confidence interval (CI) are given for the effects included in the model. For this particular interval, the hazard function models the probability of a cow being submitted after the start of mating given that she is at 'risk' of being submitted (i.e. she has calved and is undergoing postpartum involution with the intention of being submitted to AI). In line with the univariate survival analyses, there was no difference between genetic lines in the probability of submission. There was also no effect of percentage of USA Holstein genes in H and L cows on the probability of submission. However, the probability of submission of a cow induced to calve was only 56% that of a herdmate having a normal calving. Similarly, the probability of submission of cows treated for anoestrus was only 57% that of a herdmate resuming normal oestrus cycle, and cows calving later in the season were more likely to have lower chances of being submitted to AI (Table 7.8).

Table 7.8: Regression coefficient estimates, standard errors (SE), hazard ratios (HR), 95% confidence intervals for HR and significance tests obtained from the stepwise proportional hazards multiple regression analysis for the interval SMFS of heavy or light Holstein-Friesian cows.[1]

Item	Regression coefficient	SE	Hazard ratio	95% CI	Probability
Genetic line					
(Heavy =1)	-0.064	0.154	0.938	0.69 to 1.27	NS
(Light = 0)	0.0		1.0		
Percentage of USA Holstein genes in cows	0.463	0.515	1.590	0.58 to 4.36	NS
Calving type					
(Induced = 1)	-0.582	0.229	0.559	0.35 to 0.88	0.01
(Normal = 0)	0.0		1.0		
Anoestrus treatment					
(Yes = 1)	-0.600	0.193	0.566	0.38 to 0.83	0.001
(No = 0)	0.0		1.0		
Calving date[2]	-0.005	0.002	0.995	0.99 to 1.00	0.03

[1] The analysis was stratified by year of calving and genetic line and percentage of USA Holstein genes were first forced into the model.
[2] Days since January the 1st on the calving year.

Interval start of mating to conception (i.e. herd in-calf rate)

The results from the stepwise multiple regression analysis for the interval SMCO are summarised in Table 7.9. For this particular interval, the hazard function models the probability that a cow becomes pregnant at any given day, *t*, after the start of mating, given that she is at 'risk' of becoming pregnant (i.e. she has been submitted to AI and has been mated at least once). In line with the univariate analyses for the interval SMCO, cows from the L line were slightly more fertile than H cows. After adjusting for the effect of USA Holstein genes, the probability of an H cow becoming pregnant during the period of mating was still lower at 73.5% that of an L cow (i.e. HR = 0.735) but the difference only approached significance (P = 0.056). In the range from 0 to 0.75, the increase in the proportion of USA Holstein genes in cows had no effect on the probability of pregnancy. However, for a cow calving one day later during the calving season the probability of becoming pregnant was only 0.992 of that of a cow calving one day earlier. Finally, cows sired by bulls with above than average BV for rump angle were more likely to get in calf during the mating season than cows sired by bulls with lower than average BV for rump angle (Table 7.9).

Table 7.9: Regression coefficient estimates, standard errors (SE), hazard ratios, 95% confidence intervals (CI) for hazard ratios and significance tests obtained from the stepwise proportional hazards multiple regression analysis for the interval SMCO of heavy or light Holstein-Friesian cows.[1]

Item	Regression coefficient	SE	Hazard ratio	95% CI	Probability
Genetic line					
(Heavy = 1)	-0.307	0.166	0.735	0.53 to 1.01	0.056
(Light = 0)	0.0		1.0		
Percentage of USA Holstein genes in cows	1.048	0.954	2.854	0.96 to 8.46	NS
Calving date[2]	-0.008	0.002	0.992	0.98 to 0.99	0.03
Sire of cow BV for rump angle	0.644	0.292	1.905	1.07 to 3.38	0.02

[1] The analysis was stratified by year of calving and genetic line and percentage of USA Holstein genes in cows were first forced into the model.

[2] Days since January the 1st on the calving year.

Discussion

Sires of cows breeding values for production traits and TOP

As planned, sires contributing to the formation of the H line had higher BV's for LW and other traits related to size such as stature and capacity than sires contributing to the formation of the L line. In addition, H sires also had higher BV's for yield of milk, milkfat, milk protein, fat percentage, and protein percentage than L sires. This positive relationship between size and yield agrees with the moderate to high genetic correlation between size and yield reported for New Zealand dairy cattle (Ahlborn and Dempfle, 1992).

Induction, breached calvings, dead calves, anoestrus cows

Cows from the H line were almost three times more likely to be induced to calve than L cows (10.5% *v.* 4.2%) and almost 6 times more likely to face a breached calving than L cows (3.5% *v.* 0.6%). The H and L cows had similar percentage of dead calves, anoestrus cows and empty cows. The available survey data indicates that empty rates in New Zealand dairy herds are between 7% to 8% per annum (Castle, 1963; Macmillan et al. 1997). The empty rates of H and L cows from the present experiment were within this range.

Induction of premature calving using synthetic corticosteroids was introduced into New Zealand during the early 70's (Welch, 1971; Welch et al. 1973; McGowan, et al. 1975). Since then, its popularity has increased to become a necessary management tool to achieve a concentrated calving pattern in the New Zealand seasonal system (Macmillan, 1995). One of the major benefits of induction is that it increases the cow's lifetime to about 5 lactations compared to 3.5 to 4 lactations if the technique was abandoned. In other words, induction has allowed herd wastage rates of 20% instead of 25 to 30% (Macmillan, 1995). For some people in the dairy industry, however, induction is regarded as a tool that saves cows at the cost of some calves (Balvert, 1995). Average induction rate for commercial farms derived from survey data has been reported at about 11% (Armer et al. 1993; Balvert, 1995). A figure similar for the induction rate of H cows was found in the present study. Induction of calving and the use of CIDR to treat anoestrus cows have also increased steadily over the recent years and people in the industry are asking if the national breeding programme is producing cows with increased yield at the expense of decreased reproductive performance (Balvert, 1995).

Their significantly later calving date (thus shorter calving to first mating intervals) and the higher incidence of induction might have been the major determinants of H cows achieving lower reproductive performance. In contrast, the slightly shorter gestation lengths and higher conception rate to the first service for L cows translated into fewer inductions, earlier calvings and more concentrated calving pattern than that of H cows. Calving intervals for H and L cows were only 375 and 373 days, respectively, and reflect the high reproductive performance of New Zealand cows and the need of the seasonal system of maintaining a 365 days CI. These figures agree with the range of 364 to 384 days CI reported in other New Zealand experiments (Fielden et al. 1980; Grosshans et al. 1996; Macmillan and Moller, 1977).

Calving pattern

The calving patterns of H and L cows pooled for the six calving years (1992 to 1997) were different as assessed by the intervals proposed by Macmillan et al. (1984a). Despite their higher induction rate, cows from the H line calved on average 6 days later than L cows. Cows from the L line not only calved earlier than H cows, but also a higher proportion of them calved during the first 21 days after the PSC. This more compact calving pattern was evidenced by their shorter intervals from **PSC-to-median** calving date (H: 15 *vs.* L: 12 days), and median to 75% (H: 20 *vs.* L: 13 days). The longer interval from **75% to end-of-calving** for L cows (H: 52 *v.* L: 65 days) clearly reflected the higher induction rate for the late calving cows from the H line. Despite this shortening through induction of the interval **Median-to-75%** for H cows, the final **calving period** was very similar for H (86 days) and L cows (90 days). This calving pattern largely reflected the conception pattern of H and L cows (as discussed later) and the differences between the H and L cows in their dates of first calving as two-year-olds. Macmillan et al. (1984a and 1984b) suggested that a more concentrated calving pattern should result in a higher submission rate and a higher conception rate because of a longer interval from calving to the next AI programme. Differences between genetic lines in the selected intervals clearly reflected the comparative success of both the first (PSC to median) and the second round of mating (Median to 75%), as well as the time and extent of induced calving (75% to end-of-calving) (Macmillan et al. 1984a and 1984b).

Postpartum intervals

Interval from calving to first heat

The interval from calving to the first recorded postpartum heat was similar for cows from the H (43.5 days) and L (42.4 days) lines. These values are within the range of 31 to 62 days reported in other grazing studies with field data of commercial herds (MacDiarmid and Moller, 1981) and research herds of Holstein-Friesian cows in New Zealand (Burke et al. 1995; Macmillan and Clayton, 1980; McDougall et al. 1995a and 1995b).

Interval from calving to first service

The interval from calving to the first mating was slightly longer for the L (83 days) than for the H cows (78 days) cows. This difference reflected the L cows' earlier calving date of about 6 days. These values are comparable to those reported for field data of New Zealand Holstein-Friesian cows in other studies (range 76 to 87 days: Fielden et al. 1980; Grosshans et al. 1997). After calving, New Zealand cows require about 32 days to complete uterine involution and about 42 days to start resuming oestrus cycles (Moller, 1970). Shorter intervals from calving to first mating have been associated with lower conception rate to the first service especially with high yielding dairy cows (Dhaliwal et al. 1996). On the other hand, longer CFS intervals will be associated with an increase in days open (Oltenacu et al. 1980), longer calving intervals and ultimately lower milk yield per day of life in the herd (Macmillan, 1979). For the New Zealand seasonal system, all cows seen in oestrus are mated after the commencement of the mating period, regardless of their post-calving interval (Macmillan, 1974).

Interval calving to conception (Days open)

Despite having longer CFS intervals, cows from the L line achieved similar days open as H cows. The average of 93.5 days open obtained for cows from the H and L line was slightly larger than that of 89.5 reported by Grosshans et al. (1997) for second lactation Holstein-Friesian cows using a large data set.

Interval from the start of mating to first service

Cows from the H and L lines did not differ for the interval from the start of mating to the first mating. The average duration of 13 days for the SMFS interval of H and L cows was similar to values reported in other New Zealand experiments (range 9.9 to 13 days; Macmillan et al. 1987; Macmillan et al. 1997; Wilson et al. 1985). However, the average SMFS calculated from the present experiment was lower than the 18.7 and 19.4 days reported by Grosshans et al. (1996) for first and second lactation New Zealand Holstein-Friesian cows, respectively.

Interval from the start of mating to conception

The interval from the start of mating to the last recorded mating resulting in a pregnancy (SMCO) was lower for L (24.4 days) than for H (28.5 days) cows. The values obtained are in agreement with other values reported in the literature for New Zealand dairy cows (range 19.9 to 33.3 days; Grosshans et al. 1996; Macmillan, 1995; Macmillan et al. 1987; Xu et al. 1995 and 1996).

Interval from the first service to conception

The interval from the first service to the last recorded AI service or NM resulting in a pregnancy (FSCO) was lower for L (13.2 days) than for H (17.2 days) cows. The value obtained for L cows agrees with that of 11 days calculated by Fielden et al. (1980) for 20 town supply herds ranging from 75 to 350 cows herd size with lactation lengths of 291 days and yielding 3730 *l* milk per cow per lactation. More recently, Grosshans et al. (1997) using a larger data set calculated similar values of 14.5 and 13.3 days for the interval FSCO of first and second lactation cows in New Zealand. Values much larger than the ones obtained in the present study are reported for European Friesian cows (range 22 to 39 days; Dhaliwal et al. 1996; Hoekstra et al. 1994; Ouweltjes et al. 1996a and 1996b) and USA Holstein cows (average 45 days; Silva et al. 1992; Simerl et al. 1992).

Submission rate

First service submission rates to the 4th week after the start of mating were not different for H (92.2%) and L cows (92.3%). However, the figures were slightly higher than the 88.3% calculated from survey data of 294 New Zealand commercial herds by Fielden and Macmillan (1973), and the 88% reported by Macmillan (1975) for 315 seasonal herds for the season 1972.

First service conception rate

Conception rate to first service was higher for cows from the L line at 63.5% compared to 53.7% of H cows. The average value for cows pregnant to first service in New Zealand is around 60%, with some farmers achieving values as high as 75% (Xu et al. 1995). Although the CR1st of the two lines is in the range of these values, the value for the L cows was consistently higher than that of the H cows. Conception rate at first service is increased by a longer period between calving and first mating (Butler and Smith, 1989) especially for high yielding cows (Dhaliwal et al. 1996), and the occurrence of at least one heat before mating (Macmillan and Clayton, 1980). On the other hand, lower conception rates are expected for induced cows compared to cows undertaking a normal calving (Welch and Kaltenbach, 1977). In the present experiment there was no difference in the number of pre-mating heats shown by cows from the H and L lines nor in the proportion of cows mated at their first heat after calving. However, cows from the H line had slightly shorter calving to first mating intervals than L cows (L: 83 days *vs.* H: 78 days), and a higher proportion of them were induced to calve.

A negative relationship between cow body size and conception rate has been reported for dairy cattle (Badinga et al. 1985; Markusfeld and Ezra, 1993; Hansen et al. 1998). Markusfeld and Ezra (1993) reported lower probabilities of conception rate to the first service, independent of milk yield, for taller and heavier Israeli Holstein-Friesian cows. In addition, there is substantial evidence of a moderate to high (range –0.1 to –0.8) negative genetic correlation between measures of yield (milk, milkfat and protein) and the measures of fertility which are less likely to be influenced by the farmer's management decisions, such as first service conception rate and pregnancy rate to all inseminations (Biochard and Manfredi, 1994; Grosshans et al. 1997; Hodel et al. 1995; Hoekstra et al. 1994; Janson and Andréason, 1981; Oltenacu et al. 1991; Pryce et al. 1997; Van Arendonk et al. 1989; Weller and Ezra, 1996). Moreover, lower first service conception rates have been reported for high yielding (45.5%) compared to low yielding (52.8%) British Friesian cows (Dhaliwal et al. 1996). Similarly, for Dutch Black and White cows upgraded to USA Holstein, Ouweltjes et al. (1996b) found a negative correlation between milk yield and 56-day non-return rate. In the present experiment, cows from the H line not only had heavier mature live weights but also produced significantly more milk, milkfat, milk protein, and milksolids than L cows, and were sired by bulls with a higher proportion of USA Holstein genes in their pedigrees (See Chapter 1 and Chapter 8).

There is growing evidence that pregnancy rates per AI for the USA Holstein strain have decreased from 66% in 1951, to about 50% in 1975, to about 40% currently (Barton et al. 1996; Nebel and McGilliard, 1993; Pursley et al. 1997a and 1997b; Spalding et al. 1975); and more recently, reduced fertility has been reported in populations of dairy cattle heavily upgraded towards the USA Holstein such as the Dutch Black and White (Hoekstra et al. 1994; Ouweltjes et al. 1996a and 1996b). In contrast to the lower fertility of the USA Holstein cow, the fertility of the New Zealand HF cow is relatively high. Retrospective analyses of survey data (Castle, 1963; Moller, 1967; Fielden et al. 1980; Macmillan et al. 1984b; Macmillan and Clayton, 1980; Macmillan and Watson, 1973; Moller and Fielden, 1981) and research data (Macmillan and Taufa, 1983; McDougall et al. 1995a and 1995b; Xu et al. 1995 and 1996) on submission and conception rates indicate that the fertility of New Zealand dairy cows is indeed very high. In these studies conception rates to the first service ranged from 55% to 75%. In the present experiment, conception rate to the first service was within this range for cows from the L line (i.e. 64.5%), which were mainly of New Zealand ancestry (See Chapter 1).

Herd in-calf rate

Reflecting the differences in conception rate, herd in-calf rates to the first 4 weeks (H: 57.7%; L: 63.5%) and at the end of the 7-weeks of AI (H: 78.9%; L: 85.2%) were higher for cows from the L line. Reported values from field data for 4-weeks HIR range from 52.4 to 54.0% (Macmillan, 1974; Macmillan and Watson, 1973). Corresponding values for herd in-calf rate at the end of the 7-weeks AI range from 72% to 85.5% (Macmillan, 1974; Macmillan and Watson, 1973; Macmillan et al. 1981; Xu et al. 1996).

Results from the multiple regression analyses

Interval start of mating to first service (i.e. submission rate)

The probability of being submitted to AI was the same for H and L cows, and there was no effect of percentage of USA Holstein genes on the probability of H and L cows being submitted to AI. However, lower probabilities of submission were estimated for induced cows, cows treated for anoestrus problems and later calvers. The lower probability of submission for induced cows is explained almost entirely by the fact that cows in this category are often the tail end of the calving distribution. The negative effects of induction on postpartum reproductive performance are well-recognised and they include: longer calving to conception interval for induced cows, retention of foetal membranes after calving requiring veterinary treatment, a higher proportion of induced cows are culled for disease and reproductive failure, lower production (about 4% less) than that of a non-induced cow, calves from induced calvings are more likely to be dead at birth or submitted to an emergency slaughter (Armer et al. 1993; MacDiarmid and Moller, 1981; McGowan et al. 1975; Merral, 1972; Welch and Kaltenbach, 1977). Moreover, the effect of induction itself on New Zealand dairy cows has been associated with lengthening the intervals from calving to conception (Welch and Kaltenbach, 1977) and from PSM to conception (Macmillan et al. 1997). These effects, coupled with the restricted mating period of the seasonal system, leave fewer mating days for induced cows, and therefore their probability of being submitted is reduced to only 56% of that of a non-induced herdmate.

Similarly, anoestrus cows and cows calving later in the calving season are exposed to less mating days and their probability of submission is lower than that of cows calving early during the calving season and resuming oestrus cycles soon after calving. As pointed out by Macmillan et al. (1997), anoestrus is the major form of infertility in New Zealand dairy herds and often is closely linked to low levels of feeding during early lactation.

Interval from the start of mating to conception (i.e. herd in-calf rate)

After adjusting for the percentage of USA Holstein genes in H and L cows, the differences in herd in-calf rate between H and L cows detected by the univariate survival analysis of the interval SMCO were accounted by the differences in calving date and sire of cow BV for rump angle. The probability of a cow becoming pregnant given that she calved one day later during the calving season was 0.992 that of a herdmate calving one day earlier. Although this appears to be a small difference in fertility, if the different calving patterns of cows from the H an L lines are considered (i.e. the interval PSC to median was 15 days for H and 12 for L cows), the probability of an H cow becoming pregnant given that she calved at the median calving date was predicted to be only 88% of that of an H cow calving at the PSC. The corresponding figure for an L cow was slightly higher at 91% of that of an L cow calving at the PSC.

The sire of cow's breeding value for rump angle showed a significant effect on the probability of a cow becoming pregnant during the mating season. In the present experiment cows from the L line were sired by bulls with significantly higher breeding values for rump angle (i.e. more sloping pelvises). That is cows with sloping pelvises are more likely to get in-calf once mating commences. This finding is not new, Van Vleck et al. (1969) found a positive relationship (i.e. unfavourable) between reproductive problems and level rumps for USA Holsteins. Van Vleck and Norman (1972) also reported that cows with sloping rumps were culled less frequently for reproductive failure than cows with level rumps. Honnette et al. (1980) reported that first calving interval for cows with sloping rumps were shorter than average. Analysis for calving difficulty with data from the same population as used in the present analysis (García-Muñiz et al. 1998a; and Chapter 6) indicated that cows from sires with above average breeding value for rump angle were less likely to face a difficult calving. These results suggest that TOP (especially BV for rump angle) deserve more attention if improvements in fertility are desired.

Conclusions

Cows from the L line calved earlier during the calving season, had higher conception rates to the first service, a more concentrated calving pattern, were less likely to be induced to calve and ultimately showed a better reproductive performance than cows from the H line under the conditions of the present experiment.

Implications

Up to this point of the selection experiment, there is evidence of a slightly higher reproductive performance of the L cows and a higher probability of induction by H cows. This higher induction rate by H cows might be seen as an undesirable management practice due to the growing concern on animal welfare issues. Therefore, the results from the present experiment suggest that regardless of the benefits of farming high yielding, heavier mature live weight Holstein-Friesian cows, their lower fertility and proneness to induction must be given serious consideration in future breeding decisions.

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CHAPTER 8

Growth curves and productivity of Holstein-Friesian cows bred for heavy or light mature live weight

Abstract

This chapter presents data for live weights (LW) from birth to maturity, and for yields of milk and milk components per lactation of Holstein-Friesian cows from the heavy (H) and the light (L) mature LW selection lines at Massey University, New Zealand. Four non-linear equations (Brody, Gompertz, Logistic, and Von Bertalanffy) were fitted to the lifetime LW-age data of 97 cows (50 H and 47 L) and their goodness of fit was compared. At any lactation, yields per cow per lactation of milk, milkfat, milk protein, milksolids, and average LW predicted from the growth curve were used to calculate individual feed requirements and productivity indicators for the comparison of H and L cows. Productivity indicators were i) yields per lactation of milk and milk components; ii) output per cow of milk and milk components per kg of metabolic LW, and iii) annual feed conversion efficiency of dry matter (DM) into milksolids. The Von Bertalanffy function provided the best fit to the LW-age data, and prediction from this function was used in the present analyses. The breeding values (BV's) for LW of the sires (86.3 *vs.* 31.0 kg; s.e.d = 3.6; $P < 0.001$) used to develop the H and L lines were higher for the H line than for the L line, and cows from the H line were heavier at birth (41 *vs.* 35 kg; s.e.d = 3.6; $P < 0.05$) and at maturity (520 *vs.* 467 kg; s.e.d = 12; $P < 0.001$) than the L cows. Sires of H cows also had significantly higher BV's for yield of milk (1037 *vs.* 737 *l*; s.e.d = 64; $P < 0.001$), milkfat (33.0 *vs.* 27.5 kg; s.e.d = 1.0; $P < 0.001$), and milk protein (31 kg *vs.* 22 kg; s.e.d = 1.6; $P < 0.001$), and the H cows produced more milk (4708 *vs.* 4323 *l*/lactation; s.e.d = 80.9; $P < 0.001$), milkfat (207 *vs.* 198 kg/lactation; s.e.d = 3.4; $P < 0.05$), milk protein (157 *vs.* 150 kg/lactation; s.e.d = 2.5; $P < 0.05$) and milksolids (364 *vs.* 348 kg/lactation; s.e.d = 5.4; $P < 0.05$) than the L cows. However, the L sires had slightly higher value for Breeding Worth than the H sires (46 *vs.* 37 $; s.e.d = 4.1; $P = 0.07$), and there were only small differences in yields of milk or milk components between H and L cows when these were expressed per kg of $LW^{0.75}$ or per tonne of dry matter required (H: 84 *vs.* L: 87 kg milksolids yield/tonne DM eaten; s.e.d = 2.9; $P = 0.17$). The results indicate that the extra milksolids yield/lactation by the H cows (+ 16 kg) almost compensated for the effect of their extra LW (+ 46 kg), so that the H cows were only slightly less efficient than the L cows, as predicted by their respective sire's Breeding Worth.

Introduction

Relative to average live weight (LW) animals, heavier LW cows typically produce more milk (Ahlborn and Dempfle, 1992). However, cow LW also affects dairy farm profitability in the New Zealand pasture-based dairying system through maintenance requirements and marginal returns from beef from culled cows and calves sold for slaughter (Spelman and Garrick, 1997). The genetic evaluation system of cows and bulls in New Zealand includes LW of the lactating cow in the selection index and places a negative relative economic value on this component. This is done because the cost of the higher maintenance requirements is relatively larger than the benefit of the higher return from beef (Livestock Improvement, 1994).

Since 1989 two genetic lines of Holstein-Friesian cows, selected for heavy (H) or light (L) mature LW, have been developed at the Dairy Cattle Research Unit, Massey University. The overall aims of the project are to investigate the effects of genetic differences in cow LW on i) the pattern of growth from birth to maturity, ii) onset of puberty of the replacement heifer, iii) the feed conversion efficiency of lactating cows and growing heifers, iv) incidence of calving difficulty, and v) reproductive performance.

The pattern of growth of individual cows contained in a sequence of live weight-age data points can best be summarised in a few biologically interpretable parameters by means of growth curve analyses (Fitzhugh, 1976). Describing this pattern of growth from birth to maturity is particularly important in helping to assess the effect that selection for live weight has had on the parameters of the growth curve of H and L cows. This chapter presents the results from the analysis of growth curves of individual cows, the yield of milksolids and the estimated feed conversion efficiency of cows from the H and L lines born between 1990 and 1994.

Materials and methods

Source of data

The information consists of live weights recorded throughout the animal's life and yields per lactation of milk and milk components of Holstein-Friesian cows which were born between 1990 and 1995 from the H and L lines at the Dairy Cattle Research Unit, Massey University, New Zealand. In total, data on live weight were available for 120 cows (61 H and 59 L), sired by 28 bulls (13 H and 15 L). Corresponding figures for yield per lactation of milk and milk components were available for 96 cows (50 H and 47 L) sired by 24 bulls (12 H and 12 L).

Experimental design

High genetic merit Holstein-Friesian cows from the base (B) herd at the Dairy Cattle Research Unit, Massey University, New Zealand, were stratified by LW within parities, heavier cows were mated to bulls with high BV for LW and lighter cows were mated to bulls with low BV for LW. In the subsequent years, H-sired and L-sired cows were mated back to H or L bulls, respectively. Details of the mating strategy followed to develop the H and L lines were given by García-Muñiz et al. (1998) and have also been described in Chapter 1.

Breeding values of bulls

Breeding values of bulls for the production traits yield of milk (*l*), milkfat (kg), milk protein (kg), live weight (kg), survival (%), and values for Breeding Worth ($), were available for the July 1997 sire evaluation (Livestock Improvement, 1997) at the time when the analyses of the present Chapter were undertaken.

Breeding values were also available for the 14 traits other than production (TOP) described in Chapter 1. Bulls used to inseminate the herd were chosen so as to differ as much as possible in their BV for live weight. The aim of the project was to generate two lines of Holstein-Friesian cows with marked differences in mature live weight, but with similar genetic merit for farm profitability (See also Chapter 1).

Management of animals and information recorded

Data for live weight

Every year calves were born in spring during August to October. All heifer calves sired by H or L bulls were kept as replacements and reared on milk and colostrum until weaning at about 12 weeks of age. All heifer calves sired by H or L bulls were kept as replacements. Live weight was recorded at birth (except for the 1993 born calves) and at weaning. After weaning, all heifer calves were grazed as one single group at the home-farm until May the following year when they were 8 to 10 months old. At the end of May each year, the growing heifers were sent to graze at a neighbouring farm until about two months before first calving. During this period live weight was recorded every two or three months for heifers born in the years 1990-93. For heifers born in 1994-95, live weight was recorded monthly after weaning up to six months of age, fortnightly from six months to one year of age, monthly from one year to three months before first calving, and at calving (See Chapters 2 and 3). After calving live weight was recorded monthly until three months before the following calving.

Yield of milk and milk components

Milk yield by individual cows was recorded daily in the morning and in the afternoon using an automatic milk recording system (Westfalia Separator). Milk composition (fat % and protein %) and milk volume were measured on individual cows on 6 to 8 occasions at each lactation by routine herd testing carried out by Livestock Improvement Corporation personnel. Records for dates of calving and drying off, lactation length (days), culling dates, and yields per lactation of milk (*l*), fat (kg), protein (kg), and milksolids (kg) were also available for each cow. The structure of the data set for these variables is shown in Table 8.1.

Table 8.1: Number of lactations per month, year of calving and lactation number for heavy and light Holstein-Friesian cows.

	Month of calving			Year of calving				Lactation number			
Genetic line	Jul-Aug	Sep	Oct-Nov	91-93	94	95	96	1	2	3	≥4
Heavy	83	35	8	27	28	33	38	50	36	24	16
Light	87	19	9	28	20	31	36	47	32	18	18
Total	170	54	17	55	48	64	74	97	68	42	34

Number of cows: 97 (50 H, 47 L).
Number of sires: 24 (12 H, 12 L).
Number of records (i.e. lactations): 241 (119 H, 113 L).

Equations fitted to the live weight-age data

Non-linear regression [PROC NLIN, SAS, 1989)] was used to fit to the lifetime live weight-age records of individual cows the following four non-linear equations (Fitzhugh, 1976):

$$W_t = A\left(1 - be^{-kt}\right) \quad \text{............ Brody} \quad [8.2]$$

$$W_t = A\left(1 - be^{-kt}\right)^3 \quad \text{............ Von Bertalanffy} \quad [8.3]$$

$$W_t = A\left(1 + be^{-kt}\right)^{-1} \quad \text{............ Logistic} \quad [8.4]$$

$$W_t = Ae^{-be^{-kt}} \quad \text{............ Gompertz} \quad [8.5]$$

For each equation, W_t is live weight (kg) at age t (months), e is the base of the natural logarithms, and A, b and k are parameters to be estimated. A is asymptotic value for LW as $t \rightarrow \infty$, generally interpreted as average mature weight; b is constant of integration or the time scale parameter that adjusts for situations in which W_0 (initial weight) and/or t_0 (time of origin) do not equal zero, and k is the rate at which a logarithmic function of live weight changes linearly per unit of time, and is generally interpreted as a maturation index (Fitzhugh, 1976). Large k values indicate early maturing animals, and vice versa (López de Torre et al. 1992). These equations have been used to describe the growth curve of dairy cattle (Brody, 1945; Perotto et al. 1992; Russell, 1975) and beef cattle (Brown et al. 1976; DeNisse and Brinks, 1985; Goonewardene et al. 1981; López de Torre et al. 1992).

Properties of these equations as given by Richards (1969) and Fitzhugh (1976) are summarised in Table 8.2.

Table 8.2: Properties of the four non-linear equations fitted to the lifetime live weight-age records of genetically heavy or light Holstein-Friesian cows.

Function	Equation for W_t[1]	Linear form[2]	Value of W_t at $t = 0$	Value of W_t at $t = \infty$	Co-ordinates of the point of inflection t_i	Co-ordinates of the point of inflection W_i	Absolute growth rate (dw/dt)
Brody	$W_t = A(1-be^{-kt})$	$\ln[(A-W_t)/A] = \ln(b) - kt$	$A(1-b)$	A	---	---	$Akbe^{-kt}$
Gompertz	$W_t = Ae^{-be^{-kt}}$	$\ln[\ln(A/W_t)] = \ln(b) - kt$	Ae^{-b}	A	$k^{-1}\ln(b)$	A/e	$(Akbe^{-kt})(e^{-be^{-kt}})$
Logistic	$W_t = A(1+be^{-kt})^{-1}$	$\ln[(A-W_t)/W_t] = \ln(b) - kt$	$A(1+b)^{-1}$	A	$k^{-1}\ln(b)$	A/2	$(Akbe^{-kt})(1-be^{-kt})^{-2}$
Von Bertalanffy	$W_t = A(1-be^{-kt})^3$	$\ln[(W_t/A)^{1/3}] = -\ln(b) + kt$	$A(1-b)^3$	A	$k^{-1}\ln(3b)$	$A(2/3)^3$	$(3Akbe^{-kt})(1-be^{-kt})$

[1] *A*, Mature weight (kg); *b*, constant of integration; *k*, maturation rate parameter; *t*, age (months).
[2] ln = natural logarithm.

Criteria to assess model goodness of fit were i) the relative size of the mean square of the residuals after the iterative procedure converged (Papajsick and Bodero, 1988; Sherchand et al. 1995; Ramírez et al. 1994); ii) difficulty of fitting, as assessed by the number of cows failing to converge within the specified restrictions for parameter estimates, and iii) bias of the observed weights at birth and at maturity from those predicted by the growth equation (López de Torre et al. 1992; Mezzadra and Miquel, 1994). In the context of the present experiment, observed mature weight was the average LW recorded during the last lactation.

Production variables analysed

Milk production data were analysed per lactation using the yields of milk, fat, and protein obtained from the herd testing results. In total H and L cows provided for analyses 241 lactations with yields of milk and its components.

Derived variables

For each cow and lactation, LW's at calving, at mid lactation, and at drying off were predicted from the parameters of each cow's growth curve. The average of these predicted live weights was used to calculate yield per cow per lactation of milk, fat, protein, and milksolids per kg of $LW^{0.75}$. Additionally, dry matter intake per cow per year was estimated from the average LW during lactation (predicted from the growth curve), and the yields of milk, milkfat and milk protein using the following expression (Van der Waaij et al. 1997):

$$\text{DMI (kg cow}^{-1}\text{year}^{-1}) = \frac{1.83\ \text{MY} + 56.10\ \text{FY} + 31.77\ \text{PY} + 231.26\ \text{LW}^{0.75}}{10.8} \quad [8.6]$$

Where:

MY = milk yield (kg/lactation),
FY = fat yield (kg/lactation),
PY = protein yield (kg/lactation),
$LW^{0.75}$ = metabolic live weight (kg) calculated from the growth curve, and
10.8 = the concentration of MJ ME per kg of herbage dry matter.

From these data and the yield per lactation of milksolids, feed conversion efficiency was estimated for each cow as:

$$\text{FCE (kg milksolids tonne DMI}^{-1}) = \frac{\text{Milksolids yield cow}^{-1}\text{lactation}^{-1}\text{ (kg)}}{\text{Tonne DMI}} \quad [8.7]$$

Statistical analyses

Fitting of the growth equations

The four equations were fitted to the live weight-age data from each cow by non-linear regression using the MARQUARDT option available in PROC NLIN (SAS, 1989). Appendix 8.1 shows the SAS program used to fit each equation. Also the first partial derivatives with respect to the parameters of each of the functions fitted are given in Appendix 8.2. Only those cows with more than 15 live weight-age records and that had finished their second lactation were considered for growth curve analysis. In total there were 97 cows (50 H and 47 L) that met the criteria.

Initial values for the parameters to start the iterative procedure were obtained by choosing an estimator of $\boldsymbol{A}$ from the plot of live weight *vs.* age. This value for $\boldsymbol{A}$ was substituted in the linear form of each of the equations given in Table 8.2, and for each cow and equation, linear regression using PROC REG (SAS, 1989) was used to obtain estimates for the parameters $\boldsymbol{b}$ and $\boldsymbol{k}$. These estimates were used to provide a grid of starting values for the iterative procedure. For both the Brody and the Von Bertalanffy equations, when the parameter $\boldsymbol{b}$ exceeds 1, the component $(1\text{-}be^{-kt})$ could become negative, representing both biologically infeasible values and mathematically impossible computations (Perotto et al. 1992; Brown et al. 1976), therefore constraints should be imposed for the estimation of the parameters. Ranges of initial values for the parameters of the growth curve to start the iterative procedure were: a) for the mature weight parameter $300 < \boldsymbol{A} < 600$, subject to the constraint $\boldsymbol{A} \leq 700$; b) for the maturation rate parameter $0.0001 \leq \boldsymbol{k} \leq 0.008$; and c) for the constant of integration $0.3 \leq \boldsymbol{b} \leq 0.9$, subjected to the constraint $\boldsymbol{b} \leq 0.99$.

Comparison of equations

The relative size of the mean square of the residuals (MSR) after the iterative procedure converged was used as the criterion to compare the goodness of fit of the four equations. Normality of the dependent variable MSR was checked using the PROC UNIVARIATE (SAS, 1989). In an attempt to approximate the assumption of normality, the values of the dependent variable MSR were substituted by their corresponding ranks using the PROC RANK (SAS, 1989). Ranking of the MSR was done within each cow, and equations were compared using the 'Friedman' test on the ranks (Conover, 1980). This is a nonparametric test equivalent to the analysis of variance of a completely randomised block design, where the blocks in this case are the cows and the treatments are the equations being compared. Similar approaches have been used when comparing the goodness-of-fit of non-linear models fitted to lactation curves of dairy cattle (Papajsick and Bodero, 1988; Sherchand et al. 1995), and beef cattle (Ramírez et al. 1994).

Analysis of growth curve parameters and cow birth weight

Differences between genetic lines for birth weight of the cow and the parameters (***A***, ***b***, and ***k***) of the equation giving the best fit, were tested by least squares analysis of variance (ANOVA) using PROC GLM (SAS, 1989). The following linear model was fitted:

$$Y_{ijkl} = \mu + P_i + L_j + S(L)_{k(j)} + bDOB_{ijkl} + e_{ijkl} \qquad [8.8]$$

Where:

Y_{ijkl} = dependent variable recorded on cow l from genetic line j born from a dam in parity i and daughter of sire k;

P_i = effect of dam parity i ($i = 2, \geq 5$);

L_j = effect of genetic line j ($j = 1, 2$);

$S(L)_{k(j)}$ = effect of sire k nested within genetic line j ($k = 1, 24$);

b = partial regression coefficient of Y_{ijkl} on day of birth of the cow;

DOB_{ijkl} = date of birth (i.e. days since January the 1st in the year she was born) of cow l daughter of sire k born to genetic line j from a cow on parity i; and

e_{ijkl} = residual.

All effects in model equation [8.8] except the residual and the sire effect were regarded as fixed. Estimation of type III sums of squares and F-values were computed using PROC GLM (SAS, 1989). The option LSMEANS in PROC GLM was used to calculate least-squares means, and the TEST option was used to test differences between fixed effects. Differences between genetic lines were tested against the mean square of sire nested within genetic line. All other tests of significance used the residual mean square.

Relationships between growth curve parameters and BV's of bulls

The relationship between the sire of cow BV for LW and the cow's weight at birth and at maturity was determined by linear regression.

Yield of milk and milk components and productivity measures

Lactations shorter than 100 days were excluded from the analyses. Differences between genetic lines for yield per lactation of milk and milk components, estimated herbage dry matter intake, feed conversion efficiency and output per kg of $LW^{0.75}$/year were tested by least-squares ANOVA using PROC GLM (SAS, 1989). The following linear model was fitted to the data:

$$Y_{ijklm} = \mu + A_i + P_j + G_k + S(G)_{l(k)} + C(SG)_{m(kl)} + \beta_1(LL)_{ijklm} + \beta_2(LL)^2_{ijklm} + e_{ijklm} \qquad [8.9]$$

Where:

Y_{ijklm} = response variable measured on the m^{th} daughter of the l^{th} sire from the k^{th} genetic line milked at the j^{th} parity and calving in the i^{th} year;

μ = overall mean;

A_i = effect of calving year i (i = 1991-93, 1996);

P_j = effect of parity j (j = 1, ≥4);

G_k = effect of genetic line k (k = 1, 2);

$S(G)_{l(k)}$	=	effect of sire l (l = 1, 24) nested within genetic line k,
$C(SG)_{m(kl)}$	=	effect of cow m (m = 1, 93) daughter of sire l and from genetic line k,
b_1	=	partial regression coefficient of Y_{ijklm} on days in milk,
b_2	=	partial regression coefficient of Y_{ijklm} on days in milk squared,
LL_{ijklm}	=	lactation length (days) for cow m from genetic line k daughter of sire l milked at parity j and calving in year i,
e_{ijklm}	=	residual.

In a preliminary analysis, two and three-way interactions between the main effects were not significant, and therefore were excluded from model equation [8.9]. Sires within genetic lines, cows within sires and the residual were regarded as random effects in the model. The mean square of sire nested within genetic line [$S(L)_{l(k)}$] was used to test differences between genetic lines. The corresponding test for sires used the mean square of the random effect of cow nested within sire and genetic line [$C(SL)_{m(kl)}$]. All other tests of significance used the residual mean square in the denominator of the corresponding *F*-test. Results are given as least-squares means and the standard error of the difference between the means for the contrast H *vs.* L.

Results

Breeding values of sires

As planned, sires contributing to the development of the H line had significantly higher breeding values for live weight than L sires. Sires of the H cows also had significantly higher breeding values for yield milk, milkfat and milk protein. However, the L line sires had a slightly higher (P = 0.07) Breeding Worth than the H (Table 8.3).

Table 8.3: Least squares means of Breeding Worth and Breeding Values for production traits of the sires used to develop the heavy and the light mature live weight selection lines of Holstein-Friesian cows.[1]

Item	Units	Genetic line		s.e.d	*P*
		Heavy	Light		
Breeding worth BW	$	39.5	44.5	4.1	0.068
Milk volume BV	*l*	1025.5	737.0	63.9	0.0001
Milkfat yield BV	kg	32.2	27.3	1.0	0.0001
Milk protein yield BV	kg	30.0	20.8	1.6	0.0001
Live weight BV	kg	86.0	31.0	3.6	0.0001
Survival BV	%	0.29	0.33	0.28	0.41

[1] 50 Heavy cows sired by 12 H bulls, and 47 Light cows sired by 12 L bulls.

Goodness of fit of equations

The Brody and the Von Bertalanffy equations predicted immature live weights more accurately than the Logistic or the Gompertz functions, as evidenced by the smaller differences between the observed and the predicted birth weights. Regarding mature weight, the Logistic function showed the highest agreement between observed and predicted weights, with the other three functions slightly overestimating this parameter. Overall, however, the Von Bertalanffy function provided the best fit as it had the lowest residual mean square when fitted to the data of L cows, and ranked similar to the Brody and Gompertz when fitted to the data of H cows (Table 8.4). Thus, the Von Bertalanffy function was used for the rest of the calculations in this Chapter. Figure 8.1 shows the fit of this function to the live weight-age data of H and L cows.

Table 8.4: Average residual mean squares (MS) and their ranks, and agreement between weights at birth and at maturity with those predicted from the Brody, Gompertz, Logistic or Von Bertalanffy growth equation for heavy or light Holstein-Friesian cows.

Genetic line	Equation	Residual MS	Rank MS[1]	Cow birth weight (kg)			Cow mature weight (kg)		
				Observed	Predicted	Difference[2]	Observed	Predicted	Difference[2]
Heavy	Brody	843	3[a]	41	32	-9	492	556	64
	Gompertz	791	1[a]	41	161	120	484	522	38
	Logistic	913	4[b]	41	73	32	484	482	-2
	Von Bertalanffy	820	2[a]	41	49	8	485	522	37
Light	Brody	763	2[b]	35	28	-7	433	497	64
	Gompertz	780	3[b]	35	137	102	430	510	80
	Logistic	729	4[b]	35	63	28	428	427	-1
	Von Bertalanffy	700	1[a]	35	44	9	430	470	40

[1] Residual MS were ranked from smallest to largest.

[a,b] Within column and genetic line, ranks with different superscript are different ($P < 0.05$).

[2] Difference = Predicted – Observed.

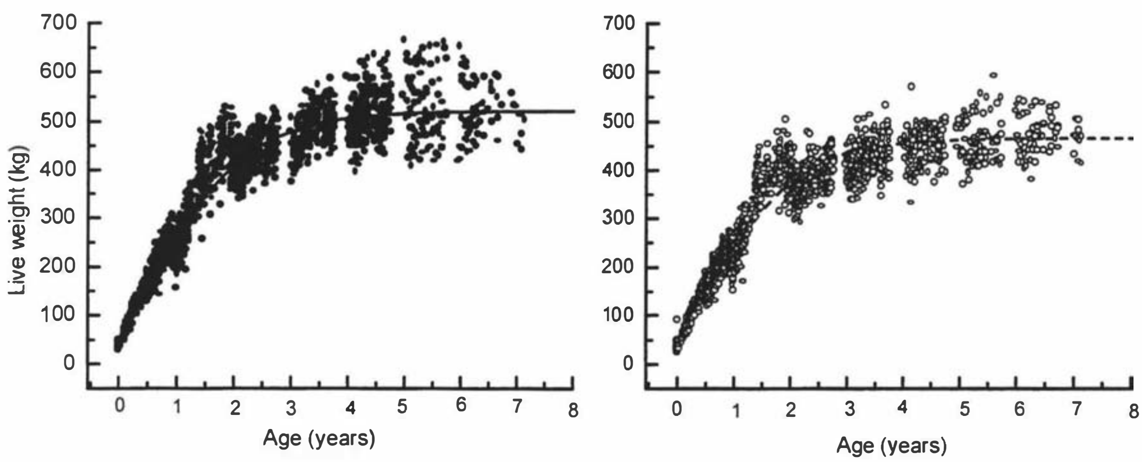

Figure 8.1: Data for age and live-weight of genetically heavy (—●—) or light (—○—) Holstein-Friesian cows fitted by the Von Bertalanffy function.

Cow weight at birth and at maturity

On average H cows were 6.0 kg or 17% heavier at birth and 54 kg or 11% heavier at maturity than L cows, and there were no differences between genetic lines for the parameters ***b*** and ***k*** of the Von Bertalanffy function (Table 8.5).

Table 8.5: Least squares means for birth weight and the parameters of the Von Bertalanffy function fitted to live weight-age data of genetically heavy or light Holstein-Friesian cows.[1]

Item	Genetic line: Heavy	Genetic line: Light	s.e.d[2]	Significance
Cow birth weight (kg)[3]	40.7	34.7	3.6	*
Parameters of the growth curve[4]				
A (kg)	526	472	12.0	***
b	0.53	0.54	0.09	NS
k (%/month)	8.2	8.5	0.33	NS

[1] Model $\hat{y} = \mu$ + dam parity + genetic line + sire(genetic line) + *b*(cow date of birth) + error.

[2] s.e.d = standard error of the difference.

[3] Birth weight records: 47 H, 36 L.

[4] $W_t = A(1 - be^{-kt})^3$ where W_t = LW at time *t* (months); *A* = asymptotic (mature) weight; *b* = constant of integration; *k* = growth rate parameter. Number of records 50 H and 47 L cows.

The breeding values for LW of sires of the cows were significantly related to the cow's birth weight (Figure 8.2) and mature weight (Figure 8.3). The respective regression coefficients predicted an average difference of 10 kg at birth and 76 kg at maturity for cows sired by bulls that differed by 100 kg in BV for LW. The regression coefficient of 76 kg/100 kg sire of cow BV for LW did not differ significantly from its expected value of 50 kg.

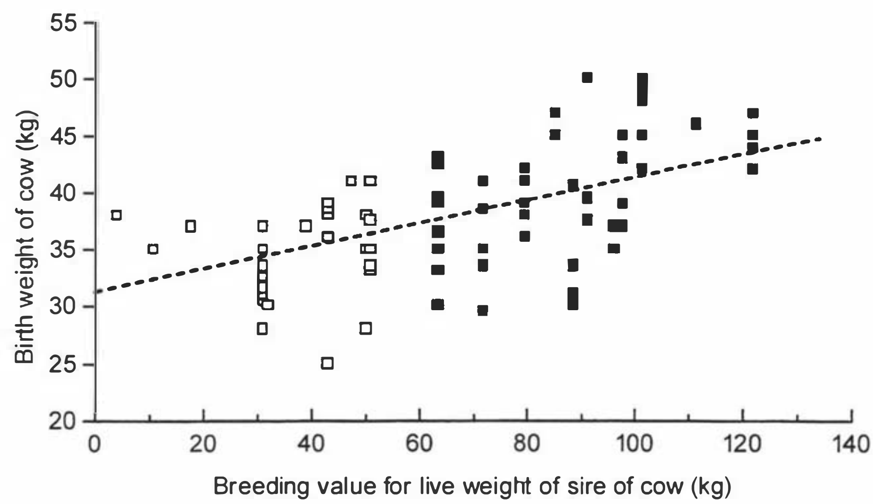

Figure 8.2: Relationship between breeding value for live weight of sires and daughters' birth weight for cows from the heavy (■) and the light (□) mature live weight selection lines. The regression equation is: $Y = 31.3\ (\pm 1.16) + 0.10\ (\pm 0.016)\ X$; $R^2 = 33\%$; RSD = 4.7; $P < 0.0001$; n = 83 (47 H and 36 L).

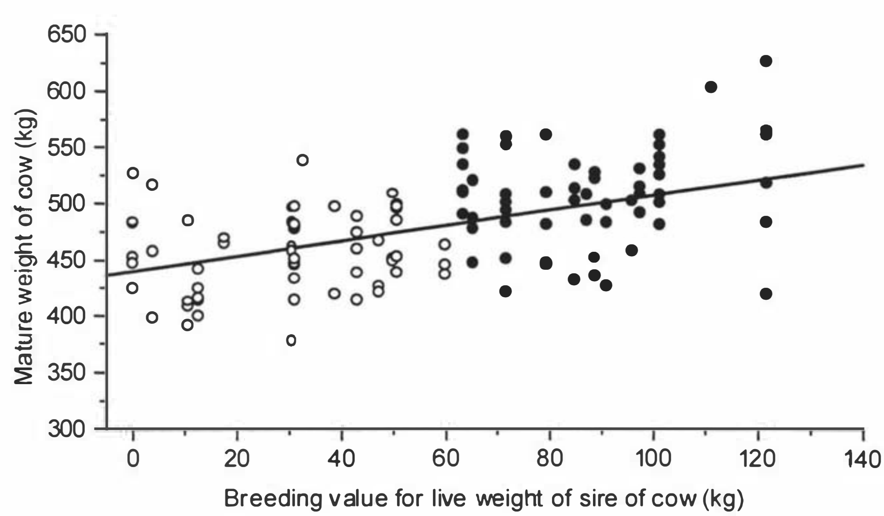

Figure 8.3: Relationship between breeding value for live weight of sires and daughters' mature weight for cows from the heavy () and the light () mature live weight selection lines. The regression equation is: $Y = 437\ (\pm 7.3) + 0.73\ (\pm 0.1)\ X$; $R^2 = 29\%$; RSD = 39.5; $P < 0.001$; n = 118 (61 H and 57 L).

Yield and productivity of H and L cows

Least squares means for yield per lactation, expressed per cow and per kg of metabolic weight, of milk, and milksolids are presented in Table 8.6. Live weight during lactation was calculated from the growth curve as the mean of LW predicted at calving, mid lactation and at drying off. As expected, H cows had higher calculated feed requirements and they produced more milk, milkfat, milk protein and milksolids per lactation than L cows. However, when yields per lactation were scaled by $LW^{0.75}$ or per calculated tonne of dry matter required the differences between the H and L cows disappeared.

Table 8.6: Least squares means for yield of milk and milk components per lactation and per kg of metabolic weight, dry matter intake per cow per year and estimated feed conversion efficiency of genetically heavy or light Holstein-Friesian cows.[a]

Item	Genetic line		s.e.d[b]	Significance
	Heavy	Light		
Milk lactation^{-1}				
l cow^{-1}	4708	4323	80.9	***
l cow^{-1}kg LW$^{0.75}$	46.5	45.9	0.86	NS
Milkfat lactation^{-1}				
kg cow^{-1}	206.8	198.0	3.4	*
kg cow^{-1}kg LW$^{0.75}$	2.0	2.07	0.037	NS
Milk protein lactation^{-1}				
kg cow^{-1}	157.0	150.0	2.5	*
kg cow^{-1}kg LW$^{0.75}$	1.54	1.59	0.023	NS
Milksolids yield (MSY) lactation^{-1}				
kg cow^{-1}	364	348	5.4	*
kg cow^{-1}kg LW$^{0.75}$	3.54	3.66	0.06	NS
Calculated dry matter required (kg/cow/lactation)[c]	4349	4022	62.0	***
Calculated feed conversion (kg of MSY/tonne DM)	84	87	2.9	NS

[a] Model $\hat{y} = \mu$ + year of calving + parity + genetic line + sire(genetic line) + b_1 (days in milk) + b_2(days in milk)^2 + error. There were 97 cows (50 H and 47 L), 24 sires (12 H and 12 L), and 241 lactations (126 H and 115 L).

[b] s.e.d = standard error of the difference.

[c] Calculated as: Dry matter intake (kg/cow) = [1.83* Milk yield (l) + 56.10*Fat yield (kg) + 31.77*Protein yield (kg) + 231.26* $LW^{0.75}$] / 10.8.

Discussion

Results for the comparison of growth equations are similar to those reported in the literature for dairy and beef cattle. In a study comparing the growth curves of Dutch Friesian, British Friesian, and Holstein-Friesian cows, a reparameterized form of the Von Bertalanffy function also provided the best fit to the data when compared to the Gompertz, Brody and Logistic functions (Bakker and Koops, 1977). López de Torre et al. (1992) found similar results when the Gompertz, Richards and Von Bertalanffy functions were fitted to the live weight-age data of Retinta breed cows. Mezzadra and Miquel (1994) also obtained lower residual sums of squares with the Von Bertalanffy function, when they fitted LW-age data of Angus, Criollo and reciprocal crossbred cows to the Brody, Gompertz, Logistic, Richards and Von Bertalanffy functions. Jolicoeur (1985) argues that the poor fitting of the Gompertz and the Logistic functions to post-natal growth is due to the fact that these two functions are exclusively sigmoid in shape and have both a lower as well as an upper asymptote. For the present data set, increases in LW after birth with advanced age did not show a sigmoid pattern of growth (Figure 8.1). Thus, growth functions like the Brody or Von Bertalanffy that pass through the origin or near to it and have an upper asymptote are more appropriate to describe this type of data (Jolicoeur, 1985).

The estimated regression coefficient of mature LW on sire of cow BV for LW of 76 kg was not significantly different from the expected value of 50 kg. The observed difference between estimated and expected may be due to the fact that the Von Bertalanffy equation slightly overestimated the cow's mature weight.

Cows from the H line were heavier and produced more milk and milk components per lactation than L cows, as predicted from the BV's of their sires. The differences in LW and MSY in favour of the H cows were expected, since they were the offspring of sires with significantly higher BV for LW, milk volume, fat and protein yield. However, the H cows were heavier throughout their life, and when yields per lactation were scaled by $LW^{0.75}$ the differences in yield between the lines disappeared. Despite their heavier mature weights and higher MSY, cows from the H line were expected to be as efficient as cows from the L line since their sires had similar genetic merit for farm profitability (i.e. similar breeding worth). This was indeed the case. When feed requirements were calculated for both lines from the actual LW and milksolids yield, the resultant values for feed conversion efficiency (kg of MSY/tonne of DM required) were similar for both lines. This conclusion agrees with direct measurement of feed intake and milk production by some of these cows in another experiment (See Chapter 4). The results from this study suggest that the published figures for Breeding Values of sires are reliable predictions of their daughters' actual performance, and that the overall estimate of Breeding Worth is closely related to the cows' feed conversion efficiency.

Conclusions

Sires contributing to the formation of the H line had significantly higher breeding values for live weight, milk and milk components, but slightly lower values for breeding worth than the L sires. The H cows were significantly heavier all the way through from birth to maturity, produced significantly higher yields of milk and milk components than L cows but were slightly less efficient than the L cows, as predicted from their sires Breeding Worth. Under the conditions of the present experiment the breeding values of the sires were reliable predictors of their daughter's actual performance and the estimator of breeding worth is closely related to the cow's feed conversion efficiency. These results suggest that the assumptions of the Animal Evaluation Model of dairy cattle in New Zealand for economic feed conversion efficiency seem to be adequate.

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CHAPTER 9

General Discussion

The research on the effects of breeding grazing dairy cattle for heavier or lighter mature live weight described in this thesis can be divided into four broad areas. The first focused on the design of the selection experiment on live weight. The second focused on the heifers and on the effects of genetic differences in live weight on growth, herbage intake and feed conversion efficiency and onset of puberty of the replacement heifer (Chapter 2 and Chapter 3). The third area was focused on short-term grazing experiments with cows, which measured herbage intake, yield of milksolids, feed conversion efficiency (FCE) and grazing behaviour of H and L cows offered generous or restricted herbage allowances during early and mid-lactation (Chapter 4 and Chapter 5). The fourth area used the data collected for each cow during 1992 to 1997 to evaluate differences between genetic lines for calving difficulty (Chapter 6), reproductive performance (Chapter 7), growth from birth to maturity and lifetime lactation yields of milk and milk components and FCE (Chapter 8).

The results of this thesis have been discussed in detail in the relevant individual chapters. This general discussion is intended to summarise and integrate the main points from all the chapters. The design of the experiment is discussed first, followed by a discussion on the effects of breeding cows for heavier or lighter mature live weight on growth, feed requirements, herbage intake, milk yield, feed conversion efficiency, ingestive behaviour, calving difficulty and reproductive performance. The section ends by listing some areas where further research is needed.

Design of the experiment

Bulls used to develop the H and L lines were New Zealand born and progeny tested under New Zealand conditions. Bulls contributing progeny to the H and L lines were selected on the basis of their breeding values for live weight but with similar genetic merit for farm profitability (i.e. Payment Breeding Index from 1989 to 1995 and Breeding Worth since 1996 to the present date). The original plan was to generate a divergence in mature live weight of cows with high genetic merit for milksolids yield (Chapter 1). However, the H bulls also had higher BV's for milk, milkfat, milk protein, and for traits other than production (TOP) related to body size such as stature and body capacity, than the sires of L cows. In addition to a difference in cow mature weight, there was also a difference in strain of Holstein. Bulls contributing progeny to the H line had a higher percentage of USA Holstein genes in their pedigrees than L bulls, which were mainly of New Zealand ancestry (Chapter 1), a finding which is retrospectively not unexpected.

Effects of selection for heavier or lighter mature live weight

Growth from birth to maturity

As expected from their sires BV's for LW, cows from the H line were heavier at birth, at puberty, at first calving (Chapter 2 and Chapter 3) and at maturity (Chapter 8) than cows from the L line. At the conclusion of the experiments reported in this thesis, cows from the H line were on average 6.0 kg heavier at birth and 50 kg heavier at maturity than L cows. These cows were mainly first and second generation of breeding. The difference in mature LW achieved between the H and L cows agreed with that expected from the differences in BV for LW of their sires (Chapter 8). Thus, selecting bulls from the national team of artificial breeding with high or low BV's for LW has been an effective method to change the growth curve of cows from the H and L lines (Chapter 8).

In a selection experiment in Minnesota, Hansen et al. (1998) reported that after 20 years of selecting USA Holstein cows for heavier or lighter mature live weight, the cows from the heavy line are still getting heavier, whereas the cows from the light line are not becoming lighter. To develop these lines, bulls were selected from the top 50% of active artificial insemination bulls in the USA for production, and size of daughters based on standardised transmitting abilities for stature, strength, and body depth with the index: size = .5(stature) + .25(strength) + .25(body depth). The three most extreme bulls were selected once each year for each of the two lines, to transmit large or small body size (Hansen et al. 1998). The lack of response of the light live weight selection line in that experiment could be explained by the fact that North American Holsteins have been selected for increased body size (Mahoney et al. 1986). The Holstein Associations of USA and Canada continue to place very favourable ratings on cows with large body size (Hansen et al. 1998). Therefore, even if the sires of the light live weight line were the most extreme in the market for transmitting small size, they were likely to have higher scores for size than the sires used in previous years.

In contrast to the emphasis on large body size by USA dairy farmers, in New Zealand live weight of the lactating cow is given a negative relative economic value in the system of genetic evaluation of dairy cattle. The bulls used to generate the H and L cows used in the experiments reported in this thesis have been selected based solely on their BV's for live weight and Breeding Worth (Chapter 1). Thus, it is likely that for some years to come, the cows from the H and L lines at Massey will continue to become heavier or lighter respectively. However, the extent of such continued changes in the H and L lines, and how much of these changes are desirable, are questions that can not be answered from the present data. Answers to these questions will require data from several more years.

Feed requirements and herbage intake

Cows from the H line were expected, from their heavier yearling weights (Chapter 2) and mature live weights, and their higher yields of milk and milk components (Chapter 4, Chapter 5 and Chapter 8) to have higher feed requirements. This expectation was confirmed in the present experiments. Higher intakes of herbage dry matter have been reported previously for phenotypically heavier Holstein-Friesian cows, either grazing rye-grass/white clover pastures or fed indoors on fresh cut pasture (Holmes et al. 1993), and for heavier Holstein-Friesian cows fed indoors on fresh cut pasture (Stakelum and Connolly, 1987). Thus, as expected from theoretical calculations of feed requirements, yearling heifers and lactating cows from the H line did in fact have higher daily intakes of herbage dry matter due to higher feed requirements for maintenance and growth (heifers) and for maintenance and milk yield (lactating cows).

Yield of milk and milk components

Cows from the H line also produced more milk and milk components than L cows, whether yield of milk and milk components was measured in short-term grazing experiments with high herbage allowances (Chapter 4), or high and low herbage allowances (Chapter 5), or during the whole lactation (Chapter 8). The superiority of the

H cows was expected since they were the offspring of sires with significantly higher breeding values not only for LW but also for yields of milk volume, milkfat and milk protein (Chapter 1). This positive relationship between LW and yield of milk and milk components agrees with most reports from the literature of a positive genetic correlation between live weight and yield (Ahlborn and Dempfle, 1992; Lin et al. 1985; Mahoney et al. 1986). By design, bulls contributing progeny to the H and L lines were required to have similar Breeding Worth (Chapter 1). Thus, for sires of H cows to have similar Breeding Worth to the sires of L cows, they must have had higher BV's for some or all of the production traits in order to compensate for their higher BV's for LW. This was indeed the case in the present experiment. Thus, cows from the H and L lines are expected to be equally efficient in converting herbage dry matter into profit, as predicted from their sires' Breeding Worth (Livestock Improvement, 1997b).

Feed conversion efficiency

There were no significant differences between genetic lines in feed conversion efficiency of growing heifers during the three years that herbage intake was measured (Chapter 2). Similarly, there was no difference in the FCE of H and L cows when herbage intake was measured in early lactation (Chapter 4). In both the experiments with the heifers and those with the cows, H and L sires had similar Breeding Worth, and this could have been the reason for the similar FCE of their daughters. However, in the experiment designed to measure herbage intake and FCE in mid-lactation offering high or low herbage allowances (Chapter 5), the sires of L cows had higher Breeding Worth than the sires of the H cows, and the L cows were more efficient in converting herbage dry matter into milk solids.

Feed conversion efficiency was also calculated using the lifetime lactation yields and LW's predicted from individual growth curves for cows that had completed two or more lactations (Chapter 8). In these analyses, sires of H cows had significantly higher breeding values for live weight, milk and milk components, but slightly lower values for Breeding Worth than the L sires. Consequently the H cows were significantly heavier all the way through from birth to maturity, produced significantly higher yields of milk and milk components but were slightly less efficient (from theoretical calculations of feed requirements) than the L cows, in agreement with the fact that sires of H cows had slightly lower average Breeding Worth. These results, taken together, indicate that the breeding values of H and L sires are reliable predictors of their daughter's actual performance, and that the estimator of Breeding Worth is closely related to the cow's feed conversion efficiency. These results suggest that the assumptions included in the Animal Evaluation Model of dairy cattle in New Zealand appear to provide a sound basis for predictions of economic feed conversion efficiency.

Ingestive behaviour

Growing heifers

Growing heifers from the H and L lines showed only minor differences in their pattern of grazing behaviour (Chapter 2). The grazing times and total daily bites from both lines were all within the range of published values for animals of similar age and weight (Hodgson and Jamieson, 1981; Jamieson & Hodgson, 1979a and 1979b; Zoby and Holmes, 1983). However, the calculated bite sizes were lower than most of the figures reported in these studies, which could be due to the different methods used to calculate bite size and the type of animal used in the grazing experiments. In most of the previous studies, bite size was calculated using oesophageally fistulated steer calves, whereas in the present experiments, bite sizes were calculated on female calves and by the indirect method using the measured intake and measurements of grazing behaviour. Similar results of lower bite sizes of British Friesian calves were reported by Jamieson and Hodgson (1979b) when calculated by the indirect method.

Overall, there were only minor differences between the two lines in the pattern of grazing of yearling heifers. This was in contrast with the results for lactating cows (discussed below), and could be due to the smaller differences in live weight, herbage intake and feed requirements between the H and L heifers, compared to the larger differences between the lines in live weight and feed requirements of lactating cows.

Lactating cows

There were significant differences between the lines in the pattern of grazing behaviour, the size of the bites taken and the digestibility of the herbage eaten by H and

L cows (Chapter 4). Cows from the L line had longer grazing times (8.67 *vs.* 8.31 hours), shorter rumination times (7.9 *vs.* 9.5 hours), faster rates of biting (58 *vs.* 52 bites/min), higher total number of daily bites (29765 *vs.* 26049), took smaller bites (528 *vs.* 428 mg DM/bite), and selected herbage of higher digestibility (72 *vs.* 69%) than H cows.

Cows from the H line had larger mouths with slightly wider incisor arcade breadth and they took larger bites that took longer to process, as evidenced by their longer rumination time and the lower digestibility of the herbage eaten. Larger bite sizes have been observed for beef heifers of large mature weight or slower maturation rate (Erlinger et al. 1990) and for heavier dairy cattle (Zoby and Holmes, 1983), and for beef cattle (Ferrer Cazcarra and Petit, 1995) differing in size due to differences in age. In the present experiments cows were of similar age and were at a similar degree of maturity in body weight. Thus the lower bite weights of L cows probably were a direct reflection of their smaller mouths.

Higher concentrations of the C_{33} alkane used to calculate the digestibility of the herbage eaten (Robaina et al. 1993) are found in the most digestible parts of the leaf lamina of perennial rye grass (Dove et al. 1996). Hodgson (1977) suggested that differences in digestibility between different animal classes might simply reflect the existence of digestibility gradients within the swards rather than the deliberate exercise of choice by the grazing animal between different components of the sward. Thus, cattle feeding predominantly on the upper layer of the sward (i.e. shallow grazers) are expected to harvest more digestible herbage in each bite taken. Thus, the higher digestibility of the herbage eaten by the L cows may indicate that they were grazing less deeply into the sward than H cows.

Faster rates of biting and shorter periods of mastication and rumination have been observed for lactating dairy cows grazing perennial ryegrass/white clover swards, when they are forced to graze down to a sward surface height of 4 cm compared to 8 cm (Rook et al. 1994). This increase in biting rate is regarded as a compensatory mechanism triggered by a lower bite weight, and it is displayed in order to maintain total daily intake when sward height becomes limiting (Phillips, 1993). In the present experiment, the grazing conditions ensured both a high pre-grazing (18.2 ± 4.1 cm) and a high post-grazing (12.0 ± 3.4 cm) (mean ± SD) sward height and an easily prehended pasture was presented as a new strip of fresh pasture in the morning and in the afternoon. It was therefore unlikely that the sward conditions would have limited intake per bite and thus triggered an increase in biting rate, grazing time and hence total number of bites (McGilloway and Mayne, 1996). Therefore, the data from the present experiment suggest that lighter mature LW lactating Holstein-Friesian cows have a faster biting rate possibly because of their smaller mouths, or their mainly New Zealand ancestry (Chapter 1), or both.

Cows from the L line were the offspring of bulls with mainly New Zealand ancestry in their pedigrees, whereas the bulls contributing to the formation of the H line had a higher proportion of USA Holstein genetics in their ancestry (Chapter 1). New Zealand dairy bulls are nationally progeny-tested across-breeds in commercial herds which are managed on a seasonal system of milk production based almost entirely on grazed pasture (Livestock Improvement, 1997a). Thus, their daughters might be expected to display a pattern of grazing behaviour like the one displayed by cows from the L line in the present experiment.

Despite the differences between the lines in milksolids yield, grazing behaviour, herbage intake, bite size and digestibility of the herbage eaten, cows from the H and L lines achieved similar rates of herbage intake and similar feed conversion efficiency when they were presented with abundant and easily prehended pasture. However, with grazing management practices aimed at harvesting as much as possible of the grass grown on the farm, it is likely that genetically heavier cows with their larger mouths will be less able to harvest shorter herbage compared to genetically lighter cows with smaller mouths. Therefore, these differences in grazing behaviour may be an advantage for the L cows when faced with less favourable grazing conditions, such as those experienced at high stocking rates with little use of supplementary feeds.

Calving difficulty and calf mortality

Calving difficulty

Calving difficulty, evaluated separately for primiparous and multiparous cows, was similar for both genetic lines (Chapter 6). Calving difficulty of primiparous cows was higher (20%) compared to only 8.3% for multiparous cows. The average calving difficulty for multiparous cows is in agreement with the 9.5% reported by Elliot (1992) for New Zealand Holstein-Friesian cows. The higher incidence of difficult calvings for primiparous cows agrees with other reports from the literature for European Friesians (McGuirk et al. 1998; Philipsson, 1976a), but is considerably higher than the relatively low estimate of 5.9% reported by Ahlborn-Breier (1989) for New Zealand Holstein-Friesian heifers mated to Holstein-Friesian bulls.

For primiparous cows, male calves and calves sired by Friesian bulls were more likely to face a difficult calving compared to female calves and calves sired by Jersey bulls. The sire-of-cow breeding value for rump angle showed the highest association with the probability of calving difficulty. Thus, cows with genetically sloping pelvises were less likely to face a difficult calving. Results from European studies with Friesian heifers (Philipsson, 1976b) have also shown that higher calving difficulty is experienced by first calving heifers with smaller pelvic inlet dimensions before or after parturition. The effective dimensions of the pelvic inlet are also influenced by hormonal changes around parturition and may be affected by the external shape of the rump (Meijering, 1984). Thus primiparous cows with sloping pelvises may be more likely to have larger pelvic inlet dimensions or may be more likely to relax muscles and joints around the pelvis before and during parturition, or both (De Jong, 1998). The results from the present analyses indicate that the external shape of the rump (given in this case by rump angle) may be used as a rough guide to score for difficult calvings of primiparous cows.

For multiparous cows, there was also no effect of cow genetic line on the probability of calving difficulty, and, as for primiparous cows, male calves were more likely to cause difficult calvings. Younger cows were more likely to face difficult calvings, which agrees with the decrease in the incidence of difficult calvings in beef cattle from the first to the fourth parturition (Brinks et al. 1973; Burfening et al. 1978). The sire-of-calf breeding value for rump width was positively associated with the probability of calving difficulty, i.e. calves sired by bulls that had BV's for rump width one standard deviation above average were over 1.6 times more likely to cause difficult calvings. Thus, calves with wider pelvises at birth were expected to be more difficult to deliver than calves with narrower pelvises. Despite these observed effects on calving difficulty, up to this point of the selection experiment, selection for heavier or lighter mature live weight has had no effect on the probability of calving difficulty in grazing Holstein-Friesian cows.

Calf mortality

There was no difference between the H and L lines in the percentage of dead calves. However, across genetic lines calves born to a difficult calving were over three and a half times more likely to die or undertake an emergency slaughter than calves born to a free calving. By far the main cause of death or emergency slaughter among new born calves was the use of induction, since induced calves were over 14 times more at risk of death than their non-induced counterparts, and L cows were less likely to face an induced calving. High mortality rates in induced calves are well documented for dairy herds in New Zealand (Armer et al. 1993; MacDiarmid and Moller, 1981; McGowan et al. 1975; Merral, 1972; Welch and Kaltenbach, 1977) and in Australia (Morton and Butler, 1995). In the New Zealand studies, calf mortality of induced cows ranged from 15% to 30%, compared with 2 to 8% dead calves for non-induced cows, whereas in the Australian studies calf mortality was as high as 70% for calves from an induced calving compared to only 7% for calves from a normal calving (Morton and Butler, 1995).

The higher calf mortality rate for induced calvings may be due to a lower vitality of calves born after a relatively short gestation period (Meijering, 1984). In the present experiment, gestation length of induced calves was significantly shorter by 9 days compared to that of non-induced cows. Thus, the lower risk of calf mortality for cows from the L line compared to that of H and B cows was greatly influenced by their lower induction rate and consequently gestation lengths close to the average (282 days in this case for non-induced cows). The significant quadratic and cubic effects of gestation length on calf mortality certainly suggest lower calf mortality for gestation lengths close to the average of 282 days.

Calving difficulty, and especially induction, had major effects on calf survival regardless of genetic line. Induction affected calf survival mainly through shorter gestation lengths. Higher induction rates were experienced by cows from the base herd and the H line compared to cows from the L line, and thus their calves were more at risk of death than by cows from the L line.

Due to the overriding effect of induction on calf mortality, it is likely that calves from cows more prone to induction will face a greater risk of death than those from cows having a non-induced calving. The available data shows that cows from the L line are less likely to undertake an induced calving and therefore their calves have greater chances of survival under the management practices of the seasonal system of milk production in New Zealand. Therefore, the lower induction rate and consequent lower risk of calf mortality by cows from the L line suggest that it is advantageous to farm smaller mature live weight cows under the conditions of the present experiment.

Reproductive performance

Puberty in heifers

Heifers from the H line were heavier (+ 20 kg) and older (+ 25 days) at puberty than L heifers (Chapter 3). The average weights at puberty recorded for the H (241 kg) and the L (221 kg) heifers agree with the 220 kg LW at puberty for New Zealand Holstein-Friesian heifers recommended by Penno (1994). These puberty weights are also in agreement with those reported for New Zealand Holstein-Friesian heifers reared under the management policies of the beef breeding herd (Dalton et al. 1975; Pleasants et al. 1975). However, they were much lighter (especially those from the L heifers) than those reported for Holstein heifers from North America (Bortone et al. 1994; Stelwagen and Grieve, 1990).

The lighter mature LW of New Zealand dairy cattle (Chapter 8) and the fact that they are solely fed on grazed pasture might explain these lower LW's at puberty of heifers in the New Zealand experiments. The higher mature LW of heifers from the H line may have contributed to their later puberty, since there is evidence, at least for beef cattle, that breeds of larger mature size achieve puberty at older and heavier weights (Bagley, 1993).

For seasonal systems of reproduction with a short mating season, delayed onset of puberty will be associated with a higher proportion of heifers being prepubertal and anoestrus at the commencement of mating (Penno, 1995). Thus, this delay may mean some heifers will either conceive to their pubertal oestrus, at the end of the mating period, or not conceive at all. For beef heifers, higher conception rates were obtained from insemination to the third oestrus (78%) after puberty, compared to the pubertal (57%) oestrus (Byerley et al. 1987).

Heifers from the H line attained puberty at an older age but at the same degree of maturity in LW (i.e. actual LW/mature LW) as L heifers, of about 47%. Hafez (1993) states that dairy heifers tend to attain puberty at a fixed proportion of their mature weight of around 30 to 40%, but the H and L heifers in the present experiment were well above this range, perhaps due to the fact that they were raised on grazed pasture. These results suggest that unless genetically heavier heifers grow faster than genetically lighter heifers, they will not be able to achieve their 'target weights' (i.e. actual weights as proportion of mature weight) that enable them to become pubescent before 15 months. Thus, a low daily LWG during the rearing period are expected to have a more detrimental effect on replacements with the genetic potential to grow to a heavier mature LW.

According to Penno (1995 and 1997), optimum yearling fertility is achieved when New Zealand heifers reach 60% mature weight by the planned start of mating at 15 months of age. In the present experiment, H and L heifers were 14.2 and 14.4 months old at the start of mating and had achieved 273 and 283 kg or 57% and 58% of their mature weight, respectively, which agrees with the recommended target. By the end of the 12-weeks natural mating period, H and L heifers had achieved 384 and 367 kg LW or 76% and 79% of their mature weight, respectively. The fact that only one heifer out of a total of 72 heifers did not become pregnant during the three years of the study indicates that the pattern of growth achieved by these H and L heifers did not compromise their reproductive performance up to their first calving. Heifers from the H and L lines calved for the first time at similar age (H: 728 *vs.* L 733 d) and percentage of mature weight of 82% and 83% respectively. These figures are slightly lower than the 90% of mature weight at 22 months of age proposed by Penno (1997) to optimise milksolids production during the first lactation. Nevertheless H and L heifers achieved lactation yields of 278 and 277 kg milksolids respectively, which compares with the national average of 257 kg milksolids for first lactation Holstein-Friesian cows during the 1996-1997 season (Livestock Improvement, 1997a).

In summary, selection for heavier live weight has delayed the onset of puberty of H heifers by about 25 days, but this has resulted in the failure of only one heifer (an HH heifer) to conceive by the end of the NM period. Despite their later puberty, H heifers conceived within the 12-weeks breeding season and calved at the same date and similar age and degree of maturity as L heifers. However, it is likely that further generations of breeding will produce larger differences in mature LW, and in age and LW at puberty. Eventually, it is possible that the H heifers may be at a higher risk of failing to conceive by 15 months of age at the end of the restricted period of mating.

Reproduction after first calving

The reproductive performance of H and L cows was evaluated using insemination and calving records generated during 1991 to 1997 (Chapter 7). There were no differences between genetic lines for the intervals from calving to first heat (H: 43.5 *vs* L: 42.4 days), calving to first service (H: 78 *vs.* L: 83 days), days open (H: 94 *vs.* L: 94 days), start of mating to first service (H: 13 *vs.* L: 13 days), and calving interval (H: 375 *vs.* L: 373 days). However, cows from the L line had shorter intervals from the start of mating to conception (24 *vs.* 29 days; $P < 0.05$) and from the first service to conception (13 *vs.* 17 days; $P < 0.05$).

In the L cows the shorter intervals from the first service to conception and from the start of mating to conception were due to higher first service conception rates (65 *vs.* 54%; $P < 0.05$) and this caused higher herd in-calf rates to an AI service (86 *vs.* 79%; $P < 0.05$), earlier and a more concentrated calving pattern, as assessed by the percentage of cows calving from the PSC to the first 21 days (70 *vs.* 57%; $P < 0.05$) and a lower induction rate (10.5% *v.* 4.2%; $P < 0.05$). The average value for cows pregnant to first service in New Zealand is around 60%, with some farmers achieving values as high as 75% (Xu et al. 1995; Macmillan et al. 1996).

Lower conception rates to the first service have been reported for taller compared to shorter Israeli Holstein cows (Markusfeld and Ezra, 1993), for genetically heavier compared to genetically lighter USA Holstein cows (Hansen et al. 1998), for high yielding compared to low yielding cows (Dhaliwal et al. 1996; Macmillan et al. 1996; Nebel and McGilliard, 1993; Ouweltjes et al. 1996; Pryce et al. 1997), and for induced cows compared to cows undertaking a normal calving (Welch and Kaltenbach, 1977).

In the present experiment, cows from the H line not only had heavier mature live weights but also produced significantly more milk, milkfat, milk protein, and milksolids per lactation (Chapter 8) and were more likely to face an induced calving than the L cows (Chapter 6 and Chapter 7). Therefore the lower reproductive performance of the H cows in the present experiment was not unexpected. Similar results of lower reproductive performance were obtained for high genetic merit (PIN_{95} (£) = 67) compared to medium genetic merit (PIN_{95} (£) = 3) cows when they were managed on grazed pastures and a very tight seasonal system of reproduction in Northern Ireland (Mayne, 1998).

The reasons for the reduced reproductive performance of high genetic merit cows at pasture has been attributed to their proneness to partition energy intake into milk rather than tissue and to their inability to eat enough of a high forage diet to fuel their potential extra yield (Mayne, 1998). Results from experiments with USA Holsteins (Kolver et al. 1998) have shown that high yielding cows (> 44 kg milk/d; 603 kg LW) fed solely on grazed pasture achieved intakes of herbage dry matter that were only 80% of those achieved when they were fed a total mixed ration (TMR) (i.e. 19.0 *vs.* 23.4 kg DM/d). Milk yield of the pasture-fed cows was only 67% of the yield by the cows on the TMR (i.e. 29.6 *vs.* 44.1 kg/cow/d), and they lost more live weight (562 *vs.* 597 kg) and body condition score (2.0 *vs.* 2.5) than the cows on the TMR treatment.

In the present experiment, even though H and L cows were expected to have similar economic feed conversion efficiencies, as predicted from their sires' Breeding Worth, it is likely that the H cows were under a more stringent nutritional situation than the L cows due to their higher requirements of ME for maintenance and milk yield. Additionally, these requirements had to be met within the constrained environment of a very tight seasonal calving and a system of feeding based almost entirely on grazed pasture. Under the conditions of the present experiment, cows from the H line produced more milk and milk components than L cows but at the cost of lower reproductive efficiency.

Conclusions

Up to this point of the selection experiment the following conclusions can be drawn:

- Using bulls with high or low BV for live weight has caused differences in the growth pattern of H and L cows from birth to maturity.

- Selecting for heavier live weight has produced H cows that were heavier, ate more herbage dry matter, produced more milk and milk components and had similar feed conversion efficiencies when compared with the L cows at high herbage allowances. However, in another experiment, at both high and low herbage allowances, the L cows were more efficient converters of feed dry matter into milksolids.

- Onset of puberty of H heifers has been delayed significantly but has had no practical consequences on the pregnancy rate, calving date, calving spread, calving difficulty and first lactation performance of H and L heifers.

- There were no differences between genetic lines in the incidence of difficult calvings or dead calves. However higher risk of mortality was expected for calves from an induced calving, and the L cows were significantly less likely to be induced to calve.

- There were significant differences in favour of the L cows regarding first service conception rate, pregnancy rate, induction rate and a more concentrated calving pattern.

These results indicate that the Breeding Worth is a relatively good predictor of feed conversion efficiency for the heavy and light cows. However if the difference between the lines in fertility is validated with data from more years, then the effect of this difference must be included in the Breeding Worth. Taken collectively, the findings from this thesis suggest that it is advantageous to farm smaller mature live weight Holstein-Friesian cows under the New Zealand seasonal system of milk production.

Areas for further research

The following is a list of questions that may need to be answered in the future with the information generated in the project:

- What are the long-term consequences on the sward of being grazed by heavier or lighter mature live weight cows with differences in their pattern of grazing behaviour? What sort of adjustments do H and L cows require in the grazing management (i.e. heavier weights and larger mouths may require lower stocking rates and/or longer post-grazing residuals).

- Studies on calf vigour within the first 24-hours after calving (i.e. time to stand, time to suckle, birth weight, etc).

- Economic comparison between the H and L lines using the production and health data from the farm's database, and the derived figures for calf mortality, calving difficulty, reproductive performance and herbage intake generated in this thesis.

- Biological and economical evaluation of lifetime performance of cows from the H and L lines.

- What are the main reasons for disposal of H and L cows?

- What is the effect of heavier mature live weight on the incidence of feet and leg problems?

- Are there any differences between the H and L cows in their ability to walk long distances (i.e. a growing trend of farms becoming larger and cows have to walk longer distances for milking and grazing).

- Are there any differences between the H and L cows in the incidence of mastitis and udder related problems?

- Does breeding for heavier mature live weight and higher yield compromise further the reproductive performance of grazing cows?

- Differences between genetic lines for once daily milking. That is, do H and L cows in fact reduce daily milk output or maintain it even at the expense of body reserves when subjected to once daily milking?

- Are there any differences in the shape of the lactation curve and the pattern of live weight and body condition score change after calving between H and L cows? How these components relate to the energy balance, reproductive performance and risk of post-partum diseases of H and L cows?

- What are the physiological factors that make the H cows heavier and the L cows lighter?

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APPENDICES

Appendix 1.1: Description of the traits other than production evaluated for New Zealand dairy cattle.

Traits scored by the herd owner:	
1. Adaptability to milking	Describes how soon the animal settles into the milking routine after calving. (Slowly 1---5---9 Quickly).
2. Shed temperament	Describes the temperament of the animal in the shed while milking. (Vicious 1---5---9 Placid).
3. Milking speed	Describes the milking speed of the animal, i.e. time from putting cups on to the time milking stops or the cups are taken off. (Slow 1---5---9 Fast).
4. Overall opinion	Describes the farmers overall acceptance of the animal in the herd. (Undesirable 1---5---9 Desirable).
Traits scored by the inspector:	
5. Stature	Describes the height at shoulders of the animal. Each score represents 5 cm height at withers. (Under 105 cm 1---5---9 Over 140 cm).
6. Capacity	Describes the capacity of the animal as a combination of strength and depth of body as viewed from side, rear and front in relation to the physical size of the animal. (Frail 1---5---9 Robust).
7. Rump angle	Describes the angle of a line between the hips and the pins. (Pins high 1---5---9 Pins low/sloping).
8. Rump width	Describes the width of the pins, hips and thurls. (Narrow 1---5---9 Wide).
9. Legs	Describes the angulation of the rear legs as viewed from side. (Straight 1---5---9 Sickled/curved).
10. Udder support	Describes the udder support and suspensory ligaments as viewed from the rear and the side. (Weak 1---5---9 Strong).
11. Front udder	Describes the attachment of the fore udder. (Loose 1---5---9 Strong).
12. Rear udder	Describes the height of the rear udder attachment. (Low 1---5---9 High).
13. Front teat placement	Describes the placement and angle of the front teats relative to the center of the quarter. (Wide 1---5---9 Close).
14. Rear teat placement	Describes the placement and angle of the rear teats relative to the center of the quarter. (Wide 1---5---9 Close).
15. Udder overall	Describes the overall udder conformation including any other traits which are not explicitly described above. (Undesirable 1---5---9 Desirable).
16. Dairy conformation	Describes the overall udder conformation including any other traits which are not explicitly described above. (Undesirable 1---5---9 Desirable).

Appendix 2.1: Recording sheet for the monitoring of grazing behaviour of yearling heifers during the 1995 and 1996 experiments.

	Animal Ear tag																					
Time-interval																						

G = Grazing, R =Ruminating, I = Idling.

Appendix 4.1: Recording sheet used for monitoring of grazing behaviour of lactating cows offered generous herbage allowances during the spring of 1996.

		Shift from: _____ hours to: ______ hours. Recorded by (name): ______________________ Date: / /																			
		Time interval							Time interval							Time interval					
Cow ID		0-10	10-20	20-30	30-40	40-50	50-60		0-10	10-20	20-30	30-40	40-50	50-60		0-10	10-20	20-30	30-40	40-50	50-60
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G = Grazing, R = Ruminating, I = Idling.

Appendix 8.1: SAS program to obtain the estimators of the growth curve parameters for the Brody, Gompertz, Logistic, and Von Bertalanffy equations.

```
options ls=74 ps=66 nocenter nodate;
Data weights;
      set sasuser.Wgth9093;
      if Equation=' ' then Equation='Brody' ;
*   if Equation=' ' then Equation='Gompertz' ;
*   if Equation=' ' then Equation='Logistic' ;
*   if Equation=' ' then Equation='VBertal' ;
label t='Age (days)' Bwo ='Cow Birth weight kg' Wt ='Live weight'
   SireNo='Sire AB code' SireGL='Sire genetic line' DamLID='Dam lifeID'
   DamGL='Dam genetic line' Dambirth='Dam birth date' CowGL='Cow genetic line'
   CowLID='Cow life ID' Cowbirth='Cow birth date';
run;quit;
proc sort data = weights; by CowLID; run;quit;
Title 'Plot of LW vs age to look for an initial value of A';
options ls=74 ps=30 nocenter nodate;
proc plot data= weights; plot Wt*t= SireGL / vaxis=0 to 700 by 100 box vref=500;
run;quit;
Title 'Generating linear functions of LW for each growth equation';
Data one; set weights;
   Wt1=log((500-Wt)/500);/*For Brody lineal: Wt1=ln(b)-kt */
*  Wt1=log(log(500/Wt));/*For Gompertz lineal: Wt1=ln(b)-kt */
*  Wt1=log((500-Wt)/Wt));/*For Logistic lineal: Wt1=ln(b)-kt */
*  Wt1=log((Wt/500)**(1/3));/*For V.Bertalanffy lineal:Wt1=-ln(b)+kt*/
run;quit;
Title 'Obtaining starting values for b and k by linear regression';
proc reg  data=one outest=Coeffts;
   by CowLID;
   model Wt1=t; output out=two p=lwpred r=lwresid;
run;quit;
Title 'Plot of ln((A-Wt)/A) vs age and lwpred vs age';
proc plot data=two Vpercent=100 Hpercent=100 uniform;
       by CowLID;
       plot Wt1*t='*' lwpred*t='p' /  box  overlay;
run;quit;
Title 'Regression estimates for b and k by cow';
proc print data=Coeffts; /*For a check */
run;quit;
Title 'Retransforming regression coefficients for a proc means';
data paramet; set Coeffts;
/****For Brody, Gompertz, and Logistic functions********/
b=exp(intercep);
k=-(t);
/****For the Von Bertalanfy function********/
b=exp(-intercep);
k= t;
run;quit;
proc means data=paramet mean min max std;
   var b k;
run;quit;
Title 'Fitting the equations using PRC NLIN and MARQUARDT method';
proc nlin  best=5 step= 60 method=MARQUARDT maxiter=100; by CowLID;
/********For Brody equation************/
parms A=300 to 600 by 25 B=0.3 to 0.99 by 0.3 k=0.0001 to 0.008 by 0.001;
       bounds A<= 700, b<= 0.99;
       model Wt=A*(1-B*(exp(-k*t)));
       if _model_ then return;
       con1=b*(exp(-k*t));
       con2=exp(-k*t);
       der.A = 1-con1;
       der.b = -A*con2;
       der.k = A*t*b*con2;
```

```
/********For Gompertz equation************/
parms A=300 to 600 by 25 B=0.5 to 3 by 0.5  k=0.001 to 0.005 by 0.001;
        bounds A <= 700;
        model Wt=A*(exp(-B*(exp(-k*t))));
        if _model_ then return;
        con1=exp(-B*(exp(-k*t)));
        con2=exp(-k*t);
        der.A =con1;
        der.b = Wt*(-con2);
        der.k = Wt*b*t*con2;
/********For Logistic equation************/
parms A=350 to 650 by 25  B=2 k=0.003;
        bounds  A <= 700;
        model Wt=A/(1+B*(exp(-k*t)));
        if _model_ then return;
    con1=(1+B*(exp(-k*t)));
        con2=exp(-k*t);
        der.A =1/con1;
        der.b =-Wt*(con2/con1);
        der.k = Wt*((b*t*con2)/con1);
/********For Von Bertalanffy equation************/
parms A=300 to 600 by 25 B=0.3 to 0.99 by 0.3 k=0.0001 to 0.008 by 0.001;
        bounds A<= 700, b<= 0.99;
        model Wt=A*(1 - B*exp(-k*t))**3;
        if _model_ then return;
        con1 = (1-B*(exp(-k*t)))**3;
        con2 = (1-B*(exp(-k*t)))**2;
        con3 = 3*A*(exp(-k*t));
        der.A = con1;
        der.B = -con3*con2;
        der.k = con3*B*t*con2;
        output out=pp1 p=lwpred r=lwresid ESS=ErrorSS parms=A B k;
run; quit;
Title 'File with growth curve parameters and residual MS for each cow';
proc means data= pp1 noprint;by CowLID;
        id equation SireNo SireGL DamLID DamNo DamGL Dambirth CowGL CowNo
        CowLID Cowbirth Yrbrth BWo ;
        var ErrorSS  A b k;
        output out=dd2 mean=ErrorSS A b k;
run;quit;
Data dd3;set dd2;
        MSResid= (ErrorSS)/(_freq_ -3);
proc means data=dd3 noprint;
    id equation SireNo SireGL DamLID DamNo DamGL Dambirth CowGL CowNo
        CowLID Cowbirth Yrbrth _freq_;
        var  MSResid  A b k;
        output out=dd4 mean= MSResid A b k;
        by CowLID;
proc print;
run;quit;
Title 'Program to calculate the Durbin-Watson d-statistic';
Options linesize=78 pagesize=2000 nocenter nodate;
proc sort data= pp1; by cowlid;
Proc reg;
        model lwresid=  / noint dw;
        by CowLID;
run;quit;
Title 'Plots of residuals';
Options linesize=78 pagesize=30 nocenter nodate;
proc plot Vpercent=100 Hpercent=100 uniform;
        by CowLID ;
        plot Wt*t='*' lwpred*t='p'/ haxis=0 to 2555 by 365 vaxis=0 to 600 by 100 box overlay;
        plot lwresid*Wt='*' / vref=0 vpos=25 box;
        plot lwresid*t='*' / vref=0 vpos=25 box;
        plot lwresid*lwpred='*' / vref=0 vpos=25 box;
run; quit;
```

Appendix 8.2: First partial derivatives of the Brody, Gompertz, Logistic, and Von Bertalanffy functions with respect to each of their parameters.

Brody function

$$\frac{\partial W}{\partial A} = \left(1 - be^{-kt}\right)$$

$$\frac{\partial W}{\partial b} = -A e^{-kt}$$

$$\frac{\partial W}{\partial k} = A t b e^{-kt}$$

Gompertz function

$$\frac{\partial W}{\partial A} = e^{-be^{-kt}}$$

$$\frac{\partial W}{\partial b} = A\left(e^{-be^{-kt}}\right)\left(-e^{-kt}\right)$$

$$\frac{\partial W}{\partial k} = Abt\, e^{-kt} e^{-be^{-kt}}$$

Logistic function

$$\frac{\partial W}{\partial A} = \frac{1}{\left(1 + be^{-kt}\right)}$$

$$\frac{\partial W}{\partial b} = \frac{-A\, e^{-kt}}{\left(1 + be^{-kt}\right)^2}$$

$$\frac{\partial W}{\partial k} = \frac{A b t\, e^{-kt}}{\left(1 + be^{-kt}\right)^2}$$

Von Bertalanffy Function

$$\frac{\partial W}{\partial A} = \left(1 - be^{-kt}\right)^3$$

$$\frac{\partial W}{\partial b} = -3A\, e^{-kt}\left(1 - be^{-kt}\right)^2$$

$$\frac{\partial W}{\partial k} = 3Abt\, e^{-kt}\left(1 - be^{-kt}\right)^2$$

Curriculum Vitae

José Guadalupe García-Muñiz was born to the late Agustin García (1921-1962) and Victoria Muñiz (1926-) on August 23rd 1961 in San Nicolás de Los Agustinos, Guanajuato, México. From 1967 to 1974 I attended primary school at Escuela Primaria Estatal Nicolás Bravo and Escuela Primaria Federal 20 de Noviembre, San Nicolás de Los Agustinos, Guanajuato, México. From 1974 to 1977 I attended secondary school at Escuela Tecnológica Agropecuaria No. 373, San Nicolás de Los Agustinos, Guanajuato, México. In 1977 I sat the national examination to attend Universidad Autónoma Chapingo, Chapingo, México. From 1977 to 1980 I did my Agricultural College at the Departamento de Preparatoria Agrícola and from 1980 to 1984 my undergraduate studies at the Departamento de Zootecnia, Universidad Autónoma Chapingo, Chapingo, México, where I graduated as an Agronomist with a major in Animal Husbandry in 1984. From 1984 to 1986 I worked for the Bank of México as an advisor on dairy cattle management in the state of Jalisco, México. In 1986 I gained a position as a Junior Lecturer in Dairy Cattle Production at the Departamento de Zootecnia, Universidad Autónoma Chapingo, Chapingo México, where I worked until 1992. From 1992 to 1994 I did my Masters of Agricultural Science at the Department of Animal Science, Massey University, Palmerston North, New Zealand. From 1994 to 1998 I did my PhD in Animal Science at Massey University, Palmerston North, New Zealand, which I completed in September 1998. In October 1998 I will go back to the Departamento de Zootecnia, Universidad Autónoma Chapingo, Chapingo, México, and resume my duties as a Junior Lecturer and teach undergraduate and post-graduate courses in Dairy Cattle Production.