Comparison of milking characteristics and feed conversion efficiency of two lines of Holstein-Friesian cows which differ genetically in live weight

A thesis presented in partial fulfilment

of the requirements for the degree of

Master of Applied Science

in

Dairy Production

at Massey University, Palmerston North,

New Zealand

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2002

ABSTRACT

Tolosa, M. X. 2002. *Comparison of milking characteristics and feed conversion efficiency of two lines of Holstein-Friesian cows which differ genetically in live weight.* MAppSc Thesis, Massey University, Palmerston North, New Zealand.

Milking characteristics during peak yield in two consecutive lactations (seasons 2000 and 2001, experiment one); daily milk production and composition, somatic cell count, live weight and body condition score during a complete lactation (2000 season, experiment two); and metabolisable energy intake and feed conversion efficiency during peak lactation (1999 season, experiment three) were studied in three experiments with grazing Holstein-Friesian cows from two selection lines, which differed genetically for live weight. *Experiment one (a & b)*: the heavy line yielded more milk at each milking than the light line but this difference was not significant for any season. Average flow rates were similar for both lines in both lactations (~2.0 litres/min for both lines). Maximum flow rates did not differ between lines either (~3.2 litres/min for both lines). Consequently, total milking times were similar for both lines in both lactations (7.5 *vs*. 7.3 min and 7.6 *vs*. 7.8 min for the heavy and the light line for seasons 2000 and 2001 respectively). *Experiment two*: Cows from the heavy and the light line yielded 22.2 and 20.6 litres/day respectively ($p<0.01$). Fat yield was similar for both lines because the milk from the light cows had a higher fat concentration than milk from the heavy (4.8 *vs*. 5.0%; $p<0.05$). The heavy line yielded more milk protein than the light line (0.8 *vs*. 0.7 kg/day; $p<0.05$), however, there were no significant differences between lines for protein concentration. Log transformed milk somatic cell counts were slightly lower for the heavy line both in peak lactation and during the whole lactation, however, this difference was significant only during peak lactation in 2001 (10.8 *vs*. 11.4×10^3 cells/ml of milk, $p<0.001$; and 10.3 *vs*. 10.8×10^3 cells/ml of milk, $p<0.05$ for the heavy and light line for period one and two respectively). Differences in live weight between the heavy and the light line were significant (517 *vs*. 474 kg for the heavy and the light line respectively; $p<0.001$). Body condition score during the whole lactation was similar for both lines (4.2). *Experiment three*: metabolisable energy intake and feed conversion efficiency in peak lactation were similar for both lines (158 *vs*. 161 MJ ME/cow/day and 108 *vs*. 106 g MS/kg DM intake for the heavy and the light line respectively). The regression coefficient of metabolisable energy intake on metabolic live weight was 0.65 MJME/kg $LW^{0.75}$ for both lines. In summary, selection for cow live weight affected the live weight of the cows, had no effect on milk production, and in contrast with other experiments, had no effect on individual pasture intake either per cow or per kg of metabolic live weight nor on energy requirements for maintenance. Finally, selection for cow live weight did not have a consistent effect on milking characteristics or milk somatic cell counts.

Key words: dairy cows; live weight; milk production; milking characteristics; somatic cell counts; feed efficiency.

ACKNOWLEDGEMENTS

In conducting this research, I was fortunate to have the help of many people. I would firstly like to thank my chief supervisor, Professor Colin Holmes. It is a pleasure to acknowledge his guidance and feedback regarding the development of this thesis. Without his great and permanent assistance and accessibility, this project would not have been possible. I benefited tremendously from his wisdom and advice. Colin has inspired me to be further involved in research. I would also like to express my thanks to Nicolas Lopez-Villalobos for assisting me with statistical analysis, and for his advice in interpreting the results. I enjoyed working with Nicolas and I am still impressed by his wide-ranged knowledge. I am very grateful to Graham McCool, manager of the Dairy Cattle Research Unit, Massey University, for his expert animal handling, wonderful disposition and patience. The help provided by Geoff Purchas in recording information and by Alex Chaves for his technical advice is very much appreciated. I wish to extend my thanks to Duncan Mackenzie for his time, willingness to discuss the results and comments on the review of literature; to Tom Barry, Gavin Wilson, Ian Brookes, John Hodgson and Cory Mathews. It was a privilege to attend their lectures.

I would like to thank Joanne Wrigley who proofread the early draft, helped me improve my writing with her suggestions, for her friendship and support during the two years I stayed in New Zealand; and to Marcela and Norman Russ's family, owners of the 'open home', for their generosity and for sharing a bit of their lives with me. A special word of thanks goes to my mother, Fernanda Tolosa, for her unconditional support. Finally, I would like to thank Chris McCorkindale for the 'ride' and for making my life especial and enjoyable even in the hardest times. Thank you all for making my stay in New Zealand more fruitful than I ever imagined.

I am particularly grateful to the New Zealand Ministry of Foreign Affairs and Trade for providing the scholarship that made this unique experience possible. Furthermore, the financial support of the Livestock Improvement Corporation is gratefully acknowledged.

In memory of Jorge H. Tolosa Brown

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CHAPTER ONE

LITERATURE REVIEW

Part One

1. MILKING CHARACTERISTICS OF DAIRY COWS

1.1 Introduction

The productivity of the dairy farm is affected by many factors. The average genetic merit of the herd determines the potential milk production and the feed conversion efficiency of that herd. Selection and breeding practices have a key role in that respect. However, achieving the potential yield of milksolids per year depends mainly on the feeding level, ability of the cow to convert this feed into milk, and health status of the animals. These are the most obvious factors that influence milk secretion and therefore milk yield, but are not the only ones. Milking management also influences the amount of milk that is secreted within the udder, particularly milking frequency (Turner, 1955; Barnes *et al.*, 1989) and completeness of milk removal at each milking (Dodd and Clough, 1962; Hamann and Dodd, 1992). Milk management directly influences the milk ejection reflex and therefore the amount of milk available for removal. Completeness of milk removal was reported to influence the activity and rate of regression of the secretory tissue, probably through the effects of the 'feedback inhibitor of lactation' (Knight *et al.*, 1994.). The successful removal of milk is important if the full benefits of high genetic merit cows and their maximum feed efficiency are to be achieved (Phillips, 1978).

The objective of machine milking is to remove all milk quickly, under hygienic conditions, whilst maintaining high milk yield, milk quality and optimum animal health, at low cost (Bruckmaier and Blum, 1998). Fast milking is especially important when considering that milking accounts for 30-50% of the total labour requirements, and that the costs of labour and average herd size are both increasing (Ovesen, 1972; Arave *et al.*, 1987). The length of time it takes to milk a herd depends on the size of the herd, the number of milking units, the number of people milking plus the individual total milking time (Whipp, 1992). Furthermore, individual total milking time is dependent on teat anatomy, milk flow rate and milk yield. To understand the factors that affect milking characteristics and their relationship with somatic cell count, it is first necessary to understand the physiology of milk removal. Therefore, this review deals with the factors that affect the rate of milk removal, total milking time and milk somatic cell count.

1.2 Factors Influencing Milking Characteristics

1.2.1 Physiological and Anatomical Factors Influencing Milking Characteristics

The Milk Ejection Reflex

The alveolar milk fraction, which is located in small ducts and alveoli and represents more than 80% of all the milk stored in the udder, is fixed by capillary forces and is removed after a forceful expulsion into the cisternal cavities, termed milk ejection (Lefcourt and Akers, 1983). Milk ejection is defined as the transfer of milk from the lobulo-alveolar spaces and fine ducts into the larger ducts and cisterns (Cowie *et al.*, 1980). The cow's milk ejection can occur in response to sustained and vigorous tactile stimulation (*i.e.*, suckling of the calf, washing or massaging the teats and lower portion of the udder, and the action of the teat cups; Lincoln and Paisley, 1982; Gorewit and Gassman, 1985). Visual, auditory and olfactory stimuli also induce milk ejection when they consistently occur in close association with milking or suckling (Lefcourt and Akers, 1983; Willis and Mein, 1983). The latter is called a conditioned milk ejection reflex because it develops but it is not inborn. The division between conditioned and unconditioned milk ejection reflex is not clear. However, the actions of either or both types of reflexes result in a more effective milk ejection and therefore faster milking (Cowie, 1977). Selection of cows that have an effective conditioned milk ejection in response to stimuli of these types has played an important role in fast milking of modern dairy cows (Phillips, 1987).

Milk ejection is an innate reflex, which occurs through a neuroendocrine arc (Mepham, 1987). Neural receptors are present in the skin of the teat ends (Findlay, 1966). When these pressure-sensitive teat receptors are activated, nerve impulses travel thorough mammary nerves and the spinal cord to the brain. The signal is then transmitted to the supraoptic and paraventricular nuclei of the hypothalamus, where the cells that synthesise oxytocin are located. Oxytocin is released from these cells in response to stimulation of the teat, and travels via their axons to the posterior pituitary gland (Ely and Petersen, 1941). The terminal axonal dilatations of the pituitary, which serve as a storage site of oxytocin, then release the hormone into the bloodstream (Crowley and Armstrong, 1992). Elevated concentrations of oxytocin reach, and cause contraction of, the myoepithelial cells that surround each alveolus and the longitudinally orientated cells located along the walls of the small ducts (Linzell, 1955). The resultant increase in pressure inside the alveoli causes the expulsion of milk out of the alveoli into the larger ducts. In addition, the diameter of the duct increases when the myoepithelial

cells that cover the walls of the small ducts contract, assisting the passage of alveolar milk to larger ducts and into the cisterns of the gland and teat (Schams *et al.*, 1984; Bruckmaier *et al.*, 1994). Once the milk has drained towards the teat it is removed from the cisterns by the milking machine or calf.

Ejection of alveolar milk into the cistern during early milking is not sufficient to empty the udder (Bruckmaier, 2001). Maintaining a threshold concentration of oxytocin, the perfusion of all alveoli with blood containing oxytocin and continuous removal of milk are necessary to cause repeated contractions of the myoepithelial cells, and thus, a more complete emptying of the alveoli (Bruckmaier *et al.*, 1994). Repeated contraction of the myoepithelial cells throughout the milking process results in complete and fast milk removal. However, it appears that blood flow to individual alveoli is intermittent, therefore only those alveoli that are perfused when blood oxytocin concentrations are elevated will contract. Partial milk ejection was observed when insufficient amounts of oxytocin reached the myoepithelial cells, and when oxytocin was only transiently released (Bruckmaier *et al.*, 1996). If this occurs during the whole milking process, the amount of milk remaining in the udder after milking would be increased. Incomplete removal of milk is related to a decrease in milk yield, which could be due to the presence of the feedback inhibitor of lactation (Knight *et al.*, 1994). The feedback inhibitor of lactation is a protein of small molecular mass that is active in alveolar milk and exerts an autocrine inhibitory action on the secretory cells (Wilde and Peaker, 1990).

The amount of oxytocin necessary to evoke maximum ejection was 3-5 pmol/l (Schams *et al.*, 1984) or 0.02 IU (Gorewit *et al.*, 1983) when basal oxytocin concentrations were 1.5 pmol/l plasma. Releases of oxytocin occur as a series of peaks and occur at intervals of 2-10 minutes, ranging between 11-65 μU/ml blood plasma (Gorewit, 1979). In order to achieve these concentrations, a mature cow would have to release 0.4-2.6 IU of endogenous oxytocin (Gorewit and Sagi, 1984). This was demonstrated in a study that compared milk yields, milking dynamics and the amount of residual milk after injection of 5 doses of oxytocin (Gorewit and Sagi, 1984). Results indicated that injection of 2.0 or 3.0 IU of oxytocin promoted more efficient milk ejection compared to 0.5, 1.0 or 1.5 IU. The higher doses resulted in a 3% reduction in residual milk. Milk flow dynamics were not affected but fat percentage increased from 3.3 to 3.7% because of the higher concentration of fat in the residual milk. Approximately one third of oxytocin stored in the pituitary is released at

milking (Gorewit *et al.*, 1983) and has a half-life of 1-3.6 minutes (Momongam and Schmidt, 1970; Gorewit, 1979).

The Pattern of Oxytocin Release

As a consequence of alveolar milk ejection, pressure within the teat cistern rapidly increases from 1.3-4.0 kPa to 4.0-8.0 kPa, measured before and after stimuli respectively (Mayer *et al.*, 1991), and the cisternal cavity becomes enlarged (Bruckmaier and Blum, 1992). Milk ejection stops when intramammary pressure reaches the maximum value due to limited cisternal space, which occurs when milk is not being removed (*i.e.,* late attachment of the cups or during the intervals between milkings; Bruckmaier *et al.*, 1994). If ejection stops before the commencement of milking, the milk flow will be interrupted after the cisternal milk fraction is removed (Gorewit and Gassman, 1985). This scenario would result in longer milking times and lower milk flow rates (Bruckmaier *et al.*, 1996). This was observed in experiments that compared milking characteristics of cows that were intensively stimulated (0.5-1.0 min) with others that had no premilking stimulation. Premilking stimulation consisted of udder cleansing, massage of the teats and of the lower parts of the udder, hand stripping of 1-3 squirts of milk before attachment of the cluster. Average flow rates tended to be greater in cows that received stimulation, resulting in shorter milking times. Values for total milking times and average flow rates in mid lactation were 6.2 *versus* 6.8 minutes and 1.7 *versus* 1.5 kg/min, for stimulated and unstimulated cows respectively. No differences were found in peak flow rates at this stage of lactation (3.6 kg/min). In addition, the time before reaching peak flow rate was 1.6 and 2.4 minutes for stimulated and unstimulated cows respectively. It was concluded that delayed milk ejection occurred in the milkings without stimulation and in the four German breeds tested. Nevertheless, milk yields were not affected by the treatment and the faster milking did not compensate for the time spent on stimulation (Bruckmaier *et al.*, 1995). Similar effects on milking time were found by Momongan and Schmidt (1970) where unstimulated Holstein-Friesian cows took longer to milk than stimulated cows (5.9 *versus* 5.2 minutes) but yielded similar amounts of milk (10.5 *versus* 10.8 kg, measured in the afternoon). The lack of premilking stimulation caused increased milking times and reduced average and peak flow rates in various stages of lactation (Zinn *et al.*, 1982). Values for total milking time in mid lactation, average flow rates and maximum flow rates were 5.4 min *versus* 6.4 min, 2.6 *versus* 2.2 kg/min and 3.8 *versus* 3.5 kg/min for the cows with and without stimulation respectively (Zinn *et al.*, 1982). The unfavourable changes in milking performance occurred despite the small differences in peak concentration of oxytocin

measured (16.6 *versus* 16.0 µU/ml; Sagi *et al.*, 1980). Peak oxytocin concentration occurred after 2 minutes of the start of milking in stimulated cows whereas in unstimulated cows oxytocin peaked after 5 minutes from the start of milking (Sagi *et al.*, 1980). Thus, the importance of the time when stimulation begins in relation to the time milk removal begins (*i.e.,* attachment of the cups) was recognised as a key factor influencing milk removal rate. Early induction of alveolar milk ejection (before the start of milking) improved the efficiency of milk removal through increased milk flow rate and reduced total milking time (Bruckmaier and Blum, 1996). This occurs through the avoidance of a decrease in milk flow or a total interruption in milk flow after removal of the cisternal fraction, resulting in another benefit; a reduction in the risk of continuing to milk empty teats (Bruckmaier *et al.*, 1996). This hypothesis was further tested in an experiment that compared the effect of one-minute manual premilking stimulation and no stimulation, on the pattern of oxytocin release and milking dynamics. Peak oxytocin concentrations occurred within one minute of attachment of the machine in stimulated cows and one minute later in cows without stimulation. Yields of milk and average flow rate did not significantly differ between treatments. Milking time was shorter, and maximum flow rates were higher in stimulated cows (6.0 *versus* 7.3 min and 2.3 *versus* 1.9 kg/min; Bruckmaier and Blum, 1996). A study that compared four different durations of stimulation, 15, 30, 60 and 120 seconds, showed that 15 sec was not significantly different from no stimulation at all, in terms of maximum flow rates (3.2 kg/min), and 30 sec resulted in the same values for maximum flow rates as 60 and 120 seconds stimulation (3.9 kg/min). Similar results were reported in another study where there was no difference between 0 and 15 sec stimulation, and more than 30 sec of stimulation resulted in a significantly higher average flow rates compared with no stimulation (2.4, 2.6 and 2.8 *versus* kg/min for 30, 60 and 120 sec respectively; Gorewit and Gassman, 1985).

Furthermore, faster milk ejection and faster milking occurred when the udder was close to maximum storage capacity. During early lactation and after longer milking intervals, when the degree of udder filling was high, ejection began more quickly than in late lactation and following short intervals between milkings (Bruckmaier and Hilger, 2001). Earlier ejection after 12 h milking interval, which occurred in both groups of cows that received one-minute stimulation (S) and in cows that received none (NS), resulted in higher milk yields and higher average flow rates compared to the shortest interval between milkings (milk yield was close to 20 kg and less than 8 kg after the 12 and 4 h intervals, respectively). Values for average flow rates after the 12-hour interval were 2.4 and 1.9 kg/min for S and NS cows respectively.

In contrast, when the udder was less full after the 4 h interval, corresponding values were 1.3 kg/min for both NS and S cows (Bruckmaier and Hilger, 2001).

The milk ejection reflex is the most important factor influencing the milk removal process but it is not the only one (Lefcourt and Akers, 1983). Milk removal is also affected by teat end morphology and environmental factors that enhance (regular and good milking routine) or inhibit (*i.e.*, stressful situations) the milk ejection reflex.

Effect of Premilking Stimulation on Milk Ejection

The lack of response in milk yield to stimulation suggested that it is not necessary to stimulate cows to maximise oxytocin release and ensure adequate milk removal from the udder in high-producing Holstein Friesian cows (Mein and Thompson, 1993). These cows can probably be milked completely, and release oxytocin, in response to the stimuli provided by the frictional contact between the teat cup liner and the teat, and various conditioned stimuli. This conclusion is supported by a series of experiments carried out in New Zealand since 1958 (Phillips, 1987). In the early experiments, stimulation of Jersey cows resulted in a milk fat production response of over 30% (Phillips, 1965). Responses dropped to 6% in 1974 and were reduced to 0% twenty years later (Phillips, 1987). This reduction in the dependency on premilking stimulation for maximum production could be explained by the milking management changes experienced in the 1950's. Hand stripping (equivalent to post milking manual stimulation) was considered unpractical due to the increasing herd size, and was therefore abandoned (Mein and Thompson, 1993). Stimulus requirement was found to be lower in high producing cows. Consequently, low producers were more likely to be culled. In addition it was recommended that animals with high stimulus requirement should not be used as herd replacements (Phillips, 1963). The incorporation of Friesians into the mainly Jersey herds since 1960, also contributed in reducing the need for stimulation (Phillips, 1978).

Inhibition of Milk Ejection

Factors that inhibit oxytocin release from the posterior pituitary (central inhibition), reduce or prevent oxytocin from reaching the myoepithelial cell (peripheral inhibition) will inhibit milk ejection (Gorewit and Aromando, 1985). Pain, sudden fright, or other noxious stimuli may block the release of oxytocin from the posterior pituitary gland. Central inhibition of milk ejection occurred in cows which were machine milked in unfamiliar surroundings (Bruckmaier *et al.*, 1993b; Bruckmaier *et al.*, 1996), in primiparous cows immediately after

parturition (Bruckmaier *et al.*, 1992), during peak oestrus (Bruckmaier *et al.*, 1994), when changed from suckling to machine milking (Wellnitz and Bruckmaier, 2001), sometimes, in cows exposed to low voltage during milking (Aneshansley *et al.*, 1992), and in any other stressful situation (Nickerson, 1992). The cause of the disturbed milk ejection, which was similar under all the circumstances mentioned above, was inhibition or reduction of oxytocin secretion by the pituitary gland (Bruckmaier and Blum, 1998). In addition, peripheral inhibition of milk ejection was reported in cows with induced mastitis (Bruckmaier *et al.*, 1993[a]).

To investigate the effects of central inhibition of milk ejection, cows were milked in an unfamiliar operating theatre and in a familiar barn (Bruckmaier *et al.*, 1993[b]; Bruckmaier *et al.*, 1996). Oxytocin remained at basal concentrations during milking in the unfamiliar surroundings but increased markedly in the familiar barn. Consequently, only 9% of milk, equivalent to the cisternal milk, was removed in unfamiliar surroundings compared to 77% of the total milk (with 23% residual milk) that was obtained in the familiar barn. Elevated concentrations of β-endorphin and cortisol indicated that cows milked in unfamiliar surroundings were considerably stressed (Bruckmaier *et al.*, 1996). In addition, maximum flow rates were lowered in the stressed cows (1.4 *versus* 3.9 kg/min, for stressed and control cows respectively). Injection of 1.0 IU oxytocin (within the physiological range) allowed the removal of most of the remaining milk in unfamiliar surroundings, which proved that the inhibition had not occurred at the mammary gland level.

Stress is generally associated with increased concentrations of catecholamines (epinephrine and norepinephrine), which in turn increase the tone of the smooth muscles of the mammary ducts and blood vessels. The subsequent decrease in blood flow results in reduced amounts of oxytocin reaching the myoepithelial cells, therefore, reduced contraction by them. In addition, catecholamines impede oxytocin from binding with its receptor. It was reported that exogenous catecholamines reduced milk removal by 8.6% through a peripheral mechanism (Blum *et al.*, 1989). Furthermore, norepinephrine administration (0.95 nmol/kg) increased milking time by approximately 2.4 min, reduced maximum flow rates from 2.9 (control cow) to ~2.4 kg/min (treatment cow), and increased time to peak milk flow by approximately half a minute in low and medium yield animals, but did not affect the pattern of milk flow in high-yield cows (Lefcourt and Akers, 1984).

Electrical current (> 5 mA) delivered through the milk line caused not only peripherally inhibited milk ejection but also disturbed the release of oxytocin (partial and delayed release of oxytocin). Milk yield and milking time decreased during application of constant current to first lactation cows (Aneshansley *et al.*, 1992). Electroshocks enhanced release of catecholamines, which possibly caused reduced milk removal (Blum *et al.*, 1989).

Besides the economic importance of incomplete and slow milk removal, these factors can also increase the risk of raised somatic cell count (Bruckmaier and Blum, 1998). Following a regular milking routine, and avoiding incidents which might cause discomfort to the cow, encourages the normal functioning of the milk ejection reflex and enhances the release of oxytocin from the pituitary gland, therefore contributing to complete and fast milk removal (Cowie *et al.*, 1980).

Shape of Udder, Structure of the Teat and Teat Canal

While maximum flow rate is constant during and in succeeding lactations, it varies greatly between cows (Rathore, 1976[b]). Milking rate was controlled mainly by the teat anatomy, particularly teat canal diameter, rather than by the milk ejection mechanism or milk yield of the cow, because nearly all variation was removed if the diameters of the teat canals were made equal with uniform bore cannula (Baxter *et al.*, 1950). Teat canal diameter varies greatly, ranging from 2.3 to 5.0 mm. Slow milking was reported in cows with narrow teat orifices (Rathore and Sheldrake, 1977). Peak milk flow rate was positively correlated with teat canal diameter (Schultze, 1979). In addition, a higher stretchability of the teat orifice was found in high-yield cows, cows with fast milk flow rates, funnel-shaped, large-diameter teats and hind teats (Rathore and Sheldrake, 1977).

Even though milk flow rate seems to depend mostly on the size of the teat orifice, teat length has also been associated with milking rate (Seykora and McDaniel, 1985). A significant negative correlation was found between teat length and milk flow rate in studies where Danish cows with shorter teats (less than 5 or 6 cm depending on breed) had faster and more complete milking. An increase in teat length of 1 cm resulted in 0.06 to 0.21 kg/min increase in average flow rate and 0.08 to 0.42 min increase in total milking time (Ovesen, 1972). However, no relationship between teat thickness and milking characteristics was found (Ovesen, 1972). In another experiment, an average flow rate of 0.95 kg/min was found in 5.3 cm long teats whereas flow rates of 0.68 kg/min were observed in 6.1 cm teats whereas

diameter of the teat orifice did not influence milking rate (Thiel *et al.*, 1969). The observation that milk flow disturbances occurred in teats that were 11mm and did not occur in 8 mm long teats (Geishauser and Querengasser, 2000), further supports that teat length affects milk flow. In addition, teat end shapes classified as pointed, round, flat, disk shape and inverted influenced milking characteristics. The general trend was that disk and inverted teat ends had wider streak canals and higher flow rates than those with pointed or round teat ends, therefore, as teat end shape varies from pointed to inverted, milk flow rate increased (Ovesen, 1972). Flow rate, measured as the percentage of total yield removed in 2 min, increased from 27% to 60.5% in pointed and inverted respectively (Hodgson *et al.*, 1980). However, teat shape seems to have little influence on milking characteristics unless it is very extreme (Ovesen, 1972). In general, cylindrical and slightly funnel shaped teats are the most satisfactory because they are firmly held by the teat cups. Finally, udder shape had an indirect effect on milking characteristics because it affects the ease of milking. Widely spaced teats or teats that angle outwards on poorly shaped udders were difficult to milk because of the uneven distribution of the weight of the milking unit on each quarter. Udders that hung too close to the ground were also a problem because of the lack of space to apply the teat cups (Nickerson, 1992).

Breed

Milking times of Friesian and Jersey cows in commercial herds during mid to late lactation were compared (Arave *et al.*, 1987). Friesians produced 37% more milk (14.9 *versus* 10.9 kg/cow/day). The higher milk yield of the Friesian cows was associated with longer total milking times (9.8 *versus* 9.1 min for Friesian and Jersey cows respectively). Average daily flow rate was 28% higher for Friesian compared to Jersey cows (1.72 kg/min *versus* 1.34 kg/min). Comparison of total milking times after adjustment for milk yield indicated that Jersey cows would take longer to be milked (9.8 *versus* 10.6 min for the Friesian and Jersey cows respectively). This indicates that the introduction of a high-yielding breed resulted in higher average flow rates (Arave *et al.*, 1987).

Milk Yield

There is controversy in the literature regarding the relationship between rate of milking and total lactation yield. The correlation coefficient of milk flow rate on milk yield was 0.5 (Rathore, 1976[b]). An increase of 1 kg/min in peak milking rate was related to 400 extra kg in early lactation (Dodd and Foot, 1953). The positive correlation between milking rate and milk yield may indicate that as the cows are selected for higher milk yield they will have faster

milking rates too. High producing cows have lower premilking stimulus requirements than low producers, which may partly explain the higher maximum and average flow rates of those cows (Mein and Thompson, 1993). In the third month of the lactation, an increase of one kg in milk volume was associated with 0.12 kg/min increase in average flow rate and 0.35 min increase in total milking time (Markos and Touchberry, 1970). The correlation coefficients of average flow rate and total milking time on milk volume increase as lactation progresses. Corresponding coefficients in the fourth month of lactation were 0.13 kg/min and 0.36 min (Markos and Touchberry, 1970). Others found that flow rates increased with increasing milk yield up to a limit of 13 kg, and thereafter, stretchability of the teat orifice becomes a limiting factor (Rathore and Sheldrake, 1977). They suggested that cows with low maximum flow rates were likely to have low breeding values for milk yield as well. Moreover, studies have also shown that there was no relationship between rate of milking and total lactation yield (Hamann and Dodd, 1992). Therefore, anatomy of the teat seems to explain differences in milking characteristics between cows to a greater extent than yield production differences (Nickerson, 1992).

A further experiment showed that differences in milk yield caused by contrasting levels of feeding can also influence milking characteristics. The effect of two contrasting levels of feeding on milk production and rate of milking was studies for Jersey cows grazing tropical pastures under a leader and follower system (Stobbs, 1978). Cows grazing a the higher quality pasture and on the higher planes of nutrition (leaders) had higher levels of milk production (8.7 *versus* 6.3 kg of milk/cow/day; $P<0.001$), took longer to milk out (5.17 *versus* 4.83 minutes, $P<0.05$) but had significantly higher milking rates (2.4 *versus* 2.0 kg/min, $P<0.001$) compared with the followers. The same pattern was observed in cows fed Rhodes grass managed identically (Stobbs, 1978). In summary, factors that influence milk yield can also influence milking characteristics (i.e., age, stage of lactation, level of feeding, breed, genetic merit, etc).

Genetic Merit

Milking characteristics were studied throughout the lactation in Friesian cows with high (126) and low (102) breeding indices (Davey *et al.*, 1983). Mean maximum flow rate of morning and afternoon milkings combined were 2.2 and 1.6 litres/min for cows with a high and low breeding index respectively. Even though the low breeding index cows yielded 10% less milk than the high breeding index cows they took 15% longer to milk (Davey *et al.*, 1983).

Another study comparing high and low breeding index cows had similar results (Carruthers and Woolford, 1983). Morning total milking times measured four times throughout the lactation were 8.0, 6.9, 6.5 and 5.3 min, and 7.2, 6.0, 5.4 and 4.7 min, for cows with a high and low breeding index respectively. The corresponding values for average flow rate were 1.46, 1.40, 1.31 and 1.20 kg per minute for high breeding index cows and 1.36, 1.28, 1.13 and 1.02 kg per minute for low breeding index cows (Carruthers and Woolford, 1983). Similar results were obtained in another experiment that compared high and low breeding index cows (Arave and Kilgour, 1982). The high breeding index cows produced an average of 3 kg more per day throughout the lactation but took less time to milk out both in the morning and afternoon milkings than their counterparts (5.9 *versus* 6.7 and 5.1 *versus* 6.7 min for the morning and afternoon milkings for high and low breeding index cows respectively). Differences in total milking time between lines became smaller as lactation advanced (4.8 *versus* 4.7 and 4.1 *versus* 4.2 min for the morning and afternoon milkings for the high and breeding index cows respectively during the last month of the lactation). Unfortunately none of these studies compared flow rates after adjustment for milk yield.

1.2.2 Milking-Machine Factors Influencing Milking Characteristics

Some of the main milking-machine factors that affect milking characteristics and teat health are vacuum level and stability, pulsation characteristics (*i.e.*, pulsation rate and ratio), weight of the cluster and liner design (Mein, 1992). During milking, cyclic pressure difference or pulsation, which normally occurs 50-60 times per minute, is applied to the teat and results in repeated closing and opening of the liner. During the release phase of the pulsation cycle, vacuum of 50 kPa opens the teat canal, whereas, during the squeeze phase, the collapsed rubber liner compresses the teat and closes the canal, stops milk flow and massages the teat to reduce congestion (Williams and Mein, 1982).

Machine design affects vacuum level, therefore affecting milking characteristics. Low-level milk lines show higher vacuum levels at the teat during maximum flow rate and result in higher flow rate than high line milking machines, when operated at the same vacuum level at the regulator valve (Clough, 1972). Similar flow rates were obtained with low-line machines at 40 kPa and with high lines operating at 50 kPa (Clough, 1972).

During milking, the milk flow rate is proportional to the magnitude of the vacuum (Thiel and Mein, 1977). Increasing the vacuum level results in increased maximum flow rate (from ~3.1 kg/min at 40 kPa to ~ 4.5 kg/min at 70 kPa) and shorter milking times. The velocity of milk flow from the teat during the peak flow rate period was estimated to be ~ 8.5 m/s with a liner vacuum of 50 kPa and 7.5 m/s at 40 kPa (Williams and Mein, 1986). However, excessive vacuum tends to cause incomplete milking, teat congestion, and increased risk of tissue damage (Mein, 1992). A vacuum of 50 kPa is generally the most satisfactory compromise (Williams and Mein, 1982).

Extremely poor vacuum stability generated within the cluster, which could result from blocked air admission into the cluster, a very elevated milk line, inadequate bore of the short milk tube, liner slips or abrupt cup removal at the end of milking, affects udder health through reverse flow (Fell, 1964; Mein, 1992). However, vacuum stability did not consistently affect milking characteristics (Thiel *et al.*, 1968).

Pulsation characteristics play an important role in determining the efficiency of milking (Clough and Dodd, 1956). Typically, the pulsation rate or number of cycles per minute (number of times the liner opens and closes per min) is between 45 and 65 (Holmes *et al.*, 1987). Milking rate increased with increases in the pulsation rate, because the rate of milk flow from the teat decreases after about 0.5 sec of the release phase, even though the liner remains open (Williams *et al.*, 1981). Thus, closing the liner just before the flow starts to decrease rapidly (increasing the pulsation rate) for many cycles results in faster flow rates. For instance, increasing the pulsation rate from 40 to 160 cycles/min while the ratio was maintained at 50%, increased maximum flow rate by ~40% (Clough and Dodd, 1956). Furthermore, increasing the pulsation rate, from 52 to 61 cycles/min while maintaining a constant pulsator ratio of 61% resulted in an increase in milk yield (measured at morning milking; O'Callaghan, 1998). The fastest rates used in practice are about 60 cycles per minute (Holmes *et al.*, 1987).

The ratio of the duration of the release phase in relation to the duration of the squeeze phase, in one cycle, is referred to as the pulsation ratio. In a pulsation cycle, the milking phase is usually equal or longer than the massage phase. For example, with a 70:30 pulsator ratio the liner would be open for 70% of the cycle and closed for 30% of the cycle. Milking rate is increased by increases in the pulsation ratio; however, the squeeze phase should not be shorter

than 0.15 sec (O'Callaghan and O'Shea, 1982). Increasing the pulsation ratio from 50 to 75% increased maximum flow rate by ~45% (Clough and Dodd, 1956). In a similar manner, reducing the pulsation ratio from the usual 70:30 to 50:50 reduced peak flow rate and prolonged the period of rapid milk flow, whereas the main flow rate did not change significantly (Pfeilsticker *et al.*, 1995). Milking time was significantly longer when the pulsator ratio was reduced from 71 to 61% (O'Callaghan, 1998).

Changes in milk flow rate within a pulsation cycle result from the influence of congestion on the effective diameter of the dilated teat canal (Williams *et al.*, 1981). During the collapse phase, the liner compresses the teat end and the teat canal is flattened (Mein, 1992), which massages the teat to reduce congestion by facilitating the flow of venous blood and interstitial fluid. Nevertheless, some congestion usually occurs after the end of peak milk flow (Woolford, 1984).

Weight of the cluster is another factor that affects milking time and completeness of milking. Light clusters predispose the cup to move or crawl upward along the teat, occluding the junction between the cisterns of the gland and the teat (Thiel and Mein, 1977). Uneven distribution of the weight of the cluster between the teats (i.e., front teats higher than rear teats or non-horizontal floor of the udder) also increases the occurrence of cup crawl (Holmes *et al.*, 1987). However, cluster weight does not affect milking characteristics as much as liner design (O'Shea and O'Callaghan, 1978).

Liner design affects milking characteristics more than any other machine factor (O'Shea *et al.*, 1983). If the liner's mouthpiece is too deep compared with the teat length (high liner), the teat might not reach the collapsing point of the liner. As a consequence of pulsation failure, the effects of congestion are not overcome and the tissues of the teat wall swell (Mein *et al.*, 1983). Furthermore, mastitis infections and teat end lesions were elevated (Bramley *et al.*, 1978). The effect of liner design on milking characteristics was studied in an experiment with Danish Holstein cows (Ramussen *et al.*, 1998). Liners of 30 mm mouthpiece cavity height (high liner), which had greater pulsation chamber volume, showed longer total milking times compared to low liners with 18 mm mouthpiece cavity height (5.51 *versus* 5.00 min respectively, $P<0.05$). Average flow rate was higher in cows milked with the low liner although this difference was not significant. In addition, more slips were observed in the low liner, which had a narrower bore than the high liner. The increase in the number of liner slips

was related to maximum flow rate; when peak flow rate was higher than 4 kg/min, cows milked with the higher liner had less slips than those milked with the low liner (one *versus* four slips respectively; Ramussen *et al.*, 1998). In addition, lines of inadequate length (i.e., shorter than the teats) can cause damage to the teat end (Williams *et al.*, 1981).

Keeping the liner stable on the teat is important as it affects the work routine (Thiel and Mein, 1977) and teat health (O'Callaghan, 1996), and could prolong milking time. Liner stability is related to the size of the mouthpiece (Ramussen *et al.*, 1998). An increase in frequency of liner slips resulted in a decrease of 6-8 kPa in milking vacuum (Spencer and Rogers, 1991). These vacuum fluctuations and reverse pressure gradients across the teat canal are mainly associated with an increase in new intramammary infections (Galton *et al*., 1988; Bramley, 1992). A small mouthpiece chamber is more likely to maintain the cluster in position due to the small vacuum reserve it provides when the seal or the friction between the teat surface and the liner barrel is lost (Ramussen *et al.*, 1998). Furthermore, liners that don't cause air leakage between the teat and mouthpiece lip are less likely to slip or fall off.

1.3 Mastitis and Milk Somatic Cell Count

Mastitis is an inflammatory response of the mammary gland to the presence of microorganisms (Bramley, 1992). Mastitis is usually caused by bacterial infection (*Staph. aureus*, *Str. agalactiae*, *Str. dysgalactiae*, *Str. uberis*, coliforms, etc) although trauma, hormonal imbalances and other microorganisms can also be responsible (i.e., fungi, algae, *Mycoplasma sp*.). Microorganisms gain entrance through the teat canal and colonise the duct system (Oliver and Sordillo, 1988). They cause tissue damage and affect the activity of the secretory cells (Paape *et al.*, 1979). As a consequence, milk yield is reduced (Woolford and Williamson, 1988), milk composition changes (Rogers *et al.*, 1989), and the concentration of enzymes and somatic cells is altered.

Somatic cells, mainly macrophages and also neutrophils, lymphocytes and monocytes, are always present in healthy udders. Mastitis causes a rapid and marked migration of some of these cells from the peripheral circulation to the site of infection (Reiter and Bramley, 1975). Their action is to assist in resisting the infection by means of inhibiting bacterial attachment to the epithelial surface, neutralising toxins produced by microorganisms (Nickerson and Pankey, 1984), and inhibiting bacterial growth in the secretory tissue (Bramley, 1992).

Relationship Between the Milking Machine and Mastitis

The milking machine is considered as an important factor affecting the risk of mastitis infection and the spread of the disease between quarters and between cows (Fell, 1964). The milking machine can contribute towards increasing the risk of mastitis in many ways. It influences growth and penetration of mastitis pathogens from the teat into the duct system and their transmission between cows or quarters (Bramley, 1992). Furthermore, the milking machine can affect the susceptibility of the cow to infection.

The role of the milking machine in promoting growth of pathogenic bacteria

Teat lesions, occurring as a consequence of milking machine malfunction, are readily colonised by pathogenic microorganisms. Teat damage takes the form of teat canal eversion, haemorrhagic blisters and teat chapping. Some of these lesions occur as a result of very high vacuum levels (>55kPa) and are more frequent among cows with long milking times (Bramley, 1992). Furthermore, severe overmilking, combined with other deleterious factors, is known to increase teat end and sinus lining lesions (Natzke *et al.*, 1978; Mein *et al.*, 1986).

The Role of the Milking Machine in the Penetration of Pathogenic Bacteria into the Teat

Certain milking conditions that lead to back jetting of the milk can aid penetration of microorganisms into the teat sinus (Natzke, 1981). Milk backflow can propel bacteria into the teat sinus and can cause increased infection rates (Fell, 1964). Higher incidence of mastitis infection was reported in cows milked with high and unstable vacuum level, and high pulsation rate (Watts, 1951). In addition, severe vacuum fluctuations in the teat cup liner caused increased outbreaks of mastitis (Nyhan and Cowhig, 1967; Griffin *et al.,* 1983). Machine factors that lead to unstable vacuum in the pulsation chamber of the teat cups include short milk tube with small bore and inadequate air admission at the cluster. The effect of irregular vacuum fluctuations (occurring 6 times per minute) on all stages of the milking process was studied in cows exposed to pathogenic bacteria to determine when the cow is at increased risk of infection (Cousins *et al.*, 1973). The number of infected quarters that resulted from applying conditions conductive to infection to 40 quarters during the peak milk flow period, low milk flow period or end of milking were 8, 12 and 19 respectively. The number of infected quarters was similar when predisposing conditions were applied either at the end of milking, or throughout the whole milking, suggesting that the cow was at increased risk near the end of milking (Cousins *et al.*, 1973). Liner slips and overmilking had been associated with increased new infection rates (Thiel, 1978; O'Callaghan *et al.*, 1976). Liner

slips, which often occurred in the hindquarters, were associated with irregular vacuum fluctuations at the teat end, rapid air admission and impacts of milk droplets on the fore teats. Also, the relationship between inadequate pump capacity, and hence vacuum stability and somatic cell count demonstrated the importance of the milking machine as a factor influencing new infection rates (Bramley and Dodd, 1984).

Furthermore, high somatic cell count and teat injury were reported where a pulsation rate of 75 compared to 49 cycles/min was used (Fell, 1964). In that study the increased pulsation rate was associated with a higher risk of milk backflow. Alternatively, cows milked with pulsationless machines (no compressive lead applied to the teat) were reported to show increased bacterial contamination at the teat end and increased mastitis outbreaks (Bramley *et al.*, 1978). Increased bacterial growth could result from an increased rate of keratin removal (which is present in the teat canal and possesses antibacterial properties) or decreased rate of keratin production (Bramley, 1992). In addition, the lack of teat massage, associated with teat oedema, also favours bacterial growth. The reduction of liner closure from 0.3 to 0.2 seconds per cycle increased the number of infected quarters from approximately 20 to 30% (Reitsma *et al.*, 1981). However, as pointed out before, a squeeze phase of no less than 0.15 sec is used in practice (O'Callaghan and O'Shea, 1982) possibly because it represent a sound compromise between fast flow rates and udder health.

Increasing the pulsation rate has a tendency to increase teat congestion, especially towards the end of milking. During the latter stages of milking, the volume of the teat tissue increases due to venous swelling with decreases in the size of the cistern and the diameter of the teat canal. Therefore, the compression imposed on the teat end by the liner at the end of milking may increase the risk of infections (Woolford, 1984). In general, a significant association between pulsation characteristics and mastitis occurs only in extreme cases.

Current milk line design does not seem to affect the risk of mastitis infection. Cows milked with a low liner presented higher somatic cell count (log transformed) than cows milked with a high liner although this difference was not significant. No difference was found in somatic cell count between cows that had liner slips and cows that had no liner slips (Ramussen *et al.*, 1998). Nevertheless, if the liner was not able to collapse at the teat end due to inadequate design, the risk of mastitis would increase (Bramley, 1992).

The Role of the Milking Machine in the Transmission of Pathogenic Bacteria

The teat surface of infected cows is contaminated with microorganisms, which may have been contracted from the environment or could be present in teat sores (Bramley, 1992). Milking infected and uninfected cows with the same equipment plays a major role in the transmission of mastitis pathogens within and among cows (Wilson *et al.*, 1995). The number of microorganisms present in the teat cups, and the extent of their transmission, depend on the number of quarters infected, the presence of teat end lesions, the number of cows milked per unit, the time the unit remains contaminated, temperature in the teat cups, and condition and hygiene of the milking equipment (Natzke, 1981; Bramley, 1992). Vacuum fluctuations also contribute towards transmission because they cause transfer of milk between cups.

The Role of the Milking Machine in Increasing Susceptibility to Mastitis Infection

The milking machine assists the growth of microorganisms. Furthermore, teat injuries stress the animal, thus, affecting susceptibility to infection. An increase of teat sores was associated with increased new mastitis infections (Jackson, 1971). In addition, pain caused by clinical mastitis leads to the release of adrenaline which inhibits milk ejection and, as a result, bacteria and their toxins would remain in the udder. Consequently, incidence of clinical mastitis would increase (Schalm and Head, 1943).

Relationship Between Mastitis and Somatic Cell Count

An increase in somatic cells, for instance from 250,000 to several million cells/ml, occurs as a result of infection (Holmes and Woolford, 1992). Therefore, bulk milk somatic cell count data are an indicator of the incidence of mastitis infection in a herd (Holmes and Woolford, 1992). In addition, individual somatic cell count data are a tool for identifying cows with subclinical mastitis. For instance, mastitis pathogens were found in 20% of the cows in a herd with 100,000 cells/ml (bulk milk), whereas a higher cell count the bulk milk (~900,000 cells/ml) was associated with a higher percentage (54%) of cows infected (Gill and Holmes, 1978).

Subclinical mastitis, which can be identified by an increased cell count, is related to a decrease in milk yield. An increase in ~250,000 somatic cells/ml of milk is associated with a decrease of 5 kg of milk fat per lactation (Gill and Holmes, 1978). Individual yield losses are extremely variable and range between 10-45%, depending on the type of pathogen present, age of the cow, stage of lactation when the udder becomes infected, number of quarters infected, length of the infection and infection status among others factors (Woolford, 1985).

Somatic cell count is also slightly higher in older cows, in early lactation and near drying off although it generally remains below 250,000 cells/ml (Bramley and Dodd, 1984). The effect of age on somatic cell count could be explained by a number of factors, such as the accumulation of chronic infections, increased teat canal diameter and teat damage due to pendulous udders. On the other hand, an increased infection rate in early lactation could be explained by stress at parturition and changes in immune system response. Likewise, the risk of mastitis infection is variable and can be influenced by season, climate, milk yield, teat anatomy and the action of the milking machine (Bramley, 1992).

Relationship Between Mastitis, Somatic Cell Count and Teat Canal Morphology

Mastitis infection by environmental bacteria was associated with teat canal morphology, mainly length and patency of the teat canal (Menzies and Mackie, 2001). Higher somatic cell counts were found on teats with shorter and less patent streak canals (Thiel *et al.*, 1969). Correlation coefficients of somatic cell count on length and patency of the streak canal were -0.62 and -0.78 respectively (Thiel *et al.*, 1969). In addition, cows that tend to leak milk between milkings are associated with higher somatic cell count (Pearson and Mackie, 1979; Schukken *et al.,* 1990). Other factors that increase somatic cell count and risk of mastitis are decreased distance from teat end to floor, asymmetry of the udder and relatively large teat diameters (Rogers and Spencer, 1991; Slettbakk *et al.,* 1995). Large teat diameter was associated with increased liner slips, which, in turn, was correlated with a greater risk of slip-induced reverse flow (Slettbakk *et al.,* 1995). Furthermore, Friesian cows with funnel shaped teats had lower somatic cell counts and higher milk yields than cows with cylindrical teats (208 *versus* $441x10^3$ cells/ml; Rathore, 1976[a]). The correlation between teat gradient (difference between the proximal end and the distal end of the teat) and somatic cell count was -0.23 (Rathore, 1977). A lower incidence of cup crawl was probably the reason for the lower somatic cell count in 'V'-shaped teats. Finally, somatic cell count tended to be lower in milk from heifers with pointed teat ends than from heifers with cone-shaped teat ends; pointed teat ends had $88x10^3$ cells/ml, flat teat ends had $420x10^3$ cells/ml and cone-shaped teat ends had $1,222x10^3$ cells/ml (Hodgson *et al.*, 1980). In summary, udder and teat characteristics such as, asymmetric udders, short distance between the teat-end to floor, large teat diameters, wide streak canals and flat-shaped teat ends, seem to favour the transfer of infective material into the teat cistern.

Relationship Between Milking Characteristics and Somatic Cell Count

There are differing conclusions regarding the relationship between milking characteristics and somatic cell counts (Schultze, 1979). Cows with higher flow rates (which are associated with higher yields and wider streak canals) had lower somatic cell counts in some experiments (Rathore, 1976[b]) while the opposite occurred in other studies (Thiel *et al.*, 1969). For instance, the correlation between maximum flow rate and somatic cell count was -0.23 ($P>0.05$; Rathore, 1976[b]) and 0.63 ($P>0.05$, Thiel *et al.*, 1969). High milk flow rates, measured as yields greater than 5.2 kg of milk over the first two minutes of milking, were associated with a higher risk of increased cell count in milk (Dodd and Neave, 1951; Slettbakk *et al.,* 1995). However, total milking time was not associated with somatic cell count (Moore *et al.*, 1983).

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Part Two

2. IMPORTANCE OF COW LIVE WEIGHT IN THE PASTORAL DAIRY SYSTEM

2.1 Overview of Dairy Farming in New Zealand

Increasing the profitability of the pasture based dairy system is one of the major goals of farmers. Pastoral farm productivity depends on the quantity of feed eaten per hectare and the efficiency with which feed eaten is converted into milk by the cow (Deane, 1993). Feed conversion efficiency is mainly affected by those factors that determine the yield of milksolids per cow per year and the cow live weight (Holmes *et al.*, 1993). These factors are the ability of the cow to calve each year, the feeding level, cow genetic merit, breed, age, and health status.

Live weight determines the quantity of energy required for maintenance, and thus may be relatively more important in grazing systems, because of the lower milk yields expected per cow. The question of whether to farm heavy or light cows is very relevant to pasture based systems considering the extent of the influence that the live weight of the cow has on the efficiency of the dairy operation. This question is also related to the use of foreign genetics in New Zealand, which could change the type of cow to be farmed (Kolver *et al.*, 2000). The relationship between increased live weight due to the use of foreign genetics and a risk of a suboptimal overall performance of these cows in the pasture-based system has been discussed by Holmes (1995) and Mayne (1998).

In addition, the amount of pasture grown per ha and its distribution throughout the year are key factors when considering the intake of the whole herd, measured as the quantity of feed eaten per ha (Holmes, 1987). Stocking rate affects the total feed demand on the farm because it determines how much of the pasture grown is actually eaten (Holmes and Macmillan, 1982). Furthermore, the amount of supplementary feed inserted into the system influences how much of the pasture offered would be eaten and how much would be substituted (Holmes, 1999). Dates of calving and drying-off also affect the herd's ability to eat the pasture, through the degree of synchrony achieved between the pasture supply and feed demand. A concentrated calving pattern in late winter/early spring is used to achieve this synchrony and is therefore a key factor in efficient seasonal dairy systems (Macmillan *et al.*, 1990).

2.2 Introduction

The live weight of the cow affects the amount of feed required for maintenance, the amount of energy directed towards milk production (Bauman *et al.*, 1985), dry matter intake (Persaud *et*

al., 1991), maximum intake capacity (Caicedo-Caldas *et al.*, 2001), grazing behaviour (Laborde *et al.*, 1998[b]) and reproductive efficiency (Laborde *et al.*, 1998[a]). Nutrient absorption and uptake, management and environment also indirectly influence the animal's feed conversion efficiency (Parke *et al.*, 1999). In addition, the cow's live weight or body size and its genetic merit for milk production and milk components have a strong impact on feed efficiency (Livestock Improvement Corporation, 1991; Ahlborn and Dempfle, 1992). The rest of this section reviews the effect of selection for heavy or light dairy cow live weight on intake, milk production and feed conversion efficiency, under grazing conditions.

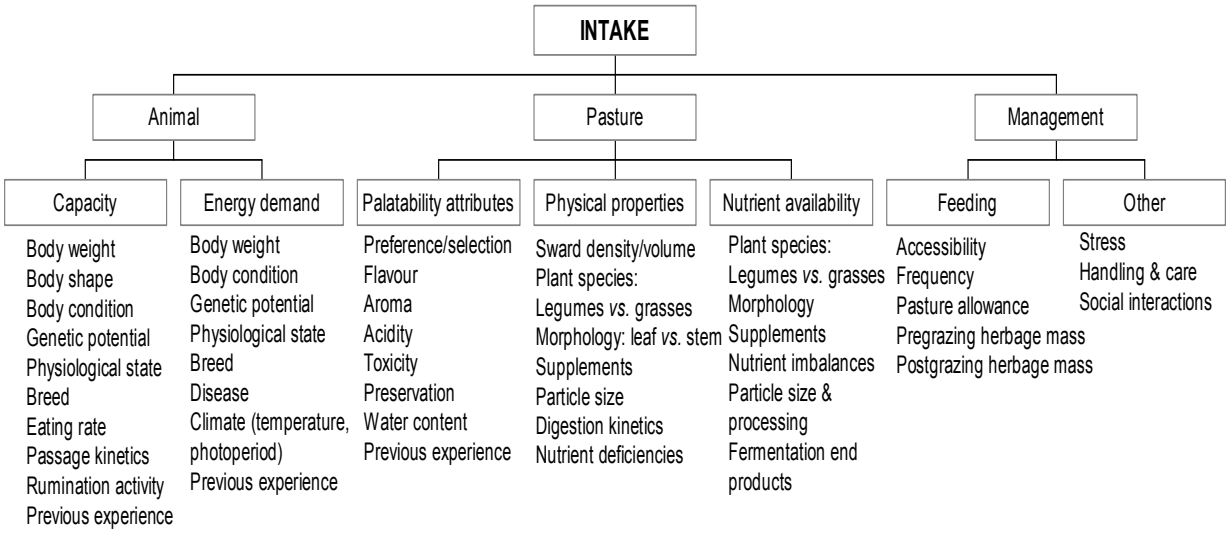
Finally, it is important to consider the difficulty of measuring feed intake and feed conversion efficiency in grazing cows. Therefore, the methods that can be used to measure the intake of grazing cows, particularly the alkane method, are also reviewed here.

2.3 Live Weight and Dry Matter Intake

2.3.1 Factors that Influence Dry Matter Intake

Intake is not solely controlled by the live weight or size of the animal but by a combination of physical and metabolic factors, physiological state and genotype of the animal, the ability of the cow to harvest pasture, pasture characteristics, and other external factors, such as climatic variables (Poppi *et al.*, 1987). These variables regulating intake can be divided into three broad categories: animal, pasture and management factors (Mertens, 1994; Figure 1.1).

Figure 1.1 Factors affecting feed intake in ruminants (adapted from Mertens, 1994)



Pasture characteristics

Pasture characteristics, especially availability, are the most important factors that limit intake under grazing conditions (Hodgson and Brookes, 1999). Bite size is a key variable that influences daily intake and grazing time (Woodward, 1998). The structure of the sward (plant spacing), sward height, and other plant characteristics (i.e., stiffness) determines how much forage can be ingested per bite (Stobbs, 1973). Sward conditions that enable the animal to easily take big bites result in higher intakes (Hodgson, 1990). For instance an increase in pasture height from 20 to 40 cm was associated with an increase in bite size of 1g/kg live weight (for a 500 kg cow; Hodgson, 1990). On the other hand, extremely short swards can result in reductions in intake per bite, rate of biting and grazing time (Poppi *et al.*, 1987). However, high intake is not always correlated with high herbage allowance if quality (Holmes, 1987) and/or availability of the pasture (Ungar, 1996) are not adequate. In other words, low quality (high proportion of mature and dead material) or very short pasture (i.e., less than 10 cm) will limit the intake, even at high allowances due to difficulties in harvesting the grass, and to physical limitations (rumen fill and rate of passage of feed particles through the digestive tract). Therefore, intake would be depressed if a critical bite size cannot be reached because the cow will not be able to increase grazing time or biting rate to fully compensate for the smaller bite size (Stobbs, 1973; Hodgson, 1985). In addition, a cow grazing a pasture of high fibre content would have an increased ruminating time. As a consequence, less time would be available for grazing and intake would be reduced (Woodward, 1997). For instance, summer pastures generally contain lower percentages of leaf and higher percentages of stem than spring pastures, therefore, at a similar allowance, intake is 20% higher in spring pastures (Holmes, 1987). A detailed consideration of pasture characteristics affecting intake is not within the scope of this review but some excellent reviews are available (Laca *et al.*, 1992; Woodward, 1998).

Another factor with an important role in grazing behaviour, therefore affecting intake, is selection by the dairy cow, particularly when the pasture is very heterogeneous in height and nutritive value or species, but otherwise available in adequate quantity. However, selecting a diet of higher digestibility content than that of the total forage may not be reflected in higher intakes because intake per bite and biting rate tend to decrease when intensity of selection increases (Hodgson, 1990). Under such conditions (i.e., low quality and patchy pastures), the cow spends more time searching instead of apprehending grass (Woodward, 1997). In addition, at lower pasture allowances (i.e., with a higher stocking rate), the animal cannot

select the better quality grass anymore, resulting in a double disadvantage: lower intake values and lower quality of the diet eaten (Hodgson, 1990).

Animal Factors

The main regulators of intake within the animal are (1) factors that influence feed requirements and (2) factors that affect the ability of the animal to digest, metabolise and hold food (Holmes *et al.*, 1987). Feed requirements are influenced mainly by the size of the animal, its level of milk production, stage of lactation, genetic merit for milk production, live weight changes, pregnancy, body condition (thin *versus* fat) and health status of the animal. In addition, feed intake of the cow can be modified by management practices that reduce the requirements, such as milking once a day (Parker, 1966; Holmes *et al.*, 1992) and climate. Animals adjust their intake to maintain a thermal balance. They eat more in cold conditions and less at high temperatures when the ability to dissipate heat is reduced (Poppi *et al.*, 2000).

Large animals consume more feed to meet their increased maintenance requirements of a larger tissue mass (Holmes *et al.*, 1987). The size of the animal also relates to the quantity of grass that can be ingested per bite and the quantity of feed that it can accommodate (intake capacity). Intake was reported to increase at 2 kg DM per 100 kg increase in live weight (Leaver, 1983). For instance, the size of the mouth, tongue and teeth of the animal can affect the bite size (Illius *et al.*, 1995). Large animals take deeper bites (i.e., closer to the ground surface) than small animals. The size of the animal also has implications in the grazing mechanics. A bigger mouth size allows the animal to cope better with taller pastures, therefore, larger animals are less constrained by the physical properties of the vegetation (Illius *et al.*, 1995). However, interactions between grazing mechanics and size of the animal are not the only factors. Genetic merit also modifies the grazing behaviour. High genetic merit cows have a more aggressive grazing pattern; they are less selective in their grazing, spend less time masticating, take bigger bites and graze for longer periods (Bryant, 1983). Their effective search time is zero, because they are masticating while they are looking for the next bite. In addition, the relationship between size of the animals, milk production and intake is modified by the body condition of the cow (Leaver, 1983). Thin cows, have higher nutrient diversion (greater rate of tissue turnover) and a greater drive for intake than fatter animals.

The cow's metabolic demand for lactation depends on the stage of lactation and the potential production of the animal, which is determined by her genetic merit. When the demand for

nutrients increases, feed intake increases too. Feed intake for lactating cows is 30 to 60% (depending on milk yield) higher than for non-lactating cows (Holmes *et al.*, 1987). An over-simplified calculation serves to illustrate this point: intake increases by 0.2 kg DM for each kg increase of milk (Leaver, 1983). Expressed differently, differences of 5-15% in intake are related to differences between 20 to 30% in milk production (Holmes *et al.*, 1987). However, it appears that milk yield drives dry matter intake in early lactation whereas the reverse occurs after peak lactation (Tamminga and Hof, 2000). The requirement for energy is at its highest in early lactation, and can be even higher than the intake capacity with milk yield maintained by tissue mobilisation. Intake increases to a peak 4-16 weeks after calving depending on a number of factors (Leaver, 1983). Peak intake occurs earlier in animals with a greater tissue demand (i.e., high genetic merit, thin) and in animals eating high quality diets. Afterwards, intake decreases and is lifted again after the 5^{th} month of pregnancy. However, at advanced stages, intake cannot increase proportionally with the increase in nutrient requirements because of reduced rumen capacity and hormonal inhibition (Holmes *et al.*, 1987).

Finally, rate of digestion, feed retention time (which depends on the digestibility of the feed) and concentrations of metabolic products (metabolic control) are important in regulating feed intake when the pasture allowance is adequate (Poppi *et al.*, 1987). Intake of the grazing animals is usually dominated by the effects of plant cell wall material in the digestive tract and by the rate at which digesta particles leave the rumen (Dove, 1996). Therefore, a cow eating a low digestibility feed would reach a full digestive tract relatively quickly and material would be retained in the rumen for longer, limiting further intake. It was reported that animals eat until a certain rumen distension is achieved (Forbes, 1995). Possibly, physical dimension and pressure on the internal organs limit rumen fill (Poppi *et al.*, 2000). Concentrations of acetate and other metabolites in blood or gut lumen limit the intake, however, they seem to be more important when the animal is fed highly digestible feeds (Conrad *et al.*, 1964). It was proposed that intake regulation is the result of the interaction between many physical and metabolic factors (Poppi *et al.*, 2000).

2.3.2 Effect of Genetic Selection for Live Weight on Dry Matter Intake

Feed intake was studied during two production cycles in two lines of Holstein-Friesian cows selected genetically to be large or small and subjected to a high input system (maize silage and lucerne haylage *ad libitum* plus concentrates; Donker *et al.*, 1983). Cows from the large

and small line in their second lactation were 575 and 525 kg respectively (postpartum weight). Cows from the large line had higher DM intake than small cows in both lactations. Large cows ate 0.7 kg DM more than the small cows across three different levels of supplementation. However, DM and energy intake per kg of metabolic weight were similar for both lines. These results suggest that the increased energy requirement for maintenance of the large line resulted in a nil increment in the quantity of energy eaten above maintenance. These results agree with other studies that investigated the effect of genetic selection for body size on cow's intake (Yerex *et al.*, 1988) or the effect of high or low calving live weights (manipulated through level of feeding) on DM intake of cows (Mackle *et al.*, 1996). Furthermore, the differences in intake between lines became smaller at higher levels of milk production because the latter had a larger effect on intake than live weight. A similar experiment studied the feed intake and milk yield in heifers and cows from divergent genetic lines for body size over whole lactations (Metzger *et al.*, 1991). It was concluded that live weight affected feed intake, but to a lesser extent than milksolids production. Those results reported similar genetic correlations between food intake and live weight (in the range of 0.28 to 0.46), which are smaller than the genetic correlation between food intake and milk yield (Persaud *et al.*, 1991).

2.4 Live Weight and Milk Production

Milk yield and live weight were positively correlated both genetically (Ahlborn and Dempfle, 1992) and phenotypically (Sieber *et al.*, 1988). Conversely, Parke *et al.* (1999) found no phenotypic correlation between milk fat yield and live weight, and a low and moderately negative genetic correlation between these variables (-0.07 to -0.29). Therefore, selecting cows on the basis of high milk yield (as is the case in the United States, Canada and some European countries) may bring about a correlated increase in the cow's average live weight. As a consequence, these high-producing cows may have lower feed conversion efficiencies (Yerex *et al.*, 1988; Parke *et al.*, 1999).

There is some controversy in the literature regarding milksolids production of cows that genetically differ in live weight. Some studies, under grazing conditions, found that cows genetically selected for heavy live weight, produced a larger amount of milksolids than those selected for light live weight. A whole lactation study reported that genetically heavy cows produced 364 kg MS/cow compared to 348 kg MS/cow produced by light cows (Garcia-Muniz *et al.*, 1998[a]). The heavy cows used in that experiment were 57 kg heavier than the

light cows. In addition, another study with the same lines of cows which differed in 77 kg, reported that heavy cows out-produced the light cows by 8% at peak lactation (1.70 *versus* 1.54 kg MS/cow/day for the heavy and the light line respectively; Laborde *et al.*, 1998[b]). However, these two lines of cows had been selected to be equal in breeding worth ($ income/t DM eaten). Therefore, the heavy cows were genetically superior for yields of milk, fat and protein.

On the other hand, others reported no differences in milksolids between the two lines in early lactation (Laborde *et al.*, 1998[b]) or during peak yield (Lopez-Villalobos *et al.*, 2001). Similarly, under feedlot conditions, dairy cows selected for large or small body size produced similar milk yields for both primiparous and multiparous cows (Donker *et al.*, 1989; Hansen *et al.*, 1999). Size did not affect milk yield in high input systems but small cows gave more milk per kg of metabolic weight and were more efficient in converting feed into milk (i.e., ate less feed/kg of milk than large cows); therefore, the small cows were more efficient (Donker *et al.*, 1983). Yield of milk was slightly higher for the small line of cows compared to the large line (23.9 *versus* 23.2 and 28.0 *versus* 27.7 kg milk/day for primiparous and multiparous cows respectively; Donker *et al.*, 1989).

A whole lactation study carried out at Massey University reported no significant differences between lines of heavy or light cows in the time taken to reach peak of milk yield (27-31 days after calving) or in persistency of milk, fat and protein production during lactation of mature cows. No significant differences in the shape of the lactation curve between the two lines of cows were found either (Lopez-Villalobos *et al.*, 2001).

2.5 Live Weight and Feed Conversion Efficiency

Cows of contrasting genetic merit but similar live weight differ in their feed conversion efficiencies (Grainger, 1981; Bryant, 1982; Bryant, 1981). Furthermore, the reported genetic correlation between feed efficiency and live weight was in the range of -0.81 to -0.99 (Persaud *et al.,* 1991). This is because the quantity of energy required for maintenance in cows with high milk yields accounts for a smaller proportion of the total ingested energy. In addition, these cows partition more dietary energy towards milk production and less to tissue deposition when compared with lower genetic merit cows (Bauman *et al.*, 1985). It was reported that high genetic merit cows lose more weight and body condition during their lactation than lower genetic merit cows (Fulkerson *et al.*, 1997). Therefore, it was suggested

that whenever necessary (i.e., inadequate level of feeding in relation to potential for production) they utilise energy made available from tissue mobilisation to support the increased demand from the mammary gland. However, increasing genetic merit increases the overall efficiency used for milk production but it does not affect the digestibility of the dietary energy nor the efficiency with which ME (dietary or from body tissues) is used for milk production (Gordon *et al.*, 1995).

Differences in feed conversion efficiency of more than 10% were calculated between high and low genetic merit cows (Holmes, 1988). These high genetic merit cows also achieve higher intakes (~6% higher) and milksolids production (~25%) than their counterparts. However, increasing the live weight of the high genetic merit cows, through genetic selection, could offset the advantages they possess in terms of increased feed conversion efficiency. Theoretical calculations show that cows of high genetic merit but different live weights differ in their feed efficiencies (i.e., a 450 kg cow producing 200 kg of milk fat/year has a calculated efficiency of 20.2 *versus* 18.5% for a 550 kg cow producing the same amount of milk fat, assuming that 78 MJ ME are needed to produce 1 kg of milk fat and that pasture contains 11 MJ ME/kg DM; Holmes, 1988).

This negative effect of increased live weight on the performance of the high genetic merit cows has been studied in cattle managed indoors and fed total mixed rations (Hansen *et al.*, 1999). Cows selected for large size in their first month of lactation were 52, 70 and 88 kg (1st, 2nd and 3rd parity respectively) heavier than cows selected to be small ($P<0.01$). However, the lines did not differ significantly for any of the production traits (kg of milk, fat and protein). In another study within the same programme it was reported that these two lines of cows selected for contrasting sizes differed in feed efficiency (profit/feed cost), which favoured the small line by 3%, measured over complete lactations (Yerex *et al.*, 1988). Those lines of cows differed by 50 kg after three generations. Negative genetic correlations between live weight and feed efficiency agree with those findings (Gill and Allaire, 1976; Holmes, 1988).

Similarly, under the pasture-based, seasonal system of milk production, increases in the live weight of a high genetic merit cow have been associated with a negative effect on overall farm profitability (Livestock Improvement Corporation, 1991). As a result, live weight has a negative economic value in the Index of Farm Profitability which is measured in units of expected net income per unit of feed (Dempfle, 1986; Livestock Improvement Corporation,

1996). This negative weighing is given to live weight because the greater feed costs of cows with increased maintenance requirements is not compensated by the extra income received from selling a heavier carcass (Spelman and Garrick, 1997). In addition, farming heavier cows imposes a reduction in the stocking rate because of the increased maintenance cost per cow; consequently fewer cows would be available for sale. The impact of live weight on the optimum stocking rate necessary to obtain a certain production was studied by Penno and Kolver (2000). They compared the optimal stocking rate of Friesian cows required at the DRC No. 2 Dairy (Hamilton) over the last 20 years to produce 1150 kg MS/ha from 16 t DM/ha grown. For that level of production the optimal stocking rate was considered to be 1790 kg LW/ha (3.77 cows/ha) and 1500 kg LW/ha (3.16 cows/ha) for 1976 and 1998 respectively (Penno and Kolver, 2000).

In order to utilise the increased efficiency of the high genetic merit dairy cows under intensive grazing with little use of supplements, it would be sensible to breed cows with relatively low requirements for maintenance (i.e., lighter live weight). Conversely, under feedlot conditions where relatively inexpensive concentrate feeds are available and considering the high space and time/cow cost, breeding larger cows of very high production potential seems to be more appropriate in terms of economic efficiency (Allaire and Thaen, 1985). For instance, in a high input system a 750 kg cow producing more than 30 kg milk per day would be more profitable (less dollars spent to produce 1000 kg milk) than a 600 kg cow of lower milk production at the same cost/cow/day (Brown *et al.*, 1981). In other words, fewer larger cows are needed to produce the same amount of milk than the smaller cows, which represents a better use of time and space.

2.6 Other Effects of Live Weight

2.6.1 Effect of Live Weight on Grazing Behaviour

The effect of selection for heavier or lighter mature live weight on grazing behaviour was evaluated for yearling heifers and lactating cows (Laborde *et al.*, 1998[b]). Results from two experiments with early and mid lactation cows from the heavy and the light lines, are shown in Table 1.1. Cows were rotationally grazed as a single mob and offered a generous herbage allowance of 45 kg DM/cow/day.

Table 1.1 Grazing time, biting rate and calculated bite size of genetically heavy or light mature Holstein-Friesian cows grazing rye-grass white clover pastures during early (Exp 1; n=42) and mid-lactation (Exp 2; n=60; Laborde *et al.*, 1998b).

	Genetic line		
	Heavy	**Light**	SD
Experiment 1			
Grazing time (minutes/day)	515	521	ns
Biting rate (bites/minute)	50	55	*
Bite size (g DM/bite)	0.60	0.48	**
Experiment 2			
Grazing time (minutes/day)	508	522	ns
Biting rate (bites/minute)	53	58	**
Bite size (g DM/bite)	0.46	0.40	*

ns = not significant, * P<0.01, ** P<0.001

In addition, three short-term grazing experiments with yearling heifers differing genetically in live weight and offered an allowance of 20 to 30 kg DM pasture/cow/day showed that the heavy heifers ate more than the light ones (4.3 *versus* 3.8 kg DM/day; P<0.001), there were no differences in 24-hs grazing time (528 *versus* 534 min/day for the heavy and the light heifers respectively) nor in ruminating times. Number of bites per day was similar for both lines but heavy heifers took slightly larger bites than light heifers (Garcia-Muniz, 1998b). As a result, and in contrast to the results obtained in the experiment with lactating cows, heavy heifers achieved higher intakes and higher rates of intake (7.0 *versus* 6.3 mg DM/min of grazing; P<0.05) due to these differences in grazing behaviour.

2.6.2 Effect of Live Weight on Reproductive Characteristics and Survival Traits

Age at Puberty

Increased live weight has resulted in slower maturity rate in heifers in a three-year experiment. Heavy heifers tended to show puberty at an older age (325 *versus* 300 days; P<0.05) and with a larger live weight compared to the light live weight line heifers (241 *versus* 221 kg; P<0.05; Garcia-Muniz, 1998b). These differences in the onset of puberty between lines did not affect age at first calving (728 *versus* 733 kg for the heavy and light lines respectively) or date of calving but it certainly affected weight at first calving (411 *versus* 386 kg for the heavy and light lines respectively; P<0.01).

Calving Difficulty

Selection for heavy or light live weight had no effect on calving difficulty or calf mortality, neither in primiparous nor in multiparous grazing cows (Garcia-Muniz, 1998[b]). Those findings agree with other results of selection for body size (Hansen *et al.*, 1999).

Reproductive Performance

Genetically heavy cows had shorter intervals from calving to first ovulation than for light cows (28 *versus* 31 days $P<0.05$) but there was no difference between the lines in the interval between calving and first heat detected (50 *versus* 43 days, for the heavy and light respectively; ns; Laborde *et al.*, 1998[a]). However, in the cows older than 2 years, the heavy cows had a lower conception rate at first service (58% *versus* 70% for the heavy and light respectively; $P<0.05$), which extended the conception and calving pattern of the heavy cows. During the first 21 days of the calving period, 66% of the cows in the light line had calved *versus* 53% of the cows in the heavy line (Laborde *et al.*, 1998[a]).

A comparison of the reproductive performance between the same two lines of Holstein-Friesian cows also reported that the light cows had a higher conception rate at first service than the heavy cows (65 *versus* 54%; $P<0.05$); thus, they calved 6 days earlier and they achieved a more concentrated calving pattern. In this experiment there was no difference between lines for calving interval, interval between calving and first heat detected, interval between calving and first service or days open (Garcia-Muniz, 1998[b]). Additional evidence supports these results. Smaller heifers required fewer services per conception (1.8 *versus* 2.1 services/conception for the large and small line respectively; $P<0.05$; Hansen *et al.*, 1999).

Health Problems and Reasons for Disposal

It is well known that reproductive problems in heavier animals can significantly reduce their chance of staying in the herd. A negative effect of selection for live weight is decreased fertility (Holmes *et al.*, 1999). A similar effect was reported in cows selected for very high levels of milk yield in grazing (Verkerk *et al.*, 2000; Holmes, 2001) as well as in high input feeding systems (Lucy *et al.*, 1992). In fact, in the selection for divergent sizes carried out in the US, the main reasons for disposal (>33%) were reproduction problems and mastitis (>15%). Both reproduction problems and mastitis were extremely high and not different for both lines (Hansen *et al.*, 1999). Reasons for disposal of bigger animals in that study were leg and feet problems, and internal infections. The legs and feet of large cows supported more

body weight compared to the small cows and, consequently, could be expected to be more prone to injury. Also, larger cows have a higher centre of gravity, especially if they are taller, than do small cows and might be more likely to slip and fall. The main reason for disposal in the small line was udder conformation. Because cows in the small line had shorter legs, udders were closer to the ground and, therefore, were predisposed to have difficulties for milk removal and might have increased risk of mastitis. Cows in the smaller line had longer productive lives, by 88 days than those in the larger line.

An earlier experiment that compared health problems in 503 lactations from 220 cows selected for large size and 475 lactations from 191 cows selected for small size (between 1969 and 1983) reached a similar conclusion (Mahoney *et al.*, 1986). The large line of cows had, on average, 50 kg live weight more than the small line at peak lactation (464 *versus* 514 kg). Primiparous cows from the large line had almost twice the health cost of the small cows. Much of this difference was explained by a higher incidence of digestive disorders (displaced abomasum). Multiparous cows followed the same trend (4.5 *versus* 1% cases of displaced abomasum). Large cows with displaced abomasum were above the group average for live weight. In addition, small cows with digestive disorders were the largest of the group (Mahoney *et al.*, 1986). A further experiment with cows selected for contrasting milk production, which resulted in heavier cows as a correlated response, investigated health care requirements and changes over time (from 1977 until 1992). It indicated that the higher yielding large line had 85% higher health costs (veterinary treatment, health supplies, drugs, and labour of animal attendants) per lactation than the small line and these were largely due to mastitis treatment and to a lesser extent, feet and leg problems (Jones *et al.*, 1994). Mastitis infections and thus money spent on its treatment, was higher for the large line across the years (i.e., the differences were maintained from 1977 to 1992). However, during the 16-year period, the large line had increasingly higher incidences of digestion, reproduction and metabolic (i.e., ketosis) disorders (measured as 5 years averages) than the small line. Strangely, the higher incidence of mastitis in the higher yielding heavier cows did not translate into a higher somatic cell count, even though the high-yielding line produced 6400 kg more milk than the low-yielding, smaller line (Hansen, 2000). The higher milk yield might have reduced the somatic cell count (dilution effect) whereas the higher incidence of mastitis might have increased it. Possibly, both effects might have balanced out.

3. REVIEW OF METHODS AVAILABLE FOR INTAKE ESTIMATION OF GRAZING COWS

Methods for estimation of intake by grazing animals can be classified into two main categories: the pasture-based and the animal-based methods (Meijs *et al.*, 1982). Pasture methods require estimation of pasture mass before and after the grazing period; the difference between them (assumed to have been eaten) is calculated and then divided by the number of animals. Pasture mass can be estimated using cutting techniques (at ground level or 4 cm), with a rising plate meter which is calibrated to correlate pasture height with pasture mass (Earle and McGowan, 1979); or by visual appraisal (Burns *et al.*, 1994). Pasture techniques for estimating intake have many disadvantages. These are (1) intake cannot be estimated for individual animals; (2) overestimation and underestimation occurs due to the assumption that there are no other causes of forage disappearance but consumption by the grazing animal, or failure to take account of pasture growth rate; (3) estimating herbage mass precisely is difficult because of variable botanical composition, structure, morphology, density and moisture content of the pasture; and (4) a large number of samples is required to obtain an adequate estimate of the change in herbage mass. The obvious advantage of pasture methods for intake estimation is that it imposes minimal disturbance in the normal grazing pattern of the animal (Meijs *et al.*, 1982).

Animal-based techniques are more desirable for estimation of intake in grazing trials because they allow estimation of intake for individual animals. Daily intake of grazing animals can be obtained directly by either weighing the cows continuously before and after each grazing event, or through monitoring grazing behaviour. However, this technique estimates intake in the short-term and must account for weight loss due to respiration, defecation and urination (Burns *et al.*, 1994). Monitoring grazing behaviour requires an estimate of total grazing time, number of bites and bite weight (Hodgson, 1982). Its limiting factors are estimating bite size, DM intake per bite, and the high cost and limited availability of the necessary equipment. Its main advantage is that animals may be relatively undisturbed and its applicability to most pasture conditions (Burns *et al.*, 1994).

The most commonly used animal-based technique is based on the estimation of faecal production and diet digestibility (Le Du and Penning, 1982; Peyraud, 1998). Daily faecal output is measured and intake is then estimated using the following formula:

(1) Intake = Faecal Output / (1 – Digestibility)

Total faecal output can be measured using faecal collecting bags. This method is simple but unsatisfactory with cattle due to loss of bags. Collection from female animals is more difficult because it requires separation of faeces from urine (Le Du and Penning, 1982). Furthermore, the load of the bag is likely to affect the animal's grazing behaviour and therefore reduce animal performance (Burns *et al.*, 1994). Distortion of hind legs due to weight of the faeces was reported (Burns *et al.*, 1994). This is especially true in low-density swards when the animal has to walk longer distances to harvest grass (Van Soest, 1994).

Alternatively, faecal output can be estimated indirectly using indigestible markers. The general equation for estimation of faecal output with a marker is the following:

$$(2)\quad \text{Faecal output (g/day)} = \frac{\text{amount of marker dosed (g Cr/day)}}{\text{mean concentration of the marker in faeces (g Cr/g faeces DM)}}$$

Some markers also have a number of difficulties (i.e., considerable disturbance of experimental animals, the large number of analyses required; Luginbuhl *et al.*, 1994). However, this is the best alternative available (Burns *et al.*, 1994). There are two types of markers: external and internal. External markers can be added to the diet, given orally or inserted into the rumen. A commonly used external marker is chromium sesquioxide: Cr_2O_3. External markers have been reviewed in detail elsewhere (Pond *et al.*, 1987) and will not be further discussed. Internal markers are naturally occurring indigestible substances found in the feed. They can be used to estimate digestibility, faecal output and digesta kinetics. The most widely used internal markers in New Zealand are alkanes; long-chain hydrocarbons of plant cuticular waxes. In summary, all of the commonly used methods have limitations and include various assumptions that may introduce error (Owens and Hanson, 1992).

3.1 The Use of Alkanes to Estimate Pasture Intake

Plant alkanes are indigestible substances found in cuticular waxes, with chains of 25 to 35 carbon atoms, and are thought to be involved in the water economy of the plants (Dove and Mayes, 1991). They can be used to estimate faecal output because they are recoverable in the faeces (Mayes *et al.*, 1986). It was hypothesised that rumen microflora do not metabolise

plant alkanes, and that they are probably absorbed in the small intestine since their major disappearance occurs between the duodenum and the ileum (Dove and Mayes, 1991). Alkanes with an odd number of carbon atoms in the chain (C_{29}, C_{31} and C_{33}) are present in much larger amounts in all pasture species than the even-numbered alkanes. Therefore, the percentage of alkanes recovered in faeces increases as their chain length increases. Alkanes are widely spread in plant tissue and their concentration can be analysed easily (Dove and Mayes, 1991). Intake estimation is based on a pair of alkanes adjacent in chain length with similar recoveries in faeces, one that is externally administered (the even-chained alkane) and another one which is naturally occurring. Even though there is a discrepancy between recoveries of naturally occurring and synthetic alkanes, intake estimates would still be valid provided that their faecal recoveries are similar, because errors that arise from their incomplete recoveries cancel out in the calculation (see equation 3; Mayes *et al.*, 1986).

Intake is estimated using the following formula which results from rearranging Equation 1:

$$\text{(3) Daily intake (kg DM/day)} = \frac{\frac{F_i}{F_j} * D_j}{H_i - \frac{F_i}{F_j} * H_j}$$

Where

F*i* = concentration of faecal odd-chain alkane

F*j* = concentration of faecal even-chain alkane

H*i* = concentration of herbage odd-chain alkane

H*j* = concentration of herbage even-chain alkane

D*j* = daily dose of synthetic even-chain alkane

The accuracy of the intake estimates calculated using equation 2 depends upon the following factors: accurate administration and dosage of the even-chained alkane to the grazing animal, obtaining a representative sample of consumed herbage, obtaining a representative sample of faeces, value of faecal recovery of the adjacent pair of alkanes assumed, accurate preparation of the sample of faeces and pasture, and accurate alkane extraction for analysis.

The alkanes can be administered in many ways. These are: (1) as paper pellets containing alkanes (Hameleers and Mayes, 1998), (2) as gelatine capsules containing either alkanes

impregnated into powdered cellulose, or a mixture of alkane, solvent and cellulose powder (Mayes *et al.*, 1986), and (3) as intra-ruminal capsules for controlled slow release of alkanes (Berry *et al.*, 2000; Garcia *et al.*, 2000). The first two have a number of weaknesses. They are costly, time consuming, involve disturbance of the animal's grazing behaviour (because they are administered once or twice daily) and cause significant diurnal variation in alkane recovery in faeces (Stakelum and Dillon, 1990; Mayes *et al.*, 1988). In contrast, the intra-ruminal capsule proved to be the most satisfactory technique in terms of the accuracy of the estimate and the ease and time required to administer the alkanes (Malossini *et al.*, 1996; Dove and Mayes, 1991). This method overcomes the difficulties of the other techniques previously mentioned, but it relies on a known constant rate of alkane release into the rumen.

Ratios of faecal concentrations that could be used to estimate intake are C_{28}/C_{29}, C_{32}/C_{33} or C_{36}/C_{35} (C_{28}, C_{32} and C_{36} derived from the capsules; C_{29}, C_{35} and C_{33} derived from the diet) depending on which alkane is administered. The pair C_{28}/C_{29} had lower recoveries than C_{32}/C_{33} and the pair C_{36}/C_{35} was significantly more erratic because their recoveries were different (Dove *et al.*, 1991). In addition, few pasture species contain concentrations of C_{35} which are sufficiently high to allow its use in intake estimation. Therefore, C_{32}/C_{33} is the most commonly used pair of alkanes for intake estimation. Comparisons between intake estimates of fresh herbage using C_{32}/C_{33} with known intakes for dairy cows in late lactation have shown a small discrepancy between measured and estimated herbage intakes of -0.6 to -0.8% (Dillon and Stakelum, 1989; Stakelum and Dillon, 1990). Further evidence that the pair C_{32}/C_{33} is the most accurate for intake estimation of dairy cows is presented elsewhere (Berry *et al.*, 2000). The fact that ryegrass and white clover, the main components of New Zealand pastures, contain high concentrations of long chain alkanes (Mayes *et al.*, 1986; Malossini *et al.*, 1990) and the many advantages of the alkane technique over others, makes this technology the most appropriate under New Zealand conditions.

4. OBJECTIVE OF THE STUDY

The aim of this study was to measure the differences between two genetic strains of Holstein-Friesian cows, which had been selected for heavy or light live weight in milking characteristics during peak lactation (total milking time, average flow rate and maximum flow rate (*experiment 1a & 1b,* chapter 2); lactational milk yield, milk composition and somatic cell count, live weight and body condition score during a complete lactation (*experiment 2*, chapter 2); and milksolids yield, dry matter intake and feed conversion efficiency during mid lactation (*experiment 3*, chapter 3) in cows grazing on pasture and subjected to the traditional spring-calving system.

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Milking characteristics, Milk Production and Live Weight of Holstein-Friesian Dairy Cows of Genetically Heavy and Light Live Weight

ABSTRACT

Two experiments were conducted at Massey University, New Zealand, with Holstein-Friesian cows from two selection lines, which differed genetically for live weight but with similar Breeding Worth, grazing on pasture. *Experiment 1* studied milk volume at each milking, average and maximum milk flow rate, and total milking time during peak yield in two consecutive lactations (*Experiment 1a & 1b* studied seasons 2000 and 2001 respectively). *Experiment 2* measured, over a whole lactation, daily milk production and composition, somatic cell count, live weight and body condition score (season 2000-01). *Experiment 1 (a & b)*: The heavy line yielded slightly more milk at each milking than the light line but this difference was not significant for any season (13.4 *vs.* 13.0 litres and 14.2 *vs.*14.0 litres for the heavy and light line for seasons 2000 and 2001 respectively). Maximum flow rates (measured only in season 2001) did not differ between lines (~3.2 litres/min for both lines). Average flow rates were also similar for both lines in both seasons (~2.0 litres/min for both lines and both seasons). Consequently, total milking times were similar for both lines in both lactations (7.5 *vs.* 7.3 min and 7.6 *vs.* 7.8 min for the heavy and the light line for seasons 2000 and 2001 respectively). Log transformed milk somatic cell counts were lower for the heavy line both in peak lactation (10.8 *vs.* $11.4x10^3$ cells/ml, $P<0.001$; and 10.3 *vs.* $10.8x10^3$ cells/ml, $P<0.05$ for the heavy and light line for period one and two respectively) *Experiment 2*: For the whole lactation, cows from the heavy line produced more milk than cows from the light line (22.2 *vs.* 20.6 litres of milk respectively; $P<0.01$), nevertheless, there were no significant differences between lines for milksolids production (1.79 *vs.* 1.72 kg MS/cow/day for the heavy and light line respectively). Fat yield was similar for both lines because the milk from the light cows had a higher fat concentration (5.0 *vs.* 4.8 %, $P<0.05$). There were no significant differences between lines for protein concentration; however, the heavy line yielded slightly more milk protein due to their higher milk production (0.76 *vs.* 0.72 kg/day; $P<0.05$). Log somatic cell counts during the whole lactation were 11.2 *vs.* $11.3x10^3$ cells/ml for the heavy and light line respectively (ns). Differences in live weight between the heavy and the light line were significant (517 *vs.* 474 kg for the heavy and the light line respectively; $P<0.001$). Body condition score was similar for both lines during the whole lactation (4.2 for both lines). Lactation number had a significant effect only on live weight (452 *vs.* 540 kg for primiparous and multiparous respectively; $P<0.001$). In summary, selection for heavy or light cow live weight at a common Breeding Worth and under grazing conditions affected the live weight of the cows, had no effect on milksolids production and did not have a consistent effect on milking characteristics or milk somatic cell counts.

Keywords: dairy cows; live weight; milk production; milking characteristics; somatic cell counts.

1. INTRODUCTION

Increasing the efficiency of the milking operation, by increasing the number of cows milked per man per hour is of main importance, as a high proportion of the non-feed cost in dairying is due to work time (Rathore, 1976). Over 50 % of the labour and fixed cost of dairying is expended for milking cows (Bruckmaier *et al.*, 1994). Approximately 18 million person hours a year were spent milking cows in 1990 across 13,600 New Zealand dairy farms (Woolford *et al.*, 1990). Milking efficiency is influenced by the rate of milk removal and time required to milk individual cows. Slow milking cows can disrupt the flow of a herd through a herringbone milking-shed, which is the most common design on New Zealand dairy farms (Holmes *et al.*, 1987). In farm practice, the difficulty of slow milking cows can be overcome by choosing a milking system that accommodates large herds while reducing labour requirements (i.e., rotary milking parlours; Clough, 1992). Many farmers are conscious of the effect of the herd's milking time on an efficient milking routine, especially as the average number of cows per herd is increasing (Arave *et al.*, 1987). Milking rate of the cow is the main factor influencing the total milking time of individual cows (Dodd and Griffin, 1992). Therefore, a reduction in TMT and an increase in average flow rate would be of considerable economic importance in relation to the labour input and labour utilisation per unit of milk yield. Furthermore, the milking machine is the main source of teat canal erosion, haemorrhagic blisters near the teat end and teat chapping (Fell, 1964; Kingwill *et al.*, 1977). During the time when the cups are on, the teats are potentially exposed to infections (Bramley and Dodd, 1984). There is a greater risk of slip-induced reverse flow especially towards the end of milking. Pressure changes in the teat cup can direct milk droplets back into the teat duct, which assist the penetration of pathogens (Cousins et al, 1973). Thus, reducing total milking time is also relevant from the animal-welfare point of view to minimise infection and unnecessary wear and tear of the teat.

Since 1950, in New Zealand, genetic selection against slow milking cows (regardless of their milk yield) probably contributed to increased flow rates combined with increased milk yields. In addition, selection for increased milk production affected both the structure and function of the mammary gland (Akers, 2000). The increased use of Friesian semen in New Zealand herds since 1961 has increased average flow rates but total milking times have increased slightly because of even greater increases in milk yield. This effect was probably more pronounced in the first cross, and less noticeable thereafter (Arave *et al.*, 1987). Differences

in milking characteristics between breeds were caused by the higher milk yield of Friesian cows and other unidentified factors.

Furthermore, differences in total milking times between two different genotypes (US and Dutch versus New Zealand) of Holstein-Friesian dairy cows were reported (Penno and Kolver, 2000). The overseas genotype showed longer milking times, slower flow rates and greater milking volumes, although the yield of milksolids was not higher. This is of particular importance since the amount of overseas Holstein genetics being used in New Zealand has been increasing (Harris and Kolver, 2001).

The cow's live weight, which is closely related to the energy requirements for maintenance and growth, is included in the Animal Evaluation System used on New Zealand dairy cattle because it affects dairy farm profitability. The present experiment was the last of a larger programme to study the effects of genetic selection for live weight on efficiency of dairy cattle (García-Muñiz *et al.*, 1998[b]). The experiment started at Massey University in 1989 with the generation of two lines of high genetic merit Holstein-Friesian cows that differed in mature live weight. Differences in production (García-Muñiz *et al.*, 1998[b]; Laborde *et al.*, 1998[a]), grazing behaviour (Laborde *et al.*, 1998[a]), maximum feed intake capacity (Caicedo-Caldas *et al.*, 2001), feed conversion efficiency (García-Muñiz *et al.*, 1998[b]; Laborde *et al.*, 1998[a]; Tolosa *et al.*, 2001), reproductive performance (Laborde *et al.*, 1998[b]), calving difficulty (García-Muñiz *et al.*, 1998[a]) and shape of lactation curves for milk, fat and protein yields, live weight and body condition score (Lopez-Villalobos *et al.*, 2001) between the two lines were evaluated. However, the effect of genetic selection of dairy cattle for live weight on average flow rate and total milking time has not been explored previously.

This final study consisted of two experiments. The objective of *experiment 1 (a & b)* was to study the effect of selection of dairy cattle for heavy or light mature live weight on milking characteristics (volume at each milking, average flow rate and total milking time) and somatic cell count during peak yield. The aim of *experiment* 2 was to measure daily milk yield and composition, somatic cell count, live weight and body condition score during one complete lactation in Holstein-Friesian cows from two selection lines, which differed genetically for live weight grazing on pasture and subjected to the traditional spring-calving system.

2. MATERIALS AND METHODS

2.1 Animals, Management and Farm Conditions

Experiment 1a

The experiment was carried out at Massey University Dairy Cattle Research Unit, Palmerston North, New Zealand, between the 1st and 15th of November 2000. A herd of 78 Holstein-Friesian dairy cows; 39 from the heavy and 39 from the light line, was used. The selection of two lines of Holstein-Friesian cattle began in 1989 using proven sires with either high or low estimated breeding value for live weight, but all with high genetic merit for milksolids yield and similar breeding worth, which is a measure of relative net farm profit per 4.5 tonne of pasture dry matter eaten. Further details of the mating strategy followed to develop the heavy and light lines were given by Garcia-Muñiz *et al.*, (1998). Averages of breeding worth, breeding values for live weight, yields of protein, fat and milk, and for survival for the heavy and the light lines are presented in Table 2.1. The heavy cows had higher breeding values for live weight as well as for yields of milk, fat and protein, but there was no difference in Breeding Worth between the lines.

The herd calved between 20 July and 3rd October of 2000 (19% of the herd calved during the last 12 days of July, 64% of the herd calved in August, 13% of the herd calved in September and 4% calved during the first 3 days of October). Mean calving date was 15 August. Cows were in months 1 to 4 of their first to eighth lactation, 12 were primiparous (8 were from the H line and 4 from the L line) and 66 cows were multiparous (31 were from the H line and 35 from the L line). Cows were dried off on the basis of a combination of the following factors: body condition, pasture supply and somatic cell counts. When body condition was less than 3.5 (scale 1-10), pasture availability less than 2000 kg Dm/ha, SCC higher than 200-300 cells 10^3/ml or feed in deficit, cows were dried off. This is in accordance to practices in commercial herds in New Zealand.

All cows were rotationally grazed as one herd on the 35-ha farm (2.3 cows/ha) and offered a generous daily pasture allowance of approximately 65 kg DM/cow as assessed by a Rising Plate Meter (Ashgrove Pastoral Products, Palmerston North, New Zealand). The Rising Plate Meter (RPM) was calibrated using seasonal equations recommended by the Livestock Improvement Corporation (Hamilton, N.Z.), commonly used by New Zealand farmers (i.e., September herbage mass (kg DM/ha) = x115 + 650, where x is the RPM reading and represents the compressed height based on -0.5 cm units). Pasture comprised mainly perennial

ryegrass (*Lolium perenne* L. > 70%) and white clover (*Trifolium repens* L.). Cocksfoot (*Dactilis glomerata*), prairie grass (*Bromus willdenowii*) and tall fescue (*Festuca arundinacea*) were also present in small quantities. Management tried to maintain average whole-farm herbage mass at 2000 kg DM/ha, with post-grazing residual herbage mass at no less than 1600 kg DM/ha and pre-grazing herbage mass at around 2500 kg DM/ha during the whole lactation. Apparent average daily pasture dry matter intake per cow in the herd was estimated from the difference between the pre- and post-grazing herbage masses using the following formula:

DMI = (pregrazing HM - postgrazing HM / number of cows) * A

Where:

DMI = pasture intake (kg DM/cow/24 h)

HM = herbage mass (kg DM/ha)

A = area grazed (ha/24 h)

Experiment 1 b

The experiment was carried out between 22 October and 23 November 2001. A herd of 81 Holstein-Friesian dairy cows; 39 selected from the heavy and 42 from the light line, was used. Sixty-three cows used in *experiment 1a* were also used in *experiment 1b* (30 of the heavy and 33 of the light line). Fifteen cows used in *experiment 1a* were culled (9 from the H and 6 from the L line) while 17 two-year old cows (8 of the heavy and 9 of the light line) plus one 8-year old cow (from the heavy line) were incorporated into the herd used in *experiment 1b*. Averages of breeding worth (BW), breeding values (BV) for live weight, yields of protein, fat and milk, and for survival for the heavy and the light line are presented in Table 2.1. The herd calved between 26 June and 5th October of 2001. Mean calving date was 17 August 2001. Cows were in months 1 to 4 of their first to eighth lactation, 17 were primiparous and 64 cows were multiparous. Grazing management was identical to that described in *experiment 1a*.

Table 2.1 Average values of breeding worth (BW), breeding values (BV) for live weight, yields of protein, fat and milk, and survival for the heavy and the light lines of cows used in *experiment 1a* (n=71) and *1b* (n=57).

Genetic Line	BW ($)	Live weight BV (kg)	Protein BV (kg)	Fat BV (kg)	Milk BV (kg)	Survival BV (%)
***Exp 1 a* & Exp 2**						
Heavy (n=37)	42	68	27	30	900	0.6
Light (n=34)	44	31	21	25	695	1.0
Exp 1 b						
Heavy (n=33)	43	68	27	30	910	0.7
Light (n=24)	44	33	21	25	700	1.1

Note: Data for 2 heavy and 5 light cows for exp 1a and exp 2; and 6 and 20 light cows for exp 1b were not available.

Experiment 2

The experiment was carried out during one complete lactation from September 2000 to May 2001. Animals and grazing management were those used in *experiment 1a* (78 Holstein-Friesian dairy cows, 39 selected from the heavy and 39 from the light line).

2.2 Milking Management

Cows were milked twice daily at 0600 and 1500 h in a 10-bail walk-through milking-parlour with a high-line milking machine (Westfalia Landtechnik N.Z. Ltd.). All cows were milked with the same equipment and by the same people. Milking was performed at 45 kPa vacuum, 60 pulsation cycles/min (pulsation rate) and 65:35 pulsation ratio. The udders were not prepared or stimulated before the start of milking. Teats were not washed unless they were dirty, therefore cups were usually put on to dry teats.

2.3 Measurements

2.3.1 *Experiments 1a* and *1b*: Milking Characteristics

Experiment 1a

Total milking time, average milk flow rate and total milk volumes were measured during 6 consecutive milkings in each of two 3-day periods when all cows were in peak lactation. Period one was from 1/11/00 to 3/11/00 and period two from 13/11/00 to 15/11/00. Milk somatic cell count was measured once, either during or soon after each period (31 October 2000 for period 1=SCC_1 and 28 November 2000 for period 2=SCC_2).

During experimental milkings in both periods, milk volume, average milk flow rate and total milking time were measured by Metatron flow meters (Westfalia Landtechnik N.Z. Ltd.) and continuously recorded using the computer program Dairy Plan 5 (Westfalia Landtechnik N.Z. Ltd.). Milk volume (MV) was equivalent to total litres of milk removed per milking. Average milk flow (AFR) rate represented the milk volume divided by the milking time, in litres/minute. The Metatron calculated the milking time as the period from the time when the bottom electrode of the measurement chamber became wet until the time of low milk flow, which was the time of the last completed milking cycle (not necessarily end of milking). When milk flow fell below 0.2 kg/min the vacuum was cut off and the cluster withdrawn. Total milking time (TMT) was defined as total machine-on time, which is equal to the length of time (minutes) for which the cluster was attached to the cow. It is necessary to emphasize that the time used to calculate AFR differed from the time the cups remained on the cows which was the measure used for TMT. Milk somatic cell count (10^3/ml) was measured from aliquot milk samples taken at the morning and afternoon milkings, using a Milkoscan 104 infrared analyser and a Fossomatic cell counter (A/S N. Foss Electric, Denmark) at Livestock Improvement Corporation (Hamilton, N.Z.).

Experiment 1b

This experiment was similar to *experiment 1a,* but was carried out in the following year during two periods in peak lactation. Maximum flow rate was also recorded for all cows during both periods in addition to milk volume, average flow rate and total milking time. Milking characteristics were recorded for ten consecutive milkings in each experimental period. The first period of the *experiment 1b* took place between the 22nd and 26th of October 2001, and the second period between the 19th and 23rd of November 2001. Milk somatic cell count was measured once during each period (23 October 2001 for period 1 = SCC_1 and 21 November 2001 for period 2 = SCC_2). Milk volume, total milking time, average flow rate and maximum flow rate were measured as in *experiment 1a*. Maximum flow rate was calculated as the average between the three highest flow rates recorded. Milk volume, average milk flow rate, total milking time and somatic cell count were calculated as for *experiment 1a*.

2.3.2 *Experiment 2:* Average Daily Milk Yield and Milk Composition, Somatic Cell Count, Live Weight and Body Condition Score During a Complete Lactation

The lactation was divided into two-week periods, beginning at 2 days postpartum and continuing until drying off. Analysis was of daily averages within two-week periods. Daily milk yield was measured throughout the lactation and at each milking during both experiments using the in-line milk meters (Metatron, Westfalia Landtechnik N.Z. Ltd.). Milk yield and composition, and somatic cell count for each cow was assessed on eight occasions during the lactation by monthly herd testing carried out by Livestock Improvement Corporation (from September 2000 to April 2001). For both experiments, concentration of fat, protein and somatic cell count were analysed from aliquot milk samples taken at the morning and afternoon milkings, using a Milkoscan 104 infrared analyser and a Fossomatic cell counter (A/S N. Foss Electric, Denmark).

Live weight and body condition score of the cows were measured every two weeks after the afternoon milking from 20 July 2000 until 29 May 2001. Live weight was measured using platform scales (Tru Test, Ag 500) and body condition score was evaluated by visual assessment employing the 1-10 scale (1=very thin, 10=very obese).

2.4 Statistical Analysis

Experiment 1a and *1b*

Milk volume (MV), average flow rate (AFR) and total milking time (TMT) were all calculated as the average of the morning and afternoon milkings. Values for MV, AFR, TMT and SCC were analysed using a mixed linear model for repeated measurements. The model used for analysis of milk volume per milking included the effects of selection line, measurement day, time of the day when milking took place (morning or afternoon) and the interaction between selection line and time of the day when milking took place (see (1)). The model used for analysis of average flow rate, maximum flow rate and total milking time included the effects of line, measurement day, time of the day when milking took place (morning or afternoon), the interaction between selection line and time of the day, and the interaction between milk volume per milking and line. Furthermore, the correlation between MFR and AFR was also calculated (see (2), (3) and (4)). Lactation number, total lactation yield and days in milk were included as covariates in all models. Somatic cell count data were transformed to natural logarithms to create a normal distribution (Ali and Shook, 1980). Transformed somatic cell count ($logSCC_1$ and $logSCC_2$) was analysed using a model

which included the effects of live weight selection line, lactation number, the interaction between line and lactation number and the interaction between line and average daily milk yield (see (5)). In addition, the interaction between line and average flow rate, maximum flow rate and total milking time were analysed for somatic cell count for *experiment 1b* (see (6)). Data for *experiment 1a* were analysed as one block (i.e., periods one and two were merged because they were separated by only 10 days), whereas for *experiment 1b* data were analysed for each period because the two periods were separated by 24 days.

```
(1) MV = line day am_or_pm line*am_or_pm lac tot_my dim
(2) AFR = line day am_or_pm line*am_or_pm dim tot_my mv*line lac
(3) MFR = line day am_or_pm line*am_or_pm dim tot_my mv*line lac
(4) TMT = line day am_or_pm line*am_or_pm dim tot_my mv*line lac
(5) log SCC = line lac line*lac line*adm
(6) log SCC = line lac line*lac line*adm line*afr line*mfr line*tmt
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Experiment 2

Daily yields of milk (MY, see (7)), fat (FY), protein (PY) and milksolids (MSY), concentrations of fat (FP) and protein (PP), somatic cell count (SCC), live weight (LW) and body condition score (BC) were analysed using a mixed linear model for repeated measurements. SCC data was transformed to natural logarithms. Models used for analysis of milk traits included the effects of selection line, month when measurement was taken and the interaction between selection line and month. The models used for analysis of live weight (see (8)) and body condition score contained the effects of selection line, fortnight after calving and the interaction between selection line and fortnight. Lactation number was included as a covariate. Analyses were carried out using PROC MIXED (SAS, 2000). Values were considered significantly different when $P<0.05$.

```
(7) MY = line month line*month
(8) LW = line fortnight line*fortnight lac
```

3. RESULTS

3.1 *Experiment 1a* and *1b:* Milking Characteristics

Least square means estimates for milking characteristics, calculated as the average of the morning and afternoon milkings, for genetically heavy or light Holstein-Friesian cows in peak lactation for *experiment 1a* and *1b* (period one) are shown in Table 2.2. There were no

significant differences between the two lines for any of the milking characteristics for any experiment. In both experiments (*1a* & *1b*), there was a tendency for cows in the heavy line to yield more milk. Milking characteristics for the second period of *experiment 1b*, again, were not significantly different between lines. Period two of *experiment 1b* showed the same results as period one and are therefore presented in the Appendix (Table A.1).

Table 2.2 Least square mean estimates for milking characteristics (calculated as the average of the morning and afternoon milkings) for genetically heavy and light Holstein-Friesian cows for *experiment 1a* and period one (PI) of experiment *1b* (see Appendix Table A.1 for period two).

	Genetic lines		
Experiment 1a	**Heavy** (n=39)	**Light** (n=39)	SD
MV (litres)	13.40	13.05	ns
AFR (litres/min)	1.99	2.01	ns
TMT (min)	7.48	7.30	ns
Experiment 1b (PI)	**Heavy** (n=39)	**Light** (n=42)	SD
MV (litres)	14.18	13.47	ns
MFR (litres/min)	3.19	3.26	ns
AFR (litres/min)	1.99	1.96	ns
TMT (min)	7.64	7.79	ns

SD = significance of the difference; ns = not significant, * P<0.05

There were significant differences between morning and afternoon milkings for milk volume in both experiments (P<0.001; Table A.2 in Appendix), with larger volumes of milk obtained during the morning milkings (pooled data for both lines). Average flow rate was similar for morning and afternoon milkings in both experiments. Maximum flow rate, which was only measured in *experiment 1b*, was slightly faster for afternoon milkings in both periods (P<0.05). Total milking time was higher for the morning milkings and this difference was significant for *experiment 1a* and period two of *experiment 1b* only (P<0.01). In period two, of *experiment 1b* the morning milking took 0.47 minutes longer than the afternoon milking.

Table 2.3 presents means for morning and afternoon milking characteristics for each line of cows. There were no differences for milking characteristics between lines and within time of the day when milking took place (am or pm milking) for *experiment 1a* and *1b* (period one) except for the morning milk volume, which was slightly higher for the heavy cows in both experiments (P<0.05; Table 2.3). There were no differences for milking characteristics

between lines and within time of the day when milking took place, for the second period of *experiment 1b*, therefore those results are presented in the Appendix (Table A.3)

Table 2.3 Least square mean estimates for morning and afternoon milking characteristics for the heavy and the light lines for *experiment 1a* (n=78) and period one (PI) of experiment *1b* (n=81; see Appendix Table A.3 for period two).

	am		**pm**	
Experiment 1a	Heavy	Light	Heavy	Light
MV (litres)	15.12	14.67 (*)	11.68	11.43 (ns)
AFR (litres/min)	1.94	2.00 (ns)	2.05	2.02 (ns)
TMT (min)	7.65	7.40 (ns)	7.30	7.21 (ns)
Experiment 1b (PI)				
MV (litres)	16.56	15.97 (*)	11.79	11.98 (ns)
MFR (litres/min)	3.08	3.26 (ns)	3.30	3.26 (ns)
AFR (litres/min)	1.93	1.99 (ns)	2.05	1.93 (ns)
TMT (min)	7.85	7.84 (ns)	7.43	7.75 (ns)

Note: significance of the difference between lines within am or pm milking is indicated in parentheses;
ns = not significant, * P<0.05

There were no significant differences between primiparous and multiparous cows for any milking characteristic for *experiment 1a* (Table 2.4). For *experiment 1b*, period one, there were no significant differences between primiparous and multiparous cows for MFR, AFR and TMT. However, the primiparous cows produced 1.3 litres/milking less than the multiparous cows (P<0.01, Table 2.4). There were no differences for milking characteristics between primiparous and multiparous cows in *experiment 1b*, period two (Table A.4 in Appendix).

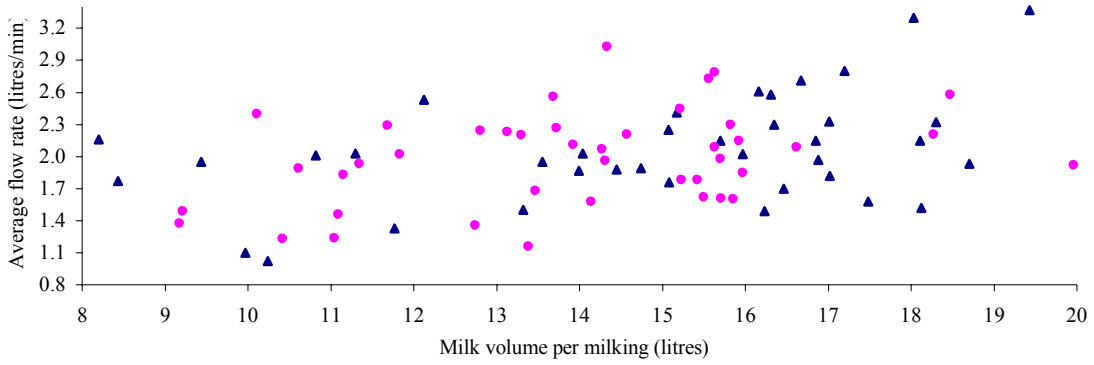
Table 2.4 Least square mean estimates for milking characteristics (data pooled for the heavy and the light lines and calculated as the average of the morning and afternoon milkings) for primiparous and multiparous Holstein-Friesian cows, for *experiment 1a* and period one (PI) of experiment *1b* (see Appendix Table A.4 for period two).

Experiment 1a	**Primiparous** (n=12)	**Multiparous** (n=66)	SD
MV (litres)	13.27	13.18	ns
AFR (litres/min)	1.94	2.06	ns
TMT (min)	7.62	7.16	ns
Experiment 1b	**Primiparous** (n=17)	**Multiparous** (n=64)	SD
MV (litres)	13.41	14.74	**
MFR (litres/min)	3.00	3.45	ns
AFR (litres/min)	1.89	2.06	ns
TMT (min)	7.95	7.49	ns

SD = significance of the difference; ns = not significant; ** P<0.01

Regression coefficients of milking characteristics on milk yield per milking for genetically heavy and light Holstein-Friesian cows for *experiment 1a* and both periods of *experiment 1b* are presented in Table A.5 (in Appendix). There was a significant relationship between milk volume per milking and average flow rate for each line for *experiment 1a*. For every extra litre of milk volume per milking there was a concurrent increase in average flow rate of 0.08 litres/min for both the heavy and light line. The relationship between milk volume per milking and average flow rate for *experiment 1b* (period one) is presented in Figure 2.1. An increase in milk yield per milking of one litre was associated with an increase in average flow rate of 0.07 and 0.03 litres/min for the heavy and light line respectively.

Figure 2.1 Relationship between milk volume and average flow rate for heavy and light cows for period one of *experiment 1b* (n = 81)

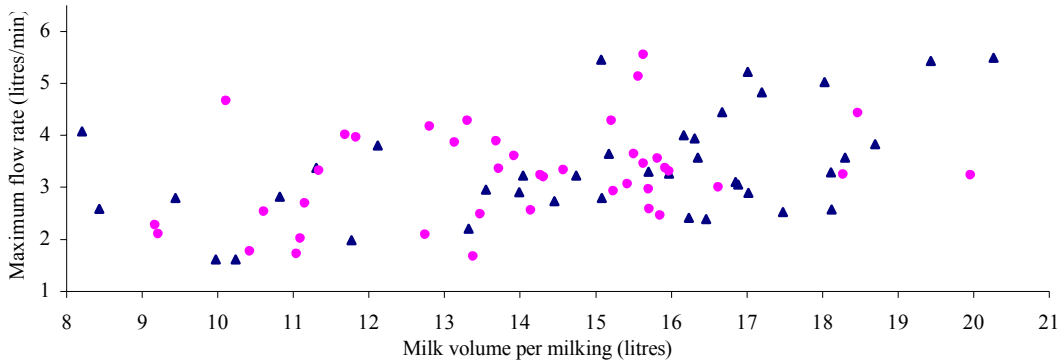


The regression coefficients of average flow rate on milk volume were 0.066 ±0.009 ($p<0.0001$) and 0.030 ±0.006 ($p<0.0001$) for the heavy and the light line respectively

▲ Heavy cows ● Light cows

There was a significant relationship between milk volume per milking and maximum flow rate for both lines in both periods of *experiment 1b* ($P<0.001$). For every extra litre of milk volume per milking there was a concurrent increase in maximum flow rate of 0.08 and 0.04, and 0.09 and 0.06 litres/min for the heavy and light line, for period one (Figure 2.2) and two respectively.

Figure 2.2 Relationship between milk volume and maximum flow rate for heavy and light cows for period one of experiment *1b* (n = 81)

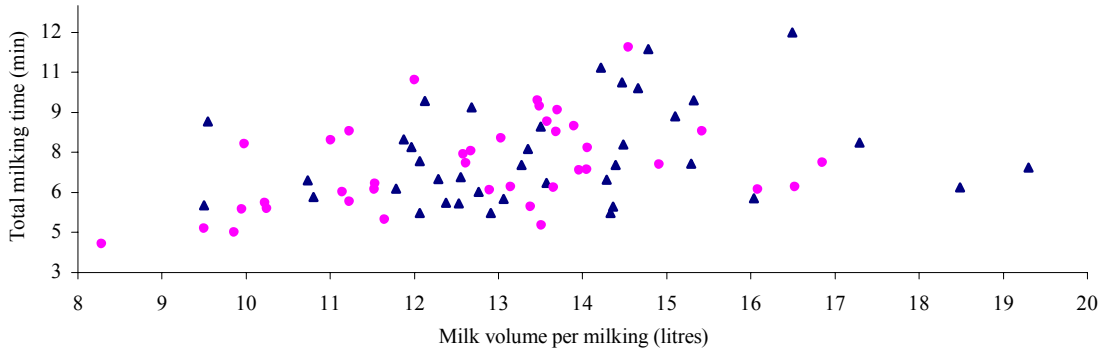


The regression coefficients of maximum flow rate on milk volume were 0.075 ±0.015 ($p<0.0001$) and 0.043 ±0.009 ($p<0.0001$) for the heavy and the light line respectively

▲ Heavy cows ● Light cows

The relationship between milk volume per milking and total milking time was also significant for both lines in both experiments. In *experiment 1a*, an increase in one litre of milk was associated with an increase of 0.24 and 0.27 minutes in total milking time for the heavy and light line respectively (Figure 2.3). The regression coefficients of TMT on milk volume for *experiment 1b* (period one) were 0.13 and 0.22 minutes for the heavy and light line respectively. Regression coefficients of AFR and TMT on milk volume for period two of *experiment 1b*, are present Table A.5 in the Appendix.

Figure 2.3 Relationship between milk volume and total milking time for heavy and light cows for *experiment 1a* (n = 78)



The regression coefficients of total milking time on milk volume were 0.239 ±0.029 ($p<0.0001$) and 0.274 ±0.031 ($p<0.0001$) for the heavy and the light line respectively

▲ Heavy cows ● Light cows

The correlation between MFR and AFR was positive and significant for both periods of *experiment 1b*. Correlation coefficients were 0.804 and 0.799 for period one and two respectively (P<0.001).

Somatic Cell Count

There was no difference between lines for log somatic cell count for *experiment 1a* (Table 2.5). However, for *experiment 1b* the light line had a significantly higher log SCC in both periods (Table 2.5). This difference was approximately 44,150 and 22,500 somatic cells/ml of milk in period one and two respectively.

Table 2.5 Least square mean estimates for log milk somatic cell counts measured twice at peak lactation ($logSCC_1$ = period one and $logSCC_2$ = period two, measured as 10^3/ml) for genetically heavy and light Holstein-Friesian cows for *experiment 1a* and *1b*.

	Genetic lines		
Experiment 1a	**Heavy** (n=39)	**Light** (n=39)	SD
$logSCC_1$	10.719 (45.2)	10.921 (55.3)	ns
$logSCC_2$	10.500 (36.3)	10.654 (42.4)	ns
Experiment 1b	**Heavy** (n=39)	**Light** (n=42)	SD
$logSCC_1$	10.773 (47.7)	11.428 (91.8)	***
$logSCC_2$	10.262 (28.6)	10.841 (51.1)	*

SD = significance of the difference; ns = not significant, * P<0.05, *** P<0.001
SCC values transformed to the nominal scale are in parentheses (10^3/ml)

There was no effect of parity on log somatic cell count for *experiment 1a* whereas for *experiment 1b* this effect was very small and not consistent for both periods (Table 2.6). In period one of *experiment 1b* the multiparous cows had a slightly higher log somatic cell count than the light cows, while the opposite occurred in period two.

Table 2.6 Least square mean estimates for log milk somatic cell counts measured twice at peak lactation ($logSCC_1$ = period one and $logSCC_2$ = period two, data pooled for the heavy and the light lines) for primiparous and multiparous cows, for *experiment 1a* and *1b*.

Experiment 1a	**Primiparous** (n=12)	**Multiparous** (n=66)	SD
$logSCC_1$ (10^3/ml)	10.47	11.08	ns
$logSCC_2$ (10^3/ml)	10.36	10.86	ns
Experiment 1b	**Primiparous** (n=17)	**Multiparous** (n=64)	SD
$logSCC_1$ (10^3/ml)	11.22	11.98	*
$logSCC_2$ (10^3/ml)	10.66	10.44	*

SD = significance of the difference; ns = not significant, * P<0.05

There was a significant interaction between line and parity for log somatic cell count for *experiment 1b* only (Table A.6 in Appendix). Primiparous cows of the light line had ~150,000 (period one) and ~50,000 cells/ml of milk (period two) more than their pairs of heavy line. The opposite occurred for the multiparous cows, where the heavy line had significantly higher somatic cell counts than the light line for period one only.

Relationship between somatic cell count and milking characteristics

When the model for log SCC included the interaction between daily average milk yield and line only (as in *experiment 1a*), there was no significant relationship between daily average milk yield and log somatic cell count ($logSCC_1$ nor $logSCC_2$). However, when the interaction between all milking characteristics and SCC was added to the model, this interaction became significant (Table 2.7). The relationship between log SSC and milking characteristics for both periods of *experiment 1b* is presented in Table 2.7.

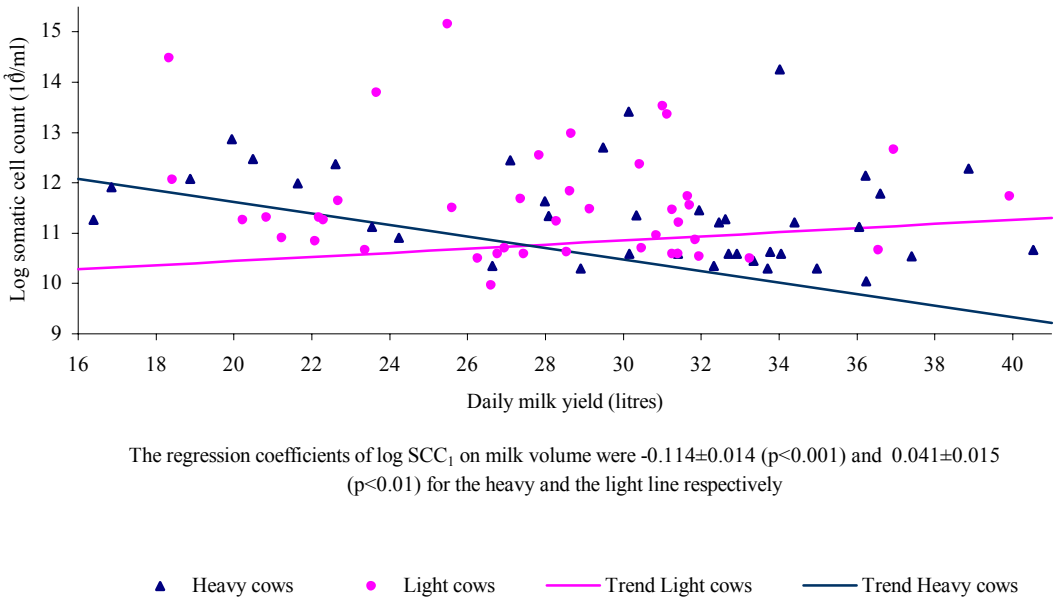
Table 2.7 Regression coefficients of milking characteristics on log somatic cell counts for genetically heavy and light Holstein-Friesian cows for both periods (PI & PII) of *experiment 1b* (n=81).

Experiment 1b (PI)	Daily yield (litres)	MFR (litres/min)	AFR (litres/min)	TMT (min)
Heavy	-0.11 (***)	0.72 (***)	-0.70 (***)	0.01 (ns)
Light	0.04 (**)	0.41 (***)	-0.44 (**)	0.00 (ns)
Experiment 1b (PII)				
Heavy	-0.04 (**)	0.40 (**)	-0.50 (**)	-0.04 (ns)
Light	0.00 (ns)	0.16 (*)	0.29 (ns)	-0.05 (ns)

Note: significance of the relationship between milking characteristics and SCC is indicated in parentheses; ns = not significant, * = P<0.05, ** = P<0.01, *** P<0.001

The relationships between daily average milk volume and log somatic cell count for period one of *experiment 1b* ($logSCC_1$, Figure 2.4) were significant for both lines, whereas for period two ($logSCC_2$) the relationship was significant for the heavy cows only (Table 2.7). In period one, for every extra litre of milk yield per day there was a decrease in log SCC of $0.11x10^3$ somatic cells/ml in cows from the heavy line. On the other hand, every extra litre of daily milk yield was associated with an increase in log SCC of $0.04x10^3$ somatic cells/ml in cows from the light line. For period two, again, log SCC for the heavy cows decreased when daily average milk volume increased but this relationship was not significantly different from zero for the light line.

Figure 2.4 Relationship between daily milk yield and log somatic cell count for heavy and light cows for period one of *experiment 1b* (n = 81)



The regression coefficients of log SCC_1 on milk volume were -0.114±0.014 ($p<0.001$) and 0.041±0.015 ($p<0.01$) for the heavy and the light line respectively

▲ Heavy cows ● Light cows — Trend Light cows — Trend Heavy cows

A small but significant antagonistic relationship between log SCC and average flow rate was observed for the heavy line in both periods of experiment (*1b*) as well as for the light line in the second period (Table 2.7). It was calculated that for every extra litre/kg of AFR there was a decrease in log SCC of 0.70×10^3 somatic cells/ml in cows from the heavy line and a decrease of 0.44×10^3 somatic cells/ml in cows from the light line for period one. However, no relationship was found between SCC and AFR for the light line in the first period of the experiment. Furthermore, the relationships between log somatic cell count and maximum flow rate were significant and similar in magnitude as the previous ones but positive, for both lines and both periods of the experiment. Every extra litre/kg of AFR was associated with an increase in log SCC of 0.72 and 0.41×10^3 somatic cells/ml in cows from the heavy and the light line respective (period one). Finally, no relationship between TMT and log SCC was detected for any of the two lines in any period.

3.2 *Experiment 2*: Daily Milk Yield and Milk Composition, Somatic Cell Count, Live Weight and Body Condition During One Complete Lactation

Daily Milk Yield, Daily Milk Composition and Somatic Cell Count

Lactation performance of the heavy and the light is summarized in Table 2.8. There was a significant difference between genetic lines for daily milk yield, milk protein yield and milk fat concentration. Cows from the heavy line of cows produced 8.2% more milk ($P<0.01$) and yielded 5.5% more milk protein ($P<0.05$) than the light line in the whole lactation. However, the light line yielded milk with a higher fat concentration than that of the heavy line ($P<0.05$).

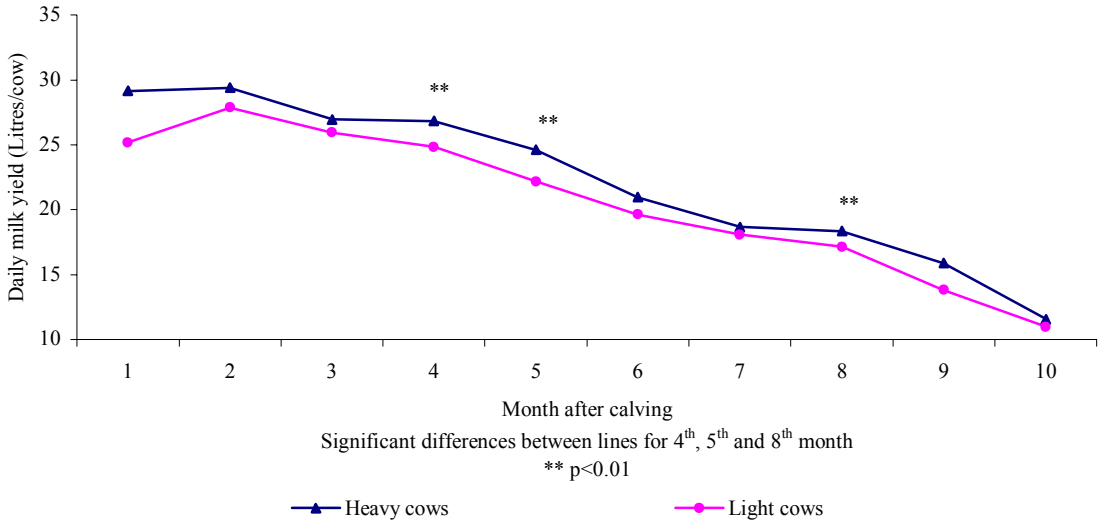
Table 2.8 Least square means for daily milk yield and milk composition traits, and log transformed somatic cell count for the heavy and the light cows, averaged for the whole lactation (*experiment 2*; n=78).

	Genetic lines		
	Heavy (n=39)	**Light** (n=39)	SD
Milk yield (litres)	22.25	20.57	**
Fat yield (kg)	1.04	1.00	ns
Protein yield (kg)	0.76	0.72	*
Milksolids yield (kg)	1.79	1.72	ns
Fat (%)	4.78	4.95	*
Protein (%)	3.44	3.53	ns
Log somatic cell counts (10^3/ml)	11.21	11.27	ns
Live weight (kg)	517	474	***
Body condition score	4.2	4.2	ns

SD = significance of the difference; ns = not significant, * P<0.05, ** P<0.01, *** P<0.001

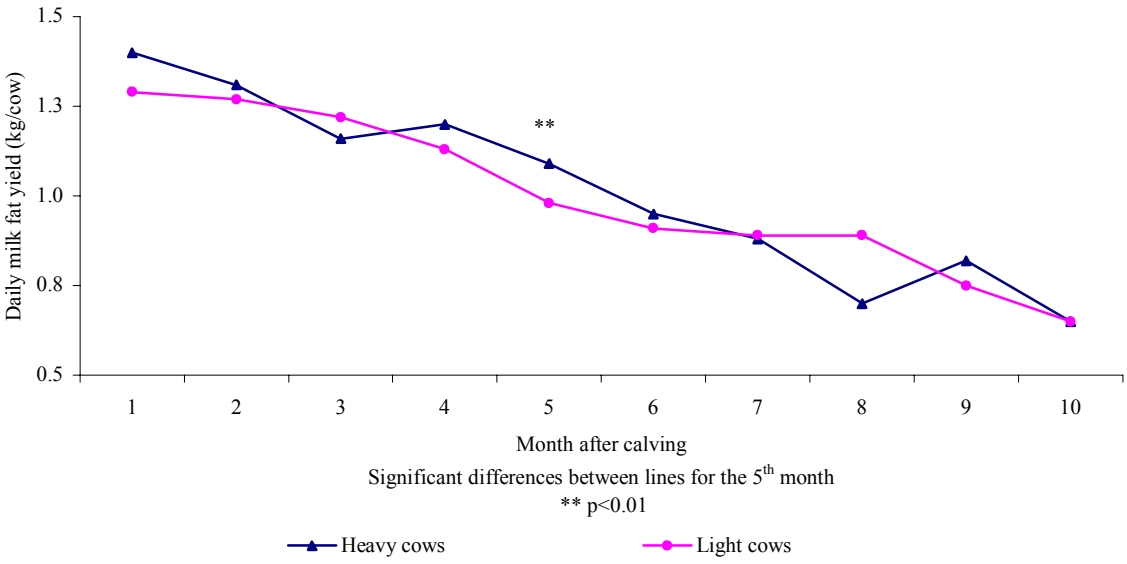
Figure 2.5 shows mean daily milk yield in each month of the lactation, for the whole lactation. There were significant differences between lines only for the 4th, 5th and 8th month of the lactation ($P<0.01$). For those months the heavy line produced 2.0, 2.4 and 2.1 litres more than the light line, respectively.

Figure 2.5 Experiment two: Daily milk yield for the heavy and the light line of cows for each month of the lactation (n = 78)



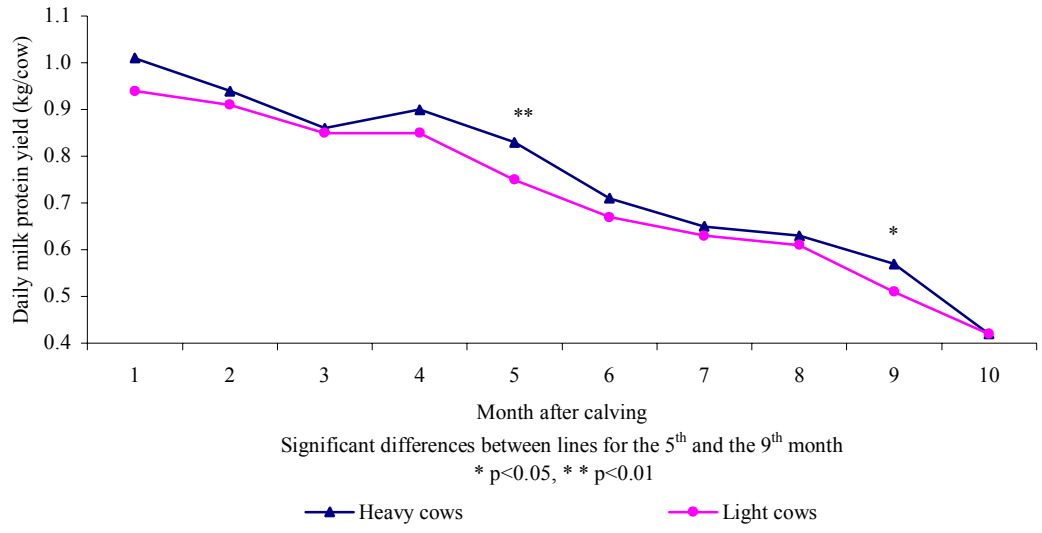
There was a significant difference in daily milk fat yields between the heavy and the light line of cows only for the 5th month of the lactation (P<0.01; Figure 2.6). For that month the heavy line produced 1.09 kg of fat and the light line, 0.98 kg of fat.

Figure 2.6 Experiment two: Daily milk fat yield for the heavy and the light line of cows for each month of the lactation (n = 78)



There were significant differences between lines for daily milk protein yield in the 5th (P<0.01) and the 9th month (P<0.05) of the lactation, where the heavy line produced 0.08 and 0.06 extra kg of protein respectively (Figure 2.7).

Figure 2.7 Experiment two: Daily milk protein yield for the heavy and light line of cows for each month of the lactation (n = 78)



Daily yield of milksolids was similar for both lines (Table 2.8). There were significant differences between the heavy and the light lines for milksolids yield in the 5th month of the lactation only, where the heavy line produced 0.2 kg MS more than the light line (Figure 2.8).

Figure 2.8 Experiment two: Daily milksolids yield for the heavy and the light line of cows for each month of the lactation (n = 78)

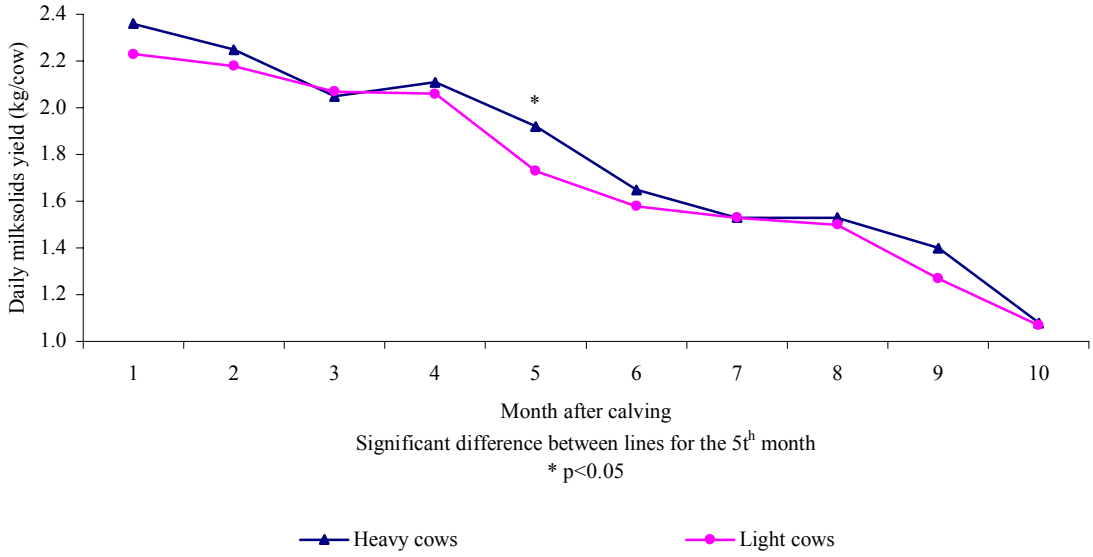
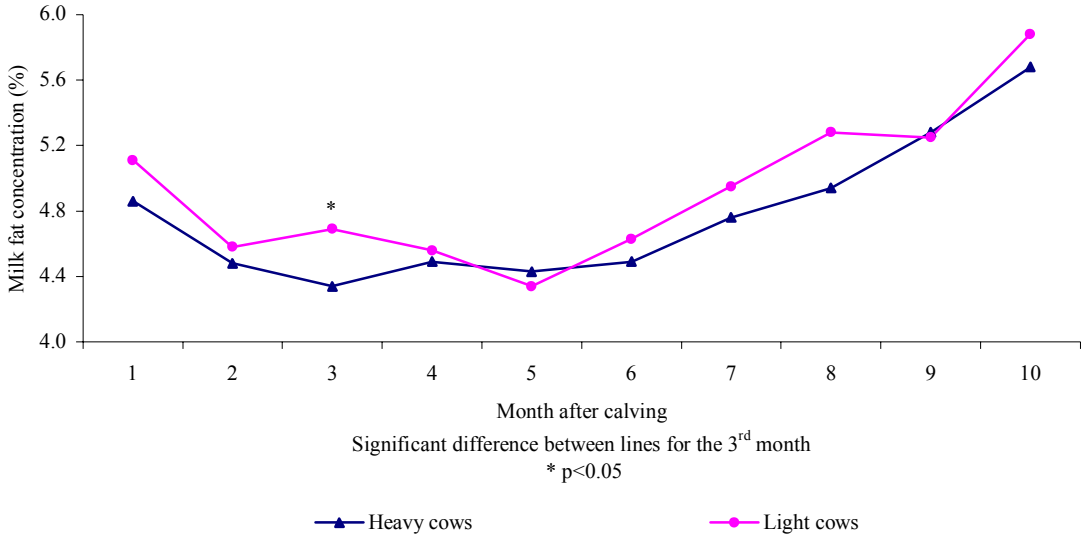


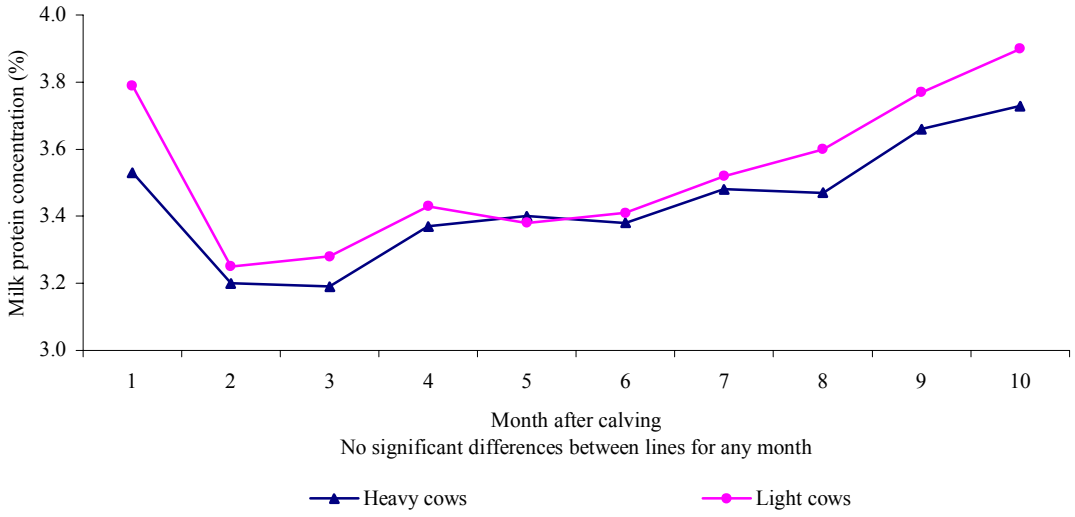
Figure 2.9 and Figure 2.10 present data for milk fat concentration and milk protein concentration for the heavy and the light line of cows for each month of the lactation. Milk fat percentage was higher in the light line, although the difference was significant only for the 3rd month of the lactation (light = 4.7%, heavy = 4.3%; P<0.05).

Figure 2.9 Experiment two: Milk fat concentration for the heavy and the light line of cows for each month of the lactation (n = 78)



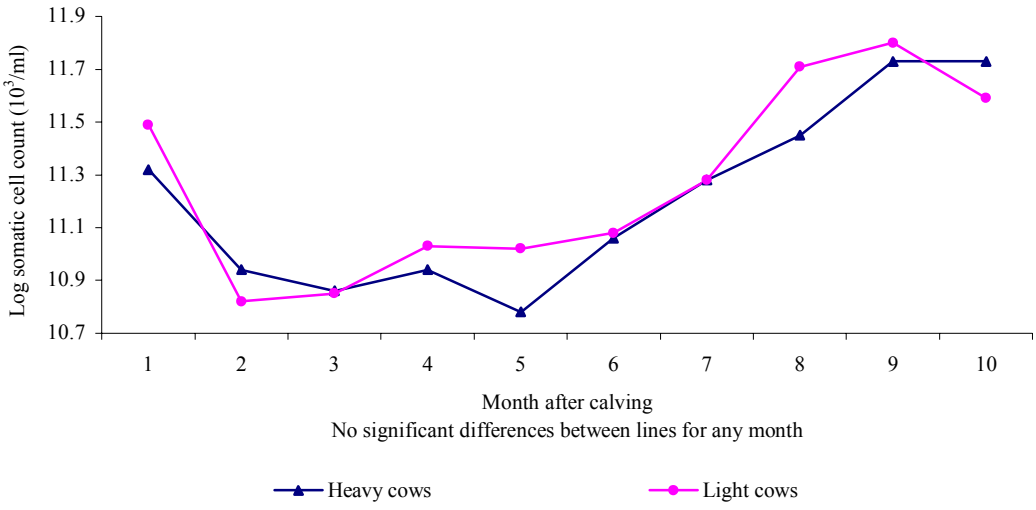
There were no significant differences between the heavy and the light lines for milk protein concentration for any month of the lactation.

Figure 2.10 Experiment two: Milk protein concentration for the heavy and the light line of cows for each month of the lactation (n = 78)



Log transformed somatic cell count (logSCC) were not significantly different between lines for any month of the lactation (figure 2.11). Somatic cell count was ~74,000 and ~79,000 cells/ml for the heavy and the light line.

Figure 2.11 Experiment two: Milk somatic cell count for the heavy and the light line of cows for each month of the lactation (n = 78)

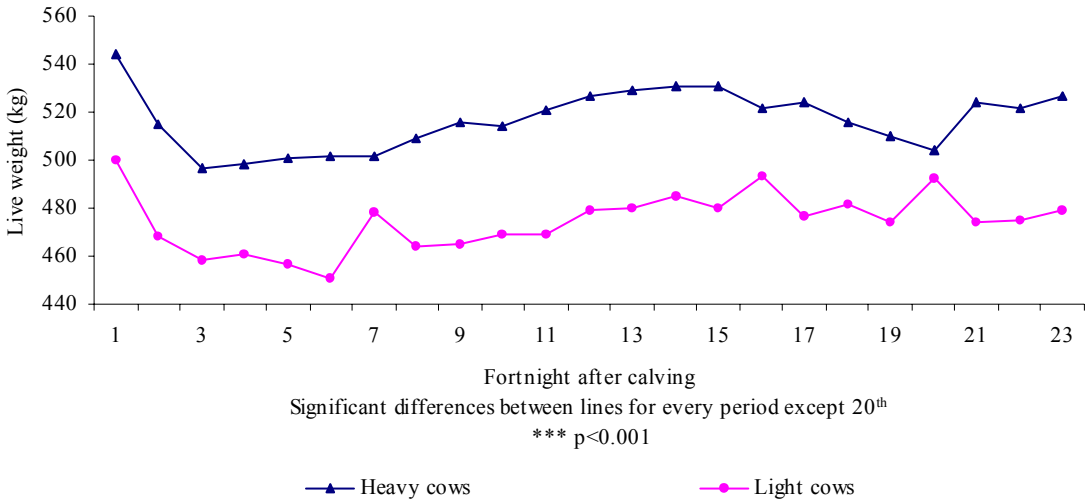


Month of lactation had a significant effect on all the parameters studied when data for both lines was pooled, however, there was no interaction between line and month for any of them.

Live Weight and Body Condition Score During One Complete Lactation

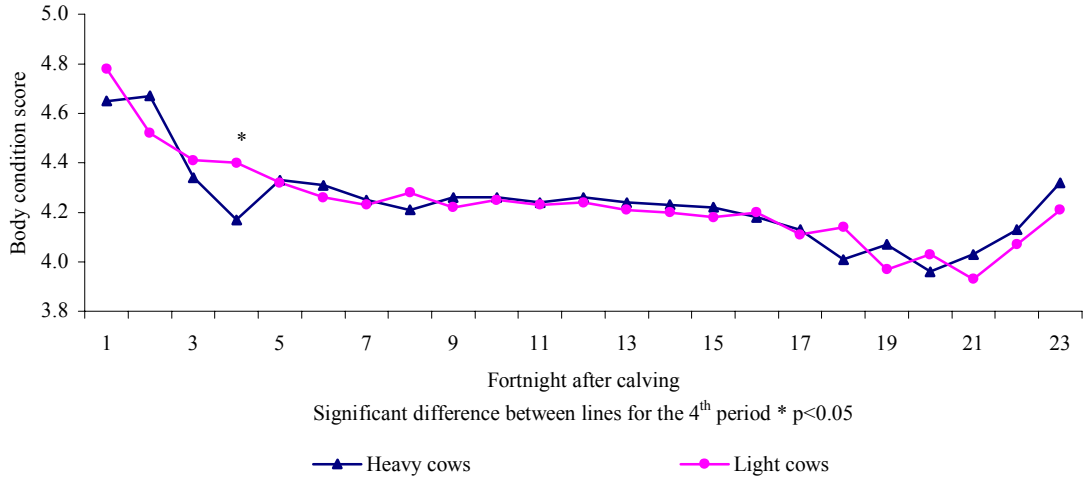
Cows from the heavy weighed 43 kg more than cows from the light line (P<0.001; Table 2.8). Lactation number (parity) had a highly significant effect on the live weight of the animals when data for both lines was pooled (452 *versus* 540 kg for primiparous and multiparous respectively; P<0.001). Figure 2.12 presents data for live weight for the heavy and the light lines of cows during one complete lactation (23 fortnightly periods). Excluding the 20th period, live weight was significantly different between the heavy and light line for every period (P<0.001). Live weight changes followed a similar pattern in both lines, decreasing from calving until the 3rd fortnight and increasing thereafter. The light line lost slightly more live weight during the lactation than the heavy line (21 versus 17 kg of live weight loss, respectively).

Figure 2.12 Experiment two: Live weight for the heavy and the light line of cows during one complete lactation (n = 78)



Least square means for body condition score were very similar for both lines (Table 2.8). However, over the whole lactation, the cows from the light line lost more body condition than the cows from the heavy line (0.6 *versus* 0.3 units loss, respectively). Figure 2.13 presents body condition score data for each line during one complete lactation. Body condition score was significantly different for the 4th fortnight only (4.2 and 4.4 for the heavy and the light line respectively; P<0.05). Lactation number did not have a significant effect on the body condition score for pooled data for both lines (4.3 *versus* 4.2 for the primiparous and multiparous cows respectively).

Figure 2.13 Experiment two: Body condition score for the heavy and the light line of cows during one complete lactation (n = 78)



Stage of lactation had a significant effect on live weight and body condition score when data for both lines was pooled. Furthermore, there were no differences between lines within stage of lactation.

4. DISCUSSION

Increases in live weight that occurred as a correlated response to selection for high milk yields are well documented (Yerex *et al.*, 1988; Parke *et al.*, 1999). Changes in udder conformation (Young *et al.*, 1970), that can adversely affect milking characteristics or somatic cell counts (Zeman and Neumann, 1973; Chyr *et al.*, 1974), resulting from selection for milk yield have also been recorded (Petersen *et al.*, 1985). The present selection for genetic differences in live weight might have been associated with other changes, which might in turn have influenced the cows milking characteristics. Therefore, it was important to measure the milking characteristics and somatic cell counts in the two selection lines.

Milking Characteristics

Lactation averages showed that heavy cows produced by 1.7 litres per day more than the light cows throughout the lactation. However, milk volume per milking was similar for both lines during peak lactation, when the milking characteristics were measured (Table 2.2). Peak lactation daily milk volume values for the heavy and the light lines observed in the present study (26.8 and 26.1 litres/day respectively, ns, from Table 2.2) agree with those reported by Lopez-Villalobos *et al.* (2001) of 27.6 and 25.6 litres/day for the heavy and the light lines respectively (ns). In addition, both lines had very similar average flow rates. That explains the lack of difference between the live weight lines for total milking time. In the following lactation, again, there was no difference in milk volume and no difference in average flow rate between lines, therefore, no difference in total milking time (Table 2.2). However, other experiments carried out in New Zealand and overseas that compared milking characteristics between groups of cows (Table 2.9) found considerable differences in total milking time partly due to significant differences in milk production and partly due to differences in average or maximum flow rate. Differences in total milking time between genetically different groups of cows much larger or much smaller than those in daily milk production were obtained when large differences in average or maximum flow rate occurred at the same time (lines 3, 5, 6 and 7 in Table 2.9). Moreover, some of those experiments also reported significant differences in fat yield, which did not occur in the present experiment.

Table 2.9 Summary of experiments carried out in New Zealand, the US and Canada that compared milking characteristics between cows of differing breeding index (BI), breeds, genotypes (origin of genetics) or live weight lines.

Comparison between	Breed	Milk Volume (kg/ milking)	Average Flow Rate (kg/min)	Maximum Flow Rate (kg/min)	Total Milking Time (min/milking)	Reference
High BI	Jersey[1]	6.9	-	-	5.2	
Low BI		5.4	-	-	5.9	Arave & Kilgour, 1982
High BI	Friesian[1]	7.2	-	2.1		
Low BI		6.5	-	1.5	15% longer	Davey *et al.*, 1983
Friesian		7.4	1.7	-	4.9	
Jersey[2]		5.5	1.3	-	4.5	Arave *et al.*, 1987
High BI	Holstein	13	2.2	-	6.0	
Low BI		10	2.1		4.6	Barnes *et al.*, 1989[2]
First parity	Holstein	12.2	2.1	2.8	4.9	
2+ parity			2.5	3.5	5.7	Petersen *et al.*, 1986[1]
Holstein-Friesian		11.0	2.1	-	6.3	Moore *et al.*, 1983[1]
North American genotype	Holstein--Friesian[1a]	7.4	1.5	-	10.2	
New Zealand genotype		6.3	1.7	-	7.3	Penno & Kolver, 2000* (1998 season)
North American genotype	Holstein-Friesian[1b]	11.3	1.8	-	12.6	
New Zealand genotype		9.4	2.3	-	8.0	Penno & Kolver, 2000* (1998 season)
Heavy Line	Holstein-Friesian[3]	12.5	1.9	3.0	7.3	
Light Line		12.2	1.9	3.1	7.2	Present study, 2001 (period II experiment 1b)

[1] Whole lactation study; [2] mid-late lactation; [3] peak lactation

[a] grazing feeding system; [b] high input feeding system (cows fed TMR)

- not measured

* AFR calculated as the quotient between milk volume and total milking time

Other factors that greatly affect total milking time are milking parlour design (Whipp, 1992), age (Sharaby *et al.*, 1979; Arave *et al.*, 1987), stage of lactation (Markos and Touchberry, 1970), interval between milkings, efficiency of the milking routine (Brumby, 1956) and anatomical structure of the teat (Baxter *et al.*, 1950). In the present experiments, cows from both lines were milked with the same machine, in the same milking plant and were subjected to the same milking interval (15-9h) and milking routine (no wash). Age and stage of lactation were covariates in the statistical model. Age had a significant effect on milk volume per milking but not on the AFR, MFR or TMT and only in the second season of the experiment. Stage of lactation had a significant, and consistent for both experiments, effect on milk volume per milking but not on the AFR, MFR or TMT. Comparative evaluations of anatomical structure of the teat were not carried out.

Total milking time and milk volume were both higher in the morning than in the afternoon milkings ($P<0.001$, $P<0.01$ respectively), for the whole herd (both lines pooled; Table A.2). More milk was removed in the morning milkings in the heavy line than in the light line, in both experiments ($P<0.05$). Averaged across experiments, 38 and 33% extra milk was removed in the am milking compared to the pm milking for the heavy line and the light line respectively (Table 2.3 and Table A.3) whereas the extra total milking time at the am milkings was only 6% for the heavy line and 3% for the light line. In addition, milking interval had no effect on average flow rate. These results do not agree with other studies that demonstrated that longer milking intervals (16 *vs.* 8h) resulted in both larger yields of milk per milking and higher average flow rates (Arave *et al.*, 1987) and higher average and maximum flow rates (Brumby, 1956). However, differences in methodology particularly in the calculation of AFR mentioned in section 2.3.1 between this (AFR = MV/actual milking time) and earlier experiments (MV/total milking time) could explain differences in the results. For instance, if AFR is calculated as MV/total milking time as opposed to MV/actual milking time then values for AFR in Table A.2 for *experiment 1a* would be 1.98 and 1.45 litres/min for am and pm milking respectively. Thus, it would appear that morning AFR in the morning are higher than in the afternoon. In addition, the difference between calculated values for actual milking times and those for total milking times in Table A.2 for all experiments suggests that there is a longer lag time between the end of milk removal and cup removal in the afternoon (5.18 *vs.* 7.25, 5.96 *vs.* 7.59 and 5.41 *vs.* 7.00 minutes for *experiment 1a*, *experiment 1b* PI and *experiment 1b* PII respectively). This is important from the udder health point of view, as vacuum fluctuations and overmilking are likely to aid penetration of bacteria into the teat and

had been associated with increased new infection rates (Thiel, 1978), which are more likely to occur near the end of milking when the milk flows are low (Cousins *et al.*, 1973).

The values for milk yield per day for the heavy and the light line of Holstein-Friesian cows in peak lactation obtained in the present experiment (25-28 l/day) agree with those of Laborde, (1998; 23 and 22.5 litres/day for the heavy and the light line respectively, measured as the average of the first three months of the lactation) and with those reported by Lemus-Ramirez, 2000 (both lines ranged between 23 and 26 l/day in peak lactation). None of those studies, which used cows of the same genetic lines of live weight, found significant differences between lines for milk yield in peak lactation. Previous experiments have shown similar yields of milk per milking for Holstein cows. Values reported for Holstein cows in peak lactation were 12.4 litres per milking (for a herd containing primiparous and multiparous cows; Petersen *et al.*, 1986) and 10.3-13.4 litres per milking (for cows in their second lactation only; Barnes *et al.*, 1989). The latter experiment, however, used a drastically different milking routine, where cows were intensely stimulated and injected 20 IU of oxytocin before milking, and another 20 UI oxytocin before stripping to obtain residual milk.

Total milking time and flow rate measurements are within the range of values reported in previous experiments (Moore *et al.*, 1983; Penno and Kolver, 2000; line 6 and 7 in Table 2.9) for Holstein-Friesian, Holstein (Barnes *et al.*, 1989) but higher than those reported for Friesian cows (Arave *et al.*, 1987) in peak lactation (lines 3 and 4 in Table 2.9). The lower rates of flow observed in the latter study are probably attributed to the lower genetic merit for milk production of the cows compared to the cows used in the present experiment. This hypothesis agrees with the finding that milk yield is positively correlated with average and maximum flow rate both genetically (0.46 and 0.49 for AFR and MFR respectively, Petersen *et al.*, 1986) and phenotypically (0.34 and 0.35 for AFR and MFR respectively). Possibly for the same reason, maximum flow rates in the present experiment are much higher than those reported by Davey *et al.*, (1983; Table 2.9).

Regression coefficients of AFR, MFR and TMT on milk yield per milking were all positive and significant but of very small magnitude (Table A.5). For instance from the data for period one it can be predicted that an increase in milk yield per milking from 8 to 15 litres in the heavy line would be associated with an increase in MFR from 3.73 to 4.26 litres/min, in AFR from 2.38 to 2.91 litres/min and in TMT from 5.31 to 6.23 min. Corresponding increments in

MFR and AFR in the light line would be of smaller magnitude but they would be greater for TMT (from 5.98 to 7.49 min). Smith *et al.* (1978) reported almost identical values for the regression coefficient of milking rate traits on milk yield per milking (0.088, 0.057 and 0.095 for MFR, AFR, TMT respectively). Results from the present study are also similar to those of Touchberry and Markos (1970).

Further, for TMT the regression coefficient on MV increases in magnitude as stage of lactation increases (from 0.13 in October-exp 1a- to 0.24 in early November -period one of exp 1b- to 0.27 in late November -period two of exp 1b- for the heavy line and in similar magnitude in the light line). The same occurred with maximum flow rate but to a lesser extent, while average flow rate stayed stable. These findings, again, are similar to those of Markos and Touchberry (1970). The main evidence to be drawn is that in both lines total milking time was affected to a markedly greater extent by the amount of milk removed per milking than by flow rate measurements.

Somatic Cell Count

Herd means for SCC without age or milk yield adjustments were, for both seasons, less than 150,000 somatic cells/ml in peak lactation and less than 80,000 somatic cells/ml for the whole lactation. This low SCC indicates that the incidence of mastitis infection was very low. Mean absolute values obtained in this study are comparable to those by Holdaway *et al.* (1996) in uninfected udder quarters in peak lactation who studied three New Zealand commercial dairy herds and to those reported by Garcia and Holmes (2001) from a spring calving experimental herd in peak lactation (between 150,000 and 200,000 somatic cells/ml). The values for SCC obtained in the present study were much lower than those reported by Moore *et al.* (1983) of 381,000 somatic cells/ml, which was a lactation average for a herd of Canadian Holstein-Friesian cows.

There was no effect of parity on log somatic cell count for *experiment 1a*, however multiparous cows had higher SCC than primiparous cows. For period one of *experiment 1b* multiparous cows had significant higher SCC (~90,000 cells/ml) than primiparous cows. In period two of *experiment 1b* the opposite occurred but it has little relative importance because of the small magnitude of the difference (~10,000 cells/ml). Increasing parity was shown to increase SCC in many other studies (Sharaby *et al.*, 1979; Kennedy *et al.*, 1982).

An increase in daily milk yield from 16 to 41 litres was associated with a decrease of $45.7x10^3$/ml somatic cells/ml of milk in the heavy cows and, in contrast, it was associated with an increase of $10.5x10^3$/ml somatic cells/ml of milk or no relationship at all between these variables in the light cows. Both positive (Miller *et al.*, 1983; Moore *et al.*, 1983) and negative (Kennedy *et al.*, 1982; Moxeley *et al.*, 1978; Seykora and McDaniel, 1982; Haile-Mariam *et al.*, 2001) relationships between yield and somatic cell count have been reported in the literature. Moore *et al.* (1983) found a negative phenotypic relationship between SCC and average daily milk yield. That experiment used milk samples of one milking per day for the whole lactation to measure SCC whereas the present study used am and pm composite milk samples and measured SCC for peak lactation only. Logically, a cow that had a mastitis infection and possibly udder damage will have persistently high somatic cells and a reduced milk yield.

The positive relationship between SCC and average daily yield found for the light cows in the present study, although it was small (accounted only for 7% of the mean SCC), suggests that high yielder cows of the light line would have better udder health.

The significant but small antagonistic relationship between SCC and flow rate measurements was also observed in other experiments (Yener, 1974; Rathore, 1976; Seykora and McDaniel, 1982). Evidence from the present study and others indicated that faster milking cows (i.e., higher average flow rate) had a slightly lower SCC in the milk. However, others reported a positive relationship between flow rate and SCC (Schuelp, 1967; Moore *et al.*, 1983; Grindal and Hilderton, 1991) or no relationship between measures of mastitis and milking speed traits (Politiek, 1968; Brown *et al.*, 1986).

The present results indicated that there is a positive relationship between MFR and log SCC, therefore, cows with higher maximum flow rates have a higher SCC, which agrees with other studies (Dodd and Neave, 1951; Slettbakk *et al.*, 1990) findings. In addition, the regression coefficient of SCC on 2 min yield, which is a measure of speed of milking similar to MFR, found by Moore *et al.* (1983) was 0.18 log cells/kg milk and compares favourably to those obtained in this study. However, results from other experiments that studied the same relationship were non significant (Slettbakk *et al.*, 1995) or inconsistent (Shultze, 1979; Miller *et al.*, 1978). The different sign in the regression coefficient of average and maximum flow rate on SCC could be explained as follows: cows that have similar AFR can have significantly

different maximum flow rates because of a higher numerical value for peak flow or a longer duration of the peak flow period. Therefore, when considering the shape of the milk flow curve of a cow that has a high peak flow rate (i.e., high rate of increase before reaching the peak and high rate of decrease thereafter) and that of a cow with a lower peak flow rate (flatter curve) it is apparent that both cows have similar AFR yet very different SCC. The cow with the higher MFR would have higher SCC according to the positive sign of the regression coefficient of the MFR on SCC. Consequently, the cow with the lower MFR would have a lower SCC. It would be logical to think that if milk flows at a faster rate through a wide streak canal, pathogen microorganisms can also penetrate the teat in the opposite direction (Seykora and McDaniel, 1982). On the other hand, cows with a low AFR are subjected to the action of the milking machine for a long time and therefore more susceptible to infections. The positive correlation between MFR and AFR is as expected and suggests that the two modes of action of MFR and AFR on mastitis may act independently of each other even though they are correlated with each other.

The lack of relationship between TMT and SCC found in both live weight lines in the present study compares favourably with the findings of Moore *et al.* (1983). No concrete conclusions could be made in a review by Shultze (1979) in view of the differing evidence for the relationship between various mastitis measures and milking characteristics. In this respect it is important to consider that there are anatomical and physiological limits for increases in flow rate and, as previously reported (Moore *et al.* 1983) the relationship between flow rate and SCC is not linear over the possible range of values.

Milk Production and Milk Composition, Live Weight and Body Condition Traits

Heavy cows, which were on average 43 kg heavier than light cows, produced more milk than the light cows throughout the lactation by 1.7 litres per day on average ($P<0.01$). By the 4^{th} and 5^{th} month of the lactation, the difference in milk volume between the lines increased to 2 and 2.4 litres a day. These milk yield differences coincide with significant differences in body condition score (month 4). From parturition to peak lactation, both lines lost condition but the heavy cows lost significantly more. However, differences in litres of milk produced between the two lines of live weight cows were not reported in two other experiments carried out over the whole lactation (Lopez-Villalobos *et al.*, 2001) and in early lactation (Laborde, 1998).

Milk fat yield was similar for both lines over the lactation. This occurred because milk from the light cows had a higher fat concentration. Others also reported higher concentration of fat in cows selected for being light (Laborde, 1998; Donker, 1983). Laborde (1998) found significantly higher milk fat yields in the heavy line than in the light lines in weeks 7 and 11 weeks of the lactation. Findings of Lopez-Villalobos *et al.* (2001) provided further evidence that genetic selection for live weight did not affect total fat yield in the two lines which had been selected for equal breeding worth.

Differences between lines for milk protein yield were small but significant which contradicts previously mentioned experiments in that no differences were found between lines in milk protein yield. The higher milk protein yield of the heavy line was the consequence of a higher milk yield, compared to the light cows, at a similar protein concentration. Furthermore, Ahlborn and Dempfle (1992) showed that the phenotypic correlation between body size and fat concentration was low and negative. They also found that body size and protein concentration were positively correlated. These findings are consistent with present results. In addition, higher yields of milk and protein by cows from the heavy line was expected from their breeding values (900 *vs.* 695 kg milk and 27 *vs.* 21 kg protein). No differences were detected for body condition score over the whole lactation. Therefore, the higher yields of milk of the heavy line were solely explained by their production potential (BV for milk yield) and live weight. Live weight differences were, again, expected from their breeding values (68 *vs.* 31 kg live weight).

The lack of differences between lines for milksolids yield agrees with results of other experiments that studied the effect of selection for body size on cow performance under grazing (Laborde, 1998) and feedlot conditions (Hansen *et al.*, 1999). Results from the present experiment agree in general with the low to moderate phenotypic correlation reported between milk yield and live weight (Ahlborn and Demple, 1992).

No differences between live weight lines were found for average somatic cell counts for the whole lactation nor in peak lactation (experiment 1b), suggesting that selection for live weight did not influence the risk of udder infection.

Parameters describing the lactation curve were not studied, however, the light cows seemed to have a faster rate of increase in yield before peak (Figure 2.5). Furthermore, peak yields and

rate of decline after peak were very similar for both lines, therefore, they had similar shapes of lactation. Monthly rate of decline after peak observed in this study (5.5%) are similar to 5.6% reported for 9 commercial high producing farms (about 417 kg milksolids per cow) of the Manawatu area in the same season (Ercolin, 2002). This value is also in agreement with that of the regional herd average of 6.3 % (Palmerston North District and Manawatu area; LIC, 2001).

Both lines lost live weight after calving (42 and 49 kg from calving to the 6th fortnight, heavy and light line respectively) and both regained it slowly. Although differences in live weight changes throughout the lactation were not analysed, heavy cows seem to regain live weight slightly faster than light cows. The same pattern for live weight was observed in Lemus-Ramirez (2000). Finally, the absolute values and pattern of changes in body condition score over the entire lactation was almost identical in both lines despite the difference in live weight. Again, that is comparable to what Lemus-Ramirez (2000) reported. In addition, neither of the live weight lines regained body condition despite regaining live weight.

Heavy cows were 43 kg heavier than light cows over the complete lactation. This figure is almost identical to that reported by Lemus-Ramirez (2000) of 42 kg. Significant live weight differences between lines were observed at every measurement except one in late lactation. In peak lactation, as is usually the case in spring calving pasture based dairy systems, cows lost weight and body condition. Milk production during this period was, therefore, supported by tissue mobilisation, as feed intake was probably not sufficient to meet the demands of lactation. The fact that the heavy cows lost more condition during peak lactation suggests that they mobilised reserves to a larger extent than the light cows when undergoing periods of feed shortage. However, it is important to consider that one unit of body condition in the heavy line may not necessarily represent the same quantity of different tissues. Additionally, the impact of this decrease in live weight and body condition, which occurred in the second month of the lactation, was seen in the 4th and 5th month of lactation, when heavy cows presented significantly higher yields of milk and milksolids.

5. CONCLUSION

It can be concluded that the differences between lines for milk yield per milking (2.6, 5.3 and 2.6% for experiment 1a, and period one and two of experiment 1b) were not large enough to

cause variations in average flow rate and maximum flow rate between the genetically heavy and the light lines of cows. The lack of differences in yields of milk fat, fat and protein between lines further explains those results. Absolute values for measurements of rate of flow and significant relationships between milk volume per milking and average flow rate and total milking time were similar to those measured in other studies. These results suggest that there are few effective differences between the heavy and the light genetic lines in their teat structures. Therefore, genetic selection for live weight did not affect the efficiency of milk removal. However, it may have had a significant effect on somatic cell counts. The light line had a significantly higher somatic cell count in peak lactation of season 2001/02 but not in the peak, nor for the whole lactation of the previous season. The difference between lines in the sign of the regression coefficient of SCC on daily milk yield probably explained this difference. Increases in milk yield in the light line tended to result in higher somatic cells while the opposite occurred for the light line.

Results show that although the heavy cows produced more milk (litres) than the light cows, milksolids production of the two lines during the whole lactation did not differ significantly. In addition, the pattern for changes in body condition score over the entire lactation was almost identical in both lines which indicates similar nutrient partitioning.

In summary, as was assumed from the similar breeding worths of the two live weight lines, there were no differences in the milking characteristics, milksolids production, absolute values and pattern of condition score body between the lines, however there were some differences in somatic cell counts, but these were not consistent. As expected, the live weight of the cows was significantly different between lines over the whole lactation.

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CHAPTER THREE

Intake, Live Weight and Feed Conversion Efficiency of Lactating Holstein-Friesian Dairy Cows of Genetically Heavy and Light Live Weight

ABSTRACT

The objective of this study was to measure during mid lactation the effect of live weight on the metabolisable energy intake by cows in two lines of Holstein-Friesians selected for heavy or light mature live weight. Yields of milksolids and intakes of dry matter were estimated during two 3-day faeces collection periods. Live weights were measured at the start and the end of the experimental period. Intakes of pasture dry matter by individual cows were estimated using the alkane technique. Least-square means for live weight, daily yield of milksolids, intakes of dry matter, metabolisable energy and feed conversion efficiency for the heavy and the light line were obtained. Linear regression coefficients of metabolisable energy intake on metabolic live weight and yield of milksolids were obtained. Mean values were 15.0 versus 15.3 kg of dry matter/cow daily, 532 and 488 kg live weight, 1.58 and 1.55 kg milksolids/cow daily, and 108 and 106 g milksolids/kg of dry matter eaten, for the heavy and the light line respectively. The partial regression coefficient of metabolisable energy intake on metabolic live weight was 0.65 MJME/kg $LW^{0.75}$ for both lines, similar to commonly reported values. However, even though the heavy line averaged 44 kg more than the light line there had no difference in feed conversion efficiency. These data showed that the differences in live weight did not seem to have greatly affected maintenance requirements for cows in the heavy and light live weight lines. Also, it disagreed with previous data because no differences in dry matter intake were detected between the heavy and light lines of cows.

Keywords: dairy cows; mature live weight; milksolids yield; selection lines; feed conversion efficiency.

1. INTRODUCTION

Feed conversion efficiency, which is defined as the quantity of milksolids produced per kg of dry matter intake, is influenced by the live weight of the cow through the amount of feed required for maintenance (Holmes *et al.*, 1993). Live weight (LW) may therefore have a direct effect on overall farm productivity. In addition, feed conversion efficiency is mainly affected by those factors that determine the yield of milksolids per cow per year and the cow live weight (Holmes *et al.*, 1993). These factors are the ability of the cow to calve each year, the feeding level, cow genetic merit, breed, age, and health status.

The effect of the live weight of the cow on the quantity of energy required for maintenance, may be relatively more important in grazing systems, because of the lower milk yields expected per cow. Furthermore, the question of whether to farm heavy or light cows is also related to the use of foreign genetics in New Zealand, which could change the type of cow to be farmed (Kolver *et al.*, 2000). The relationship between increased live weight due to the use of foreign genetics and a risk of a suboptimal overall performance of these cows in the pasture-based system has been discussed by Holmes (1995), Mayne (1998), and Harris and Kolver (2001).

Comparisons of feed intake and feed conversion efficiency of heavy and light live weight cows from two genetic lines of Holstein-Friesian cows showed that the heavy cows produced more milksolids than the light cows but were not more efficient (Laborde *et al.*, 1998). This was probably because the heavy cows required more energy for maintenance than the light cows (Garcia-Muniz *et al.*, 1998). However, when the effect of live weight on the performance of the high genetic merit cows was studied in cattle managed indoors and fed total mixed rations, results were different. Cows selected for contrasting sizes differed in feed efficiency which favoured the small line by 3%, measured over complete lactations (Yerex *et al.*, 1988).

The effects of phenotypic differences live weight on productive performance have been researched (Holmes *et al.*, 1993), however, experimental studies about the consequence of genetic selection for heavy or light live weight on the amount of energy required by grazing cows for maintenance and milksolids yield, and using a large number of animals is scarce. The objective of the present grazing experiment was to measure the difference in metabolisable energy intake by the cows in two lines of 73 lactating Holstein-Friesian dairy cows selected for light or heavy mature live weight.

2. MATERIALS AND METHODS

2.1 Animals and Management

The experiment was carried out between 30th November to 9th December 1999. A herd of 73 Holstein-Friesian dairy cows, 35 from the heavy and 38 from the light, line was used. Ten cows were primiparous (five from each line) and 73 were multiparous (34 were from the heavy line and 39 from the light line. The formation of the two genetic lines of heavy and

light live weight cows has been described by Garcia-Muniz *et al.* (1998). Averages of breeding worth, breeding values for live weight, yields of protein, fat and milk, and for survival for the heavy and the light line are presented in Table 3.1. The heavy cows had higher breeding values for live weight as well as for yields of milk, fat and protein, but Breeding Worth was very similar in both lines.

Table 3.1 Mean values for breeding worth (BW) and breeding values (BV) for live weight, yields of protein, fat and milk, and survival for the heavy and the light lines of cows used in *experiment 3* (n=70).

Genetic Line	BW ($)	Live weight BV (kg)	Protein BV (kg)	Fat BV (kg)	Milk BV (kg)	Survival BV (%)
Heavy (n=34)	40	66	26	30	881	0.6
Light (n=36)	37	30	18	23	624	0.9

Note: Data for 1 heavy cow and 2 light cows were not available.

Mean calving date was 15 August. Cows were dried off on the basis of a combination of the following factors: body condition and pasture supply as detailed in the previous chapter. All cows were rotationally grazed as one herd on the 35-ha farm (2.3 cows/ha) and offered a generous daily pasture allowance of approximately 65 kg DM/cow as assessed by a Rising Plate Meter (Ashgrove Pastoral Products, Palmerston North, New Zealand; Stockdale, 1984). Pasture comprised mainly perennial ryegrass (more than 70%) and white clover. Management tried to maintain average whole-farm herbage mass at 2000 kg DM/ha, with post-grazing residual herbage mass at no less than 1600 kg DM/ha and pre-grazing herbage mass at around 2500 kg DM/ha during the duration of the lactation. Apparent average pasture dry matter intake per cow in the herd was estimated from the difference between the pre- and post-grazing herbage masses.

2.2 Measurements

Dry matter intake of pasture for individual cows was estimated using the n-alkanes technique (Mayes *et al.*, 1986). A slow-release alkane capsule (Captec Ltd, New Zealand) was inserted in every cow's rumen. The alkane controlled-release capsules used was designed for cattle of between 300 and 650 kg liveweight. Each capsule released C_{32} and C_{36} within the rumen at approximately 400 mg/day for a period of 20±3 days. Faecal samples were collected after a 7-day equilibration period, which was required to establish a steady state of alkane in the gut. Hand-plucked samples of grass were taken at grazing height to simulate the pasture grazed by the cows (Cosgrove *et al.*, 1998). Faecal samples from individual cows and grass samples

were collected during two periods (period 1 from 30th of November to the 2nd of December and period 2 from the 7th to the 9th of December of 1999) and frozen. These samples were then thawed, freeze-dried and ground in a mill (1mm screen). Samples were analysed to determine alkane concentrations by gas chromatography. Grass samples were also analysed for organic matter, *in vitro* digestibility of dry matter and organic matter and nitrogen. Feed intake of herbage dry matter was estimated from the concentrations of C_{33} (natural odd chain alkane) and C_{32} (dosed even chain alkane) using the analytical procedure described by Dove and Mayes (1991; see equation 3 in page 49).

Milk yield was measured once in each faecal collection period, using in-line milk meters (Metatron, Westfalia Landtechnik N.Z. Ltd.). Milk composition was assessed by Livestock Improvement Corporation. Fat, protein and lactose concentrations in milk were analysed from aliquot milk samples taken at the morning and afternoon milkings, using a Milkoscan 104 infrared analyser (A/S N. Foss Electric, Denmark). Live weight was measured once in each period using platform scales (Tru Test, Ag 500).

2.3 Statistical Analysis

Least-square means for live weight (see (1)), daily yield of milksolids, daily dry matter intake, daily metabolisable energy intake and feed conversion efficiency for the heavy and the light live weight lines were obtained using a mixed linear model. The model included the fixed effects of live weight selection line and the random effects of period, interaction between live weight selection line and period, and the residual error. Lactation number (parity) and days in milk were included in the model as covariates. In addition, efficiencies of metabolisable energy intake utilised for maintenance and milk production for each line were obtained by analysing the metabolisable energy intake for each cow with the same mixed linear model considering metabolic live weight and milksolids yield as covariates (see (2)). Analyses were carried out using PROC MIXED (SAS, 2000). In addition, the regression coefficients of LW on FCE were calculated for each line including the effect of the period.

```
(1) LW = line period period*line lac dim
(2) MEI = line period line*met_lw line*msy lac dim
```

3. RESULTS

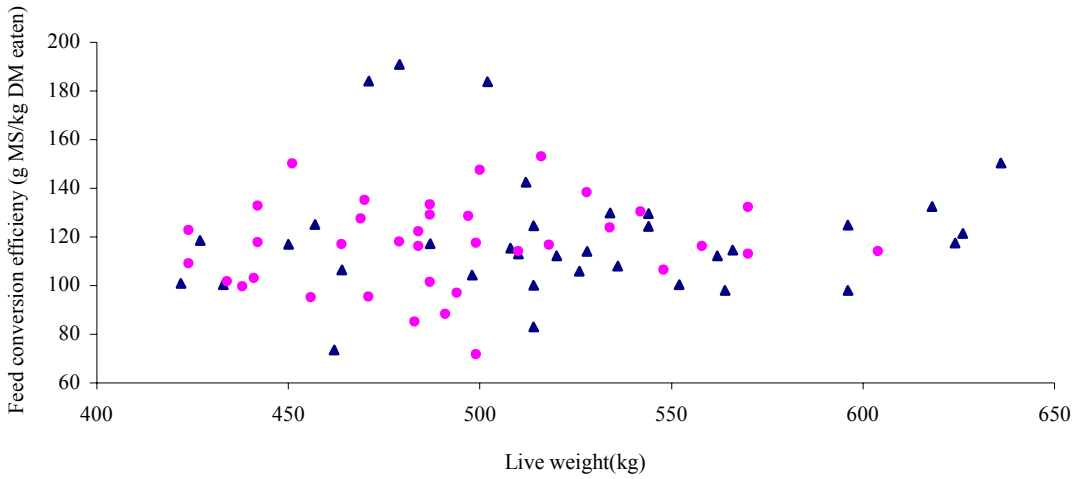
Least-square means for live weight, dry matter intake, metabolisable energy intake, milksolids yield and feed conversion efficiency for the heavy and the light lines are presented in Table 3.2. Cows from the heavy line were indeed heavier than cows from the light line (P<0.001). Differences in milksolids yield, dry matter intake, metabolisable energy intake, and feed conversion efficiency between lines were not significant. However, feed conversion efficiency of the heavy line was slightly higher than that of the light line (108 and 106 g milksolids/kg DM respectively. There was no association between feed conversion efficiency and live weight (Figure 3.1) but the light line tended to be more efficient. The regression coefficients of feed conversion efficiency on live weight were 0.055 and 0.063 g MS/kg DM for the heavy and the light line respectively. In other words, an increase in one kg live weight was associated with an increase of 0.05 (heavy line) and 0.06 g MS/kg DM (light line).

Table 3.2 *Experiment three*: Least square mean estimates (±SEM) for live weight, dry matter intake, metabolisable energy intake, milksolids yield and feed conversion efficiency for genetically heavy and light Holstein-Friesian cows in peak lactation (n=73)

	Genetic lines		
	Heavy (n=35)	**Light** (n=38)	SD
Live weight (kg)	532±7.2	488±6.9	***
Dry matter intake (kg DM/cow/day)	15.0±0.4	15.3±0.4	ns
Metabolisable energy intake (MJ ME/cow/day)	158±4.3	161±4. 2	ns
Milksolids yield (kg/cow/day)	1.58±0.04	1.55±0.04	ns
Feed conversion efficiency (g MS/kg DM intake)	108±3.2	106±3.1	ns

SD = significance of the difference; *** P<0.001

Figure 3.1 Experiment three: Relationship between feed conversion efficieny and live weight for heavy and light cows for period one (n=73)



The regression coefficient of feed conversion efficiency on live weight were 0.055±0.046 and 0.063±0.057 for the heavy and the light line respectively.

▲ Heavy line ● Light line

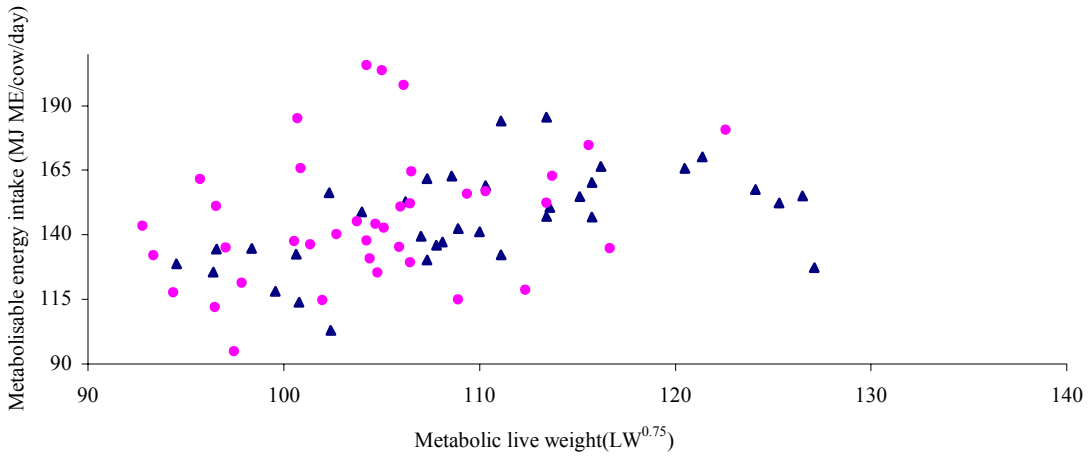
The relationships between the quantity of metabolisable energy eaten, metabolic live weight and milksolids yield (regression coefficient ± standard error) are shown in the following regression equations:

1) Metabolisable energy intake for the heavy line (MJ ME/cow/day) = 60.9 (±60.1) + 0.65 (±0.6) $LW^{0.75}$ + 14.1 (±14.7) milksolids yield + 0.12 days in milk – 0.16 parity.

2) Metabolisable energy intake for the light line (MJ ME/cow/day) = 44.8 (±60.1) + 0.65 (±0.8) $LW^{0.75}$ + 29.7 (±25.3) milksolids yield + 0.12 days in milk – 0.16 parity.
$LW^{0.75}$ = metabolic live weight

Linear regression coefficients of metabolisable energy intake on metabolic live weight were not significant for any of the lines but an increase in one kg of metabolic live weight was associated with an increase in intake of 0.65 MJ ME for both lines (Figure 3.2).

Figure 3.2 Experiment three: Relationship between metabolisable energy intake and metabolic live weight for heavy and light cows for period one (n=73)

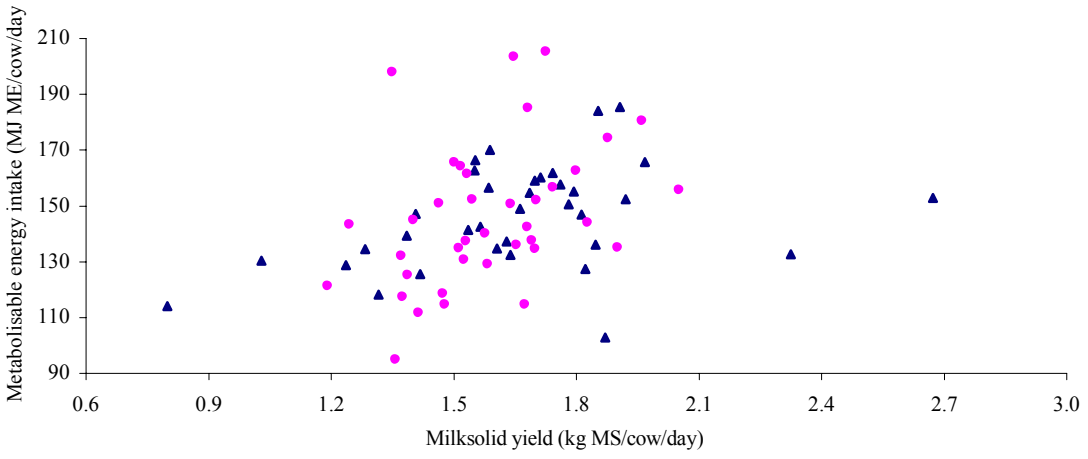


The regression coefficients of metabolisable energy intake on metabolic live weight were 0.651±0.580 (ns) and 0.654±0.807 (ns) for the heavy and the light line respectively

▲ Heavy line ● Light line

Regression coefficients of metabolisable energy intake on milksolids yield were 14.1 and 29.7 MJ ME/kg milksolids for the heavy and the light line respectively but neither was significant (Figure 3.3). Neither parity nor days in milk had an effect on metabolisable energy intake.

Figure 3.3 Experiment three: Relationship between metabolisable energy intake and milksolid yields for heavy and light cows for period one (n=73)



The regression coefficients of metabolisable energy intake on milksolid yield were 14.166±14.67 (ns) and 29.784±25.28 (ns) for the heavy and the light line respectively

▲ Heavy line ● Light line

4. DISCUSSION

The difference in average live weight between the two lines in the current experiment was smaller than that reported by Laborde *et al.* (1998; see Table 3.4) for the mature cows of the same two lines and may not have been large enough to show the commonly reported effects on dry matter intake (Holmes *et al.*, 1993). Thus, both lines had similar values for dry matter intake and for feed conversion efficiencies. The later indicates the validity of the calculations of breeding worth of these cows.

The differences in milksolids yield between the two lines were not significant. These results are in agreement with a similar experiment reported by Hansen (2000). In addition, yield of milksolids measured in early lactation in heavy and light live weight cows in the same programme were not significantly different either (Laborde, 1998)

The present values for the regression coefficient of metabolisable energy intake on metabolic LW were 0.65 MJ ME/kg $LW^{0.75}$ for both the heavy and the light line. Even though the live weight coefficients were statistically non significant, they are in accordance with corresponding estimates for maintenance requirements from calorimetric experiments calculated from indoor conditions (0.6-1.0 MJ ME/kg $LW^{0.75}$; Holmes *et al.*, 1993) and from other outdoor and indoor experiments (0.7-1.1 MJ ME/kg $LW^{0.75}$; Hutton, 1962; Curran and Holmes, 1970).

The theoretical values (Holmes *et al.*, 1987) of total metabolisable energy required by the heavy and the light cows for maintenance and production using the present values for live weight and milksolids yield were calculated at 169 and 163 MJ ME/day respectively (Table 3.3). These values are similar to the values calculated using equations 1 and 2 in this study (158 and 161 MJ ME/day, for both the heavy and the light live weight line, respectively).

Table 3.3 Total metabolisable energy requirements calculated from theoretical recommendations and obtained from the present experiment for genetically heavy and light Holstein-Friesian cows in peak lactation (n=73)

	Genetic lines	
ME requirements (MJ/cow/day)	**Heavy** (n=35)	**Light** (n=38)
ME requirement for maintenance		
MEm= 0.6 x kg $LW^{0.75}$	66.4	62.3
ME requirement for production		
MEp = 65 x kg MS	102.7	100.8
Total calculated ME requirements (MEm + MEp)	169	163
Total ME requirements derived from the present exp	158	161

It should be noted that, in theory, the regression coefficients of metabolisable energy intake on yield of milksolids should be around 70 MJ ME/kg milksolids (Holmes *et al.*, 1987). The lower values obtained in the present experiment may be explained by the facts that the other covariates in the equations 1 and 2 accounted for much of the relatively small variation in metabolisable energy intake between the cows, and that the variation between milksolids yield between cows was relatively small.

The metabolisable energy required for maintenance obtained in this experiment for each line of cows (0.65 MJ ME/kg $LW^{0.75}$) is similar to the theoretical expectations for maintenance costs. However, the present values for total metabolisable energy intake do not agree with previous work in this programme, which showed larger intakes by cows in the heavy live weight line (Laborde *et al.*, 1998; Caicedo-Caldas *et al.*, 2001; Table 3.4).

Table 3.4 Results from some grazing experiments showing the performance of the heavy and light lines of Holstein-Friesian cows developed at Massey University.

	LW (kg)		DMI (kg/cow/day)		Milksolids (kg)		FCE (g MS/ kg DMI)	
Reference	H	L	H	L	H	L	H	L
Laborde *et al.*, 1998 (exp 1)								
Laborde *et al.*, 1998 (exp 2)	492	414	12.2	10.8	1.70	1.54	144	143
Garcia-Muniz *et al.*, 1998* [1]	516	470	19.8	18.2	1.65	1.58	84	87
Lemus-Ramirez, 2000 [1]	489	447	12.8	12.1	1.52	1.51	64	67
Lopez-Villalobos *et al.*, 2001	495	436	not measured		2.2	2.1	not measured	
Caicedo-Caldas *et al.*, 2001	540	464	13.1	11.6	not measured (non lactating cows)			
Present experiment	532	488	15.0	15.3	1.58	1.55	108	106

* Assuming 220 days lactation length;
[1] DMI was calculated based on ARC estimators (ARC, 1980)

The lack of differences in intake and efficiency of feed conversion between lines could be due to the failure of the method of intake estimation to detect differences that might arise from a difference of less than 10 % in live weight between lines. In addition, live weight and even milksolids yield measurement techniques have substantial errors associated with them. Therefore, it could be argued that the present experiment would not have detected a small difference in intake even if there were a difference.

5. CONCLUSION

It is concluded that the breeding worth, which is a measure of net income per 4.5 tonnes of dry matter eaten, is a successful tool to identify dairy cows that are superior in their feed conversion efficiency, despite differing in other traits that are known to influence feed efficiency. The results of the present experiment showed that genetic selection for live weight in cows with similar Breeding Worth had no effect on feed conversion efficiency, in agreement with two other studies with the same two live weight lines. Therefore, if an economic analysis were made on these two contrasting live weight lines, the conversion of feed into profit would result in similar figures, as predicted by their similar values for Breeding Worth.

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APPENDIX

Table A.1 Least square mean estimates for milking characteristics (calculated as the average of the morning and afternoon milkings) for genetically heavy and light Holstein-Friesian cows for period two (PII) of *experiment 1b* (n=81)

	Genetic lines		
Experiment 1b (PII)	**Heavy**	**Light**	SD
MV (litres)	12.86	12.53	ns
MFR (litres/min)	3.11	3.18	ns
AFR (litres/min)	1.94	1.95	ns
TMT (min)	7.30	7.17	ns

SD = significance of the difference; ns = not significant

Table A.2 Morning and afternoon least square mean estimates for milking characteristics for pooled data for genetically heavy and light Holstein-Friesian cows for *experiment 1a* (n=78) and both periods (PI & PII) of *experiment 1b* (n=81)

Experiment 1a	**am**	**pm**	SD
MV (litres)	14.89	10.56	***
AFR (litres/min)	1.97	2.04	ns
TMT (min)	7.53	7.25	**
Experiment 1b (PI)			
MV (litres)	16.27	11.88	***
MFR (litres/min)	3.17	3.29	*
AFR (litres/min)	1.96	1.99	ns
TMT (min)	7.85	7.59	ns
Experiment 1b (PII)			
MV (litres)	14.83	10.56	***
MFR (litres/min)	3.04	3.24	**
AFR (litres/min)	1.94	1.95	ns
TMT (min)	7.47	7.00	***

SD = significance of the difference; ns = not significant, * = $p<0.05$, ** = $p<0.01$, *** p= <0.001

Table A.3 Morning and afternoon least squares mean estimates for milking characteristics for genetically heavy and light Holstein-Friesian cows for period two (PII) of *experiment 1b* (n=81)

	am		**pm**	
Experiment 1b (PII)	Heavy	Light	Heavy	Light
MV (litres)	15.06	14.60 (ns)	10.47	10.66 (ns)
MFR (litres/min)	2.96	3.12 (ns)	3.23	3.25 (ns)
AFR (litres/min)	1.92	1.96 (ns)	1.94	1.96 (ns)
TMT (min)	7.53	7.41 (ns)	6.92	7.07 (ns)

Note: significance of the difference between lines within am or pm milkings is indicated in parenthesis, ns = not significant

Table A.4 Least squares mean estimates for milking characteristics (data pooled for both lines and (calculated as the average of the morning and afternoon milkings) for primiparous and multiparous Holstein-Friesian cows for period two (PII) of *experiment 1b* (n=81)

Experiment 1b (PII)	**Primiparous**	**Multiparous**	SD
MV (litres)	12.52	12.87	ns
MFR (litres/min)	2.99	3.30	ns
AFR (litres/min)	1.94	1.95	ns
TMT (min)	7.25	7.22	ns

SD = significance of the difference; ns = not significant

Table A.5 Regression coefficients of milking characteristics on milk yield per milking for genetically heavy and light Holstein-Friesian cows for *experiment 1a* (n=78) and both periods (PI & PII) of *experiment 1b* (n=81)

Experiment 1a	MFR (litres/min)	AFR (litres/min)	TMT (min)
Heavy	-	0.085 (***)	0.239 (***)
Light	-	0.076 (***)	0.274 (***)
Experiment 1b (PI)			
Heavy	0.075 (***)	0.066 (***)	0.132 (***)
Light	0.043 (***)	0.030 (***)	0.216 (**)
Experiment 1b (PII)			
Heavy	0.088 (***)	0.058 (***)	0.262 (***)
Light	0.054 (***)	0.041 (***)	0.304 (***)

Note: significance of the difference between lines within parity is indicated in parenthesis; ns = not significant, * = $p<0.05$, ** = $p<0.01$

Table A.6 Least square mean estimates for log somatic cell counts ($logSCC_1$ and $logSCC_2$) for primiparous and multiparous cows for both lines and both periods of *experiment 1b* (n=81)

	Primiparous		**Multiparous**	
Experiment 1b	Heavy	Light	Heavy	Light
$logSCC_1$ (10^3/ml)	10.39	12.06 (***)	11.15	10.80 (***)
$logSCC_2$ (10^3/ml)	10.11	11.21 (***)	10.41	10.47 (ns)

Note: significance of the difference between lines within parity is indicated in parentheses;
ns = not significant, *** = $p<0.001$
10.11 log SCC = ~24,600 ; 11.15 log SCC = ~69,600 SCC; 12.06 log SCC = ~173,000 somatic cells/ml