An evaluation of traits other than production and its association with the survival of dairy cows milked once a day in New Zealand

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Juan Felipe Martinez Rocha

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Abstract

New Zealand dairy cows have traditionally been milked twice a day (TAD). However, an increasing number of dairy farms have shifted to once a day (OAD) milking in the last few years for several reasons. A particular emphasis has been placed on the cow's conformation and its management during the milking routine in OAD dairy farms, as these factors might have altered the culling decisions of herds after shifting from TAD to OAD milking. This thesis evaluates production traits and traits other than production (TOP) in the herd of Massey University Dairy 1 since the start of OAD milking and for three consecutive seasons (2013-2015), with an assessment of the influence that these traits have on the cow's survival. Results showed a significant effect of breed, season and lactation on TOP. The scores for most udder traits showed a gradual decrease over lactations. The main reasons for culling were low fertility (37.2%), poor udder conformation (19.9%) and low production (12.8%). Hazard ratios from a Cox proportional hazard model showed that Holstein-Friesian and crossbred cows had a higher likelihood of culling than Jerseys, which also had the highest scores for most udder traits. For some TOP, such as adaptability to milking, rump angle and udder support, higher scores were associated with a lower likelihood of culling. However, intermediate scores were optimum for traits such as body capacity and leg conformation. The results of this thesis are the first to show culling reasons and risk factors for survival in cows recently shifted from TAD to OAD. The analyses of TOP over seasons and over lactations are also unique to this thesis as most studies on this topic only include TOP on first lactation cows. The findings of this thesis indicate that TOP would have a higher priority to make culling decisions in OAD herds during the transition from TAD to OAD milking, compared to TAD herds and also established OAD herds that have used this milking frequency for several seasons. Furthermore, besides body capacity and udder support, traits such as adaptability to milking, rump angle and leg conformation could also potentially be included in a new selection index for OAD dairy cattle.

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> “. . . *Hence, if man goes on selecting, and thus augmenting, any peculiarity, he will almost certainly modify unintentionally other parts of the structure, owing to the mysterious laws of correlation*”
>
> *Charles Darwin*

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List of Abbreviations

BW	Breeding worth
BCS	Body condition score
DM	Dry matter
EBV	Estimated breeding value
EV	Economic value
FY	Fat yield
F	Holstein-Friesian
FxJ	Holstein-Friesian and Jersey crossbred
J	Jersey
LIC	Livestock Improvement Corporation
LWT	Liveweight
MSY	Milk solids yield
MY	Milk yield
NI	Net income
OAD	Once a day
PV	Production value
PW	Production worth
PY	Protein yield
SCC	Somatic cell count
SCS	Somatic cell score
SMFS	Interval from start of mating to first service
SR21	Submission rate at 21 days after the start of breeding
SR42	Submission rate at 42 days after the start of breeding
TAD	Twice a day
TOP	Traits other than production

Chapter 1

General introduction

New Zealand has a seasonal dairy system in which grazed pasture is the main component of the cow's diet and the quantities of supplements (hay, silage, concentrate) are lower compared with the milking systems of other developed countries. Moreover, two major breeds, Holstein-Friesian (F) and Jersey (J), coexist in a large number of herds as purebred and crossbreed groups of animals (Harris & Montgomerie 2007). The genetic merit of dairy cows in New Zealand is measured using an across-breed animal genetic evaluation. The breeding and production values obtained from this evaluation are used to generate two indices that allow the comparison of individual animals in terms of net income per unit of feed consumed (Harris et al. 1996). The breeding worth (BW) index is generally used to select replacements, while the production worth (PW) index is used for making culling decisions (LIC 2009).

Most dairy farms in New Zealand operate with a traditional twice-a-day (TAD) milking system. However, there has been a considerable increase in the adoption of the once a day (OAD) milking system over the last few years, with approximately 5% of dairy farms milking cows OAD during the whole season, and 17% of dairy farms using OAD as a tactical option (Stachowicz et al. 2014; DairyNZ 2016a). Full season OAD milking represents a viable and practical alternative management strategy, particularly in dairy systems where less emphasis is placed on milk production per cow (Stelwagen et al. 2013).

The full season OAD system offers animal, farm-system and labour benefits (Stelwagen et al. 2013) and it can reduce shed expenses, increase labour productivity, improve the utilisation of the milking plant, and create opportunities for alternative employment (Tong et al. 2002). On the other hand, a reduced milking frequency has resulted in lower milk yields per cow in experimental trials (Tong et al. 2002; Clark et al. 2006), although a smaller difference in milk yields between OAD and TAD has been reported when the analyses include a large number of commercial herds (Lembeye et al. 2016a). Problems related to udder conformation and milking management have also been reported in cows milked OAD, which could have important consequences for the culling decisions of these herds (Holmes 2012; McCarthy 2012). In this way, a subjective ideal udder conformation for cows milked OAD was described by Holmes (2012). However, there are no literature or research reports that indicate what are the ideal management and conformation traits for cows milked OAD, or how much these traits influence their survival in the herd.

Traits other than production (TOP) influence the survival of dairy cows (Larroque & Ducrocq 2001; Caraviello et al. 2004; Berry et al. 2005), and the improvement of TOP can increase the efficiency of dairy herds not by higher output of products but by reduced costs of input (Groen 2001). The longevity of cows affects the net income of dairy herds since cows with longer productive lives are expected to be more profitable (Pritchard et al. 2013). Longevity of dairy cattle is a complex trait determined by culling (Heise et al. 2016). However, little data on culling is available from New Zealand and the more recent related reports and studies do not provide a detailed description of culling decisions made for TOP (Xu & Burton 2000; Xu & Burton 2003; Compton et al. 2016a; DairyNZ 2016a). In both registered and commercial herds milked TAD in New Zealand, Berry et al. (2005) found that udder-related TOP exhibited the largest influence on functional longevity. Udder-related problems were reported as a cause of culling in OAD dairy farms, but no differentiation between culling for conformation and culling for other udder-related problems (e.g. mastitis, somatic cell score) was made (DairyNZ 2016a). Furthermore, TOP and its association with survival have not been studied in cows milked OAD.

The objective of the present study was to evaluate production traits and TOP between breeds, over lactations and over seasons, and to estimate the influence of these factors on the survival of cows milked OAD. In Chapter 2, the main aspects of OAD milking, assessment of traits other than production and longevity of dairy cows are reviewed. An evaluation of TOP over lactations and production seasons, with the differences between retained and culled cows milked OAD is presented in Chapter 3. In Chapter 4, the culling reasons and the factors that influence the survival of dairy cows milked OAD are examined. Finally, the main results of this research are discussed together in Chapter 5.

Chapter 2

Literature review

2.1 Introduction

In New Zealand, dairy cows have traditionally been milked twice a day (TAD) in a pasture-based system. However, there can be high labour inputs and lifestyle issues associated with the twice daily routine of paddock mustering the herd and harvesting the milk (Borges & Woodford 2005). In the last decade, some farmers have changed from the traditional TAD to the once a day (OAD) milking system (Verwoerd & Tipples 2007). Some of the reasons for OAD milking include the herd expansion and to avoid the effects of predicted feed shortfalls in particular months of the year. However, the main reason to change to full season OAD milking is the extra time, which allows farmers to build capital, increase labour flexibility and overall improve their quality of life (Bewsell et al. 2008). Hence the OAD system is seen as a strategic (long-term) option for full lactations, or as a tactical (short-term) response to adverse seasonal conditions (low pasture availability and high supplementary feed prices) within a lactation (Armstrong & Ho 2009; Stachowicz et al. 2014).

A recent analysis of the national dairy database (Holmes 2016) showed that from 8721 farms that were herd tested in the 2014-2015 season, 38% were full season TAD herds, 5% were full season OAD herds, and 57% of herds had a mixture of milking frequencies throughout the season (Table 2.1).

Table 2.1. Milking frequencies of cows with more than three herd tests during the 2014-2015 production season in New Zealand (Holmes 2016)

Milking frequency[1]	Number of herds	Proportion
Cows milked TAD at all tests	2452	38%
Cows milked OAD at all tests	267	5%
Combinations of TAD, OAD and other frequencies	3498	57%

[1]OAD = once a day; TAD = twice a day

The rate of adoption of OAD milking has steadily increased over the last 3 years, with 44% of OAD herds reporting the use of this system for five or more years (DairyNZ 2016a). Figure 2.1 shows the geographical distribution of farms under full OAD milking across New Zealand for the 2014-2015 production season.

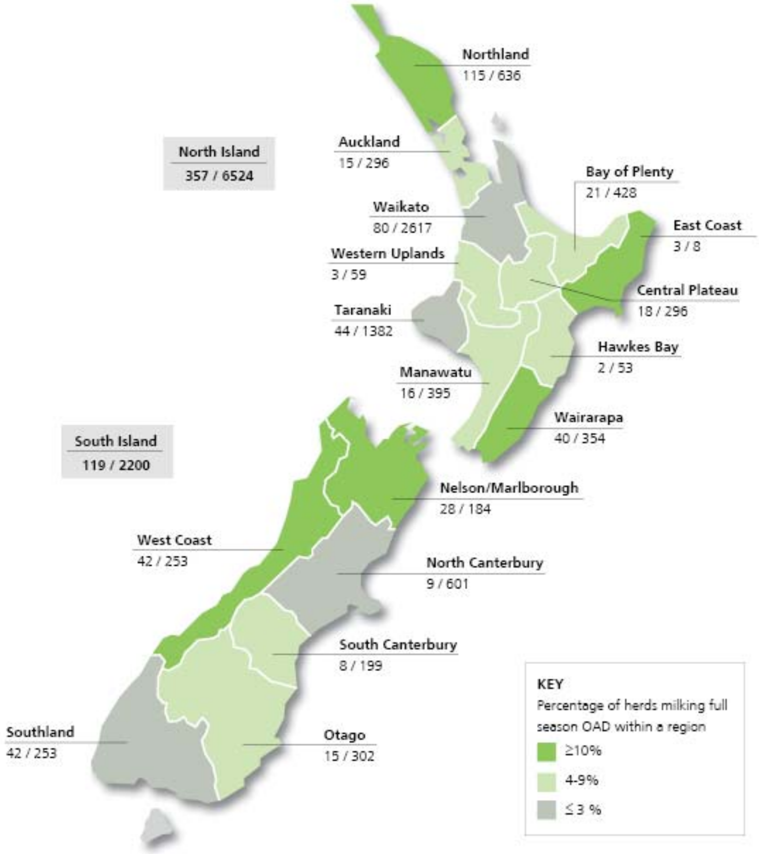


Figure 2.1. Regional distribution of OAD herds in New Zealand for the season 2014-2015 (DairyNZ 2016b)

The herd profile of dairy farms in New Zealand reveals a greater proportion of Jerseys (J) and crossbred (FxJ) cows in OAD herds than in TAD herds. A higher proportion of Holstein-Friesians (F) is observed in TAD farms compared with OAD farms (Table 2.2). OAD herds also have a lower average age, a greater proportion of 2 and 3 year olds and less cows aged over 6 years (DairyNZ 2016a). Particular advantages and disadvantages of the OAD milking system on the production efficiency of cows and herd health indicators are discussed below.

Table 2.2. Comparison of breed composition and age structure between herds milked OAD and TAD in New Zealand (DairyNZ 2016a)

		OAD[1] (%)	TAD[2] (%)	P-value
Breed	Jersey	33	20	<0.01
	Holstein-Friesian	23	44	<0.0001
	Crossbred	38	30	<0.05
	Other	6	6	0.96
Age	Average age	4.7	4.8	0.05
	Milking herd aged 2-3 (%)	40	38	0.04
	Milking herd aged 4-5 (%)	26	26	0.82
	Milking herd aged 6+ (%)	33	36	0.04
	R2 heifers (%)[3]	27	26	0.62

[1]OAD = once a day
[2]TAD = twice a day
[3]Rising two year heifers

2.2 Advantages and disadvantages of the OAD system

Milking OAD has had positive effects on the herd reproductive performance. Clark et al. (2006) found a greater 3-week submission rate (+7.3%; $P < 0.01$) and a greater 3-week pregnancy rate (+7.8%; $P = 0.055$) in cows milked OAD compared with cows milked TAD. There are potential benefits for herds using artificial breeding, as OAD reduces the amount of hormonal treatment in heat synchronisation programmes to get cows pregnant, with a reduction of 11% in the number of CIDR inserts applied in OAD cows compared with TAD cows (Clark et al. 2006). The same study also showed that cows milked OAD had an earlier conception (3 days earlier) and a shorter period from calving to conception (5 days less) than cows milked TAD. These reproductive parameters are of critical importance in spring calving schemes such as those used in New Zealand dairies (Clark et al. 2006). The spontaneous resumption of estrous cycling following calving (Stelwagen et al. 2013) and the body condition score (BCS) after calving (Clark et al. 2006) are parameters also improved under OAD conditions. For OAD herds compared to TAD herds, the mean number of days from calving to conception has been found to be 10 days shorter (Tong et al. 2002), the number of inseminations per cow has been reported to be 0.1 less, the length of artificial insemination mating has been found to be slightly shorter, and in terms of calving spread, the 3-week and 6-week calving rates are higher (DairyNZ 2016a). Additionally, another advantage of the OAD system is a better status for some herd health parameters. There is a reduced incidence of sole lesions and white line disease in the hoof of cows milked once daily, which could mean a lower risk of lameness in the herd (O'Driscoll et al. 2010).

On the other hand, these benefits are counteracted by significant drawbacks. The most evident disadvantage when cows are milked OAD is the reduction of milk yield per cow. Milking frequency modulates milk synthesis and secretion in dairy cows (Davis et al. 2015), and it has been shown that cows milked OAD produce less milk than those milked TAD (Hickson et al. 2006; Gleeson et al. 2007; Stelwagen et al. 2013). The initial effect of OAD is an acute decline in milk yield until yield stabilises at a new lower level, after which there is a chronic effect on lactational persistency that is associated with an increased rate of loss of secretory tissue and a reduced total udder body capacity after 10 weeks of implementation (Davis et al. 2015). This mechanism is the possible reason for the negative production response to OAD, not only for milk yield, but also for the total amount of fat, protein and lactose produced per cow, which are also lower in OAD dairy herds (Clark et al. 2006; Hickson et al. 2006). Holstein-Friesian primiparous cows are the most affected group of the herd (Table 2.3) when milked OAD. The study of Lembeye et al. (2016a) showed that New Zealand dairy cows milked OAD produced 722, 28 and 22 kg less milk, fat and protein, respectively, than cows milked TAD. However, this reduction was not constant across lactation numbers. The largest difference was observed in first lactation cows, which produced 21-25% less milk, fat and protein than TAD cows. This difference was smaller in mature cows (16-21%), which indicates there is an interaction between parity and milking frequency.

Table 2.3. Predicted productive performance for Holstein-Friesian (F) and Jersey (J) cows milked once a day (OAD) or (TAD) for 4 years (Clark et al. 2006).

	Breed-daily milking frequency					P-value		
	F-OAD	F-TAD	J-OAD	J-TAD	SED[2]	Breed	Frequency	Interaction
Milk yield, kg	2914	4234	2211	2839	195.4	<0.001	<0.001	0.02
Fat yield, kg	130.8	186.7	128.9	161.8	7.51	0.029	<0.001	0.035
Milk fat, %	4.48	4.42	5.83	5.67	0.099	<0.001	0.097	0.45
Protein, kg	106.2	149.1	93.5	115.8	6.29	<0.001	<0.001	0.028
Milk protein, %	3.64	3.52	4.22	4.06	0.048	<0.001	<0.001	0.54
Log_{10} SCC[1]	2.21	1.87	2.19	1.92	0.059	0.82	<0.001	0.46

[1]Logarithm base 10 for somatic cell count
[2]SED = Standard error of the difference between treatment means

With regard to the health status, cows that are milked OAD have been found with higher heel erosion scores than cows under TAD (O'Driscoll et al. 2010). The effects of OAD on the udder health, udder conformation and the animal's comfort are discussed below.

2.3 The effect of OAD on the udder

There is greater udder distension in OAD cows because of the large volume of milk that has accumulated from the previous milking time. Furthermore, there is evidence of milk leakages prior to the morning milking and higher udder firmness scores in cows milked OAD during the first third of lactation and close to peak production (Gleeson et al. 2007). These body capacity-related udder traits could also explain the lower milking persistency and the subsequent shorter lactation lengths of cows milked once daily (Hickson et al. 2006). In addition to this, there are specific udder health indicators that are negatively affected by the milking frequency.

Higher somatic cell counts (SCC) have been consistently reported in herds milking OAD (Lacy-Hulbert et al. 2005; Clark et al. 2006). New Zealand dairy cows milked OAD had higher SCS than cows milked TAD (6.20 vs 6.08), with the greatest difference between milking frequencies found in first lactation cows (6.40 vs 6.02) (Lembeye et al. 2016a). A decrease of this difference in successive lactations indicates a significant interaction between milking frequency and parity. In some cases the average individual SCC in cows milked OAD increased significantly, with no important changes in the incidence of infection at mid-lactation and drying off (Tong et al. 2002). On the other hand, although other studies such as Lacy-Hulbert et al. (2005) also showed that the higher SCC in OAD cows did not seem to be related to a higher incidence of mastitis, there was an elevated risk of developing new intra-mammary infections by major mastitis pathogens in cows at drying off in OAD.

In light of the above, the physical attributes of cows have become important for OAD dairy farmers for several reasons. Apart from the increased SCC and higher incidence of mastitis, discussion groups in Ireland (McCarthy 2012) and New Zealand (Holmes 2012) have expressed concerns about the discomfort that OAD cows could experience due to udder distension, especially in early lactation, with udders of cows becoming deformed by the weight of the milk. A particular udder conformation score has been described to identify cows that are better suited to OAD. According to Holmes (2012) "udders must be strongly attached to the body, with evenly-sized quarters, and well-placed teats that can be milked easily even when the udder is full".

Traits other than production have been studied in dairy cattle milked TAD in different countries. A review of these traits and its correlation with the productive performance and the survival of cows in the herd is presented below.

2.4 Evaluation of traits other than production in dairy cattle

Traits other than production (TOP) in dairy cattle include management and conformation traits, which contribute to the overall value of any animal, cow or bull (Ahlborn 1988) and have been mainly studied in cattle milked TAD. In some cases, management and conformation TOP have been named workability and type traits, respectively. In the present study, however, only TOP will be used to represent the group of management and conformation traits as a whole. The word "type" will be only used to describe the method of evaluation for TOP, which is explained in this same section.

Traits other than production are generally assessed on a linear scale that describes biological extremes for a range of visual characteristics of an animal (Berry et al. 2004) and are the foundation of all methods for describing the dairy cow (ICAR 2014), with the linear type classification being the most common system used to score cattle over the last decades. Type classification schemes evolved as a method of describing the physical attributes of cows, particularly those thought to be associated with functional fitness, health and longevity. It is usually performed by staff from breed societies or progeny testing agencies and the records are used both to provide a description of cows and to enable predictions of breeding values for cows and bulls. In the past there was greater disparity in the traits involved in the system, something that has changed as a result of moves towards global harmonisation of classification. Consequently, today there is a greater similarity in the measures recorded in different countries and the reliability of international conversions for these traits has considerably increased (Simm 1998).

The system of linear type classification involves the inspection of cows and scoring their appearance in a number of characteristics in relation to the biological extremes. The main advantages of this method include the individual assessment of traits and the biological range covered by the scores. Moreover, variation within traits is identifiable and degree rather than desirability is recorded. There are a number of requirements that the international standard traits must satisfy. These traits must be single traits, heritable, linear in a biological sense and with the possibility of being measured instead of scored. Likewise, information about the variation of each trait within the population must be available, along with the estimation of their economic values with reference to the breeding goal. Each linear trait describes a unique part of the cow which is not covered by a combination of the other linear traits. A full range of linear scores is used to identify the intermediate and extremes of each trait, with scales and assessment parameters covering the expected biological extremes of the current population of first lactation cows in the country of assessment (ICAR 2014).

Conformation traits are most often scored on linear scales from 1 to 9 and cows usually get a final score to summarise overall conformation. The final score is a combination of scores characterising udder, body or feet and leg quality. In the past, the classification systems in many countries were mainly focused on this final score or overall final class, giving attention to the cow, her most direct ancestors, and whether members of this family scored "Good Plus", "Very Good" or "Excellent". The emphasis was subsequently placed on the detailed appraisal of individual functional traits, which were a better effective tool to predict longevity (Atkins et al. 2008). On the other hand, and because genetic parameters vary between type traits as well as the weights used to combine them into a final score, composite indices combining genetic merit of the elementary traits in a formal way are preferable to the direct evaluation of final scores (Ducrocq & Wiggans 2015).

2.5 Functional conformation in dairy cows

Type traits are associated with functional properties of the cow, which in turn relate to profitability. These traits could increase efficiency not by higher production but by reduced costs of input (Montgomerie 2006). Profitability of dairy cows is directly influenced by longevity, which is a complex trait that depends on the cow's production, fertility, health and some physical and management characteristics. Therefore, aside from selecting for production, there are economic reasons for placing emphasis on breeding a cow with the right physical attributes. The length of a cow's productive life directly affects the herd profitability, since longer herd life reduces replacement costs and increases the proportion of lactations from higher yielding, mature animals (Atkins et al. 2008). The anatomical conformation described by the TOP scores and its relationship with functional longevity is discussed below.

2.5.1 Thoracic and abdominal body conformation

The cow's ability to process large volumes of roughage and sustain high production and desirable reproductive performance is facilitated by her thoracic and abdominal body capacity along with her dairyness and angularity (Atkins et al. 2008). Heart and lung body capacity are important functional properties of a cow, since for every litre of milk the cow makes, more than 400 litres of blood must pass through the udder to deliver the nutrients and water for making milk (Dorman 2012). Furthermore, weight and stature influence overall efficiency (Ahlborn 1988), and big animals can sometimes be larger than necessary for their level of production and could have negative effects on longevity, because feed demands for body maintenance increase with liveweight and impose associated costs (Montgomerie 2006). Therefore, extreme stature and weight are penalised in the breeding objectives of some countries (e.g. New Zealand).

2.5.2 Rump and legs

The rump and loin structures fasten the cow's abdominal and lumbar regions to her feet and legs and mammary system. The position of the hook and pin bones define the allowable width of the pelvis to accommodate a desirably high and wide rear udder (Atkins et al. 2008). Furthermore, an easier passage for the calf at birth and necessary drainage of post-calving fluids is possible in cows with a wide and correctly sloped rump. Undesirable rump angles as those present in cows with higher pin bones lead to higher susceptibility to infections of the reproductive tract and inefficient longer calving intervals (Wall et al. 2005). In addition, higher pin bones along with narrower rumps can be associated with a higher risk of difficult calvings and retained placentas (Atkins et al. 2008).

Leg conformation is important in dairy cattle, especially those under pasture-based systems in which animals have to walk long distances on a daily basis to get to the milking shed and also for grazing effectively. An inappropriate conformation of the hind legs can lead to a higher incidence of clinical lameness and fertility-related problems, e.g. cows having foot and leg problems are less likely to show signs of estrous (Wall et al. 2005; Atkins et al. 2008).

2.5.3 Udder conformation

Udder depth and suspensory udder strength are fundamental anatomical characteristics included in TOP assessments, which have facilitated the development of a functionally sound udder to accommodate the stress of high production (Atkins et al. 2008). The udder's suspensory apparatus is fundamental to udder health and longevity. Failure to keep the strength of this apparatus will result in undesirable changes in the udder's exterior characteristics and location. The suspensory ligaments are stretched as a consequence of normal maturity, but excessive stretching or tearing can cause low, pendulous udders, which are more prone to injury and infection. Additionally, cows with longer teats have a higher incidence of mastitis and may alter their gait if udders are deep and pendulous (Atkins et al. 2008). On the other hand, udders allowing easy machine milking reduce labour costs and improve milking efficiency (DairyNZ 2014).

2.6 Traits other than production in New Zealand dairy cattle

New Zealand has a national evaluation system for TOP created by the TOP advisory committee of representatives from breed and artificial breeding organisations, and implemented for all breeds of dairy cattle since 1987 (Ahlborn et al. 1990). The TOP system is based on the linear assessment of animals and allows farmers to obtain accurate and unbiased comparisons of cows and sires (DairyNZ 2014).

When assessing the animal, each trait is scored on a scale from 1 to 9, where 1 and 9 represent the biological extremes. The traits included are those currently considered the most important in dairy cattle under New Zealand conditions. Four traits are scored by the farmer, who uses a separate form called a TOP farmer list, while the inspector scores 13 conformation traits and BCS using an electronic data recorder (Table 2.4). The scoring is carried out across breeds and any additional characteristics of the animal are noted by using comment codes (DairyNZ 2014). The four TOP assessed by the dairy farmer are adaptability to milking, shed temperament, milking speed and overall opinion. These traits relate to the management of the cow and describe how well the animal fits into the milking routine. The 14 conformation traits assessed by the inspector are stature, weight, body capacity, rump angle, rump width, legs, udder support, front udder, rear udder, front teat placement, rear teat placement, udder overall, dairy conformation and BCS. A graphic illustration of these TOP is shown in Figure 2.2.

Table 2.4. Traits other than production recorded by farmers and inspectors in New Zealand dairy farms. Adapted from DairyNZ (2014)

	Description	Score[1]	
		1	9
Management TOP			
Adaptability to milking	How soon the animal settled into the milking routine after calving	Slowly	Quickly
Shed temperament	Temperament of the animal in the shed while being handled and milked	Vicious	Placid
Milking speed	Time from putting cups on to the time flow stops or cups are taken off	Slow	Fast
Overall opinion	Farmers' overall acceptance of the animal as a herd member	Undesirable	Desirable
Conformation TOP			
Stature	Height at the shoulders of the animal	<105 cm	>140 cm
Liveweight	Estimated liveweight of the animal	<250 kg	>600 kg
Body capacity	Strength and depth of chest and body as viewed from side, rear and front in relation to the physical size of the animal	Frail	Capacious
Rump angle	Angle of a line between the centre of the hips and the top of the pins	Pins high	Pins low/sloping
Rump width	Distance between the most posterior point of the pin bones relative to the size of the animal	Narrow	Wide
Legs	Straightness or curvature of the back legs from an imaginary line between thurls and the mid-hoof while the animal is walking	Straight	Sickled/curved
Udder support	Strength of the suspensory ligament as viewed from the rear and udder depth relative to the hocks	Weak	Strong
Front udder	How well the front udder is attached to the body wall	Loose	Strong
Rear udder	Height and width of the rear udder attachment	Low	High
Front teat placement	Placement of the front teats relative to the centre of the quarters as viewed from the rear	Wide	Close
Rear teat placement	Placement of the rear teats relative to the centre of the quarters as viewed from the rear	Wide	Close
Udder overall	All udder traits assessed as a whole	Undesirable	Desirable
Dairy conformation	All dairy conformation traits	Undesirable	Desirable
Body condition score	Estimate of animal's body reserves	Undesirable	Desirable

[1]Scale from 1 to 9 is the same for all traits evaluated

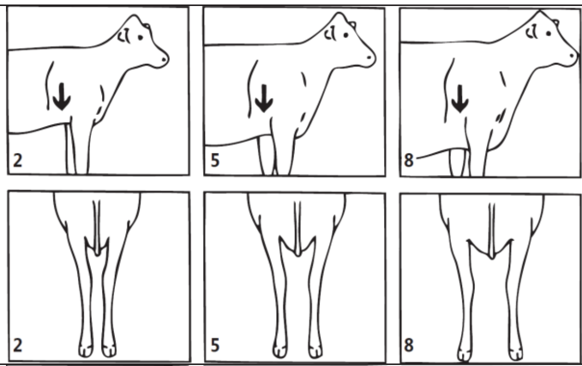
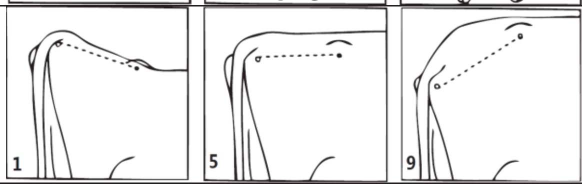
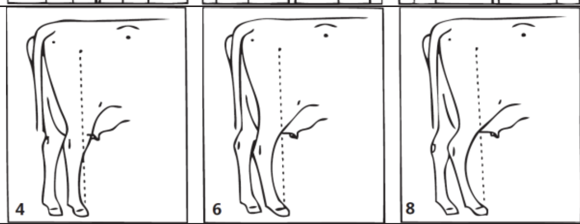
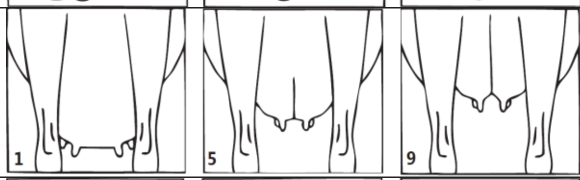
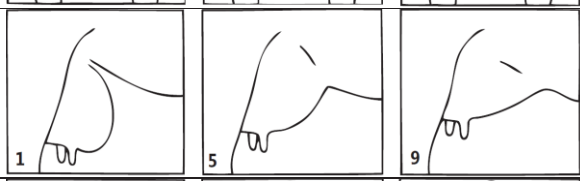
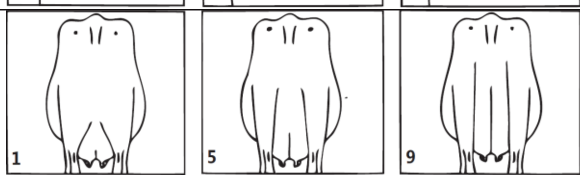
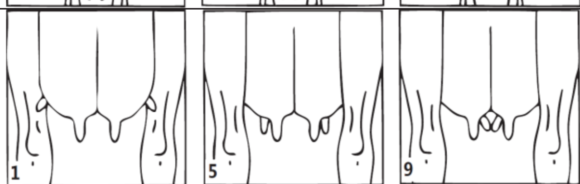
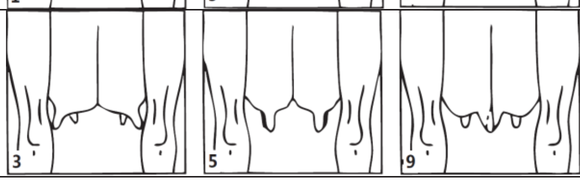
Body capacity	Frail – Capacious	
Rump angle	Pins high – Pins low	
Rump width	Narrow – Wide	
Legs	Straight – Sickled	
Udder support	Weak – Strong	
Front udder	Loose – Strong	
Rear udder	Low – High	
Front teat placement	Wide – Close	
Rear teat placement	Wide – Close	

Figure 2.2. Graphic illustration of traits other than production evaluated in New Zealand dairy cattle. Adapted from DairyNZ (2014). For most of the conformation TOP, high values (close to 9) are desirable, while intermediate scores (close to 5) for traits such as stature, rump angle, legs, teat placement would be preferred.

2.7 Comparison of TOP scores between New Zealand and other countries

Several studies have described the distribution of scores for each TOP in dairy cattle. Table 2.5 shows the means and standard deviations for each trait obtained in studies conducted in New Zealand and overseas over the last few decades. The values displayed below belong to Friesian-Holstein and Jersey animals, which are the main breeds used in New Zealand dairy farms.

Studies conducted in New Zealand during the 1990s showed lower means for conformation traits when compared with management traits. Ahlborn (1995) found considerably less variation in conformation traits between cows than management traits, especially for legs, rump angle and front teat placement. Likewise, management traits had greater variability in the study of Winkelman et al. (2000) and Cue et al. (1996), with variances being approximately twice those of the conformation traits in the latter. On the other hand, significant differences between registered and commercial herds in New Zealand have been demonstrated across breeds. Berry et al. (2005) found higher scores in registered Holstein-Friesian and Jersey cows than those found in commercial herds for all TOP except rump angle in F and rump angle, legs, front teat placement and rear teat placement in Jerseys. In the case of FxJ crossbred cows, they exhibited intermediate values between F and J breeds for most of the traits in both registered and commercial herds (Table 2.5).

Table 2.5. Means and standard deviations (SD) for traits other than production (TOP) of dairy cattle in New Zealand and other countries

TOP*	Breed	Reference						
		1	2	3	4	5	6	7
	F	5.72	5.41		5.63	5.27		
AM	J	6.12	5.73		5.80	5.29		
	FxJ			5.69	5.36	5.30		
	F	5.91	5.70		5.91	5.52	5.50	
ST	J	6.30	6.02		6.09	5.61		
	FxJ			5.87	5.65	5.58		
	F	6.04	5.50		5.65	5.30	5.50	
MS	J	6.37	5.83		5.97	5.35		
	FxJ			5.98	5.45	5.37		
	F	6.24	5.73		5.87	5.56		
OO	J	6.54	5.99		6.18	5.72		
	FxJ			6.17	5.69	5.65		
	F	5.41	5.98		6.70	6.32	4.10	4.46
S	J	3.64	4.17		5.87	5.84		
	FxJ				6.25	6.12		
	F	4.51	4.79					
W	J	2.97	3.16					
	FxJ							
	F	5.46	5.77		5.89	5.71		
C	J	6.16	6.57		6.92	6.53		
	FxJ			5.78	6.01	6.06		
	F	5.37	5.52		5.08	5.25	4.30	4.36
RA	J	5.28	5.42		5.35	5.50		
	FxJ				5.24	5.33		
	F	5.16	5.51		5.85	5.71	4.90	5.58
RW	J	5.53	5.99		6.57	6.26		
	FxJ				5.95	5.94		
	F	5.73	5.89		5.72	5.73	5.60	5.78
L	J	5.52	5.66		5.50	5.59		
	FxJ				5.71	5.69		
	F	5.19	4.92		5.16	4.94	5.70	6.04
US	J	5.72	5.50		5.60	5.08		
	FxJ				5.08	5.04		
	F	5.00	5.02		5.16	4.89	5.00	5.82
FU	J	5.58	5.63		5.67	5.16		
	FxJ			5.17	5.08	5.04		
	F	4.86	4.83		5.06	4.77	4.90	
RU	J	5.39	5.40		5.55	4.91		
	FxJ				4.96	4.90		
	F	4.29	4.51		4.72	4.57		
FT	J	4.31	4.54		4.51	4.55		
	FxJ				4.61	4.58		
	F	5.32	5.56		6.07	5.90	4.70	4.73
RT	J	5.06	5.22		5.54	5.63		
	FxJ				5.91	5.80		
	F	4.91	4.76		4.93	4.65		
UO	J	5.35	5.25		5.30	4.79		
	FxJ			5.00	4.80	4.76		
	F	5.53	5.42		5.67	5.47		
DC	J	6.12	6.19		6.53	6.02		
	FxJ			5.70	5.69	5.68		

1. Ahlborn (1995). New Zealand cattle. SD of management TOP for Holsteins = 1.41 - 1.63. SD of conformation TOP for Holsteins = 0.72 - 1.47. SD of management TOP for Jerseys = 1.15 - 1.54. SD of conformation TOP for Jerseys = 0.63 - 1.23
2. Cue et al. (1996). New Zealand cattle. SD of management TOP for Holsteins = 1.48 - 1.55. SD of conformation TOP for Holsteins = 0.84 - 1.00. SD of management TOP for Jerseys = 1.42 - 1.49. SD of conformation TOP for Jerseys = 0.74 - 1.15
3. Winkelman et al. (2000). New Zealand cattle. SD of management TOP = 1.34 – 1.62. SD of conformation TOP = 1.03 - 1.09
4. Berry et al. (2005). Registered New Zealand cattle. SD of management TOP = 1.42 - 1.53. SD of conformation TOP = 0.90 - 0.93
5. Berry et al. (2005). Commercial New Zealand cattle. SD of management TOP = 1.42 - 1.53. SD of conformation TOP = 0.90 - 0.93
6. Berry et al. (2004). Irish cattle. SD of management and conformation TOP = 0.8 – 1.6
7. Brotherstone (1994). British cattle. SD of conformation TOP = 1.08 - 1.62

*AM = adaptability to milking, ST = shed temperament, MS = milking speed, OO = overall opinion, S = stature, W = liveweight, C = body capacity, RA = rump angle, RW = rump width, L = legs, US = udder support, FU = front udder, RU = rear udder, FT = front teat placement, RT = rear teat placement, UO = udder overall, DC = dairy conformation

In general, Irish and British Holsteins show lower scores for shed temperament and milking speed, except for the latter in New Zealand commercial herds. Likewise, stature and rump angle scores are lower in overseas Holsteins, and this is also true for rump width and legs in Irish cattle (Brotherstone 1994; Berry et al. 2004). On the other hand, higher scores for udder traits such as udder support are observed in overseas cattle than in New Zealand cattle, even when results of contemporary studies such as Ahlborn (1995) and Brotherstone (1994) are compared. British Holsteins also have higher scores for front udder than New Zealand Holsteins, while Irish Holsteins have higher values for rear udder than New Zealand cattle, although not higher than the values obtained in commercial New Zealand Holsteins in more recent studies (Berry et al. 2005).

Although values of standard deviations are not shown in detail, a similar pattern is observed across all studies made in New Zealand dairy cattle, indicating higher levels of variation in management TOP than in conformation TOP (footnotes of Table 2.5). However, many conformation TOP have higher scores than management TOP. Berry et al. (2004) found that only BCS and front udder had a standard deviation greater than 1.5, while ease of milking, which was assessed by each farmer, was only 0.8. This could be explained possibly by a more conservative approach to score dairy cows for management TOP in other countries.

2.8 Inclusion of TOP within the genetic evaluation for dairy cattle in New Zealand

Despite the coexistence of different production systems and the multi-breed herd composition, the genetic merit of dairy cows in New Zealand is measured through the same across-breed animal genetic evaluation. The breeding and production values obtained from this evaluation are used along with the results from bio-economic models to generate two indices that allow the comparison of individual animals in terms of net income per unit of feed consumed (Harris et al. 1996). The breeding worth (BW) index represents the genetic ability of cows for breeding replacements, while production worth (PW) reflects their lifetime production ability. The BW includes estimated breeding values (EBV) for milk yield (MY), fat yield (FY), protein yield (PY), liveweight (LWT), somatic cell score (SCS), fertility and residual survival (LIC 2009). Recently, BCS was incorporated to the BW index (DairyNZ 2016c).

In New Zealand, TOP do not contribute directly to the BW or PW indices. In fact, when compared to indices from other major dairy countries (Table 2.6), the New Zealand dairy national breeding objective has a 20% larger emphasis on production and a 9% larger emphasis on functionality and health with no specific emphasis on conformation traits other than those included within the residual survival EBV (Dorman 2012). Table 2.6 shows the comparison between weightings in BW and selection indices from other countries.

Table 2.6. The relative weighting (%) of traits in international breeding programmes (Cruickshank 2012)

Trait type	NZ	UK	Ireland	USA	Denmark, Finland & Sweden	Holland & Flanders	Belgium
Production	66.1	45.2	45	35	31	33	48
Functionality	19.9	45.1	44	48	54	45	28
Liveweight	14	0	20	6	2	0	0
TOP[1]	0	9.7	1	11	13	22	24

[1]Traits other than production

A more detailed analysis of Holstein populations made by VanRaden (2004) showed that when compared with other national selection indices from 13 different countries, New Zealand was the only country that did not include at least one TOP within its selection index at the time. However, since 2007, some TOP are included within the dairy cattle genetic evaluation and they indirectly contribute to the BW index. The traits of milking speed, overall opinion, legs, udder overall, dairy conformation and BCS are used within a set of nine predictors, including PY, SCS and conception rate at 42 days (CR42), to estimate total longevity through a multiple trait animal model that includes four survival traits (Harris & Montgomerie 2007). All the predictors are recorded in first lactation, except CR42, which is recorded at the start of the second lactation. Factors already included in the BW which are production, fertility, liveweight and SCC, are removed so that they are not counted twice, and the resulting number is known as residual survival (Dorman 2012). Therefore, the residual survival EBV is the component of the New Zealand genetic evaluation where some TOP have been included in the last decade.

In 2003, the Livestock Improvement Corporation (LIC) started to develop a selection index specifically designed for OAD systems. Initially, and due to the insufficient data available at the time, a desired gain approach was implemented (McPherson et al. 2007), where subjective weights were given to the EBV of traits included in the BW. Subsequently, EBVs for MY, PY, FY and SCC were specifically calculated for OAD using a day test model. Farmers have suggested the inclusion of EBVs for TOP in the BW calculations. Consequently, for 2015, new desired gains were defined and a weight was given to the EBV for the traits body capacity, milking speed, udder support and front teat placement (LIC 2016).

The relative economic weight that ought to be placed on TOP versus production traits has been a major source of disagreement between scientists and breeders for decades (Simm 1998), and it has been shown that there are marked differences of their weighting within the national breeding objectives between countries. It should be noted, however, that the ultimate value or weight of these TOP depends on their relationships with production and with survival, the degree to which they can reduce the rates of involuntary culling and their contribution to efficiency of production (Cue et al. 1996). This requires knowledge of the genetic and phenotypic parameters, as well as the economic value of each trait, which are a function of the environment or particular production system.

2.9 Phenotypic and genetic parameters for TOP

The strength of the relationship between performance in one trait and performance in another trait is measured by the phenotypic correlations, which give a sense of the observable relationship between traits. On the other hand, genetic correlations measure the strength of the relationship between breeding values for one trait and breeding values for another trait. Genetic correlations are important for selection purposes and the prediction of breeding values in genetically correlated traits (Bourdon 2000). Phenotypic correlations and genetic parameters among TOP have been estimated in New Zealand dairy cattle by Ahlborn (1995) and Cue et al. (1996), and are summarised in the Appendix Table A1. All references for the values present in this section are shown in the footnotes of the Appendix Table A1.

2.9.1 Heritability of TOP

A high degree of consistency across breeds (F and J) is observed in the correlations among the farmer-scored traits (Appendix Table A1). Something similar is observed for many inspector-scored traits. However, traits such as weight, udder support, front udder, front teat placement, rear teat placement and udder overall showed a lower consistency across breeds, especially in their genetic correlations among them and with other traits. Heritability was usually low for adaptability to milking, shed temperament, overall opinion and legs (0.06 to 0.18), moderate for milking speed, weight, body capacity, rump angle, rump width, udder support, front udder, rear udder, front teat placement, rear teat placement, udder overall, dairy conformation (0.12

to 0.31), and moderate to high for stature (0.23 to 0.49). The main differences found with overseas studies are the higher heritability estimated for milking speed and legs in Irish Holsteins and the lower heritability estimates for udder support, front udder, rear udder and front teat placement in both Irish and British cattle.

2.9.2 Phenotypic correlations among TOP

Phenotypic correlations among management TOP were positive (0.18 to 0.71) in New Zealand cattle (Appendix Table A1). However, phenotypic correlations between management and conformation traits were close to zero, except for the correlation between overall opinion and udder overall and between overall opinion and dairy conformation, although those still were low (0.12 to 0.18). A similar pattern is observed in Irish Holsteins with a slightly higher correlation between the shed temperament and milking speed, and between these two management TOP and the conformation traits stature, udder support, front udder, rear udder and rear teat placement. High and positive phenotypic correlations (>0.55) were found between udder overall, udder support, and front udder in New Zealand cattle, which according to Ahlborn (1995) might indicate that part of the information from udder support and front udder is contained within the score for udder overall. This phenotypic trend is also true between these traits and rear udder but to a lesser degree (>0.42).

2.9.3 Genetic correlations among TOP

The farmer-scored traits adaptability to milking, shed temperament and overall opinion had high genetic correlations among them (0.82 to 0.99), while the genetic correlations between these traits and milking speed were much lower (0.09 to 0.34), except between milking speed and overall opinion (0.34 to 0.55) in New Zealand cattle and between milking speed and shed temperament in Irish Holsteins. Genotypic correlations between management TOP and conformation TOP are generally low, but there is a moderate to high positive correlation between milking speed and stature, rump angle, rump width, legs udder support, front udder, rear udder in Irish Holsteins, and moderate between milking speed and udder support and front udder in some New Zealand Jerseys (references shown in Appendix Table A1).

Multiple correlations from moderate negative to moderate positive are observed between stature, weight and body capacity with several conformation traits. Rump angle and legs show the highest negative genotypic correlations with other conformation TOP, particularly those associated with udder and dairy conformation. On the other hand, the highest positive genotypic correlations are observed among udder traits such as udder support, front udder, rear teat placement and udder overall in both New Zealand and overseas dairy cattle (Appendix Table A1).

2.10 Correlations of TOP with production, fertility, udder health and survival

2.10.1 Phenotypic and genetic correlations between TOP and production

Phenotypic correlations of management TOP with production traits are low and positive in New Zealand dairy cattle (0.02 to 0.15) except for overall opinion which shows intermediate values (0.23 to 0.26) (Appendix Table A2). This might indicate that dairy farmers score adaptability to milking, shed temperament and milking speed without bias from production traits. Likewise, correlations are low and close to zero between production and most of the conformation TOP (-0.04 to 0.10), except for stature, weight, body capacity, rump width and dairy conformation (Ahlborn 1995).

In New Zealand, the highest genetic correlations have been found between overall opinion and FY in Holsteins (0.51) and between stature and PY in Jerseys (0.55) (Ahlborn 1995). In general, low and medium negative correlations are observed between production with udder traits and legs, while the correlations of production with body capacity and rump-related traits are low to medium positive (Appendix Table A2). On the other hand, most of the conformation TOP evaluated in Irish dairy cattle have medium to high positive correlations with MY (Berry et al. 2004), whereas American Holsteins have medium to very high positive (but also negative) genetic correlations between production and conformation TOP. The highest values are observed between production with legs, rump angle, udder support and front udder (DeGroot et al. 2002).

The high genetic correlations between production and body capacity conformation in New Zealand cattle might indicate a population-specific pleiotropism with some genes affecting variation in production as well as in size traits (Ahlborn 1995). The magnitude of these positive associations means that selection for production traits might result in larger cows with increased growth and maintenance costs. Milk yield and liveweight are currently part of the seven breeding objective traits for dairy cattle in New Zealand, but the relative economic values for these traits are negative in order to restrain the increased body size and milk yield associated with selection for increased milk solids. This is explained by the fact that additional liveweight diverts feed resources to lowly valued farm outputs (Montgomerie 2004). In the case of milk yield, however, a negative economic value arises partly from the milk payment system penalty, and partly because additional volume effectively wastes feed that could have been diverted to milk solids (Montgomerie 2005).

2.10.2 Phenotypic and genetic correlations between TOP and fertility

Medium to high genetic correlations have been reported between some TOP and several fertility measures in Irish Holsteins. Berry et al. (2004) found that taller, wider, deeper more angular cows with high pins had a lower genetic merit for pregnancy rate both to first service and 63 days after the start of breeding, and they also required more services to get in calf. Likewise, cows with tighter front udder and higher, shallower udders with stronger udder support also had lower pregnancy rates to first service and required more services to get pregnant. Moreover, a poorer reproductive performance (lower pregnancy rate to first service and greater number of services per cow) was genetically correlated with shorter teats that were further apart from a rear view, but closer together from a side view, while cows with straighter rear legs and a steeper foot angle were served later (greater interval to first service) and had lower pregnancy rate to first service.

An examination of detailed reproductive traits and their relationship with body-related TOP in Irish Holsteins (Carthy et al. 2016) showed that a greater BCS was genetically associated with an increased likelihood of resumption of cyclicity post-partum (0.52). Likewise, wider chests and less angular bodies were genetically correlated with resumption of cyclicity (0.28 and -0.42, respectively), while wider cows had a tendency to be genetically predisposed to early ovulation, and cows with deeper bodies were predisposed to a greater likelihood of embryo loss.

2.10.3 Phenotypic and genetic correlations between TOP, udder health and survival

Traits other than production have been associated with herd indicators of udder health and productive lifetime in dairy cattle. Phenotypically, cows with higher udders (higher udder depth scores) have had lower SCC (Rogers et al. 1991). Positive genetic correlations have been reported between SCC and teat length (0.08 to 0.31) and udder support (0.45), while negative genetic correlations have been found between SCC and udder depth (-0.41 to -0.40), fore-udder attachment (-0.41 to -0.32), and teat placement (Rogers et al. 1991; Rupp & Boichard 1999; Berry et al. 2004). This indicates that cows with stronger udder support and longer teats are genetically predisposed to higher average SCCs during a lactation, while selection of animals with higher and more tightly attached udders and closer teat placement will likely improve resistance to mastitis (Rogers et al. 1991; Mrode et al. 1998). A similar pattern was found for SCS in American Holsteins (DeGroot et al. 2002), with negative genetic correlations between udder traits and SCS ranging from 0.35 (udder cleft) to 0.16 (rear udder height).

Udder traits have been found to positively influence the length of productive life a cow could have. Some studies have found traits such as udder depth and milking ease accounting for up to 84% of the total contribution of TOP to functional longevity (Larroque & Ducrocq 2001). Likewise, front udder, rear udder and udder texture (softness and expandability) are traits with a significant influence on functional survival (Sewalem et al. 2004). A study using a proportional hazards model (Berry et al. 2005) showed that all TOP had a significant influence on true and functional longevity across both pedigree and commercial herds in New Zealand, with udder-related TOP having the largest influence on functional longevity. Commercial Holsteins with a high probability of being culled tended to exhibit lower scores for udder overall, udder support, front udder, rump angle, dairy conformation and stature. Moreover, an intermediate optimum score was observed for body capacity, rump angle, rump width, front teat placement and rear teat placement, with cows at either extreme (very low or very high scores) more likely to be culled.

Cue et al. (1996) found positive and statistically significant correlations between management TOP and survival to second and third lactations in New Zealand dairy cattle, while the conformation TOP evaluated were not all significant. According to this, the inspector-scored TOP would not be related to survival of cows through to third lactation, while the producer-scored TOP would be good indicators of survival in cows up to this stage of their productive life. Similarly, Ahlborn (1995) found moderately positive genetic correlations between management TOP and survival rate from first to second lactation, indicating that these producer-scored TOP can be used to genetically improve survival rate in the herds. On the other hand, the genetic correlations between conformation TOP and survival rate were moderate and negative for udder overall and udder support in Holsteins and moderate and positive for udder overall and front udder in Jerseys, which suggests the importance of these traits in selection programmes aiming to increase survival rates. Furthermore, genetic correlations between survival and size traits are moderately positive in Jerseys, but slightly negative for Holsteins, which might indicate a breed-specific pleiotropism.

A continuation of the work initiated by Cue et al. (1996) was made by Winkelman et al. (2000) using six additional years of data and inclusion of survival up to the fifth lactation. A high genetic correlation was found between the four management TOP and survival to different lactations, with the highest correlations being observed between adaptability to milking and overall opinion with survival to third lactation (0.40 and 0.58, respectively). Traits such as body capacity, front udder, udder overall and dairy conformation showed moderate positive correlations with survival to third, fourth and fifth lactations (0.17 to 0.34). In light of these results, management TOP scored by the farmer were suggested as important predictors of survival rates in the herd, even as better predictors than TOP scored by the inspector.

2.11 Relationship between longevity and culling in dairy herds

Longevity of dairy cows is determined by culling, which in turn is the result of several factors including diseases and selection decisions (Heise et al. 2016). A high longevity in the herd is expected to be more profitable since fewer replacements are required to achieve the same herd output, with the subsequent reduction of the costs that are involved in rearing replacement heifers and also an income with those heifers reared not required as replacements and subsequently sold. Additionally, more offspring are made available from superior cows as herd replacements, resulting in increased selection intensity and a greater proportion of the potential milk yield is captured from mature cows. The interaction between the milking herd and the replacement herd determines the number of replacements required by the milking herd and, in turn, the number of replacements reared by the dairy producer (Pritchard et al. 2013). The term "replacement" has sometimes been a useful synonym for culling, and it represents any event where a departure of cows from the herd occurs because of sale, slaughter, salvage, or death (Fetrow et al. 2006). The culling rate describes the percentage of cows removed from a herd (Hadley et al. 2006), while survival rate and productive herd life are alternative indicators used to represent culling practices but are usually based on economic conditions (cost, salvage value, and returns expected from various alternatives). The former measures the proportion of cows that survive to each parity, or for a designated period of time, and the latter indicates the length of time that the cow remains in the herd after her first calving (Hare et al. 2006).

2.12 Longevity of New Zealand dairy cattle

A particular tool New Zealand dairy farmers use to determine the cow's performance and make culling decisions is the production worth (PW) index. As shown previously, BW represents the genetic ability of cows for breeding replacements, while PW reflects their lifetime production ability. Its calculation involves the estimation of production values (PVs) for MY, FY, PY and LWT. These PVs are calculated as the sum of the EBV for each trait plus non-additive genetic and permanent environment effects, including heterosis (Harris et al. 1996). These EBV are computed using the same information about the cow's ancestry, female relations and her own production. However, different weights are given to each of these sources of information in such a way that ensures a high repeatability of production performance from one season to the next. Then, for the calculation of PW, the cow's own records have a greater weight than those for ancestry and progeny, since the PVs measure the lifetime producing ability of the cow herself, rather than what she is expected to pass on to offspring (LIC 2009). Nevertheless, despite the existence of the PW index for culling decisions, farmers in New Zealand also take into account other factors such as health status or suitability of the cow for their milking system, the next expected calving date of the cow, and the expected future lifetime of the cow at the time of the decision (LIC 2009). Longevity of the national herd is then affected by multiple factors and herd culling policies, which determine in turn the replacement rate.

A decrease of 0.43 lactations was reported in the herd life of New Zealand dairy cows over a period of 30 years (Harris 1989) after estimating the mean age of the herds during 1955-1956 (5.20 lactations) and 1985-1986 (4.77 lactations). The rate of decline was lower for younger age groups and higher for older age groups, with the highest decrease of herd life being attributed to the lower survival in 4 year olds and older age classes. More recent studies to estimate survivability showed that the mean age of adult cows in herd testing farms in New Zealand is approximately 4.5 lactations, with 25% cows removed by 2.8 years and 75% removed by 7.7 years of age, with both Jerseys and FxJ having a lower risk of premature removal than Friesians. It was estimated that 20% are removed before 2 years old, which represents a high proportion of young animals failing to survive and enter the milking herd

(Brownlie & McDougall 2014). Previous studies had reported an overall replacement rate of 19.3%, which is calculated as the percentage of cows that were dead, sold or culled during the season divided by the total number of cows that calved at the start of the season (Xu & Burton 2003). Low culling rates (16%) were shown in cows aged 2 to 5 years, with the lowest culling rates being observed in 4-year-old cows (14.7%). Furthermore, culling rates increased sharply after 5 years up to reach over 45% for cows aged 10 years and over. In terms of breeds, Holsteins and Jerseys had a similar overall culling rates (19.9% and 20.0%, respectively) and higher than the rate obtained for crossbred cows (17.9%).

2.13 Culling reasons and optimal replacement rate in New Zealand dairy herds

Xu & Burton (2003) showed an overall replacement rate of 19.9% in New Zealand dairy farms over three seasons (from 1998 to 2000). From this total, 2.1%, 4.6% and 12.6% of cows left the herds due to death, sale and culling, respectively (Table 2.7). The main reason for culling was poor reproductive performance, accounting for 44.8% of culled cows over the three seasons analysed. Other main causes of culling were low production (15.9%) and udder-related problems, including mastitis and high SCC. Poor udder type only accounted for 2.9% of culling reasons. Compton et al. (2016a) showed that after low reproductive performance, udder-related problems were the second most important cause of culling in New Zealand dairy cattle, but these reasons included mainly clinical or subclinical mastitis, and no information was provided on udder conformation reasons.

Table 2.7. Replacement rates and culling reasons in New Zealand dairy farms over three seasons from 1998 to 2000 (Xu & Burton 2003)

Frequencies and culling reason	Season			Overall
	1998	1999	2000	
Total number of cows (n)	29041	43868	25322	98231
Cows left herds (n)	5984	8646	4286	18916
Replacement rates (%)	20.6	19.7	16.9	19.3
Cows left due to (%)				
Death	1.9	2.2	2.1	2.1
Sale	4.7	4.8	4	4.6
Culling	13.9	12.7	10.8	12.6
Total number of cows	4047	5587	2742	12376
Culling due to (%)				
Abortion	1.5	1.4	1.9	1.6
Facial eczema	2.0	1.3	2.1	1.7
Late conception	2.2	1.9	2.0	2.0
Low production	16.0	16.4	14.7	15.9
Mastitis	4.1	3.6	3.9	3.8
Empty	45.3	45.4	43.0	44.8
Old age	5.1	5.4	7.1	5.7
High somatic cell count	4.3	3.2	3.9	3.7
Slow milking	1.5	1.7	1.1	1.5
Temperament	1.1	1.5	2.3	1.5
Udder type and problem	2.2	2.7	4.3	2.9
Unspecified causes	9.8	9.7	6.0	9.0

The potential benefits of different replacement rates (15%, 19% and 27%) on production and profitability of dairy herds in New Zealand were evaluated by (Lopez-villalobos & Holmes 2010). After 20 years of using bulls of high BW, the annual genetic gain for milk solids production was higher at higher replacement rates. However, in terms of profitability, herds with a low replacement rate showed a better performance at year 20 of the simulation. Furthermore, farms with a low replacement rate (15%) in combination with selection of heifers with high BW and the culling of cows with low PW can achieve both the highest genetic gain for milk solids and the highest farm profit.

2.14 Culling reasons in dairy cows milked OAD and variability in the response to OAD

Low production and poor reproductive performance were general causes for removing cows in OAD cows for the 2014-2015 production season in New Zealand (DairyNZ 2016a). There were a reduced number of cows removed for reproduction in OAD farms than in TAD farms (7% vs

9%). Moreover, a significantly higher proportion of animals were culled for udder-related problems in OAD herds compared with TAD herds (15.1 vs 6.8%). However, both udder conformation and mastitis were included in the percentage of culling for udder-related reasons without differentiation of the proportion of cows specifically culled for each of these reasons. Additionally, it is important to note the high percentage of culled cows with unspecified removal reason in this report (>35%) (DairyNZ 2016a), which highlights the difficulties in analysing culling reasons from large national databases.

With respect to the productivity and milking adaptability of cows milked OAD, there are differences in the cow's individual response to the negative effects of switching from TAD to OAD. Moreover, there is a breed effect evidenced by greater milk volume and milk solids losses in Holstein-Friesians compared with Jerseys and crossbreds when they are milked OAD (Lembeye et al. 2016a). Moreover, there is a high individual variation within breeds in the volume and milk component yields (Hickson et al. 2006). No breed effects were found on SCC levels of OAD cows (Clark et al. 2006), but there is a significant breed effect on the development of new intra-mammary infection at calving and at drying off, with a higher incidence in 2 and 3-year-old Holstein cows (Lacy-Hulbert et al. 2005). In regard to lactation persistency, there is no difference in the response to OAD milking among breeds, but some animals perform well when milked once daily (Hickson et al. 2006).

Little is known about the genetic correlation between milk-production traits from OAD and TAD production systems. Sire breeding values for production and SCC calculated from first lactation cows milked OAD and from first lactation cows milked TAD have shown correlations among sire breeding values that were significantly different from one (Harris 2005). Moreover, the EBV calculated for MY, PY, FY and SCC of OAD cows had a relatively low correlation with the official EBV of BW (0.66-0.81), which suggests that OAD milking and TAD milking traits are genetically different (McPherson et al. 2007). Therefore, it has been indicated that bulls from TAD would re-rank on the basis of an OAD genetic evaluation or OAD index.

2.15 Summary and formulation of research problem

An increasing proportion of dairy farmers in New Zealand have switched to a full season OAD milking system during the last few years. Multiple benefits of this system for the animals include a better reproductive performance and improvement of several herd health indicators. Farmers also obtain associated benefits on lifestyle, capital and labour efficiencies with the implementation of this strategy on their farms. A negative effect on milk production traits has been reported consistently in herds that switch to OAD, although it is significantly higher in first lactation cows than in mature cows. In addition, the analyses have shown that in commercial farms the production difference between OAD and TAD herds are smaller than those reported in experimental trials. A long-term experiment is required to compare cows adapted to OAD after several seasons of using this system with cows adapted to TAD.

On the other hand, there are multiple udder-related problems frequently observed in OAD herds that might be related to an increased involuntary culling rate. A particular cow physical conformation has been suggested to identify animals that might better suit the OAD milking environment, although management TOP could also be good indicators of the individual adaptability to the system. TOP in New Zealand include both conformation and management traits, and have been recorded consistently in first lactation cows by farmers (management traits) and technical inspectors (conformation traits) since 1987. Different studies have shown phenotypic and genetic correlations of these traits with production, fertility, udder health and survival of dairy cows in TAD milking farms. However, there are no previous studies of TOP or its association with survival in OAD milking cows. Moreover, despite the general perception among OAD dairy farmers about the higher importance that TOP might have on the culling decisions in OAD dairy herds, there is no literature with an objective study about this topic.

The largest milk-producing countries generally include some TOP in the genetic evaluation of dairy cattle. However, the weight of these traits in the breeding objective of New Zealand dairy farms is relatively low compared with the importance given to such traits in other countries, which means that a low or null selection has been made for these traits in New Zealand dairy cattle. In the case of OAD dairy herds, and after considerable consultation with OAD dairy farmers, some TOP have recently been included in a new OAD selection index and subjectively weighted under a desired genetic gain approach using selection index theory. However, and as was discussed in the literature review, the inclusion of traits and the relative economic weights given to each trait within a breeding objective will depend on the relationship of such traits with production and survival, and the degree to which they can reduce the rates of involuntary culling.

In light of the above, the research problem of this thesis was stated as “Do traits other than production have an effect on the survival of cows milked OAD in New Zealand dairy cattle?” The general objective was to evaluate the effect of TOP on the survival of cows managed with an OAD milking system. The specific objectives were:

- To evaluate the effect of season, breed, lactation and culling on the production traits and TOP of cows milked OAD.
- To estimate phenotypic correlations between TOP with production and fertility traits in cows milked OAD.
- To identify the culling reasons and the main factors that increase the risk of culling cows milked OAD.

Chapter 3

Effect of season, lactation number, breed and culling on traits other than production in dairy cows milked once a day

Paper *"Traits other than production over lactations and production seasons in Holstein-Friesian, Jersey and crossbred cows milked once a day in New Zealand"* published in the New Zealand Journal of Agricultural Science (2017)

3.1 Abstract

Traits other than production (TOP) are associated with functional characteristics of cows and can increase profitability of dairy farms by improving the longevity of the herd. These traits have not been studied in dairy cows milked once a day (OAD). The effects of season, lactation number, breed and culling on TOP were investigated in cows from Massey University Dairy 1. Cows in different lactations were scored for 18 TOP during three consecutive seasons from 2013 to 2015. Jersey cows showed higher scores for most udder traits compared to crossbred and Holstein-Friesians. There was a decrease in the scores for stature, body capacity, rump width, legs, rear teat placement and dairy conformation over the seasons, which was accompanied by a simultaneous increase in the scores for rump angle, udder support, udder overall and body condition score. The dairy conformation of cows increased over lactations along with other correlated traits, while most udder traits showed a gradual decrease over lactations. Culled cows had a poorer adaptability to milking (7.02 ± 0.04) than non culled cows (7.23 ± 0.03). Culled cows had a poorer overall opinion (7.62 ± 0.06) than non-culled cows (7.89 ± 0.04). Moreover, culled cows also had a weaker udder support (5.56 ± 0.09) than non-culled cows (6.19 ± 0.06). Culled cows had a weaker front udder (5.48 ± 0.10) than non-culled cows (5.85 ± 0.07). Culled cows had a lower rear udder (6.01 ± 0.08) than non-culled cows (6.25 ± 0.05). The highest repeatability was observed for milking speed and stature (0.52 for both), while the traits with the lowest repeatability were overall opinion (0.13), legs (0.03) and dairy conformation (0.19). The results of this study showed a significant effect of season, lactation number and breed on TOP. However, adaptability to milking, overall opinion and udder conformation might have a higher influence than the age, breed and production worth of cows on the culling decisions of OAD dairy farms.

3.2 Introduction

Full season once a day (OAD) milking has been adopted by approximately 5% of dairy farms in New Zealand (Stachowicz et al. 2014; DairyNZ 2016a). The implementation of OAD milking has been associated with lifestyle, capital and labour advantages for farmers (Stelwagen et al. 2013) and the improvement of some fertility and health parameters in the herd (e.g. greater submission rates, earlier conception rates, reduced incidence of sole lesions and white line disease in the hoof) (Clark et al. 2006; O'Driscoll et al. 2010). Conversely, a clear negative effect of a reduced milking frequency on production traits has been demonstrated in experimental trials, where cows milked twice a day (TAD) significantly outperformed those milked OAD (Tong et al. 2002; Clark et al. 2006). However, this difference in production between OAD and TAD was smaller in studies that analysed production traits using a large number of commercial herds (Lembeye et al. 2016a).

Further disadvantages of the OAD milking system are udder-related. Cows milked OAD had a higher somatic cell count than cows milked TAD, although this increase has not necessarily been associated with a higher incidence of mastitis (Tong et al. 2002; Lacy-Hulbert et al. 2005). Some studies have shown milk leakages prior to the morning milking and higher udder firmness scores in cows milked OAD during the first months of lactation from calving to nearly peak production (Gleeson et al. 2007). Additionally, farmers have reported problems of udder conformation and management (e.g. milking speed, shed temperament) during the milking routine of cows in different lactations milked OAD (Holmes 2012; McCarthy 2012), which could have important consequences for the culling decisions of these herds.

In dairy cows, udder conformation is normally assessed along with other physical and milking management attributes using a linear evaluation system. As a whole, these characteristics are termed ‘traits other than production’ (TOP). In New Zealand, dairy cows are scored for a total of 18 TOP, from which 14 are conformation traits and four are management traits that describe how well the cow fits into the milking routine (DairyNZ 2014). However, only second lactation cows are included in the national linear evaluation, preventing the analysis of TOP over time and over lactations, which could be important in OAD cows. The objective of this study was to evaluate the effects of season, lactation number, breed and culling on TOP in dairy cows milked OAD.

3.3 Materials and methods

3.3.1 Farm and animals

Massey University Dairy 1 is a 120 ha pasture-based dairy farm located in the Manawatu region of New Zealand, at 35 m above sea level and with an average annual rainfall of 980 mm. Soils are well to excessively-well drained, prone to summer drought and high in natural fertility. Pastures are predominantly ryegrass and white clover species, with some paddocks allocated for perennial lucerne and a herb/crop mix where chicory, plantain and red clover pastures are grown. Maize and grass silage are provided to cows according to seasonal requirements, with hay being fed to dry stock when needed. Three seasons (2013-2014, 2014-2015 and 2015-2016) were analysed in this study and will be referred to hereinafter as the 2013, 2014 and 2015 seasons, respectively. The farm implemented an OAD spring calving milking system in July 2013. A higher number of animals were observed for seasons 2014 and 2015 because autumn calving cows from the 2013 season were switched to spring calving in the following seasons (Table 3.1). Cows were milked once daily in a 24-aside herringbone shed.

The breed composition and numbers of the herd for the last three seasons are presented in Table 3.1. The farm is aiming to have an equal number of Holstein-Friesian (F), Jersey (J) and crossbred FxJ cows in the long term, but currently there are more FxJ cross cows compared to F and J cows in all three seasons.

Table 3.1. Sample size (N) and breed proportion (%) of the herd at Massey University Dairy 1 by season

Season		Breed			
		F[1]	J[2]	FxJ[3]	Total
2013	N	39	44	89	172
	%	22.67	25.58	51.74	
2014	N	66	55	126	247
	%	26.72	22.27	51.01	
2015	N	70	65	127	262
	%	26.72	24.81	48.47	
Total observations	N	175	164	342	681
	%	25.7	24.08	50.22	

[1]F = Holstein-Friesian
[2]J = Jersey
[3]FxJ = Holstein-Friesian and Jersey crossbred

3.3.2 Production and fertility data

Individual milk samples were taken during several herd tests to calculate the milk production of cows using the Livestock Improvement Corporation (LIC) herd-testing service. The first herd test for each season was carried out after all cows had calved, with subsequent herd tests performed approximately every 30 days during the 2013 and 2014 seasons and every 60 days during the 2015 season. On average, each cow was herd tested eight times per season and the values for milk yield (MY), fat yield (FY), protein yield (PY) and somatic cell count (SCC) were provided by LIC. The milk solids yield (MSY) was calculated from the sum of FY and PY. The somatic cell score (SCS) for each cow was estimated as $\log_2$ (SCC/1000) and then the average SCS was calculated as the mean for the multiple SCS obtained in the herd tests. The number of days in milk (DIM) were calculated for each cow from the difference between calving date to dry-off date. Liveweight (LWT) was recorded daily using a walk-over weighing system; these values were then averaged for each season. Indicators of the herd fertility were represented by submission rates of cows at 21 and 42 days after the start of each breeding period (SR21 and SR42, respectively) and the interval from start of mating to first service (SMFS).

3.3.3 Herd characteristics

The age of each cow was calculated from birth date records. The breeding worth (BW) and production worth (PW) values for each animal were calculated by LIC and were extracted from the animal evaluation in May 2016. The breed composition of all cows and their corresponding parents were recorded in 16th's. These breed proportions were subsequently used to classify cows into Holstein Friesian, Jersey and crossbred categories. The status of purebred (F or J) was given to those cows with a breed composition ≥ 87.5% (14/16) from either Holstein-Friesian or Jersey breeds. Cows with a breed composition ≤ 87.5% (14/16) from either Holstein-Friesian or Jersey breeds were considered crossbred cows.

3.3.4 Traits other than production

A total of 18 TOP were evaluated in October-November of each season. Four management traits (adaptability to milking, shed temperament, milking speed and overall opinion) were scored by the herd manager and 14 conformation traits (stature, weight, body capacity, rump angle, rump width, legs, udder support, front udder, rear udder, front teat placement, rear teat placement, udder overall, dairy conformation and body condition score (BCS) were scored by qualified NZAEL inspectors, which were different for each season. The scores were given on a scale of 1 to 9. The interpretation of these values, along with a description of each TOP, is shown in Table 2.4 (Chapter 2). A graphic illustration of the conformation traits evaluated is shown in Figure 2.2 (Chapter 2). For all management and most of the conformation TOP, high values (close to 9) are desirable, while intermediate scores for traits such as weight, stature, rump angle, legs, teat placement would be preferred. However, classifying certain scores as desirable or undesirable is ambiguous and will depend on farmers' preferences or the particular production system.

3.3.5 Statistical analysis

The data was analysed using SAS software (Statistical Analysis System, version 9.4; SAS Institute Inc., Cary, NC, USA). In order to determine the structure and parametrisation of the models to be used, a first analysis of all of the data was conducted with the MEANS procedure of SAS to generate descriptive statistics. Additional statistics for each variable were obtained using the UNIVARIATE procedure. The results of these analyses revealed considerable levels of kurtosis and skewness for the TOP variables. Four different goodness-of-fit tests (Shapiro-Wilk, Kolmogorov-Smirnov, Anderson-Darling and Cramér-von Mises) were computed and the results confirmed a significant departure from normality for all TOP ($P<0.01$). Production and fertility data were not transformed and therefore real values of these traits were used for further analyses described below.

A Snell transformation, a scaling procedure which assumes an underlying continuous scale of measurement along which the scale categories represent intervals (Snell 1964), was applied to TOP. Other studies of TOP in New Zealand dairy cattle also transformed the scores using the Snell method in order to obtain variables with a distribution closer to normal (Cue et al. 1996; Berry et al. 2005). According to the intervals observed in the scale of scores, nine categories were defined for each TOP (intervals of 1.0 units) and 17 for BCS (intervals of 0.5 units). The method of Snell (1964) allowed to stabilise variances of TOP using three different approaches depending on the definition of the groups of observations: seasons, breeds or lactation number. After the Snell transformation, the goodness-of-fit tests still showed a non-normal distribution for all TOP. However, there was a considerable reduction of kurtosis and skewness in the distribution of all variables, except for front udder (Appendix Table A3). The best results were obtained when the groups of observations in the Snell transformation were defined by season. Average skewness and kurtosis using this approach were reduced by 50% and 32%, respectively. The resulting Snell scores using seasons as groups of observations are shown in the Appendix Table A4 and these were the scores used to evaluate the effects included in the analysis described below.

3.3.5.1 Analysis of production, fertility and TOP data

A mixed model with fixed and random effects was implemented using the MIXED procedure of SAS software. Production traits, fertility traits and TOP were modelled as a function of different effects which are described in the model below:

$$y_{ijklm} = \mu + S_i + B_j + L_k + C_l + SBC_{ijl} + b_1 d + a_m + e_{ijkl}$$

where y_{ijkl} is the production/fertility/TOP trait; μ is a general mean; S_i is the fixed effect of the i^{th} season; B_j is the fixed effect of the j^{th} breed; L is the fixed effect of the k^{th} lactation; C_l is the fixed effect of the l^{th} culling status (retained or culled); SBC_{ijl} is the interaction between the fixed effects S_i, B_j and C_l; $b_1 d$ is the regression coefficient for the covariation of days from median calving date; a_m is the animal random effect; e_{ijkl} is the random residual error.

The effects of season, breed, lactation number and culling on TOP were evaluated using the Snell scores previously obtained for all TOP except for front udder, which was analysed using actual scores (because of the reasons explained above). Therefore, P-values and significant differences between groups are based on analysis performed using Snell scores, but means and standard errors are based and reported on actual (non-transformed) TOP scores to facilitate interpretation and discussion of results.

3.3.5.2 Phenotypic correlations and repeatability

Phenotypic correlations were calculated between individual production variables and TOP. Pearson correlation coefficients were calculated using the CORR procedure of SAS. Absolute values lower than 0.20 were considered low correlations, absolute values between 0.20 and 0.40 were considered medium correlations, and absolute values higher than 0.40 were considered high correlations.

Repeatability of TOP was calculated using the variance components obtained from the analysis with the model described above. Repeatability was calculated as described in Van Vleck et al. (1987):

$$\text{repeatability} = \frac{\sigma_g^2 + \sigma_p^2}{\sigma_g^2 + \sigma_p^2 + \sigma_e^2}$$

Where σ_g^2 is the variance of genetic effects, σ_p^2 is the variance of permanent environmental effects, and σ_e^2 is the variance of temporary environmental effects.

3.4 Results

3.4.1 Descriptive statistics

Results from the analysis of the entire three seasons (2013-2015) are shown in Tables 3.2 and 3.3 for production traits and TOP, respectively. The means for MY, FY, PY and SCS were 3980 kg, 199 kg, 159 kg and 6.18, respectively, with an average lactation length of 257 days. Submission rates at 21 and 42 days after the start of mating were high (>90%). The herd had an average age of 4.85 years and the average BW and PW were 123 \$/5tDM and 150 \$/5tDM, respectively. The breed composition of the herd indicated that there was a higher proportion of Friesian genes in the herd.

Table 3.2. Mean, standard deviation (SD), minimum and maximum for production traits, fertility traits and herd characteristics of cows from Massey University Dairy 1 over three seasons

	Mean	SD	Minimum	Maximum
Production				
Days in milk	257.6	36.9	65.0	305.0
Milk yield, kg	3980.4	1064.9	1073.0	7200.0
Fat yield, kg	199.9	46.4	41.0	318.0
Protein yield, kg	159.2	38.7	42.0	259.0
SCS[1]	6.18	1.12	3.34	11.16
Liveweight, kg	480.8	56.8	349.5	640.5
Fertility				
SR21, %[2]	95.0	22.0	0.0	100.0
SR42, %[3]	99.0	9.0	0.0	100.0
SMFS, days[4]	11.10	7.82	0.00	58.00
Herd characteristics				
Age	4.85	1.96	2.00	12.00
BW, \$/5tDM[5]	122.6	38.3	7.0	255.0
PW, \$/5tDM[6]	149.5	92.3	-90.0	376.0
F[7]	0.52	0.37	0.00	1.00
J[8]	0.46	0.37	0.00	1.00
Other[9]	0.03	0.09	0.00	0.75

[1]SCS = Somatic cell score calculated as $\log_2$ (somatic cell count)
[2]SR21 = Submission rate at 21 days after the start of mating
[3]SR42 = Submission rate at 42 days after the start of mating
[4]SMFS = Interval from start of mating to first service
[5]BW = Breeding worth values extracted from the animal evaluation in May 2016.
[6]PW = Production worth
[7]F = Proportion of Holstein-Friesian
[8]J = Proportion of Jersey
[9]Other = Proportion of other breeds

Descriptive statistics for TOP had a higher variability for some particular traits (Table 3.3), especially those scored by the inspector such as stature, weight, udder support, front udder, rear teat placement and udder overall (SD >1.10). Lower variability was observed in the traits shed temperament, overall opinion, legs, front teat placement and BCS (SD <0.75). The effects of season, breed and lactation number on TOP are shown in Tables 3.8 to 3.12.

Table 3.3. Mean, standard deviation (SD), minimum and maximum for traits other than production of cows from Massey University Dairy 1 over three seasons

Trait	Mean	SD	Minimum	Maximum	Repeatability
Adaptability to milking	7.40	1.08	2.0	9.0	0.20
Shed temperament	8.01	0.26	5.0	9.0	0.45
Milking speed	6.67	0.81	2.0	9.0	0.52
Overall opinion	7.88	0.71	2.0	9.0	0.13
Stature	6.38	1.29	4.0	9.0	0.52
Weight	5.43	1.35	3.0	9.0	0.44
Body capacity	6.99	0.85	4.0	9.0	0.29
Rump angle	4.17	0.83	2.0	7.0	0.47
Rump width	6.42	0.99	3.0	9.0	0.22
Legs	6.10	0.73	4.0	8.0	0.03
Udder support	6.04	1.17	1.0	8.0	0.44
Front udder	5.67	1.29	2.0	9.0	0.37
Rear udder	6.17	0.94	2.0	8.0	0.24
Front teat placement	4.59	0.67	1.0	8.0	0.39
Rear teat placement	6.03	1.10	2.0	9.0	0.47
Udder overall	5.85	1.15	2.0	8.0	0.41
Dairy conformation	6.98	0.75	4.0	9.0	0.19
Body condition score	4.49	0.35	3.5	6.0	0.32

3.4.2 Production, fertility and herd parameters over seasons

There were significant differences between seasons for all production traits. Overall, cows had longer lactations (258 ± 2 days in milk) and a higher production of milk (3960 ± 52 kg), fat (203.4 ± 2.6 kg) and protein (157.9 ± 1.9 kg) in 2014 than the other two seasons. The lowest MY, FY and PY was observed in 2013 (3528 ± 64 kg, 178.0 ± 3.1 kg and 138 ± 2.4 kg, respectively), along with the highest average SCS (6.65 ± 0.10). No significant differences between seasons were observed for fertility traits (Table 3.4).

Table 3.4. Mean and standard error (SE) of production traits, fertility traits and herd characteristics of cows from Massey University Dairy 1 over three seasons

	2013		2014		2015		P-value
	Mean	SE	Mean	SE	Mean	SE	
Production							
Days in milk	239[b]	2	258[a]	2	239[b]	2	<0.0001
Milk yield, kg	3528[c]	64	3960[a]	52	3821[b]	52	<0.0001
Fat yield, kg	178.0[b]	3.1	203.4[a]	2.6	184.4[b]	2.6	<0.0001
Protein yield, kg	138.2[c]	2.4	157.9[a]	1.9	152.5[b]	1.9	<0.0001
SCS[1]	6.65[a]	0.10	6.25[b]	0.08	6.00[c]	0.08	<0.0001
Liveweight, kg	486.9[a]	3.17	483.8[a]	2.50	465.9[b]	2.60	<0.0001
Fertility							
SR21, %[2]	95.7	2.1	95.4	1.8	93.5	1.8	0.6587
SR42, %[3]	98.1	0.9	99.1	0.7	99.2	0.8	0.6086
SMFS, days[4]	10.86	0.74	10.25	0.61	11.10	0.63	0.6022
Herd characteristics							
Age	5.03	0.02	5.08	0.02	5.09	0.02	0.1425
BW, $/5tDM[5]	113[b]	3.14	116[b]	2.58	129[a]	2.65	0.0001
PW, $/5tDM[6]	145	8.71	137	7.16	144	7.37	0.7296
F[7]	0.50	0.01	0.51	0.01	0.50	0.01	0.8745
J[8]	0.49	0.01	0.47	0.01	0.48	0.01	0.6665
Other[9]	0.02	0.01	0.02	0.01	0.03	0.01	0.7823

[1]SCS = Somatic cell score calculated as $\log_2$ (somatic cell count)
[2]SR21 = Submission rate at 21 days after the start of mating
[3]SR42 = Submission rate at 42 days after the start of mating
[4]SMFS = Interval from start of mating to first service
[5]BW = Breeding worth values extracted from the animal evaluation in May 2016.
[6]PW = Production worth
[7]F = Proportion of Holstein-Friesian
[8]J = Proportion of Jersey
[9]Other = Proportion of other breeds

3.4.3 Production, fertility and herd parameters between breeds

Holstein-Friesian cows had a higher MY (4181 ± 71 kg) than Jerseys (3231 ± 71 kg) and crossbred cows (3897 ± 50 kg) over all three seasons (Table 3.5). PY was also significantly lower in the group of Jerseys (137.2 ± 2.6 kg), while F and FxJ had similar values for this trait (156.8 ± 2.6 kg and 154.6 ± 1.8 kg, respectively). The highest BW and PW were observed in the Jersey cows (137 ± 3 $/5tDM and 157 ± 8 $/5tDM, respectively).

Table 3.5. Mean and standard error (SE) of production traits, fertility traits and herd characteristics of Holstein-Friesian (F), Jersey (J) and crossbred cows (FxJ) from Massey University Dairy 1 over three seasons.

	F		FxJ		J		P-value
	Mean	SE	Mean	SE	Mean	SE	
Production							
Days in milk	245	2	246	2	246	2	0.9643
Milk yield, kg	4181[a]	71	3897[b]	50	3231[c]	71	<0.0001
Fat yield, kg	185.1[b]	3.4	195.1[a]	2.4	185.6[b]	3.4	0.0152
Protein yield, kg	156.8[a]	2.6	154.6[a]	1.8	137.2[b]	2.6	<0.0001
SCS[1]	6.42	0.11	6.33	0.08	6.15	0.11	0.2254
Liveweight, kg	513.1[a]	3.60	492.6[b]	2.57	430.7[c]	3.84	<0.0001
Fertility							
SR21, %[2]	95.6	2.2	93.8	1.5	95.2	2.1	0.7315
SR42, %[3]	99.1	0.9	98.3	0.6	98.9	0.9	0.6746
SMFS, days[4]	10.28	0.74	11.08	0.51	10.85	0.71	0.6679
Herd characteristics							
Age	5.09	0.03	5.05	0.02	5.06	0.03	0.3087
BW, \$/5tDM[5]	110[b]	3	111[b]	2	137[a]	3	<0.0001
PW, \$/5tDM[6]	120[b]	9	149[a]	6	157[a]	8	0.0058

[1]SCS = Somatic cell score calculated as $\log_2$ (somatic cell count)
[2]SR21 = Submission rate at 21 days after the start of mating
[3]SR42 = Submission rate at 42 days after the start of mating
[4]SMFS = Interval from start of mating (SM) to first service
[5]BW = Breeding worth values extracted from the animal evaluation in May 2016.
[6]PW = Production worth

3.4.4 Production, fertility and herd parameters over lactations

The lactation number had a significant effect on all production parameters except on days in milk (Table 3.6). Milk yield was significantly higher in cows with five or more lactations (>4258 ± 64 kg), while FY and PY were significantly higher in cows with four or more lactations (>206.5 ± 3.38 kg and 164.8 ± 2.5 kg, respectively). First lactation cows had the lowest MY, FY and PY (2587 ± 82 kg, 131.9 ± 4.1 kg and 102.4 ± 3.1 kg, respectively). The highest average SCS was found in cows in their sixth lactation (6.65 ± 0.13), while cows with four or less lactations had a significantly lower average SCS (<6.20 ± 0.10). No significant differences were found for submission rates between lactations. Moreover, the highest values for BW were observed during the first four lactations.

Table 3.6. Mean and standard error (SE) of production traits, fertility traits and herd characteristics over lactations of cows from Massey University Dairy 1

	Lactation number														P-value
	1		2		3		4		5		6		7		
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Production															
Days in milk	246	3.18	244	2.20	248	2.53	245	2.65	243	2.48	245	3.01	248	3.21	0.6192
Milk yield, kg	2587^{e}	82	2995^{d}	58	3810^{c}	63	4110^{b}	66	4258^{a}	64	4269^{a}	78	4357^{a}	93	<0.0001
Fat yield, kg	131.9^{d}	4.1	155.1^{c}	2.9	192.3^{b}	3.2	206.5^{a}	3.4	208.6^{a}	3.2	212.4^{a}	3.9	213.5^{a}	4.5	<0.0001
Protein yield, kg	102.4^{d}	3.1	120.8^{c}	2.2	153.4^{b}	2.4	164.8^{a}	2.5	168.0^{a}	2.4	168.2^{a}	2.9	169.3^{a}	3.4	<0.0001
SCS[1]	6.16^{bc}	0.13	6.17^{c}	0.09	6.20^{c}	0.10	6.16^{c}	0.11	6.18^{c}	0.10	6.65^{a}	0.13	6.56^{ab}	0.15	0.0132
Liveweight, kg	433.5^{f}	3.85	445.9^{e}	2.73	470.4^{d}	2.85	487.2^{c}	2.95	495.6^{b}	3.00	506.6^{a}	3.68	512.6^{a}	4.57	<0.0001
Fertility															
SR21, %[2]	97.4	2.9	94.7	2.0	95.0	2.3	95.1	2.4	94.8	2.3	97.0	2.7	90.0	2.9	0.6224
SR42, %[3]	99.4	1.2	97.6	0.8	98.6	1.0	98.5	1.0	99.7	0.9	99.4	1.1	98.4	1.2	0.6421
Herd characteristics															
BW, $/5tDM[5]	134^{ab}	4	137^{a}	3	131^{ab}	3	124^{bc}	4	115^{c}	3	98^{d}	4	97^{d}	4	<0.0001
PW, $/5tDM[6]	152	12	144	8	148	9	153	10	149	9	128	11	121	11	0.2263
F[7]	0.45^{c}	0.02	0.53^{a}	0.01	0.53^{a}	0.01	0.48^{bc}	0.02	0.51^{ab}	0.01	0.51^{ab}	0.02	0.50^{abc}	0.02	0.0013
J[8]	0.50	0.02	0.46	0.01	0.47	0.01	0.49	0.01	0.47	0.01	0.48	0.02	0.49	0.02	0.2141
Other[9]	0.05^{a}	0.01	0.01^{b}	0.01	0.01^{b}	0.01	0.03^{ab}	0.01	0.03^{ab}	0.01	0.01^{b}	0.01	0.02^{ab}	0.01	0.0782

[1]SCS = Somatic cell score calculated as Log_2 (somatic cell count)
[2]SR21 = Submission rate at 21 days after the start of mating
[3]SR42 = Submission rate at 42 days after the start of mating
[4]SMFS = Interval from start of mating to first service
[5]BW = Breeding worth values extracted from the animal evaluation in May 2016
[6]PW = Production worth
[7]F = Proportion of Holstein-Friesian
[8]J = Proportion of Jersey
[9]Other = Proportion of other breeds

3.4.5 Production, fertility and herd parameters in retained and culled cows

Least square means for TOP in retained and culled cows are presented in Table 3.7. Cows removed from the herd had shorter lactations (by 39 days), lower MY (by 472 kg/cow/year), FY (by 31.2 kg fat/cow/year), PY (by 22.1 kg/cow/year), and higher SCS (by 0.22) than cows retained in the herd (Table 3.7). Culled cows had a slightly lower submission rate at 42 days after the start of mating (97.7%) compared with retained cows (99.9%). Culled cows also had a lower BW (by 9 $/5tDM) compared to those that were retained in the herd. No significant differences were found in the breed composition between retained and culled cows.

Table 3.7. Mean and standard error (SE) of production and fertility traits and herd characteristics of retained and culled cows from Massey University Dairy 1 over three seasons

	Retained		Culled		P-value
	Mean	SE	Mean	SE	
Production					
Days in milk	265	1.27	226	2.12	<0.0001
Milk yield, kg	4006	41	3534	56	<0.0001
Fat yield, kg	204.7	1.9	173.5	2.8	<0.0001
Protein yield, kg	160.6	1.5	138.5	2.1	<0.0001
SCS[1]	6.19	0.06	6.41	0.09	0.0301
Liveweight, kg	478.7	2.13	479.0	2.76	0.9300
Fertility					
SR21, %[2]	95.7	1.1	94.1	1.9	0.4644
SR42, %[3]	99.9	0.5	97.7	0.8	0.0156
SMFS, days[4]	10.74	0.38	10.73	0.66	0.9931
Herd characteristics					
Age	5.06	0.01	5.07	0.02	0.8320
BW, $/5tDM[5]	124	2	115	3	0.0076
PW, $/5tDM[6]	150	4	134	8	0.0889
F[7]	0.51	0.01	0.50	0.01	0.5205
J[8]	0.48	0.01	0.48	0.01	0.8363
Other[9]	0.02	0.00	0.03	0.01	0.2014

[1]SCS = Somatic cell score calculated as $\log_2$ (somatic cell count)
[2]SR21 = Submission rate at 21 days after the start of mating
[3]SR42 = Submission rate at 42 days after the start of mating
[4]SMFS = Interval from start of mating (SM) to first service
[5]BW = Breeding worth values extracted from the animal evaluation in May 2016
[6]PW = Production worth
[7]F = Proportion of Holstein-Friesian
[8]J = Proportion of Jersey
[9]Other = Proportion of other breeds

3.4.6 Traits other than production over seasons

The TOP scores from the seasons 2013, 2014 and 2015 are shown in Table 3.8. The scores of three management TOP (adaptability to milking, milking speed and overall opinion) increased over time (more desirable scores), with significantly lower values seen in 2013 compared with the 2014 and 2015 seasons. Figure 3.1 shows more clearly the trend in the scores of management and conformation TOP over the three seasons. There were significant changes over time for most of the conformation TOP analysed. The traits of stature, body capacity, rump width, legs, rear teat placement and dairy conformation showed a significant decrease over time, with lower scores observed in the 2015 season. Conversely, rump angle, udder support, udder overall and BCS had a consistent increase over time, with the highest scores observed in 2015.

Table 3.8. Mean and standard error (SE) of traits other than production of cows from Massey University Dairy 1 for three seasons

Trait	2013		2014		2015		P-value
	Mean	SE	Mean	SE	Mean	SE	
Adaptability to milking	5.53^{b}	0.05	7.96^{a}	0.04	7.89^{a}	0.04	<0.0001
Shed temperament	7.95	0.03	8.00	0.02	8.02	0.02	0.0639
Milking speed	5.53^{b}	0.06	7.02^{a}	0.04	7.00^{a}	0.04	<0.0001
Overall opinion	7.33^{b}	0.07	7.98^{a}	0.05	7.95^{a}	0.05	<0.0001
Stature	6.34^{a}	0.07	6.43^{a}	0.06	6.10^{b}	0.06	0.0002
Weight	5.24^{b}	0.08	5.56^{a}	0.06	5.24^{b}	0.06	0.0014
Capacity	7.12^{a}	0.08	7.21^{a}	0.06	6.81^{b}	0.06	<0.0001
Rump angle	3.92^{b}	0.07	3.77^{b}	0.06	4.55^{a}	0.06	<0.0001
Rump width	6.40^{b}	0.09	6.75^{a}	0.07	6.09^{c}	0.07	<0.0001
Legs	6.38^{a}	0.06	6.37^{a}	0.05	5.76^{b}	0.05	<0.0001
Udder support	5.69^{b}	0.10	5.78^{b}	0.08	6.16^{a}	0.08	<0.0001
Front udder	5.81	0.12	5.46	0.09	5.72	0.10	0.0543
Rear udder	6.11	0.09	6.15	0.07	6.13	0.07	0.6198
Front teat placement	4.66^{a}	0.06	4.41^{b}	0.05	4.61^{a}	0.05	0.0013
Rear teat placement	6.27^{a}	0.10	5.96^{b}	0.08	5.74^{c}	0.08	<0.0001
Udder overall	5.64^{b}	0.10	5.64^{b}	0.08	5.95^{a}	0.08	0.0041
Dairy conformation	7.02^{ab}	0.07	7.12^{a}	0.06	6.86^{b}	0.06	0.0194
Body condition score	4.41^{b}	0.03	4.51^{a}	0.03	4.54^{a}	0.03	0.0056

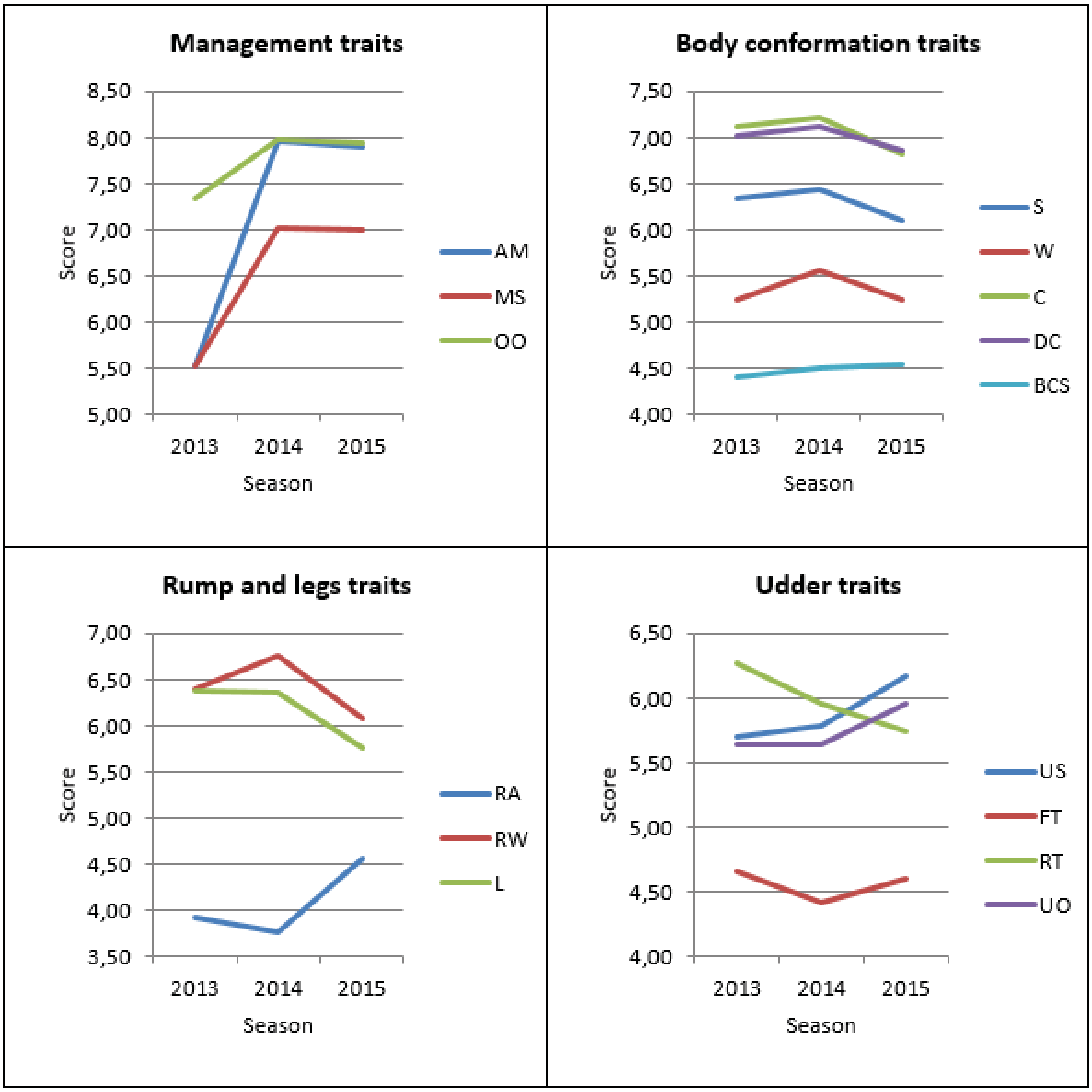


Figure 3.1. Trend of management and conformation traits from cows at Massey University Dairy 1 over three seasons. Adaptability to milking (AM), milking speed (MS), overall opinion (OO), stature (S), weight (W), body capacity (C), dairy conformation (DC), body condition score (BCS), rump angle (RA), rump width (RW), legs (L), udder support (US), front teat placement (FT), rear teat placement (RT), udder overall (UO)

3.4.7 Traits other than production between breeds

Significant differences were found between breeds for body type traits (stature, weight, rump width and dairy conformation) and udder traits (udder support, front udder, rear udder, front teat placement and udder overall). Holstein-Friesians were taller (stature=7.36), heavier (weight=6.40) and had a wider rump (rump width=6.74) than Jerseys (stature=4.88, weight=3.93 and rump width=6.05), while the crossbred cows showed intermediate values for these traits (Table 3.9). The highest scores for udder traits were observed in the group of Jerseys, which had the strongest udder support (6.19), strongest front and rear udder attachment (6.05 and 6.31, respectively) and the most desirable udder overall (6.13). On the other hand, crossbred cows showed the weakest front udder attachment (5.30). No significant differences between breeds were observed for management TOP.

Table 3.9. Mean and standard error (SE) of traits other than production of Holstein-Friesian (F), Jersey (J) and crossbred cows (FxJ) from Massey University Dairy 1 over three seasons

Trait	F		FxJ		J		P-value
	Mean	SE	Mean	SE	Mean	SE	
Adaptability to milking	7.10	0.05	7.21	0.03	7.07	0.05	0.2744
Shed temperament	7.98	0.03	8.01	0.02	7.98	0.03	0.2858
Milking speed	6.53	0.06	6.56	0.04	6.45	0.06	0.7682
Overall opinion	7.80	0.07	7.86	0.05	7.60	0.07	0.0946
Stature	7.36[a]	0.08	6.63[b]	0.06	4.88[c]	0.08	<0.0001
Weight	6.40[a]	0.09	5.71[b]	0.06	3.93[c]	0.09	<0.0001
Body capacity	7.15	0.08	6.95	0.06	7.05	0.08	0.0981
Rump angle	4.03	0.08	4.14	0.05	4.07	0.08	0.5118
Rump width	6.74[a]	0.09	6.45[b]	0.06	6.05[c]	0.09	<0.0001
Legs	6.11	0.06	6.18	0.04	6.22	0.06	0.7556
Udder support	5.73[b]	0.11	5.71[b]	0.08	6.19[a]	0.11	0.0027
Front udder	5.65[b]	0.12	5.30[c]	0.09	6.05[a]	0.12	<0.0001
Rear udder	6.02[b]	0.09	6.05[b]	0.07	6.31[a]	0.09	0.0388
Front teat placement	4.47[b]	0.07	4.50[b]	0.05	4.71[a]	0.07	0.0184
Rear teat placement	6.07	0.11	6.04	0.08	5.86	0.11	0.3774
Udder overall	5.57[b]	0.11	5.53[b]	0.08	6.13[a]	0.11	<0.0001
Dairy conformation	6.98[ab]	0.07	6.86[b]	0.05	7.16[a]	0.07	0.0029
Body condition score	4.51	0.04	4.52	0.03	4.44	0.04	0.2613

3.4.8 Traits other than production over lactations

Most conformation TOP showed significant differences over lactations. In general, there was a significant increase of stature, weight, body capacity and dairy conformation of cows as their number of lactations increased (Table 3.10 and Figure 3.2). A significant decrease in the scores for the cow's rump angle was observed over lactations (from 4.41 ± 0.09 to 3.81 ± 0.10). Rump width showed a curvilinear trend over time, with the lowest scores being observed at the beginning and at the end of the cow's productive life (6.22 ± 0.12 and 6.26 ± 0.12, respectively), while cows with the highest scores for this trait were those in their fifth lactation (6.62 ± 0.09). A similar pattern was observed in the score means for legs, with the straightest legs being observed in first lactation cows (5.94 ±0.08), while the ones with the most sickled/curved legs were cows in their fifth lactation (6.32 ± 0.07).

An overall decrease of the scores for most udder traits was observed over lactations. Udder support, front udder, rear udder and udder overall had significantly higher scores during first lactations, with a gradual decrease over time. The highest scores for udder support and front udder were observed in first lactation cows (6.38 ± 0.13 and 6.06 ± 0.15, respectively), while the lowest scores for these traits were observed after the seventh lactation (5.45 ± 0.14 and 5.31 ± 0.17, respectively). In the case of rear udder and udder overall, cows with the highest scores for these traits were those in their second lactation (6.33 ± 0.08 and 6.12 ± 0.09, respectively).

Table 3.10. Mean and standard error (SE) of traits other than production over lactations of cows from Massey University Dairy 1

Trait	Lactation number														P-value
	1		2		3		4		5		6		7		
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Adaptability to milking	7.11	0.06	7.12	0.04	7.20	0.05	7.14	0.05	7.11	0.05	7.10	0.06	7.11	0.06	0.5942
Shed temperament	7.92	0.03	7.98	0.02	7.99	0.03	7.99	0.03	7.99	0.03	8.01	0.03	8.03	0.04	0.8193
Milking speed	6.50	0.07	6.51	0.05	6.60	0.05	6.48	0.06	6.52	0.06	6.52	0.07	6.48	0.08	0.6121
Overall opinion	7.68	0.09	7.73	0.06	7.87	0.07	7.78	0.07	7.77	0.07	7.64	0.08	7.80	0.09	0.6543
Stature	5.69^{d}	0.10	5.87^{cd}	0.07	6.29^{b}	0.07	6.42^{ab}	0.08	6.53^{a}	0.07	6.58^{a}	0.09	6.64^{a}	0.11	<0.0001
Weight	4.62^{c}	0.10	4.85^{c}	0.07	5.25^{b}	0.08	5.51^{a}	0.08	5.66^{a}	0.08	5.74^{a}	0.10	5.80^{a}	0.11	<0.0001
Body capacity	6.56^{d}	0.10	6.81^{c}	0.07	6.89^{cb}	0.08	7.06^{b}	0.08	7.26^{a}	0.08	7.30^{a}	0.10	7.45^{a}	0.11	<0.0001
Rump angle	4.41^{a}	0.09	4.43^{a}	0.06	4.13^{b}	0.07	4.01^{bc}	0.07	3.94^{bc}	0.07	3.84^{c}	0.09	3.81^{c}	0.10	<0.0001
Rump width	6.22^{c}	0.12	6.37^{bc}	0.08	6.37^{bc}	0.09	6.51^{abc}	0.10	6.62^{a}	0.09	6.53^{ab}	0.11	6.26^{c}	0.12	0.0120
Legs	5.94^{c}	0.08	6.12^{bc}	0.06	6.10^{c}	0.07	6.13^{bc}	0.07	6.32^{a}	0.07	6.29^{ab}	0.08	6.28^{ab}	0.08	0.0023
Udder support	6.38^{a}	0.13	6.29^{a}	0.09	6.07^{ab}	0.10	5.84^{bc}	0.10	5.64^{cd}	0.10	5.49^{d}	0.12	5.45^{d}	0.14	<0.0001
Front udder	6.06^{a}	0.15	5.96^{a}	0.11	5.85^{ab}	0.12	5.61^{bc}	0.12	5.39^{c}	0.12	5.45^{c}	0.14	5.31^{c}	0.17	0.0031
Rear udder	6.25^{ab}	0.12	6.33^{a}	0.08	6.29^{ab}	0.09	6.12^{ac}	0.10	5.98^{c}	0.09	6.03^{bc}	0.11	5.91^{c}	0.13	0.0359
Front teat placement	4.51	0.08	4.52	0.06	4.59	0.06	4.65	0.07	4.55	0.06	4.45	0.08	4.66	0.09	0.1924
Rear teat placement	5.84	0.13	6.03	0.09	6.12	0.10	6.15	0.11	6.00	0.10	5.84	0.13	5.94	0.15	0.2213
Udder overall	6.10^{ab}	0.13	6.12^{a}	0.09	5.94^{ab}	0.10	5.78^{b}	0.11	5.42^{c}	0.10	5.46^{c}	0.12	5.38^{c}	0.15	<0.0001
Dairy conformation	6.71^{d}	0.09	6.85^{cd}	0.07	6.97^{bc}	0.08	7.06^{ab}	0.08	7.13^{ab}	0.07	7.03^{abc}	0.09	7.24^{a}	0.10	0.0007
Body condition score	4.55^{ab}	0.04	4.50^{ac}	0.03	4.42^{d}	0.04	4.42^{cd}	0.04	4.48^{ad}	0.03	4.52^{a}	0.04	4.52^{ab}	0.05	0.0496

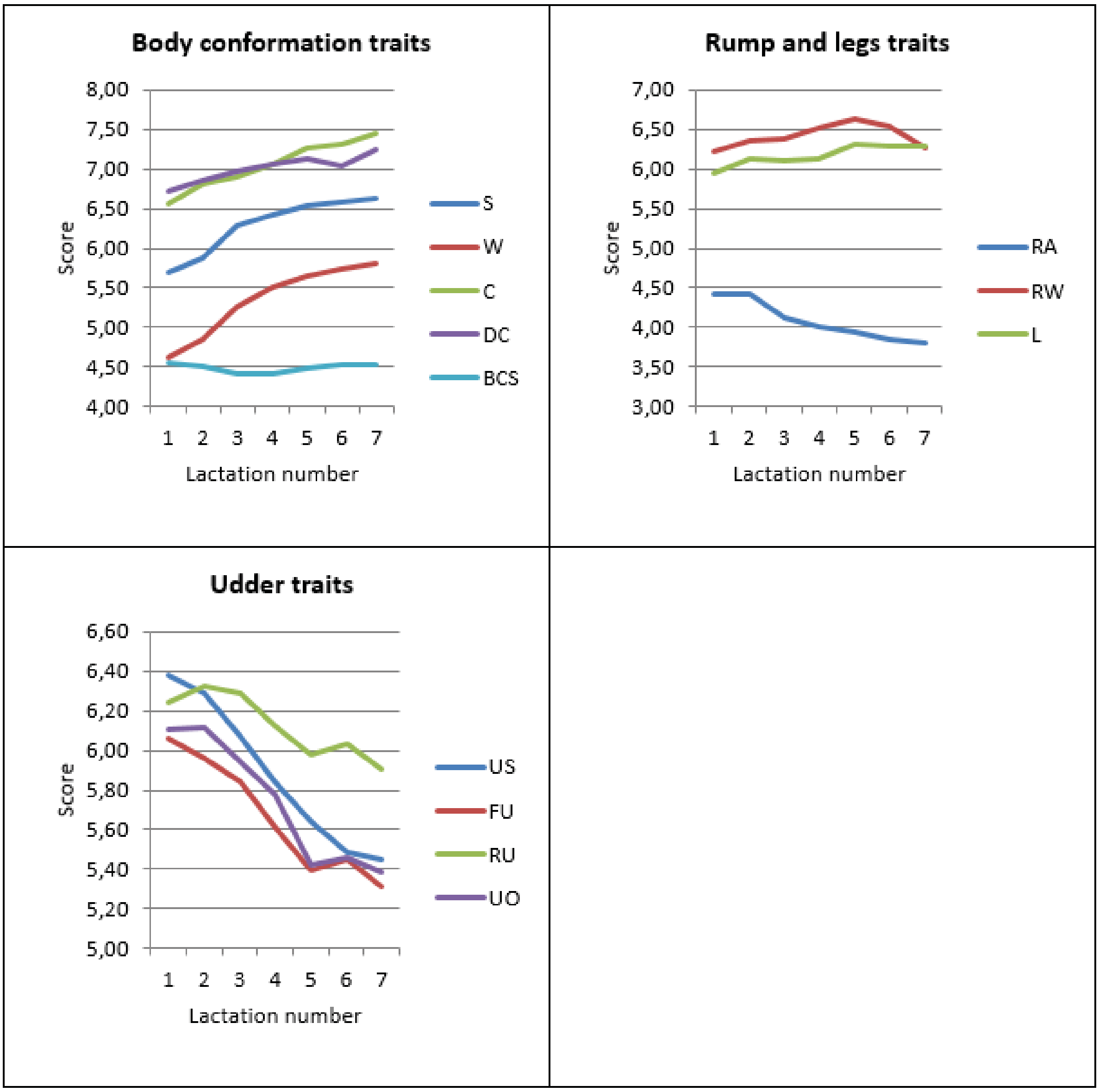


Figure 3.2. Trend of conformation traits from cows at Massey University Dairy 1 over lactations. Stature (S), weight (W), body capacity (C), dairy conformation (DC), body condition score (BCS), rump angle (RA), rump width (RW), legs (L), udder support (US), front udder (FU), rear udder (RU), udder overall (UO)

3.4.9 Traits other than production in retained and culled cows

There were significant differences between culled and retained cows for both management and conformation TOP (Table 3.11). Cows that were retained in the herd had a better adaptability to milking and overall opinion (7.23 ± 0.03 and 7.89 ± 0.04, respectively) than culled cows (7.02 ± 0.04 and 7.62 ± 0.06, respectively). Likewise, legs from cows that were removed from the herd were more sickled/curved (6.23 ± 0.06) than the legs from those that remained in the herd (6.11 ± 0.03).

The highest significant effects of culling were observed on udder type traits. Culled cows had a poorer udder overall score (5.48 ± 0.09) than retained cows (6.01 ± 0.06). Cows that were retained in the herd showed a stronger udder support (6.19 ± 0.06) and front udder attachment (5.85 ± 0.07) than those that were culled (5.56 ± 0.09 and 5.48 ± 0.10, respectively). Scores for rear udder were higher for retained cows (6.25 ± 0.05) than culled cows (6.01 ± 0.08). Moreover, culled cows showed a wider separation (lower scores) of their front teats (4.45 ± 0.06) and also a wider separation of their rear teats (5.87 ± 0.09) than cows that remained on the farm, which had their front and rear teats closer to the centre of the quarters (4.67 ± 0.04 and 6.10 ± 0.06, respectively).

Table 3.11. Mean and standard error (SE) of traits other than production of retained and culled cows from Massey University Dairy 1 over three seasons

Trait	Retained		Culled		P-value
	Mean	SE	Mean	SE	
Adaptability to milking	7.23	0.03	7.02	0.04	0.0052
Shed temperament	8.01	0.02	7.96	0.02	0.1607
Milking speed	6.59	0.03	6.43	0.05	0.3940
Overall opinion	7.89	0.04	7.62	0.06	0.0011
Stature	6.31	0.05	6.27	0.07	0.6205
Weight	5.33	0.05	5.36	0.07	0.6768
Body capacity	7.02	0.04	7.08	0.07	0.3282
Rump angle	4.11	0.04	4.05	0.06	0.3788
Rump width	6.37	0.05	6.45	0.08	0.4158
Legs	6.11	0.03	6.23	0.06	0.0458
Udder support	6.19	0.06	5.56	0.09	<0.0001
Front udder	5.85	0.07	5.48	0.10	0.0027
Rear udder	6.25	0.05	6.01	0.08	0.0153
Front teat placement	4.67	0.04	4.45	0.06	0.0015
Rear teat placement	6.10	0.06	5.87	0.09	0.0216
Udder overall	6.01	0.06	5.48	0.09	<0.0001
Dairy conformation	7.06	0.04	6.95	0.06	0.2111
Body condition score	4.48	0.02	4.50	0.03	0.8300

3.4.10 Phenotypic correlations between production and fertility traits with traits other than production

High positive phenotypic correlations were observed between stature with MY (0.53) and PY (0.41), and between weight with MY (0.55) and PY (0.44) (Table 3.12). Medium positive correlations were observed between FY with stature (0.29) and weight (0.32), and between adaptability to milking with DIM (0.25), MY (0.21) and PY (0.24). On the other hand, low to medium negative phenotypic correlations were seen between udder support with MY (-0.20), FY (-0.18) and PY (-0.19), between front udder with MY (-0.21), FY (-0.16) and PY (-0.19), and also between udder overall with MY (-0.21), FY (-0.15) and PY (-0.18). Correlations between TOP and fertility traits were generally very low (<0.1). Somatic cell score also showed very low correlations with most of the TOP, although slightly higher negative correlations were observed between SCS with adaptability to milking (-0.11), udder support (-0.13) and udder overall (-0.13).

Table 3.12. Phenotypic correlations between traits other than production, production and fertility traits in cows from Massey University Dairy 1 over three seasons

	DIM[1]	MY[2]	FY[3]	PY[4]	SCS[5]	SR21[6]	SR42[7]	SMFS[8]
Adaptability to milking	0.25	0.20	0.19	0.24	-0.11	0.00	0.04	-0.04
Shed temperament	0.04	0.08	0.08	0.09	0.06	-0.01	0.00	0.04
Milking speed	0.18	0.12	0.11	0.13	-0.06	0.04	0.06	-0.07
Overall opinion	0.06	0.10	0.08	0.09	-0.08	0.06	0.10	-0.09
Stature	-0.08	0.53	0.29	0.41	0.09	-0.01	0.02	-0.01
Weight	-0.06	0.55	0.32	0.44	0.09	-0.02	0.02	-0.03
Body capacity	0.00	0.16	0.19	0.16	0.10	0.03	0.00	-0.02
Rump angle	-0.02	-0.16	-0.21	-0.13	-0.06	-0.02	-0.04	0.00
Rump width	0.03	0.17	0.13	0.13	0.08	-0.05	-0.02	0.04
Legs	-0.06	0.00	0.05	-0.01	0.13	0.06	0.03	-0.09
Udder support	0.17	-0.20	-0.18	-0.19	-0.14	0.01	0.02	0.02
Front udder	0.08	-0.21	-0.16	-0.19	-0.10	-0.01	0.00	0.01
Rear udder	0.06	-0.12	-0.08	-0.11	-0.05	0.00	0.02	-0.01
Front teat placement	0.10	0.00	0.04	0.01	-0.04	-0.05	-0.03	0.02
Rear teat placement	0.08	0.05	0.03	0.02	0.05	0.01	0.02	0.00
Udder overall	0.14	-0.21	-0.15	-0.18	-0.12	0.00	-0.01	0.02
Dairy conformation	0.06	0.11	0.18	0.12	-0.02	0.07	0.06	-0.06
Body condition score	0.07	-0.13	-0.15	-0.12	0.08	0.00	0.00	-0.06

[1]DIM = Days in milk
[2]MY = Milk yield
[3]FY = Fat yield
[4]PY = Protein yield
[5]SCS = Somatic cell score calculated as $\log_2$ (somatic cell count)
[6]SR21 = Submission rate at 21 days after the start of mating
[7]SR42 = Submission rate at 42 days after the start of mating
[8]SMFS = Interval from start of mating to first service

3.4.11 Phenotypic correlations among traits other than production

There were positive phenotypic correlations in the group of management TOP (Table 3.13). A very high correlation was observed between adaptability to milking and milking speed (0.84), although other high correlations were found between overall opinion with adaptability to milking (0.54) and milking speed (0.60).

There were positive and negative phenotypic correlations in the group of conformation TOP. High positive correlations were observed between stature and weight (0.94), between udder support with front udder (0.64), rear udder (0.62) and udder overall (0.84), and between udder overall with front udder (0.85) and rear udder (0.73). Other high positive correlations were found between front udder and rear udder (0.62), between front teat placement and rear teat placement (0.52), and between body capacity and dairy conformation (0.49). On the other hand, medium negative phenotypic correlations were found between rump angle with body capacity (-0.21), rump width (-0.23) and legs (-0.21), and between udder support and legs (-0.27).

Table 3.13. Phenotypic correlations among traits other than production in cows from Massey University Dairy 1 over three seasons.

	ST	MS	OO	S	W	C	RA	RW	L	US	FU	RU	FT	RT	UO	DC	BCS[1]
Adaptability to milking (AM)	0.16	***0.84***	***0.54***	0.02	0.09	0.02	0.06	0.04	-0.20	0.18	-0.01	0.05	-0.05	-0.11	0.11	0.06	0.18
Shed temperament (ST)		0.09	0.26	0.05	0.07	0.10	-0.04	0.00	-0.05	0.02	-0.01	-0.02	0.00	0.03	0.00	0.01	0.12
Milking speed (MS)			***0.60***	0.04	0.09	-0.01	0.04	0.05	-0.16	0.17	0.01	0.05	-0.05	-0.10	0.12	0.02	0.17
Overall opinion (OO)				0.10	0.10	0.03	-0.02	0.03	-0.03	0.09	0.01	0.02	-0.02	-0.02	0.07	0.02	0.10
Stature (S)					***0.95***	0.32	-0.18	0.37	0.03	-0.16	-0.16	-0.09	-0.11	0.09	-0.17	0.13	0.05
Weight (W)						0.38	-0.18	0.35	-0.01	-0.16	-0.15	-0.07	-0.11	0.07	-0.17	0.12	0.12
Body capacity (C)							-0.21	0.29	0.16	-0.06	0.09	0.07	-0.06	0.00	0.04	***0.49***	0.31
Rump angle (RA)								-0.23	-0.21	0.03	-0.05	-0.06	-0.02	-0.10	-0.01	-0.10	0.04
Rump width (RW)									0.31	0.00	-0.01	0.01	-0.07	0.08	0.01	0.31	0.02
Legs (L)										-0.27	-0.11	-0.12	-0.08	0.04	-0.16	0.19	-0.01
Udder support (US)											***0.64***	***0.62***	0.31	0.20	***0.84***	0.14	0.06
Front udder (FU)												***0.62***	0.24	0.11	***0.85***	0.24	0.11
Rear udder (RU)													0.15	0.10	***0.74***	0.24	0.06
Front teat placement (FT)														***0.52***	0.30	0.04	-0.06
Rear teat placement (RT)															0.15	-0.02	-0.13
Udder overall (UO)																0.23	0.09
Dairy conformation (DC)																	0.08

[1]BCS, body condition score.

Estimates of correlation coefficients greater than |0.08| are significantly different from 0 ($P<0.05$).

Values in bold and italic text are the most relevant correlations for the results and the discussion.

3.4.12 Repeatability of traits other than production

Repeatability values of TOP ranged from 0.03 to 0.52 (Table 3.14). The highest repeatability was observed for milking speed and stature (0.52 for both), although high values (>0.40) were also observed for traits such as shed temperament, weight, rump angle, udder support, rear teat placement and udder overall. On the other hand, the scores for overall opinion, legs and dairy conformation showed the lowest repeatability (0.13, 0.03 and 0.19, respectively).

Table 3.14. Repeatability of traits other than production in cows from Massey University Dairy 1 for three seasons

Trait	$\sigma_g^2 + \sigma_p^2$	σ_e^2	Repeatability
Adaptability to milking	0.04	0.17	0.20
Shed temperament	0.03	0.04	0.45
Milking speed	0.17	0.16	0.52
Overall opinion	0.06	0.37	0.13
Stature	0.32	0.29	0.52
Weight	0.30	0.38	0.44
Body capacity	0.18	0.45	0.29
Rump angle	0.25	0.28	0.47
Rump width	0.18	0.63	0.22
Legs	0.01	0.41	0.03
Udder support	0.47	0.59	0.44
Front udder	0.54	0.91	0.37
Rear udder	0.20	0.64	0.24
Front teat placement	0.16	0.26	0.39
Rear teat placement	0.54	0.60	0.47
Udder overall	0.45	0.65	0.41
Dairy conformation	0.10	0.43	0.19
Body condition score	0.04	0.08	0.32

*σ_g^2 = Genetic variance; σ_p^2 = Permanent environment variance; σ_e^2 = Residual variance

3.5 Discussion

Production, fertility and TOP variables were analysed over seasons, between breeds and over lactations. Differences for these traits were also examined between culled cows and those that were retained in the herd. Phenotypic correlations and repeatability values of these traits were also analysed.

The lactation length, milk yield, fat yield, protein yield, SCS and average liveweight were similar to those reported by Lembeye et al. (2016b) in the same herd but using information only from the seasons 2013 and 2014. Overall, cows from Massey University Dairy 1 had a higher MY (3980.4±1064.9 kg), FY (199.9±46.4 kg) and PY (159.2±38.7 kg) than the average MY (2950±24.6 kg), FY (153.4±1.18 kg) and PY (118.0±0.95 kg) in OAD dairy farms of New Zealand (Lembeye et al. 2015). Moreover, cows in the present study had a lower average SCS (6.18±1.12) than the average SCS reported for OAD (6.46±0.02) and TAD dairy farms (6.20±0.02) (Lembeye et al. 2015). This differs from other studies that have found a higher SCS in cows milked OAD compared with cows milked TAD (Lacy-Hulbert et al. 2005; Clark et al. 2006), which could be due to differences in the management conditions of the farms.

The means for TOP are presented in Table 3.3. These means include the scores from different lactations. Studies on TOP usually report scores only from first lactation cows because this is the only group of the herd that is scored for TOP in the evaluation systems of New Zealand and other countries (Larroque & Ducrocq 2001; Caraviello et al. 2004; DairyNZ 2014). Therefore, only TOP scores from first lactation cows (shown in Table 3.10) were used to make comparisons. Most TOP analysed showed higher means than those reported by Ahlborn (1995) and Winkelman et al. (2000), although scores for traits such as stature (5.69), weight (4.62), body capacity (6.56), legs (5.94) and front teat placement (4.51) were similar to those reported in those studies. Management TOP in first lactation and all lactations (Table 3.10) showed a lower variation than conformation TOP, which differs from results of other studies in New Zealand dairy cattle where management TOP showed higher variation than conformation TOP (Ahlborn 1995; Cue et al. 1996; Winkelman et al. 2000; Berry et al. 2005). This might be explained first by the sample size used in the present study, which is small compared with other studies that over used between 20,000 to over 700,000 records (Ahlborn 1995; Cue et al. 1996; Winkelman et al. 2000; Berry et al. 2005). Secondly, the possible effect of selecting cows for better management TOP in the herd of Massey University Dairy 1 could also have reduced the variation of these traits, but this is difficult to compare with other studies since these include hundreds of herds that could have different breeding objectives.

The scores for all management TOP, except shed temperament, were significantly lower in 2013 compared with the subsequent seasons, which possibly indicates an improvement of these traits over time in the herd as selection results in the management TOP move in a positive optimal direction. The scores of management TOP in the 2014 and 2015 (not 2013) seasons were higher than those reported in both registered and commercial New Zealand dairy cattle by Winkelman et al. (2000) and Berry et al. (2005). Therefore, on average, cows from the Massey University Dairy 1 had an improved adaptability to milking, faster milking speed and a better overall opinion from farmers.

3.5.1 Traits other than production between breeds

Holstein-Friesians were taller and heavier than crossbred and Jersey cows, which has also been shown in cows milked TAD (Ahlborn 1995; Cue et al. 1996; Berry et al. 2005). However, contrary to other studies in New Zealand dairy cattle where Jerseys showed the highest scores for rump width, the group of Jerseys from the herd in this study had the lowest scores for this trait. This means that Jersey cows from Massey University Dairy 1 have a narrower rump, which could be due to a particular correlated response to previous selection schemes made in this herd and the genetic correlations between rump width with other TOP in this population. On the other hand, the highest scores for most udder traits in this study were observed in Jerseys. This has also been observed in commercial and registered New Zealand dairy cattle milked TAD (Berry et al. 2005), where Jersey cows showed better udder conformation.

3.5.2 Trends in traits other than production over seasons

There were positive phenotypic correlations within particular groups of traits (e.g. among stature, weight, body capacity, rump width, legs and dairy conformation and among udder support, front udder, rear udder and udder overall). Particular high values were observed between weight and stature (0.95), between body capacity and dairy conformation (0.49) and between udder support with front udder (0.64), rear udder (0.62) and udder overall (0.84). A previous analysis of the phenotypic correlations among TOP in Massey University Dairy 1 that only included one production season (2013-2014) also showed high correlations between weight and stature (0.95), and between udder support, front udder, rear udder and udder overall (0.55 to 0.88) (Harris 2015). Similar correlations were reported by Ahlborn (1995) and Cue et al. (1996) in New Zealand dairy cattle, with positive phenotypic correlations observed between stature, weight, body capacity, rump width and dairy conformation (0.18 to 0.96), and also between udder support, front udder, rear udder and udder overall (0.42 to 0.96). Therefore, cows with a high score for dairy conformation were taller, heavier, more capacious and with a wider rump. Likewise, cows with a higher score for udder overall had better udder support, stronger front udder and higher rear udder.

The decrease in the scores for stature, body capacity, rump width, legs, rear teat placement and dairy conformation over the seasons was accompanied by a simultaneous increase in the scores for rump angle, udder support, udder overall and BCS, which indicates that these groups of traits varied together over time but in a different direction (increase for the former and decrease for the latter). This is in part associated with the positive phenotypic correlations described above within each of these groups of traits and it might represent a correlated response to selection. Hansen (2000) showed a correlated response of conformation traits to selection for higher production over 5 years in American Holstein-Friesians, with cows from the selection line being taller, stronger and deeper, with better udder support and rear udder than cows from the control line. Kelm & Freeman (2000) also found a larger distance between front teats and deeper udders in selection lines for milk yield compared with control cows over a period of 20 years. An extended period to the present study, including future generations of cows, would be necessary in order to continue the evaluation of this correlated response to selection and to identify any change of these trends over time.

In light of the trends seen over three seasons, cows from Massey University Dairy 1 appear to have stronger udder support and more desirable udder overall conformation over time, possibly due to selection for these traits. Despite there being a reduction in the stature, body capacity and dairy conformation of cows from the herd in this study, these traits still show higher values than those reported by Winkelman et al. (2000) and Berry et al. (2005) in both commercial and registered New Zealand dairy cattle. The negative trend observed for legs over time is in part desirable as the initial higher scores in the 2013 and 2014 seasons indicated a larger curvature of the rear legs of cows, which could lead to long and curled toes with little depth of heel (Aitken 2011). Intermediate scores are preferred for leg conformation as extremely straight or curved legs have been associated with a decreased functional survival of cows (Sewalem et al.

2004; Berry et al. 2005). On the other hand, the negative trend for rear teat placement over time would indicate that, on average, the rear teats of these cows are getting closer together or, in other words, teats moved from a lateral placement towards a more medial placement in the rear quarters. These could have facilitated the milking routine in these animals, as well-centred teats fit the teat cups of the milking machine better. Nevertheless, intermediate scores for front and rear teat placement have been associated with a higher survival of Canadian and New Zealand dairy cattle (Sewalem et al. 2004; Berry et al. 2005). Therefore, cows with an extremely lateral or an extremely medial teat placement would more likely to be culled than cows with intermediate scores and nearly centre fore and rear teat placement.

Previous studies showed phenotypic correlations among conformation TOP in Massey University Dairy 1 (Harris 2015). However, apart from conformation TOP, the present study also included management TOP and the analyses of the scores for these traits over seasons. The overall improvement of adaptability to milking, milking speed and overall opinion over the three seasons might be due to a correlated response of these traits to selection for better management behaviour. This is in part corroborated by the high correlations found between these traits (Table 3.13). Indeed, selection of cows with better shed temperament, adaptability to milking and milking speed is more critical in OAD milking, as cows feel more discomfort due to the udder distension produced by reduced milking frequency (Gleeson et al. 2007; Holmes 2012). Nevertheless, it is important to note that these management TOP are scored by the herd manager. Despite the fact that there was no change of this person in Massey University Dairy 1 over the three seasons, the scoring of these management TOP might have been influenced by changing attitudes of the herd manager over time.

3.5.3 Effect of culling

Overall, culling of cows with undesirable scores for management and conformation TOP will affect the average score for these traits in the herd. Moreover, there was no significant difference for age between retained and culled cows, and therefore, culling of cows was made regardless of their age. This might explain the better average scores observed in different age groups of the herd, including the group of older cows.

Differences in production and TOP between culled and non-culled cows have not been studied in OAD milking farms. In the present study, culled cows had a lower production and poorer fertility than non-culled cows, which has also been shown in TAD herds (Compton et al. 2016a). The adaptability to milking and overall opinion was better in non-culled cows, which is expected as these traits relate to the management of the cows and describe how well they fit into the milking routine. Furthermore, the scores for udder traits were significantly lower in culled cows than in non-culled cows. Culled cows had a weaker udder support (5.56), looser front udder (5.48) and lower rear udder (6.01) than non-culled cows (6.19, 5.85 and 6.25 for udder support, front udder and rear udder, respectively). This, along with the high phenotypic correlations (0.61 to 0.84) found among udder traits (except teat placement), could explain the less desirable udder overall score observed in culled cows (5.48) compared with those that remained on the farm (6.01).

The poorer udder conformation observed in culled cows might be influenced by the strength of the suspensory ligament. It has been shown that the weakness of the suspensory ligament can cause undesirable changes in the udder exterior characteristics and location, with these changes usually being irreversible (Atkins et al. 2008). The strength of the suspensory ligament, measured through the udder support score, determines the shape and height of the udder (Aitken 2011). Therefore, the weaker udder support observed in the group of culled cows from the Massey University Dairy 1 herd could have affected the rest of the udder traits.

There were no significant differences for age, breed proportion and PW between retained and culled cows. This is contrary to other studies in dairy cattle milked TAD where cows with lower PW or of an older age were expected or tend to leave the herd sooner than younger cows with a higher PW (Xu & Burton 2003; Clark et al. 2013). Therefore, poor fertility and poor udder conformation might have a larger influence than the PW and the age of cows on the culling decisions in herds milked OAD.

3.5.4 Effect of lactation number on TOP

There was a positive trend over lactations in the scores of some conformation TOP such as stature, weight, body capacity and dairy conformation. On the other hand, there was a negative trend over lactations in the scores of most udder traits (Figure 3.2). These results indicate that older cows with a higher number of lactations were heavier and more capacious than younger cows. Moreover, cows got lower scores for udder traits and therefore a poorer udder conformation as they got older and the number of lactations increased. A significant effect of lactation number on TOP was also shown by Do et al. (2010) in American Holsteins, and more recently by Marinov et al. (2015) and Khan & Khan (2015) in Bulgarian Holsteins and Sahiwal cows, respectively. The significant effect of lactation number on udder traits is possibly caused by the stretching process that the suspensory ligaments undergo as a consequence of the cow's normal maturity. An excessive stretching of these ligaments will potentially cause low, pendulous udders which are more prone to injury and infection (Atkins et al. 2008).

3.5.5 Repeatability

Management TOP (such as shed temperament and milking speed) and conformation TOP (such as rump angle, udder support, rear teat placement and udder overall) showed high values of repeatability. Analysis of repeated records for TOP have been made in American dairy cattle. The values of repeatability for stature, legs and rump angle obtained by Gengler et al. (1997) in American Jerseys (0.57 – 0.60, 0.25 and 0.52 – 0.54 for stature, legs and rump angle, respectively) are higher than those obtained in the present study (0.52, 0.03 and 0.47 for stature, legs and rump angle, respectively). Dechow et al. (2003) also found a higher repeatability for stature in American Holsteins (0.64), while BCS had a similar repeatability (0.33) to the one obtained in the herd from Massey University Dairy 1 herd (0.32). Likewise, the score for front udder attachment had a similar value of repeatability in the present study (0.37) compared with the values obtained for this parameter by Gengler et al. (1997) in American Jersey cows (0.36 – 0.38). On the other hand, udder support had a higher repeatability in cows from Massey University Dairy 1 herd (0.44) than American Holsteins (0.36 – 0.39) (Gengler et al. 1997). These differences are possibly due to the different conditions in which animals are kept between different studies. Furthermore, repeatability of these traits in the present analysis could have differed from other studies because this parameter is also dependable on the nature of the trait and the particular genetic properties of the population analysed (Van Vleck et al. 1987). In the present study, the effect of OAD milking could have largely influenced the repeatability of TOP. Repeatability is a measure of the strength of the relationship between repeated records for a trait in a population, which includes the variance of genetic and permanent environmental effects (Bourdon 2000). These effects permanently influence an animal's performance for repeated traits such as production traits or TOP. However, the shifting from TAD to OAD represents a change in the environment that, as previously discussed, might have accelerated the normal decline rate of udder conformation, which in turn would have affected the relationship between repeated records of TOP over lactations. On the other hand, it is important to note that the inspectors who scored the conformation TOP varied over the seasons. This was a source of variation that could not be controlled in this study and it might explain the particular low repeatability value found for leg conformation.

Nevertheless studies of repeatability of these traits in New Zealand dairy cows milked TAD would be required in order to better compare and evaluate the effect of OAD on any genetic parameter. The high values of repeatability obtained in the present study for TOP such as shed temperament, milking speed, rump angle, udder support, rear teat placement and udder overall, suggest that culling on the basis of the score for these traits would improve these management and conformation characteristics in herds recently shifted to OAD. Larger studies including more TOP records from more OAD farms is recommended in order to increase the robustness of these analyses.

3.6 Conclusions

The results of this study showed a significant effect of season, lactation number and breed on TOP. The scores for some management and conformation TOP were significantly different between retained and culled cows. Adaptability to milking, overall opinion and udder conformation might have a higher influence than the age, breed and production worth of cows on the culling decisions of OAD dairy farms. The trends of TOP over time might be the result of a correlated response to selection for better udder conformation, although an extended evaluation (including future seasons) would be required in order to evaluate any change in the trends of TOP over time in herds that have moved from TAD to OAD milking.

Chapter 4

Analysis of factors that influence the survival of dairy cows milked once a day

Paper *“Culling reasons in once-a-day milking cows and differences in production and type traits between retained and culled cows”* published in the Proceedings of the New Zealand Society of Animal Production (Vol 77, 2017)

Paper *“Factors that influence the survival of dairy cows milked once a day”* submitted to the New Zealand Journal of Agricultural Science

4.1 Abstract

The departure of cows from dairy herds for reasons that are not of the farmer's choice has a negative impact on the profitability of the farm enterprise. Factors that influence the survival of cows milked once a day (OAD) in New Zealand have not been studied. Culling reasons were investigated in the herd from Massey University Dairy 1 for three consecutive seasons from 2013 to 2015. A Cox proportional hazard model was implemented to identify the factors that influenced the herd culling decisions. The main causes of culling were low fertility (37.2%), poor udder conformation (19.9%) and low production (12.8%). Overall, cows with an empty status, low milk yield and low milk solids yield had a higher likelihood of being culled than high production pregnant cows. Holstein-Friesian and crossbred cows had 2.06 (95%CI=1.13-3.74) and 2.61 (95%CI=1.58-4.31) increased likelihood of culling compared with Jerseys. Cows with a score of ≤7 for adaptability to milking were more likely to be culled than cows with a score of ≥8 (HR=2.84, 95%CI=1.75-4.59). Cows with a body capacity of ≤5 were more likely to be culled than cows with a score of 6 (HR=4.19, 95%CI=1.79-9.81), while cows with a score of 6 were less likely to be culled than cows that scored 7 (HR=0.51, 95%CI=0.30-0.88) or ≥8 (HR=0.36, 95%CI=0.20-0.66). Cows with a score of 5 or 6 for leg conformation had a lower likelihood of being culled than cows with a score ≤7 (HR=0.38, 95%CI=0.17-0.85 and HR=0.41, 95%CI=0.25-0.65, respectively). Cows that scored 3 for rump angle had a HR of 1.87 (95%CI=1.13-3.10), 3.69 (95%CI=2.06-6.61) and 3.68 (95%CI=1.19-11.37) when compared with cows that scored 4, 5 and 6 for this trait, respectively. Cows that scored 4 or less for udder support had a higher likelihood of being culled when compared with cows that scored 6 (HR=2.51, 95%CI=1.45-4.34), 7 (HR=2.01, 95%CI=1.10-3.68) or 8 (HR=3.89, 95%CI=1.47-10.29). Udder conformation had a higher influence on the culling decisions of cows milked OAD. Breed, fertility, production level, adaptability to milking, body capacity, rump angle, leg conformation and udder support are all important factors that affect the survival of cows milked OAD.

4.2 Introduction

New Zealand dairy cattle have been traditionally milked twice a day (TAD). However, in the last few years, many dairy farms have been using once a day milking for the whole season (5%) and also as a tactical option (17%) for expansion of the herd or to avoid the effects of predicted feed shortfalls (Stachowicz et al. 2014; DairyNZ 2016a). Multiple advantages in the fertility and health status of the herd have been observed in farms using whole season once a day (OAD) (Clark et al. 2006; O'Driscoll et al. 2010). On the other hand, there is a negative effect of this strategy on the milk volume and the milk solids yield of cows (Clark et al. 2006; Lembeye et al. 2016a). Moreover, problems related to udder conformation and milking management have also been reported in cows milked OAD which could have important consequences for the culling decisions of these herds (Holmes 2012; McCarthy 2012).

Culling decisions and optimal culling rates are especially important in dairy herds when replacement costs are high and milk prices are low, as these conditions would make non-optimal culling decisions expensive (Hadley et al. 2006). Culling is the result of an economic strategy to manage the risk of future economic loss, and is influenced by commercial, social, management, and animal disease factors. Understanding the extent and the causes of culling is challenging because of the several factors involved (Compton et al. 2016a; Compton et al. 2016b). Moreover, the analysis of longevity is difficult because of the presence of incomplete records (censored data), such as those from cows with unknown culling dates (Berry et al. 2005). Logistic regression analyses have been used to evaluate the influence of several factors on the survival of dairy cattle (Bell et al. 2010; Dubuc et al. 2011; Chiumia et al. 2013). However, survival analyses have the advantage of accounting for censored data and handling the non-normal distribution of longevity (Sasaki 2013).

In New Zealand, there is limited literature on the culling reasons of dairy cattle. In both TAD and OAD dairy herds, it has been reported that the most common reasons for culling cows are poor reproductive performance and low production (Xu & Burton 2003; DairyNZ 2016a). Udder-related problems were reported as a cause of culling in OAD dairy farms, but no differentiation between culling for conformation and culling for mastitis was made (DairyNZ 2016a). In a survival analysis to study traits other than production (TOP) in New Zealand dairy cattle milked TAD, the udder-related TOP had the largest influence on functional longevity (Berry et al. 2005). In the case of OAD milking systems, production performance and TOP were significantly different between culled and non-culled cows (Chapter 3). However, the specific culling reasons of cows milked OAD and the factors that influence the survival of cows milked OAD have not been addressed. The aim of this study was to investigate the reasons for culling and the main factors affecting the survival of cows that are milked OAD.

4.3 Materials and methods

4.3.1 Farm and animals

Data from the herd at Massey University Dairy 1 was used for the present study. This is a 120 ha pasture-based farm located in the Manawatu region of New Zealand, at 35 m above sea level and with an average annual rainfall of 980 mm. Soils are well to excessively-well drained, prone to summer drought and high in natural fertility. Pastures are predominantly ryegrass and white clover species, with some paddocks allocated for perennial lucerne and a herb/crop mix where chicory, plantain and red clover pastures are grown. Maize and grass silage are provided to cows according to seasonal requirements, with hay being fed to dry stock when needed. Three seasons (2013-2014, 2014-2015 and 2015-2016) were analysed in this study and will be referred to hereinafter as the 2013, 2014 and 2015 seasons, respectively.

The farm implemented an OAD spring calving milking system in July 2013 after previously being a split calving farm where 50% of the herd calved in autumn and 50% calved in spring and milked TAD. A higher number of animals were observed for seasons 2014 and 2015 because autumn calved cows milked TAD from the 2013 season were switched to calving in spring and milked OAD in the 2014 and 2015 seasons (Table 4.1). Cows were milked OAD in a 24-aside herringbone shed. The breed composition and number of animals in the herd for the last three seasons are presented in Table 4.1. The farm is aiming to have an equal number of Holstein-Friesian (F), Jersey (J) and crossbred FxJ cows in the long term, but currently there are more FxJ cross cows compared to F and J cows in all three seasons.

Table 4.1. Sample size (N) and breed proportion (%) of the herd at Massey University Dairy 1 by season

Season		Breed			Total
		F[1]	J[2]	FxJ[3]	
2013	N	39	44	89	172
	%	22.7	25.6	51.7	
2014	N	66	55	126	247
	%	26.7	22.3	51.0	
2015	N	70	65	127	262
	%	26.7	24.8	48.5	
Total observations	N	175	164	342	681
	%	25.7	24.1	50.2	

[1]F = Holstein-Friesian
[2]J = Jersey
[3]FxJ = Holstein-Friesian and Jersey crossbred

4.3.2 Culling reasons

Culling was defined as the departure of cows from the herd because of voluntary (e.g. low production, surplus to requirements, conformation) or involuntary reasons (reasons other than production, e.g. death, disease, fertility, management, conformation). The specific cause of culling was determined for those cows removed from the herd during the period of time set for the study, from July 2013 to May 2016. The cause of culling was verified by the farm's database and then confirmed with the farm manager of the herd.

4.3.3 Production and fertility data

Individual milk samples were taken during several herd tests to calculate the milk production of cows using the Livestock Improvement Corporation (LIC) herd-testing service. The first herd test for each season was carried out after all cows have calved, with subsequent herd tests performed approximately every 30 days during the 2013 and 2014 seasons and every 60 days during the 2015 season. On average, each cow was herd tested eight times per season and the values for milk yield (MY), fat yield (FY), protein yield (PY) and somatic cell count (SCC) were provided by LIC. The milk solids yield (MSY) was calculated from the sum of FY and PY. The somatic cell score (SCS) for each cow was estimated as $\log_2$ (SCC/1000) and then the average SCS was calculated as the mean for the multiple SCS obtained in the herd tests. Liveweight (LWT) was recorded daily using a walk-over weighing system; these values were then averaged for each season. Indicators of the herd fertility were represented by submission rates of cows at 21 and 42 days after the start of each breeding period (SR21 and SR42, respectively) and the interval from start of mating to first service (SMFS).

4.3.4 Traits other than production

A total of 18 TOP were evaluated in October-November of each season. Four management traits (adaptability to milking, shed temperament, milking speed and overall opinion) were scored by the herd manager and 14 conformation traits (stature, weight, body capacity, rump angle, rump width, legs, udder support, front udder, rear udder, front teat placement, rear teat placement, udder overall, dairy conformation and BCS) were scored by a qualified NZAEL inspectors, which were different for each season. The scores were given on a scale of 1 to 9. The interpretation of these values, along with a description of each TOP, are shown in Table 2.4 (Chapter 2). A graphic illustration of the conformation traits evaluated is shown in Figure 2.2 (Chapter 2). For all management and most of the conformation TOP, high values (close to 9) would be desirable, while intermediate scores for traits such as weight, stature, rump angle, legs, teat placement would be preferred. However, classifying certain scores as desirable or undesirable is ambiguous and will depend on the farmers' preferences or the particular production system.

4.3.5 Herd characteristics

The breeding worth (BW) and production worth (PW) values for each cow were calculated by LIC. The breed composition of both cows and their corresponding parents were recorded in 16^{th}'s. These breed proportions were subsequently used to classify cows into Holstein-Friesian, Jersey and crossbred categories. The status of purebred (F or J) was given to those cows with a breed composition >87.5% from either Holstein-Friesian or Jersey breeds. Cows with a breed composition ≤87.5% from either Holstein-Friesian or Jersey breeds were considered crossbred cows.

4.3.6 Statistical analysis

4.3.6.1 Data preparation

Traits with a continuous distribution (MY, MSY, SCS, BW and PW) were transformed to categorical variables, with three categories assigned (low, medium and high). In the case of TOP, categories of variables with less than 10 observations were reclassified in the most contiguous category. The initial set of explanatory variables comprised all production and fertility traits, and all TOP. Variance inflation factors (VIF) obtained with the REG procedure of SAS revealed a high collinearity for several traits, particularly for stature, weight and udder overall (Appendix Table A5). A principal component analysis (PCA) showed a total of nine axes (with eigenvalues greater than 1) accounting for more than 70% of the cumulative percent of the predictors' variability (Appendix Figure A1), indicating the possibility to reduce the number of explanatory variables to be included in the model.

Traits that had very high VIF (both stature and weight) were excluded from the analysis along with composite traits (overall opinion, udder overall and dairy conformation). Shed temperament and BCS were excluded from the analysis due to the few observations found in several categories of these traits.

4.3.6.2 Stepwise selection

After excluding the variables mentioned above, the final set of significant variables were defined using a stepwise selection procedure. The significance level for variables to stay in the model was 0.15 (based on Wald χ^2 statistics). The full statistical model to explain survival (dependent variable) before the stepwise selection comprised the following explanatory variables: MY, MSY, SCS, BW, PW, SR21, SR42, SMFS, adaptability to milking, milking speed, body capacity, rump angle, rump width, legs, udder support, rear udder, front teat placement, rear teat placement, lactation number, breed and the interactions of breed with the other covariates. Appendix Table A6 shows the results from the stepwise selection procedure. The variables SCS, BW, PW, lactation number, SR21, SR42, SMFS, milking speed, rear udder, front teat placement and rear teat placement were removed in the selection procedure.

4.3.6.3 Survival analysis

A survival analysis was implemented in order to evaluate the effect of production and non-production traits on the survival of cows milked OAD. For each cow, survival was defined as the number of days from the start of OAD milking to the date of culling. The start date of OAD varied among cows according to the specific calving date after which they became cows milked OAD. A total of 172, 115 and 77 cows started OAD in the 2013, 2014 and 2015 seasons, respectively. The end of the observation period for this study was set as 30 May 2016, and records from cows that were still alive after this time were censored. In survival analysis, censored data is obtained from individuals that do not experience the event during the observation period. In this case, cows that were not culled before 30 May 2016 were classified as censored cows (as their culling date is unknown) and the data obtained from their records is censored data. Production, fertility and TOP data for culled cows was extracted from the season in which they were culled, while for non-culled (or censored) cows this data was obtained from the last season in which they were under observation (2015).

A Cox proportional hazard model was fitted with the PHREG procedure of SAS software (Statistical Analysis System, version 9.4; SAS Institute Inc., Cary, NC, USA). Survival was modelled as a function of a linear combination of the variables with the highest significance after the stepwise selection procedure. The statistical model is described below:

$$h(t)_{ijklmnopqr} = h_0(t)\exp(\sum b1B_i + b2F_j + b3MY_k + b4MSY_l + b5AM_m + b6C_n + b7RA_o + b8L_p + b9US_q + b10RW_r)$$

where $h_0(t)$ is a baseline hazard rate depending on time t; B is the effect of the i^{th} breed; F is the effect of the j^{th} fertility status; MY is the effect of the k^{th} milk yield level; MSY is the effect of the l^{th} milk solids yield level; AM is the effect of the m^{th} adaptability to milking score; C is the effect of the n^{th} body capacity score; RA is the effect of the o^{th} rump angle score; L is the effect of the p^{th} legs score; US is the effect of the q^{th} udder support score; RW is the effect of the r^{th} rump width score.

4.4 Results

4.4.1 Culling reasons

The culling reasons in the herd of Massey University Dairy 1 for each season are listed in Table 4.2. Overall, the main causes of culling for the entire three seasons were low production (12.8%), low fertility (37.2%) and udder conformation (19.9%). There were no particular trends over time for any culling reason, although it was observed that a higher percentage of cows were culled for low production and a lower percentage of cows were culled for udder conformation in 2013 compared with the other seasons.

Table 4.2. Culling reasons for three seasons in the herd at Massey University Dairy 1

	2013		2014		2015		Total	
	N	%	N	%	N	%	N	%
Culling reason								
Abortion	0	0.0	2	3.3	4	7.3	6	3.8
Died	1	2.5	8	13.1	1	1.8	10	6.4
Low production	8	20.0	4	6.6	8	14.6	20	12.8
Leg/foot-related problems	1	2.5	1	1.6	2	3.6	4	2.6
Mastitis	2	5.0	2	3.3	3	5.5	7	4.5
Fertility[1]	14	35.0	19	31.2	25	45.5	58	37.2
Other causes	2	5.0	2	3.3	2	3.6	6	3.8
High somatic cell count	5	12.5	0	0.0	4	7.3	9	5.8
Management[2]	1	2.5	4	6.6	0	0.0	5	3.2
Udder conformation	6	15.0	19	31.2	6	10.9	31	19.9
Total	40	100	61	100	55	100	156	100.0
Culling rate	172	23.3	247	24.7	262	21.0	681	100.0

[1]Empty status
[2]Poor shed temperament or slow milking speed

4.4.2 Survival curve

Figure 4.1 shows the Kaplan-Meier curve for the survival of cows milked OAD from Massey University Dairy 1 over three seasons (2013-2015). The survival probability of cows decreases as the number of days they are in the study increases. Censored cows are indicated with markers on the curve. It is possible to observe three clusters of censored cows in Figure 4.1. The first cluster (between 252 to 320 days of survival) shows the censored cows from the group that started OAD milking in the 2015 season. The cluster on the middle of the curve (between 634 and 685 days of survival) represents censored cows that started OAD milking in the 2014 season. The last cluster (between 985 to 1052 days of survival) shows the cows that started OAD milking in the 2013 season and that were still alive at the end of the study (30 May 2016).

The mean survival time for the herd was 743±17 days and the median survival time was 967 days.

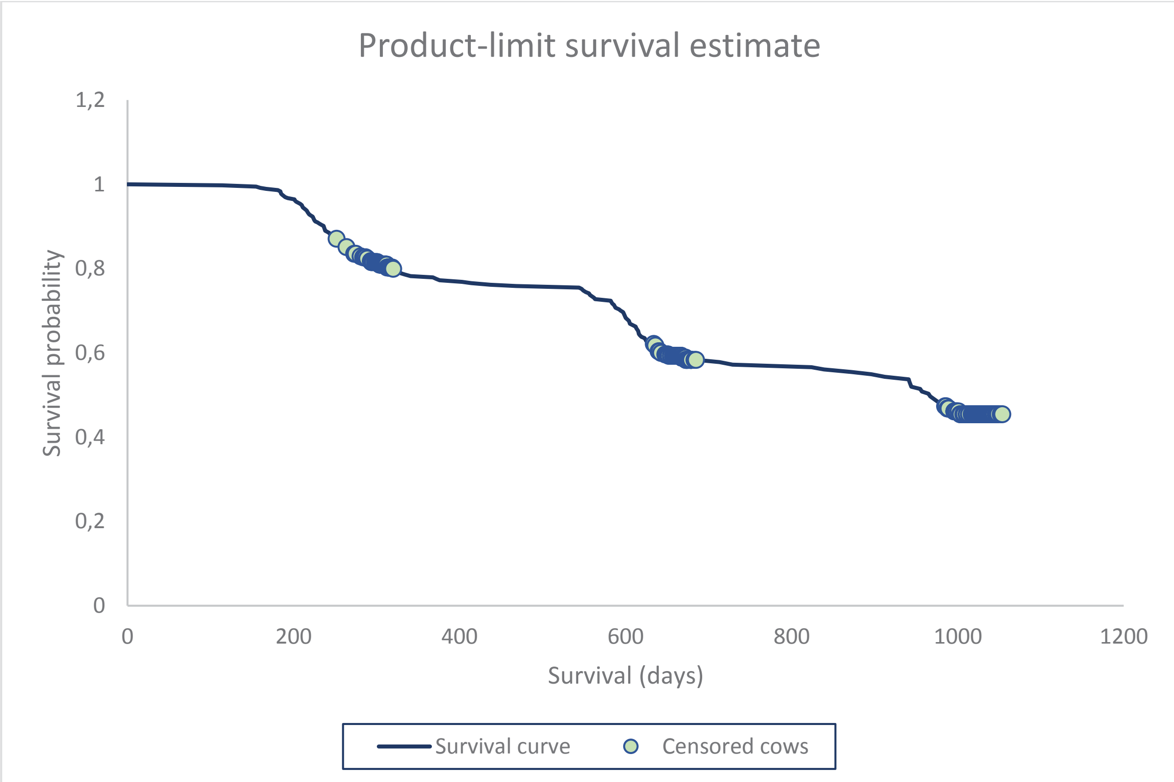


Figure 4.1. Kaplan-Meier curve for survival of cows milked once a day from Massey University Dairy 1 over the entire three seasons. Markers (O) on the curve indicate censored cows

The statistics for the Kaplan-Meier curve are shown in Table 4.3. From the 364 cows included in this study, 156 cows were culled and 208 cows were censored. From the group of cows that started OAD milking in the 2013, there was a lower percent censored compared with the following seasons. The highest percent of cows censored was observed in the group of cows that started OAD milking in the 2015 season.

Table 4.3. Number of censored and uncensored cows from Massey University Dairy 1 by season in which OAD started

Season OAD started[1]	Total	Failed	Censored	Percent Censored
2013	172	93	79	45.93
2014	115	45	70	60.87
2015	77	18	59	76.62
Total	364	156	208	57.14

[1]OAD = Once a day milking

4.4.3 Effect of explanatory variables on survival

The effects of each explanatory variable included in the final model are shown in Table A4.4 of the Appendix. Table 4.4 shows the hazard ratios (HR) for the explanatory variables with a significant effect on survival. In this table, all categories of each ordinal variable are compared only with the highest category. Hazard ratios between other categories for each variable are shown in Tables 4.5 to 4.10. Overall, ordinal variables such as MSY, adaptability to milking, udder support and rump angle showed a gradual decrease in the HR as the category increased, indicating a lower likelihood of culling for cows with higher scores for these traits. On the other hand, there was no particular increasing or decreasing pattern in the HR for body capacity and legs, and instead the lowest HR were observed for medium categories.

Table 4.4. Parameters for the Cox proportional hazards regression model on the survival of cows from Massey University Dairy 1

Variable*	Categories Compared	Regression Coefficient	Standard Error	P-value	Hazard Ratio
Breed	F vs J	0.723	0.304	0.0176	2.06
	FxJ vs J	0.958	0.257	0.0002	2.17
Fertility	Empty vs pregnant	1.508	0.208	<.0001	4.52
Milk solids yield	<294 kg vs >405 kg	1.463	0.455	0.0013	4.32
	295-404 kg vs >405 kg	0.417	0.311	0.1801	1.52
Milk yield	<3232 kg vs >4629 kg	1.501	0.467	0.0013	4.49
	3235-4614 kg vs >4629 kg	0.305	0.299	0.3085	1.36
Adaptability to milking	≤7 vs ≥8	1.042	0.246	<.0001	2.84
Body capacity	≤5 vs ≥8	0.420	0.400	0.2928	1.52
	6 vs ≥8	-1.013	0.304	0.0008	0.36
	7 vs ≥8	-0.339	0.230	0.1408	0.71
Legs	4 vs ≥7	-0.951	0.570	0.0952	0.39
	5 vs ≥7	-0.963	0.406	0.0178	0.38
	6 vs ≥7	-0.905	0.240	0.0002	0.41
Rump angle	≤3 vs ≥6	1.303	0.575	0.0235	3.68
	4 vs ≥6	0.678	0.538	0.2071	1.97
	5 vs ≥6	-0.002	0.557	0.9975	1.00
Udder support	≤4 vs ≥8	1.358	0.496	0.0062	3.89
	5 vs ≥8	0.911	0.488	0.0617	2.49
	6 vs ≥8	0.440	0.454	0.3323	1.55
	7 vs ≥8	0.659	0.462	0.1543	1.93

*For all management and most of the conformation TOP, high values (close to 9) are desirable, while intermediate scores (close to 5) for traits such as stature, rump angle, legs, teat placement would be preferred.

4.4.4 Effect of breed and fertility on survival of cows milked OAD

Cows with an empty status at the end of the production season had a HR of 4.52 compared with cows that were pregnant (95%CI=3.01-6.79). Likewise, Holstein-Friesian and crossbred cows had a 2.06 (95%CI=1.13-3.74) and 2.61 (95%CI=1.58-4.31) higher likelihood of culling compared with Jerseys, but no significant differences were found between Holstein-Friesian and crossbred cows (Table 4.5).

Table 4.5. Hazard ratios and 95% coefficient interval of risk of culling by breed, fertility and milk production in cows from Massey University Dairy 1

Categories Compared	Hazard Ratio	LL 95%	UL 95%	P-value
Breed				
F vs J	2.06	1.13	3.74	0.0176
FxJ vs J	2.61	1.58	4.31	0.0002
FxJ vs F	1.27	0.81	1.99	0.307
Fertility				
Empty vs pregnant	4.52	3.01	6.79	<.0001
Milk solids yield				
<294 kg vs 295-404 kg	2.85	1.49	5.45	0.0016
<294 kg vs >405 kg	4.32	1.77	10.53	0.0013
295-404 kg vs >405 kg	1.52	0.83	2.79	0.1801
Milk yield				
<3232 kg vs 3235-4614 kg	3.31	1.67	6.55	0.0006
<3232 kg vs >4629 kg	4.49	1.80	11.21	0.0013
3235-4614 kg vs >4629 kg	1.36	0.76	2.44	0.3085

4.4.5 Effect of production level on survival of cows milked OAD

The likelihood of culling decreased as the MSY and MY was higher. Cows with a MSY lower than 294 kg had a HR of 2.85 (95%CI=1.49-5.45) and 4.32 (95%CI=1.77-10.53) compared to cows with medium and high MSY, respectively (Table 4.5). Likewise, cows with a MY lower than 3232 kg had a HR of 3.31 (95%CI=1.67-6.55) and 4.49 (95%CI=1.80-11.21) compared to cows with medium and high MY, respectively. There were no significant differences between cows with medium and high MSY or between cows with medium and high MY.

4.4.6 Effect of traits other than production on survival

4.4.6.1 Adaptability to milking

From traits scored by the farm manager, adaptability to milking was the only trait that had a significant effect on survival (Table 4.6). Cows with a score of ≤7 for adaptability to milking were more likely to be culled than cows with a score of ≥8 for this trait (HR=2.84, 95%CI=1.75-4.59).

Table 4.6. Hazard ratios and 95% coefficient interval of risk of culling by score for traits other than production in cows from Massey University Dairy 1

Categories Compared	Hazard Ratio	LL 95%	UL 95%	P-value
Adaptability to milking				
7 vs 8	2.84	1.75	4.59	<.0001
Body capacity				
≤5 vs 6	4.19	1.79	9.81	0.0009
≤5 vs 7	2.14	1.01	4.50	0.0458
≤5 vs ≥8	1.52	0.70	3.33	0.2928
6 vs 7	0.51	0.30	0.88	0.0154
6 vs ≥8	0.36	0.20	0.66	0.0008
7 vs ≥8	0.71	0.45	1.12	0.1408
Legs				
4 vs 5	1.01	0.30	3.40	0.9848
4 vs 6	0.95	0.32	2.84	0.9332
4 vs ≥7	0.39	0.13	1.18	0.0952
5 vs 6	0.94	0.44	2.00	0.8792
5 vs ≥7	0.38	0.17	0.85	0.0178
6 vs ≥7	0.41	0.25	0.65	0.0002
Rump angle				
≤3 vs 4	1.87	1.13	3.10	0.0154
≤3 vs 5	3.69	2.06	6.61	<.0001
≤3 vs ≥6	3.68	1.19	11.37	0.0235
4 vs 5	1.97	1.27	3.07	0.0025
4 vs ≥6	1.97	0.69	5.65	0.2071
5 vs ≥6	1.00	0.34	2.98	0.9975
Udder support				
≤4 vs 5	1.56	0.88	2.79	0.1297
≤4 vs 6	2.51	1.45	4.34	0.001
≤4 vs 7	2.01	1.10	3.68	0.0228
≤4 vs ≥8	3.89	1.47	10.29	0.0062
5 vs 6	1.60	0.91	2.84	0.1061
5 vs 7	1.29	0.69	2.40	0.4272
5 vs ≥8	2.49	0.96	6.46	0.0617
6 vs 7	0.80	0.49	1.33	0.3955
6 vs ≥8	1.55	0.64	3.78	0.3323
7 vs ≥8	1.93	0.78	4.78	0.1543

4.4.6.2 Body capacity and legs

Body capacity and legs also influenced significantly the survival of cows in the OAD herd, but in this case cows with the lowest likelihood of being culled were those with medium scores. Table 4.6 shows that cows with a body capacity of ≤5 were more likely to be culled than cows with a score of 6 (HR=4.19, 95%CI=1.79-9.81). Moreover, cows with a score of 6 were less likely to be culled than cows that scored 7 (HR=0.51, 95%CI=0.30-0.88) or ≥8 (HR=0.36, 95%CI=0.20-0.66). In the case of legs, cows with a score of 5 or 6 had a lower likelihood of being culled than cows with a score ≤7 (HR=0.38, 95%CI=0.17-0.85 and HR=0.41, 95%CI=0.25-0.65, respectively). There were no differences between cows that scored 4 and 5 or between those that scored 4 and 6, but no differences were observed either between cows that scored 4 or less and those that scored ≤7.

4.4.6.3 Rump angle

Overall, cows with lower scores for rump angle were more likely to be culled than those with higher scores (Table 4.6). Cows that scored 3 for rump angle had a HR of 1.87 (95%CI=1.13-3.10), 3.69 (95%CI=2.06-6.61) and 3.68 (95%CI=1.19-11.37) when compared with cows that scored 4, 5 and 6 for this trait, respectively. Likewise, cows with a score of 4 had a higher likelihood of being culled than cows that scored 5 (HR=1.97, 95%CI=1.27-3.07).

4.4.6.4 Udder support

From the udder traits analysed, udder support showed the highest significance on survival. Cows that scored 4 or less had a higher likelihood of culling when compared with cows that scored 6 for this trait (HR=2.51, 95%CI=1.45-4.34). Likewise, the HR for cows with a score of 4 or less was 2.01 (95%CI=1.10-3.68) when compared with cows that scored 7 (Table 4.6). The highest HR was observed between cows that scored 4 or less and cows with a score of 8 or more (HR=3.89, 95%CI=1.47-10.29). The HR for cows that scored 5 and 6 also increased as they were compared with cows with higher scores, but these differences were not significant.

4.5 Discussion

Culling reasons in New Zealand dairy cattle milked TAD have been studied by Xu & Burton (2000), Xu & Burton (2003) and Compton et al. (2016a), while TOP and its relation with survival in New Zealand dairy cattle milked TAD were studied by Ahlborn (1995), Cue et al. (1996), Winkelman et al. (2000) and Berry et al. (2005). A recent report listed udder-related problems as part of the culling reasons in OAD dairy herds, but no differentiation was made between cows culled for TOP and those culled for other udder-related problems (e.g. mastitis, SCS) (DairyNZ 2016a). The present is the first study that investigates the culling reasons of New Zealand dairy cattle milked OAD, identifying the proportion of cows culled for TOP, and evaluating the productive, reproductive and non-productive factors that influence the survival of these cows in the herd.

4.5.1 Culling reasons

The average culling rate for the three seasons analysed in the OAD herd at Massey University Dairy 1 was 23%. This culling rate is higher than the average culling rate found in New Zealand dairy cows milked both TAD (19.3%) (Xu & Burton 2003) and OAD (21%) (DairyNZ 2016a). This could be due to the fact that the herd analysed in the present study recently shifted from TAD to OAD, while the figure reported in DairyNZ (2016a) shows an average culling rate that includes farms that recently started OAD, but also farms that have been using this system for eight or more years. This suggests that farms in transition from TAD to OAD milking would have a higher culling rate than farms that have been using OAD for longer. This might be the result of selection over several seasons under OAD, thus increasing the number of cows better adapted to a reduced milking frequency in this latter group of farms.

The main causes for culling OAD milking cows in the present study were low production (12.8%), low fertility (37.2%) and undesirable udder conformation (19.9%). Xu & Burton (2003) also identified low production and low fertility as the main reasons for culling in New Zealand dairy cows milked TAD (15.9% and 44.8%, respectively). However, the percentage of cows culled by udder conformation-related reasons was much higher in the present study compared to that obtained by Xu & Burton (2003) (19.9% vs 2.9%). A more recent study found that after low reproductive performance, udder-related problems were the second most important cause of culling in New Zealand dairy cattle (Compton et al. 2016a). However, these reasons included mainly clinical or subclinical mastitis without specifying the proportion of cows culled for udder conformation reasons. Likewise, no differentiation was made between the proportion of cows culled for udder conformation and the proportion of cows culled for mastitis in OAD dairy herds, and only the total percentage that included both of these reasons was reported (15.1%) (DairyNZ 2016a). Previous studies have shown an undesirable udder conformation accounting for 0.7% of the culling reasons in New Zealand dairy cows milked TAD (Xu & Burton 2000). The high culling rate for udder conformation observed in the present study might indicate the higher importance of udder traits in making culling decisions in OAD dairy farms compared with TAD dairy farms. This in part agrees with the results shown in DairyNZ (2016a) that showed that a higher percentage of animals were culled for udder-related problems (including udder conformation, mastitis, SCS) in OAD herds compared with TAD herds (15.1 vs 6.8%). The much higher percentage of cows culled for udder conformation in Massey University Dairy 1 might be explained because of the lower percentage of unknown or unspecified culling reasons (3.8%) when compared with that reported for OAD dairy herds (38.2%) (DairyNZ 2016a). Therefore, it would be important to manage a low percentage of unspecified culling reasons in future studies in order to prevent specific reasons for culling from being “hidden” within this category.

In the present study, the percentage of cows culled for mastitis and high somatic cell counts was lower than the percentage of cows culled for udder conformation. Xu & Burton (2003) observed that 3.8% and 3.7% of cows were culled for mastitis and high somatic cell count in TAD dairy farms, which are lower percentages than those observed in the present study (4.5% and 5.8%, respectively). This is consistent with other studies that have found a higher SCS in cows milked OAD than in TAD cows (Lacy-Hulbert et al. 2005; Clark et al. 2006), with bigger differences observed in first lactation cows than cows in subsequent lactations (Lembeye et al. 2016a).

Leg-related problems and management traits (e.g. shed temperament, milking speed) were the least common farmer-attributed causes for culling (2.6% and 3.2%, respectively). Similarly, (Xu & Burton 2000) showed that feet and leg problems accounted for 3.1%, while slow milking and poor temperament accounted for 1.5% and 1.2% of the culling reasons in TAD dairy farms. An extension of this study using more records showed that 3.0% of cows milked TAD in New Zealand were culled due to slow milking and poor temperament (Xu & Burton 2003).

4.5.2 Survival curve

Survival of cows in the present study was measured from the first day of the cow being milked OAD to the date in which the animal was culled. Cows that were not culled before the final date of the observation period were classified as censored and the statistical model accounted for them. The Kaplan-Meier curve in Figure 4.1 shows a decrease of the survival probability over the days of the study, since as time increases the number of cows that experience culling also increases. This curve also showed three main clusters of censored cows as they began OAD milking at different dates, with the lowest number of censored cows observed in the group that started OAD milking in the 2013 season. There is a gradual increase of censored cows in the 2014 and 2015 seasons, which is expected as cows that started OAD first (in 2013) had more time in the study and therefore had a higher chance of being culled than cows that started OAD later. The estimated median survival time of 967 days must not be confused with the actual mean age in the herd, which had been calculated as 4.85 ± 1.96 years (Chapter 3). Instead, the median survival time indicates that the probability of survival by this time (967 days after the start of OAD) is close or less than 50%. There is no previous literature published on this topic, which makes the comparison of these results difficult.

4.5.3 Effect of breed on survival

The hazard ratios were estimated from the hazard rates obtained for the different categories of each explanatory variable in the final model. The hazard ratios between the three categories of breed showed that F and FxJ cows had a significantly higher likelihood of being culled sooner from the herd than J in a OAD milking system. In New Zealand TAD dairy farms, Brownlie & McDougall (2014) showed a lower hazard ratio of premature culling in both J and FxJ compared with F cows (HR=0.94 and HR=0.88, respectively). Similarly, a study with American crossbred dairy herds milked TAD (Pinedo et al., 2014) showed lower odds ratios (OR) of culling for J and FxJ compared with F cows (OR=0.78 and 0.65; 95%CI=0.74-0.82 and 0.61-0.69, respectively). Therefore, F cows have a higher likelihood of being culled in both OAD and TAD dairy herds. However, FxJ cows would have a higher likelihood of being culled than J cows in OAD compared with TAD milking herds.

The reason that J and crossbred cows are maintained in the herd over F cows could be because milk volume and milk solid losses were lower in these breeds (≤19.0%) than F cows (19-25%)

when they were transitioned into the OAD system as was shown by Lembeye et al. (2016a). Additionally, 2 and 3-year-old F cows had a higher probability of developing new intra-mammary infection at calving and at drying off when milked OAD (Lacy-Hulbert et al. 2005). Moreover, in Chapter 3 it was shown that J cows had higher PW than F and higher BW than F and FxJ. Furthermore, J cows also had higher scores for udder support, front udder, rear udder, udder overall and dairy conformation (Chapter 3). It is important to note that there was a greater proportion of F genes (52%) and a lower proportion of J genes (43%) in the group of crossbred FxJ cows (Chapter 3), which would also explain the higher survival of J cows with respect to crossbred FxJ cows in the present study. Together these factors could be the reason why there is a higher risk of culling for F cows in OAD farms, which agrees with previous research that J cows may be more suited to OAD systems (Clark et al. 2006; Hickson et al. 2006). On the other hand, it is important to note the existing variation in the breed proportion of cows that were classified as crossbred. Further research using larger datasets should consider this in order to evaluate the differences between cows with a considerably higher proportion of J genes (e.g. J12F4) and cows with a considerably higher proportion of F genes (F12J4).

4.5.4 Effect of fertility on the survival of cows milked OAD

Fertility was another important factor influencing the survival of cows being milked OAD which was not unexpected because in TAD herds cows that are empty (or not in calf) was listed as one of the main farmer-attributed causes for culling, and agrees with the strict culling policies for reproductive-related problems in New Zealand dairy farms (Xu & Burton 2000; Xu & Burton 2003; Compton et al. 2016a). The submission rates at 21 and 42 days after the start of breeding and the interval from start of mating to first service were not significant on the survival of cows starting OAD. In Chapter 3 it was shown that SR42 was significantly lower in culled cows (97.7%) compared with those that remained on the farm (99.9%). However, this difference could have not been big enough to cause a significant effect on the variable of survival evaluated in Chapter 4.

4.5.5 Effect of production on the survival of cows milked OAD

Production level of cows was also an expected factor to influence survival, as retained cows showed a better productive performance than culled cows (Chapter 3). Low production cows (MSY<294 kg or MY<3232 kg) had a higher likelihood of being culled than medium

(MSY=295-404 kg or MY=3235-4614 kg) and high production cows (MSY>405 kg or MY>4629 kg). This agrees with the results obtained by Pinedo et al. (2014) in American crossbred dairy cattle milked TAD, where cows with a low (<−1178 kg) and medium (-1178 to 1327 kg) relative 305-days mature equivalent (305-dME) milk yield had a higher risk of being culled (OR=37.3 and 5.23; 95%CI=29.0-48.2 and 4.02-6.81, respectively) than cows with a high relative 305-dME milk yield (>1327 kg). In New Zealand dairy cattle, Compton et al. (2016a) reported an incidence risk of culling of 1.6% (1.5-1.7%) for low production cows milked TAD. Moreover, after low fertility, low production was the second most important culling reason in TAD farms of New Zealand (Xu & Burton 2003). However, in the OAD milking cows of the present study, low production was the third most important culling reason after reproductive-related problems and poor udder conformation.

4.5.6 Effect of management TOP on survival

Adaptability to milking, shed temperament and milking speed are traits that describe how well the cow fits into the milking routine (DairyNZ 2014). Scores closer to 1 describe a slow adaptability, while scores closer to 9 indicate a quick adaptability. In the present study, cows with scores for adaptability to milking ≥8 showed a lower likelihood of being culled than cows with scores of ≤7. Similarly, Berry et al. (2005) showed a decline in relative culling as the score for adaptability to milking and other management TOP increased, but these traits had a much weaker influence on true longevity than other conformation TOP. On the other hand, the survival analysis to evaluate the influence of TOP breeding values on longevity made by Winkelman et al. (2000) showed a highly significant effect of all management TOP (P<0.0001). Differences in the mean residual life (expected remaining lifetime) obtained in the same study showed that milking speed and overall opinion had a higher relative contribution to longevity than shed temperament and adaptability to milking. The higher significance of adaptability to milking on survival compared to milking speed in the present study could be due to shed temperament and overall opinion not being included in the final model (the explanation for this approach was given in Materials and Methods).

4.5.7 Effect of body capacity, leg conformation and rump angle on survival

The body capacity of cows milked OAD had an important influence on survival. The study of Winkelman et al. (2000) also showed a high significance effect of body capacity on the longevity of New Zealand dairy cows milked TAD. Berry et al. (2005) found that the relative culling rate of registered New Zealand dairy cows milked TAD declined as the score for body capacity increased. Nevertheless, these authors observed that commercial dairy cows milked TAD with medium scores for body capacity had a reduced risk of being culled than cows with both low or high scores. This agrees with the findings of the present study, where cows milked OAD with a body capacity score of 6 or 7 had a lower likelihood of being culled than cows with extreme scores (≤5 or ≥8). It would be expected that cows with higher scores also had a lower likelihood of being culled as more capacious animals could potentially produce more milk. However, the positive correlations of body capacity with stature and weight (Chapter 3) might represent an increase in the energy requirements and costs for higher body maintenance of cows with higher body capacity, which is not desired in pasture-based milking systems (Montgomerie 2006). This in part could explain the higher likelihood of culling of cows with very high scores for body capacity compared with medium scoring cows.

A similar pattern to body capacity was also observed in the back legs. Cows with scores of 5 or 6 had a lower likelihood of being culled than cows with scores of ≥7, and despite that there were no significant differences between medium scoring cows (5 or 6) and those with a score of 4, there were no differences between cows with extreme scores either (4 vs ≥7). Similarly, Berry et al. (2005) observed that registered cows milked TAD with extremely high or low score for legs were at a higher risk of being culled compared to cows with medium scores. These authors also found that commercial cows milked TAD with higher scores for legs had a greater risk of being culled, which agrees with the results of the present study. This is possibly due to the higher incidence of lameness and reproductive-related problems in cows with an inappropriate back leg conformation (Wall et al. 2005; Atkins et al. 2008), which in this case would be represented by the marked sickling of legs in high scoring cows and to a lesser extent the very straight back legs in low scoring cows.

Cows with low scores for rump angle had a higher likelihood of being culled, with a gradual decrease of this risk as the scores increased. This trait measures the angle of a line between the centre of the hips and the top of the pin bones (DairyNZ 2014), with lower scores given to cows with high pins and higher scores to those with low pins (Figure A2.1). Berry et al. (2005) observed that medium scoring cows had a lower risk of being culled than cows with extreme scores in both registered and commercial TAD dairy herds in New Zealand. Studies in Czech and Canadian Holsteins milked TAD found a similar pattern, with medium scoring cows (4 or

5) having the lowest risk of culling (Sewalem et al. 2004; Zavadilová et al. 2011). On the other hand, Larroque & Ducrocq (2001) found that steeper rumps had a positive effect on the true and functional longevity of French Holsteins milked TAD, which is similar to the pattern observed in OAD cows of this study. Unfavourable genetic correlations between rump angle and fertility traits (e.g. post-partum fertility, calving interval, embryo loss, calving difficulty) reported in New Zealand (García-Muñiz et al. 1998), French (Larroque et al. 1999), British (Wall et al. 2005) and Irish Holsteins (Carthy et al. 2016), indicate that low scoring cows with high pins would have a poorer reproductive performance than high scoring cows for rump angle, which might explain the lower likelihood of culling observed in cows with higher scores for rump angle in the present study.

4.5.8 Effect of udder conformation on survival

Udder traits have shown a significant effect on functional longevity of dairy cows in several countries (Sasaki 2013). In the present study, udder support showed a higher influence on survival than rear udder, front teat placement and rear teat placement. Studies in American (Caraviello et al. 2004), French (Larroque & Ducrocq 2001) and Czech Holsteins (Zavadilová et al. 2011) milked TAD showed that udder depth was the most important TOP with respect to functional longevity. This in part agrees with the results of the present study, as the evaluation of udder support also includes the udder depth relative to the hocks. In commercial TAD dairy herds of New Zealand, Berry et al. (2005) reported that from all the udder traits, udder support had the largest effect on true and functional longevity. Results from the present study found that cows milked OAD with a weak udder support (scores ≤4) had a higher likelihood of being culled than cows with a very strong udder support (≥8). Differences were still observed between cows with no extreme scores, with low scoring cows (≤4) having at least twice the likelihood of being culled than cows that scored 6 or 7 for this trait. A similar trend was observed in both registered and commercial TAD New Zealand dairy herds, with lower scoring cows having a higher probability of being culled (Berry et al. 2005).

An unfavourable udder conformation might increase the susceptibility to mastitis and the possibility of injury to the mammary system (Sasaki 2013). A poor udder support would involve a failure of the suspensory apparatus to keep an appropriate strength over time, with the subsequent appearance of low pendulous udders that are more prone to injuries and infection as a consequence of excessive stretching or tearing of the suspensory ligaments (Atkins et al. 2008). In cows milked OAD, the negative effect of a poor udder support could have a bigger impact on survival, as the reduced milking frequency would cause the accumulation of a larger volume of milk in the udder, creating a greater distension and affecting all mammary structures in the long term.

4.6 Conclusions

Reproductive problems and poor udder conformation were the most important farmer-attributed causes for culling in cows milked OAD. Nevertheless, factors such as breed, fertility, production, adaptability to milking, body capacity, rump angle, leg conformation and udder support all had an important effect on the survival of cows that were shifted from TAD to OAD milking. Most of these traits showed a linear relationship with survival, with higher scores generally associated to a lower likelihood of culling. However, intermediate scores appear to be optimum for traits such as body capacity and leg conformation. The significance and nature of these relationships seem to be associated with certain anatomical structures and functional conformation of the animal that have a particular importance for the survival of cows milked OAD.

Chapter 5

General discussion

The New Zealand dairy industry has been characterised by managing farming systems in which grazed pasture is the main component of the cow's diet and the quantities of supplements (hay, silage, concentrate) are lower compared with the milking systems of other developed countries (Harris et al. 2007). The provision year-round of low-cost feed from pasture (Caradus & Clark 2001) and the strategic use of crossbreeding in the herds (Lopez-Villalobos et al. 2000a; Lopez-Villalobos et al. 2000b) are key elements for the national dairy industry competitiveness. A diversification of the traditional dairy production system has occurred over the past decades. On the one hand, a trend of intensification in dairy farming practices has increased the external inputs of farms in order to maintain higher stocking rates and higher production (Foote et al. 2015), which has created a range of farming systems with different levels of total feed imported onto the farms (Hadley et al. 2006). On the other hand, alternative strategies that reduce farm inputs and manage low production costs while keeping the benefits of pasture-based systems have also been implemented. Full OAD milking represents one of these low farm input strategies, which has been adopted by an increased proportion of farmers that find lifestyle benefits and some advantages for the herd by using this system (Stelwagen et al. 2013; DairyNZ 2016a).

Regardless of the type of milking system used, dairy farmers in New Zealand try to achieve maximum profitability. Profitability of seasonal pasture-based dairy systems can be improved by increasing the net income per unit of feed consumed and increasing the number of units of feed or the scale of the operation (Harris et al. 2007). Additionally, increasing the longevity of cows also affects profitability as cows with longer productive lives are expected to be more profitable (Pritchard et al. 2013), and the loss in revenue from the salvage value of cull cows and genetic improvement through replacements is generally outweighed by an increased longevity (Berry et al. 2005). The longevity of dairy cattle is determined by culling (Heise et al. 2016), which in traditional TAD milking farms of New Zealand is mainly based on production, fertility and udder-related problems (e.g. mastitis, conformation, SCS) (Xu & Burton 2003; Compton et al. 2016a). In OAD milking farms, culling decisions are in part similar to those in TAD milking farms (DairyNZ 2016a), but according to the results of the present study, udder conformation would have a higher influence on these decisions in OAD herds.

5.1 Use of BW and PW for culling decisions in OAD dairy farms

In New Zealand dairy herds milked TAD, farmers can select and cull animals on two indices – the breeding worth (BW) and the production worth (PW). A potential drawback in the OAD milking systems of New Zealand is the possible lower genetic gain achieved in the herd by using the current national breeding objective to select cows for breeding replacements. In Massey University Dairy 1, retained cows showed a higher BW than culled cows (Chapter 3), but BW was not significant in the survival of cows compared with other factors included in a survival analysis (Chapter 4). This could be explained by the low correlation between BW and net income per 5 tonnes of dry matter consumed (NI/5tDM) that has been reported in this herd (-0.09) (Rocha 2015). Comparatively, the correlation between BW and NI/4.5tDM was much higher and positive (0.31) in Massey University dairy farm No. 4, which operates a TAD milking system (Clark et al. 2013). The use of BW would probably not be a useful index for making culling decisions in OAD dairy farms.

An alternative tool for culling cows in New Zealand dairy farms is the PW. A high positive correlation between PW and NI/5tDM (0.44) was reported in the herd of Massey University Dairy 1 (Rocha 2015), which is similar to the correlation found by Clark et al. (2013) between PW and NI/4.5tDM (0.53) in Massey University dairy farm No 4. These results support the idea that PW measures the ability of cows to convert feed into farm profit over their lifetime (Montgomerie 2004). However, no significant increase or pattern in the likelihood of culling was found in OAD cows with different values of PW (Chapter 4). Moreover, there were no significant differences for PW between culled and retained cows in the present study (Chapter 3). It is possible that PW represents an important tool to the farmer for making culling decisions, but it would not have the same importance as fertility or udder conformation in Massey University Dairy 1 and possibly in other OAD dairy farms.

5.2 Traits other than production in OAD dairy farms

After reproduction-related problems, udder conformation was the second most important reason for culling cows milked OAD (Chapter 4). A meta-analysis of culling in dairy cattle milked TAD using results from 54 studies in different countries showed that the incidence risk of culling attributed to low production has decreased over time, while that for reproduction and udder-related causes was unchanged (Compton et al. 2016b). In New Zealand dairy cattle milked TAD, udder conformation only accounted for 2.9% of the culling reasons (Xu & Burton 2003). Although Compton et al. (2016a) found a higher incidence risk of culling for udder-related causes (2.2, CI95%=2.1-2.3) than for production-related causes (1.6, CI95%=1.5-1.7), udder-related causes were mainly clinical or subclinical mastitis, with no specific incidence risk of culling reported for udder conformation. Furthermore, Xu & Burton (2000) found that only 0.7% of cows were culled for reasons specifically related to udder conformation in TAD dairy farms. Therefore, results from the present study (Chapter 3 and Chapter 4) would suggest that compared with TAD herds, udder conformation would have a higher importance than production-related problems in making culling decisions in OAD herds.

In the case of OAD herds, udder-related problems (mastitis, conformation, SCS) added up to 15.1% of all culling reasons, which is a higher percentage compared with TAD herds (6.8%) (DairyNZ 2016a). In the present study, udder-related problems (mastitis, conformation, SCS) accounted for 30.2% of all culling reasons, but udder conformation problems were the main udder-related cause of culling (19.9%). The higher proportion of cows culled for udder conformation observed in Massey University Dairy 1 might be due to the recent shift from TAD to OAD (transition during 2013 and 2014 seasons). However, the culling rates reported for OAD herds include dairy farms that recently started OAD, but also farms that have been using this system for eight or more years. Therefore, the culling rate would be higher in the first years of transition from TAD to OAD (Chapter 4). The proportion of cows culled for udder conformation though would also be higher at these first stages of OAD than in later seasons when the farms would possibly have a higher number of cows better adapted to a reduced milking frequency.

Apart from udder support, additional conformation traits that influenced the survival of cows milked OAD were rump angle, body capacity and leg conformation (Chapter 4). These traits are part of the functional conformation of cows and are related with their production potential and energy requirements, health status and reproductive performance (Wall et al. 2005; Montgomerie 2006; Atkins et al. 2008; Carthy et al. 2016). These associations are in part corroborated by the phenotypic correlations observed between TOP with production and fertility traits (Chapter 3). However, more data is required to calculate genetic correlations between these traits in New Zealand dairy cattle milked OAD in order to estimate specific genetic parameters for this population and to reveal sets of traits with a common genetic basis.

Despite that there were no significant differences for lactation number between culled and retained cows (Chapter 3), and that the effect of lactation number was not significant in the survival analysis (Chapter 4), it is important to note that rump angle and most udder traits (e.g. udder support, front udder, rear udder, udder overall) showed a gradual decrease over lactations (Chapter 3), while body conformation traits (e.g. stature, weight, body capacity, dairy conformation) and legs showed an upward trend. Therefore, older cows with a higher lactation number would have an overall poorer conformation (e.g. larger animals with a less desirable conformation for udder, rump angle, legs, body capacity) which would increase the risk of being culled (Chapter 4). The lack of a significant effect of lactation number on the survival of OAD cows could possibly be due to the higher MY and MSY observed in older cows (Chapter 3), which would have compensated their poorer type conformation.

5.3 Improvement of TOP in OAD dairy farms

The differences found between the main risk factors that influence the survival of OAD cows (Chapter 4) with respect to the main risk factors identified in other milking systems (Winkelman et al. 2000; Berry et al. 2005; Zavadilová et al. 2011; Compton et al. 2016b) might represent farmers' preferences for improvement of particular traits in cows milked OAD. These preferences were in part determined in the trends for adaptability to milking, milking speed, overall opinion, udder support, udder overall and rump angle, which showed an improvement over three seasons after the start of OAD, while traits such as stature, body capacity, rump width, legs, rear teat placement and dairy conformation showed a decrease over the same time period (Chapter 3). Martin-Collado et al. (2015) described three types of preferences for cow trait improvements in Australian dairy cattle, including production, functionality and type-focused selection. The authors of that study suggested that these preferences were intrinsic to farmers and not to production systems or breeds. Nevertheless, in the case of OAD milking systems, farmers' preferences might rely more on the production system, as it represents a new environment for cows that have been selected for TAD milking over the years, which creates the necessity to identify those animals that are better suited to a reduced milking frequency. Moreover, the effect of breed and culling on TOP (Chapter 3), along with results from the survival analysis (Chapter 4), would suggest a preference for Jersey cows in OAD herds. On the other hand, classifying the OAD farmers' preferences would be difficult, especially in the first seasons of OAD when the farmer would be selecting cows resilient to the negative impact of a reduced milking frequency on production, but at the same time with an appropriate conformation and adaptability to OAD.

The improvement of TOP has the potential to improve the longevity and workability of cows in dairy herds. There have been particular trends worldwide such as the considerable attention that size and udder depth have received in recent years (Ducrocq & Wiggans 2015). In the case of OAD milking farms, the trends for TOP discussed above would be the result of a correlated response to selection (Chapter 3) for one or several traits with a significant effect on the cow’s survival, e.g. adaptability to milking, rump angle, udder support (Chapter 4). It is important to continue to track these trends in the upcoming production seasons, especially for those traits that showed a significant decrease over time such as body capacity, dairy conformation and rump width, as cows could become less capacious and have narrower rumps.

The high culling rates reported for the herd of Massey University Dairy 1 over the seasons analysed agree with the higher average culling rate found in OAD dairy farms compared with the average culling rate in TAD dairy farms (Chapter 4). In the study of Lopez-villalobos & Holmes (2010), the annual genetic gain for milk solids production was higher after 20 years of using bulls of high BW, at higher replacement rates. However, in terms of profitability, herds with a low replacement rate showed a better performance at year 20 of simulation. According to that study, farms with a low replacement rate (15%) in combination with selection of heifers with high BW and the culling of cows with low PW would achieve both the highest genetic gain for milk solids and the highest farm profit. The high culling rate in OAD dairy herds would probably affect the genetic gain for productive traits and the overall farm profit if these rates were kept high over the seasons. However, the higher culling rate found in Massey University Dairy 1 compared to the average culling rate for OAD dairy farms suggests that farms recently moving from TAD to OAD could have a higher culling rate than farms that have been using OAD for longer. As cows age, the stretching process of the suspensory ligaments might be more pronounced in those transitioning from TAD to OAD milking, as this represents a challenging environment that generates a repetitive mechanical distension of the mammary gland caused by a fuller udder every 24 hours. Therefore, the gradual decline in udder conformation over lactations could be faster in these transitioning cows. However, TOP records in different lactations of TAD cows and also from those that have been milked OAD during their whole productive life would be required in order to compare these physiological and anatomical changes between these different groups of cows.

No significant differences for age were observed between culled and retained cows (Chapter 3). Future research with more productive and TOP records would be required in order to determine if there is a trigger point when culling older and highly productive OAD cows on TOP could be more profitable than retaining these type of animals for their high production but at the expense of a reduced productive lifespan in the herd. Further research would also be necessary to determine an optimal culling rate for OAD dairy herds and its relationship with the selection of heifers with high or low values of a new developed OAD selection index.

5.4 Inclusion of TOP in selection indices for OAD dairy farms

In light of the above, a balance between production, functionality and type is required in order to achieve optimum levels of production in cows moving from TAD to OAD, and without increasing the culling rate for functionality or type conformation in these herds. Results from the present study suggest that BW might not be an optimum selection index to select replacements, or in the case of PW, to evaluate cows by their expected ability to be profitable and efficient lifetime producers. Since 2003, the New Zealand dairy industry has tried to develop a selection index specifically designed for OAD systems. Initially, and due to the insufficient data available at the time, a desired gain approach was implemented, where subjective weights were given to the estimated breeding values (EBVs) from the BW index (McPherson et al. 2007). Farmers suggested the inclusion of TOP in the EBV or BW calculations. Consequently, for 2015, new desired gains were defined and a relative weight was given to the EBV for body capacity, milking speed, udder support and front teat placement, creating a new selection index for OAD miliking herds (OADSI) (LIC 2016) (Table 5.1). Inclusion of the farmers' preferences for improvements in animal traits in selection indices could increase the uptake of these tools and the subsequent increase of the genetic gain in breeding programmes (Martin-Collado et al. 2015). Our results indicate that other important traits such as adaptability to milking, rump angle and leg conformation should be considered in the selection indices of cows in OAD dairy herds. A previous analysis of the phenotypic correlations between conformation TOP, production and fertility in Massey University Dairy 1 suggested the inclusion of stature/weight, udder support/front udder, body condition score, udder overall, and dairy conformation as potential TOP to be included in a new OAD selection index (Harris 2015). However, that study only included TOP records from one production season. On the other hand, the present study used information from three production seasons and apart from the linear models, the phenotypic correlations and repeatability of TOP that were calculated, this study also included a survival analysis that took into account the last TOP records of each cow before being culled. Likewise, the survival analysis represents a more robust model since it accounts for censored data and it handles the non-normal distribution of longevity.

The selection index data reported for LIC bulls currently available for artificial breeding shows that Holstein bulls have higher OADSI values (1130 – 1317) than Jersey (1174 – 1287) and crossbred bulls (1181 – 1289). This would in part disagree with what has been found in the present study, where Jersey cows had a better TOP conformation to deal with the challenges of a reduced milking frequency. It is important to note that, as mentioned above, the OADSI only includes four non-negotiatble OAD functional traits that were defined in farm discussion groups. However, other TOP identified in the present study as important for the survival of cows milked OAD (such as adaptability to milking, rump angle and leg conformation) are not included in this OAD index. Further research that includes a larger dataset from multiple OAD milking farms with TOP records from cows in different lactations would be required in order to obtain more robust conclusions.

Table 5.1. Weightings for selection indices of dairy cattle in twice and once a day milking herds in New Zealand (LIC 2016)

Breeding Value	BW 2016 Weightings	OADSI Weightings
Protein	27%	29%
Milkfat	10%	11%
Milk volume	11%	14%
Liveweight	11%	12%
Fertility	15%	5%
Somatic cell count	6%	6%
Body condition score	7%	2%
Residual survival	13%	0%
Milking speed	-	5%
Body capacity	-	4%
Udder support	-	10%
Front teats	-	2%
	100%	100%

[1]BW = Breeding worth
[2]OADSI = Once a day selection index

5.5 General conclusions

Traits other than production influenced the survival of dairy cows milked OAD. There were significant differences for TOP between culled and retained cows, with culled cows obtaining a less desirable overall opinion from farmers and a poorer udder overall. Jerseys had higher scores for most udder traits and a lower likelihood of being culled than Holstein-Friesians and crossbred cows. Low fertility and poor udder conformation were the main farmer-attributed causes for culling in cows milked OAD. Udder conformation would have a higher importance in making culling decisions during the transition from TAD to OAD. However, the likelihood of being culled could be reduced for cows with a good adaptability to milking, low pin bones with steeper rumps, stronger udder support and intermediate scores for body capacity and leg conformation. On the other hand, given the high phenotypic correlations between some udder traits, cows with a weaker udder support, a looser front udder or a lower rear udder would have a higher likelihood of being culled.

A gradual decrease for the scores of rump angle and most udder traits was observed as the cows become older, while the scores for body capacity and leg conformation showed an upward trend. The poorer type conformation of older cows could have been compensated by their higher milk production, which would explain that there was no significant effect of lactation number on survival and no significant difference of age between culled and retained cows.

The trends of TOP over time might be the result of a correlated response to selection for better udder conformation, although an extended evaluation including future seasons and data from more farms would be required in order to evaluate any change in the trends of TOP over time in herds that have moved from TAD to OAD milking.

The positive trends in the scores of TOP over seasons and the particular risk factors that influenced survival might represent farmers' preferences for the improvement of particular traits in cows milked OAD. The lower correlation between NI/5tDM with BW and PW in OAD farms compared to TAD farms, and the lack of a significant effect of these selection indices on survival, could indicate that besides body capacity and udder support, additional traits such as adaptability to milking, rump angle and leg conformation should be considered in the development of new selection indices for OAD milking herds.

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Appendix

Table A1. Heritability (diagonal), genetic (below diagonal) and phenotypic correlations (above diagonal) among traits other than production in New Zealand and overseas dairy cattle. Blue for positive and red for negative correlations (the darker the colour, the stronger the association)

	Reference	AM	ST	MS	OO	S	W	C	RA	RW	L	US	FU	RU	FT	RT	UO	DC
AM	1	**0.11**	0.71	0.23	0.62	0.02	0.02	0.03	0.00	0.02	-0.02	0.06	0.06	0.06	0.04	0.03	0.08	0.07
	2	**0.18**	0.70	0.22	0.62	0.04	0.04	0.06	-0.01	0.02	-0.03	0.06	0.07	0.07	0.04	0.03	0.09	0.10
	3	**0.08**	0.69	0.21	0.61								0.05	0.07			0.08	0.07
	4	**0.13**	0.69	0.21	0.62								0.06	0.08			0.08	0.11
ST	1	0.97	**0.14**	0.20	0.67	0.04	0.04	0.04	0.00	0.04	-0.02	0.06	0.06	0.06	0.03	0.03	0.08	0.07
	2	0.98	**0.17**	0.22	0.68	0.04	0.04	0.07	-0.01	0.03	-0.03	0.07	0.07	0.08	0.05	0.04	0.10	0.11
	3	0.98	**0.10**	0.18	0.65							0.05	0.06	0.06			0.07	0.07
	4	0.99	**0.14**	0.19	0.68							0.07	0.07	0.08			0.08	0.11
	5		**0.11**	0.27		0.14			-0.04	0.07	-0.04	0.12	0.11	0.17		0.10		
MS	1	0.34	0.25	**0.18**	0.38	-0.04	-0.05	-0.05	-0.02	-0.03	0.01	0.09	0.07	0.03	0.05	0.00	0.08	0.00
	2	0.23	0.23	**0.27**	0.39	0.01	0.00	-0.02	-0.01	0.00	0.00	0.05	0.05	0.01	0.02	-0.01	0.04	0.02
	3	0.23	0.13	**0.15**	0.38							0.09	0.07	0.04			0.08	0.00
	4	0.19	0.09	**0.21**	0.35							0.06	0.06	0.03			0.06	0.02
	5		0.56	**0.12**		0.12			0.01	0.06	0.04	0.14	0.07	0.17		0.11		
OO	1	0.92	0.88	0.55	**0.12**	0.06	0.07	0.09	-0.02	0.06	-0.03	0.10	0.09	0.10	0.05	0.05	0.12	0.15
	2	0.90	0.89	0.51	**0.15**	0.09	0.09	0.12	-0.02	0.06	-0.03	0.09	0.10	0.10	0.04	0.04	0.14	0.18
	3	0.91	0.85	0.46	**0.09**							0.09	0.09	0.10			0.12	0.15
	4	0.82	0.82	0.34	**0.12**							0.10	0.10	0.11			0.13	0.18
S	1	0.13	0.19	-0.16	0.16	**0.38**	0.96	0.27	0.01	0.26	-0.02	0.05	0.01	0.03	0.02	0.02	0.04	0.24
	2	0.11	0.16	0.07	0.20	**0.27**	0.93	0.20	0.04	0.18	-0.04	-0.05	-0.06	-0.04	-0.03	-0.05	-0.04	0.18
	3					**0.49**	0.83	0.26										
	4					**0.23**	0.59	0.18										
	5		0.25	0.58		**0.43**			0.06	0.54	0.00	0.10	0.13	0.19		0.05		
	6					**0.37**			0.17	0.45	-0.02	0.09	0.12		0.10			
W	1	0.12	0.20	-0.19	0.18	0.85	**0.31**	0.41	0.01	0.28	-0.05	0.03	0.01	0.02	0.00	0.02	0.04	0.29
	2	0.13	0.18	0.08	0.25	0.67	**0.18**	0.35	0.04	0.18	-0.06	-0.04	-0.03	-0.04	-0.04	-0.04	-0.03	0.25
	3					0.96	**0.39**	0.41										
	4					0.90	**0.12**	0.34										
C	1	0.03	0.08	-0.17	0.17	0.34	0.55	**0.29**	-0.05	0.29	-0.14	0.07	0.06	0.08	0.00	0.01	0.10	0.49
	2	0.05	0.05	-0.07	0.19	0.20	0.51	**0.19**	-0.08	0.20	-0.10	0.08	0.13	0.09	-0.02	0.00	0.13	0.57
	3					0.38	0.60	**0.32**										
	4					0.12	0.50	**0.15**										
RA	1	0.15	0.12	0.04	0.04	-0.19	-0.22	-0.25	**0.25**	-0.05	0.08	-0.13	-0.12	-0.14	-0.08	-0.03	-0.16	-0.21
	2	0.13	0.09	0.05	0.10	0.11	0.04	-0.24	**0.23**	-0.06	0.09	-0.12	-0.12	-0.12	-0.06	-0.01	-0.14	-0.24
	3								**0.26**	-0.07	0.11	-0.14	-0.13	-0.15	-0.10	-0.04		
	4								**0.26**	-0.09	0.11	-0.13	-0.13	-0.11	-0.06	-0.02		
	5		-0.18	0.35		0.02			**0.24**	0.03	0.01	-0.05	-0.07	-0.15		-0.02		
	6					0.29			**0.22**	0.12	0.03	0.02	-0.05		0.01			
RW	1	0.11	0.18	-0.21	0.18	0.54	0.63	0.52	-0.28	**0.26**	-0.11	0.11	0.08	0.11	0.03	0.02	0.12	0.32
	2	0.03	0.06	-0.10	0.07	0.16	0.23	0.22	-0.21	**0.18**	-0.08	0.07	0.06	0.08	0.01	-0.02	0.08	0.25
	3								-0.22	**0.28**	-0.11	0.11	0.07	0.12	0.03	0.02		
	4								-0.14	**0.16**	-0.09	0.09	0.07	0.08	0.03	-0.01		
	5		0.18	0.38		0.68			0.17	**0.29**	0.03	0.03	0.05	0.14		0.03		
	6					0.77			0.18	**0.18**	-0.03	0.16	0.18		0.18			
L	1	0.02	-0.01	0.08	-0.03	0.00	-0.06	-0.31	0.18	-0.15	**0.08**	-0.11	-0.08	-0.11	-0.03	0.01	-0.12	-0.20
	2	0.02	-0.06	-0.04	-0.10	-0.08	-0.16	-0.31	0.42	-0.24	**0.07**	-0.10	-0.08	-0.10	-0.02	-0.01	-0.10	-0.16
	3								0.22	-0.12	**0.06**	-0.11	-0.09	-0.12	-0.04	0.00		
	4								0.39	-0.21	**0.06**	-0.11	-0.09	-0.09	-0.03	-0.02		
	5		-0.33	0.55		-0.03			0.04	0.00	**0.19**	0.04	-0.04	0.04		0.02		
	6					0.00			0.07	0.01	**0.07**	0.06	-0.03		0.04			
US	1	0.08	0.11	0.08	0.16	0.27	0.26	0.21	-0.30	0.32	-0.33	**0.25**	0.57	0.58	0.27	0.16	0.72	0.33
	2	0.06	0.09	0.01	0.12	-0.22	-0.20	0.07	-0.29	0.04	-0.21	**0.22**	0.64	0.65	0.26	0.23	0.74	0.30
	3		0.09	-0.02	0.11				-0.37	0.34	-0.33	**0.25**	0.56	0.60	0.25	0.14	0.72	0.33
	4		0.17	0.29	0.25				-0.26	0.16	-0.13	**0.23**	0.63	0.58	0.28	0.22	0.96	0.31
	5		0.05	0.50		0.22			-0.23	0.05	0.36	**0.11**	0.17	0.45		0.36		
	6					0.16			0.01	0.29	0.16	**0.17**	0.31		0.45			
FU	1	0.03	0.10	0.10	0.12	0.20	0.22	0.21	-0.31	0.32	-0.27	0.87	**0.19**	0.42	0.28	0.08	0.68	0.30
	2	0.02	0.06	0.10	0.10	-0.21	-0.16	0.18	-0.29	0.03	-0.21	0.87	**0.24**	0.54	0.20	0.14	0.70	0.34
	3	0.02	0.00	-0.01	0.00				-0.36	0.30	-0.36	0.86	**0.21**	0.45	0.21	0.06	0.68	0.30
	4	0.10	0.10	0.27	0.17				-0.23	0.08	-0.11	0.89	**0.24**	0.53	0.22	0.13	0.70	0.33
	5		0.07	0.38		0.82			0.21	0.43	0.50	0.31	**0.13**	0.27		0.28		
	6					0.21			-0.09	0.27	-0.08	0.45	**0.19**		0.39			
RU	1	0.08	0.12	-0.12	0.14	0.28	0.29	0.25	-0.29	0.34	-0.35	0.81	0.68	**0.24**	0.19	0.11	0.69	0.33
	2	-0.03	0.02	-0.15	0.01	-0.23	-0.26	0.02	-0.30	0.09	-0.15	0.85	0.70	**0.25**	0.19	0.17	0.74	0.32
	3	0.09	-0.15	0.10	0.13				-0.32	0.39	-0.32	0.86	0.69	**0.24**	0.20	0.10	0.70	0.33
	4	0.12	0.12	0.09	0.17				-0.31	0.09	-0.08	0.40	0.71	**0.23**	0.20	0.18	0.73	0.33
	5		0.49	0.46		0.46			-0.49	0.40	0.32	0.75	0.35	**0.17**		0.29		
FT	1	0.09	0.09	0.11	0.09	0.12	0.10	0.07	-0.17	0.12	0.03	0.53	0.52	0.37	**0.27**	0.35	0.43	0.15
	2	0.09	0.04	-0.02	0.08	-0.15	-0.12	0.00	-0.17	-0.10	0.04	0.53	0.38	0.30	**0.30**	0.45	0.39	0.10
	3								-0.29	0.10	0.03	0.51	0.46	0.39	**0.29**	0.33	0.44	0.16
	4								-0.17	0.19	0.03	0.50	0.27	0.26	**0.27**	0.43	0.42	0.10
	6					0.15			0.01	0.31	0.15	0.68	0.61		**0.20**			
RT	1	0.03	0.05	-0.11	0.06	0.07	0.09	0.12	-0.08	0.12	0.06	0.28	0.14	0.22	0.59	**0.29**	0.18	0.10
	2	-0.01	-0.03	-0.07	-0.01	-0.22	-0.19	-0.02	-0.12	-0.23	0.09	0.50	0.34	0.36	0.79	**0.28**	0.27	0.08
	3								-0.10	0.08	0.09	0.24	0.06	0.15	0.58	**0.28**	0.16	0.10
	4								-0.19	-0.04	0.00	0.42	0.22	0.32	0.78	**0.19**	0.22	0.07
	5		0.06	0.09		-0.18			0.02	0.02	0.19	0.54	0.40	0.54		**0.23**		
UO	1	0.09	0.13	0.05	0.17	0.25	0.26	0.25	-0.32	0.34	-0.29	0.95	0.90	0.86	0.67	0.33	**0.27**	0.40
	2	0.02	0.05	-0.05	0.08	-0.24	-0.22	0.09	-0.33	0.04	-0.19	0.97	0.87	0.88	0.61	0.54	**0.25**	0.40
	3	0.12	0.04	-0.04	0.06							0.95	0.86	0.89	0.66	0.28	**0.27**	0.41
	4	0.01	0.19	0.14	0.15							0.70	0.87	0.86	0.57	0.48	**0.24**	0.40
DC	1	0.11	0.16	-0.06	0.28	0.51	0.63	0.76	-0.59	0.65	-0.32	0.58	0.55	0.57	0.35	0.28	0.63	**0.25**
	2	0.04	0.09	-0.05	0.21	0.18	0.39	0.81	-0.59	0.33	-0.49	0.42	0.49	0.41	0.16	0.11	0.47	**0.18**
	3	0.14	0.12	-0.11	0.26							0.56	0.50	0.57	0.41	0.33	0.64	**0.30**
	4	0.12	0.11	0.09	0.32							0.44	0.52	0.49	0.04	-0.04	0.53	**0.18**

1. Cue et al. (1996) New Zealand Holstein-Friesians
2. Cue et al. (1996) New Zealand Jerseys
3. Ahlborn (1995) New Zealand Holstein-Friesians
4. Ahlborn (1995) New Zealand Jerseys
5. Berry et al. (2004) Irish Holstein-Friesians
6. Wiggans et al. (2004) American Jerseys

* AM = adaptability to milking, ST = shed temperament, MS = milking speed, OO = overall opinion, S = stature, W = liveweight, C = body capacity, RA = rump angle, RW = rump width, L = legs, US = udder support, FU = front udder, RU = rear udder, FT = front teat placement, RT = rear teat placement, UO = udder overall, DC = dairy conformation

Table A2. Genetic correlations between TOP, production and fertility traits in New Zealand and overseas dairy cattle. Blue for positive and red for negative correlations (the darker the colour, the stronger the association).

		AM	ST	MS	OO	S	W	C		RA	RW	L	US	FU	RU	FT	RT	UO	DC	BCS
								CW	BD											
MY	1	0.26	0.31	-0.10	0.41	0.29	0.33	0.30		0.04	0.24	-0.01	-0.22	-0.15	-0.03	-0.21	0.00	-0.17	0.22	
	2	0.20	0.15	-0.07	0.26	0.48	0.43	0.08		0.11	0.08	0.00	-0.10	-0.07	-0.03	-0.17	-0.23	-0.10	0.08	
	3		0.44	0.69		0.42		0.24	0.36	0.24	0.46	0.21	0.36	0.32	0.48					-0.15
	4					0.21			0.03	0.62		0.83	-0.10	-0.45		0.09				
FY	1	0.32	0.35	0.13	0.51	0.11	0.15	0.28		0.13	0.12	-0.06	-0.24	-0.15	-0.03	-0.24	-0.05	-0.11	0.18	
	2	0.23	0.20	0.03	0.29	0.54	0.51	0.16		0.13	0.15	0.02	-0.01	0.08	-0.03	-0.23	-0.34	-0.05	0.17	
	3																			
	4					0.01			0.01	0.49		0.42	-0.22	-0.41		0.10				
PY	1	0.27	0.33	-0.01	0.44	0.24	0.27	0.26		0.13	0.12	-0.06	-0.24	-0.15	-0.03	-0.24	-0.05	-0.17	0.15	
	2	0.26	0.22	0.06	0.39	0.55	0.54	0.25		0.05	0.06	-0.05	-0.02	0.06	0.02	-0.24	-0.32	-0.03	0.23	
	3																			
	4					0.48			0.20	0.57		0.94	-0.41	-0.28		0.22				
Udder Health	1																			
	2																			
	3		-0.42	0.24		-0.09		-0.39	-0.06	-0.42	-0.40	0.67	0.45	-0.25	-0.16					-0.57
	4					-0.27			-0.30	0.24		-0.61	-0.35	-0.24		-0.19				
Fertility	3a		0.74	-0.18		-0.33		-0.51	-0.17	-0.83	-0.53	-0.86	0.02	-0.52	0.36					-0.53
	3b		0.23	0.36		0.67		0.45	0.76	-0.31	0.80	0.05	0.23	0.36	0.43					0.13
	3c		-0.35	-0.16		-0.64		-0.44	-0.75	0.31	-0.80	0.36	-0.15	-0.38	-0.29					-0.14
	3d		0.08	-0.15		-0.44		-0.06	-0.49	0.42	-0.22	0.02	0.12	0.17	-0.26					0.35
Survival	1	0.20	0.19	0.33	0.33	-0.19	-0.12	0.27		0.16	0.00	-0.04	-0.16	-0.09	-0.14	-0.27	-0.02	-0.17	-0.06	
	2	0.47	0.41	0.06	0.57	0.40	0.37	0.18		0.18	-0.06	0.08	-0.08	0.19	-0.03	-0.17	-0.23	0.10	0.22	

1. Cue et al. (1996) New Zealand Holstein-Friesians
2. Cue et al. (1996) New Zealand Jerseys
3. Berry et al. (2004) Irish Holstein-Friesians. 3a interval to first service (IFS). 3b number of services (NS). 3c pregnant to first service (PRFS). 3d pregnant 63 days after the start of breeding (PR63)
4. DeGroot et al. (2002) American Holstein-Friesians

* MY = milk yield, FY = fat yield, PY = protein yield, AM = adaptability to milking, ST = shed temperament, MS = milking speed, OO = overall opinion, S = stature, W = liveweight, C = body capacity, RA = rump angle, RW = rump width, L = legs, US = udder support, FU = front udder, RU = rear udder, FT = front teat placement, RT = rear teat placement, UO = udder overall, DC = dairy conformation, BCS = body condition score

Table A3. Proportion of skewness and kurtosis reduced (blue bars) by using Snell scores obtained with the definition of three different groups of observations in cows from Massey University Dairy 1

Trait	Groups of observations					
	Season		Breed		Lactation	
	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis
Adaptability to milking	19.76	40.28	38.65	90.73	38.23	91.70
Shed temperament	8.36	55.70	8.76	55.72	8.25	55.69
Milking speed	59.66	97.17	61.46	91.85	61.22	91.62
Overall opinion	50.64	61.17	51.06	61.36	50.20	60.67
Stature	46.97	92.62	-61.88	44.21	12.90	96.96
Weight	-0.41	50.18	-189.99	60.99	-42.61	75.73
Capacity	70.13	53.83	69.93	58.67	72.04	34.63
Rump angle	41.33	88.62	19.58	56.74	16.48	62.15
Rump width	68.03	76.57	55.10	79.48	61.29	75.16
Legs	22.36	51.89	8.98	38.41	2.11	41.64
Udder support	90.26	37.29	93.44	36.82	99.49	44.89
Front udder	68.92	-476.93	71.78	-418.67	74.13	-431.29
Rear udder	62.07	51.22	66.60	54.90	63.77	53.35
Front teat placement	34.52	99.27	34.39	99.76	36.27	99.98
Rear teat placement	52.64	38.37	39.22	23.15	-0.77	1.36
Udder overall	93.25	13.31	95.63	26.99	99.16	37.23
Dairy conformation	44.19	54.13	42.78	54.40	35.03	53.04
Body condition score	71.01	92.65	72.57	89.61	78.15	90.60

Table A4. Snell scores for traits other than production obtained by using production season as groups of observations in cows from Massey University Dairy 1

	TOP Score Categories								
	1	2	3	4	5	6	7	8	9
Adaptability to milking	1.00	3.46	5.91	6.14	6.22	6.76	7.36	8.15	9.00
Shed temperament	1.00	1.94	2.30	2.53	2.69	2.96	3.19	5.76	9.00
Milking speed	1.00	1.72	2.37	2.97	3.22	4.08	6.47	8.28	9.00
Overall opinion	1.00	2.04	2.68	3.01	3.17	3.29	3.54	6.05	9.00
Stature	1.00	1.95	2.32	3.51	4.97	5.67	6.51	7.66	9.00
Weight	1.00	1.84	3.11	4.52	5.13	5.81	6.79	7.86	9.00
Body capacity	1.00	1.91	2.25	2.60	3.36	4.51	5.78	7.38	9.00
Rump angle	1.00	2.38	3.64	4.72	6.13	7.25	7.86	8.27	9.00
Rump width	1.00	1.84	2.51	3.35	3.99	4.95	6.22	7.59	9.00
Legs	1.00	1.73	2.00	2.68	3.55	4.80	6.36	7.70	9.00
Udder support	1.00	2.04	2.85	3.50	4.13	4.83	5.84	7.43	9.00
Front udder	1.00	2.23	3.26	3.90	4.47	5.15	6.05	7.49	9.00
Rear udder	1.00	1.76	2.31	3.04	3.82	4.76	5.89	7.45	9.00
Front teat placement	1.00	2.10	3.03	4.10	5.81	7.35	7.94	8.24	9.00
Rear teat placement	1.00	2.02	2.63	3.40	4.58	5.80	6.73	7.71	9.00
Udder overall	1.00	2.05	2.93	3.66	4.29	5.01	6.08	7.58	9.00
Dairy conformation	1.00	1.83	2.15	2.47	2.99	4.01	5.41	7.23	9.00

Table A5. Variance inflation factors for the potential explanatory variables of survival of cows from Massey University Dairy 1

Trait	Parameter Estimate	Standard Error	t Value	Pr > |t|	Tolerance	Variance Inflation
Milk yield	19.55	26.96	0.72	0.47	0.25	4.04
Milk solids yield	106.06	26.34	4.03	<.0001	0.26	3.82
Somatic cell score	5.41	14.65	0.37	0.71	0.83	1.21
Lactation	75.70	8.36	9.06	<.0001	0.46	2.15
Breeding worth	39.76	18.59	2.14	0.03	0.52	1.91
Production worth	-22.55	17.97	-1.26	0.21	0.57	1.74
SR21[1]	-22.55	50.25	-0.45	0.65	0.67	1.49
SR42[2]	-80.56	97.87	-0.82	0.41	0.75	1.34
SMFS[3]	24.70	15.20	1.63	0.11	0.81	1.23
Adaptability to milking	99.64	26.70	3.73	0.00	0.30	3.30
Shed temperament	41.02	48.50	0.85	0.40	0.82	1.22
Milking speed	3.85	30.98	0.12	0.90	0.32	3.16
Overall opinion	-27.11	44.71	-0.61	0.54	0.54	1.86
Stature	4.85	32.31	0.15	0.88	0.07	13.44
Weight	-34.70	32.98	-1.05	0.29	0.07	14.45
Body capacity	-22.76	17.61	-1.29	0.20	0.51	1.94
Rump angle	21.46	15.00	1.43	0.15	0.81	1.24
Rump width	1.47	13.29	0.11	0.91	0.60	1.65
Legs	-38.01	17.37	-2.19	0.03	0.58	1.72
Udder support	21.39	19.05	1.12	0.26	0.21	4.69
Front udder	-3.87	16.37	-0.24	0.81	0.23	4.44
Rear udder	-30.74	18.40	-1.67	0.10	0.35	2.82
Front teat placement	27.87	21.82	1.28	0.20	0.63	1.59
Rear teat placement	-11.55	12.14	-0.95	0.34	0.67	1.49
Udder overall	9.29	27.62	0.34	0.74	0.10	9.78
Dairy conformation	1.79	19.84	0.09	0.93	0.50	2.02
Body condition score	-46.27	36.18	-1.28	0.20	0.75	1.33

[1]SR21 = Submission rate at 21 days after the start of mating
[2]SR42 = Submission rate at 42 days after the start of mating
[3]SMFS = Interval from start of mating to first service

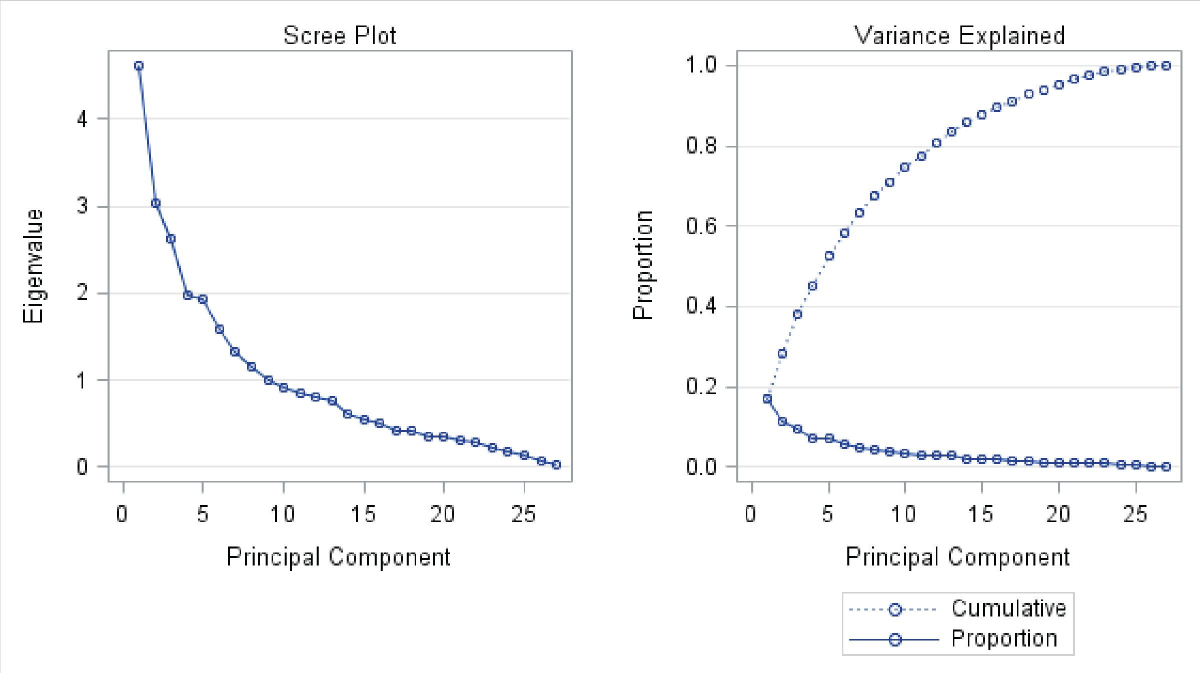

Figure A1. Eigenvalues and cumulative variance explained by potential predictor variables of culling in Massey University Dairy 1

Table A6. Summary of the stepwise selection with the variables retained and removed in the last step of model building

Step	Effect: Entered	Effect: Removed	Score Chi-Square	Wald Chi-Square	Pr > Chi-Square
1	Empty status		158.84		<.0001
2	Milk solids yield		67.35		<.0001
3	Udder support		78.52		<.0001
4	Rump angle		29.31		<.0001
5	Adaptability to milking		22.15		<.0001
6	Legs		11.90		0.0077
7	Body capacity		14.86		0.0019
8	Breed		8.62		0.0134
9	Milk yield		10.94		0.0009
10	Breeding worth		7.58		0.1083
11	SR21[1]		3.15		0.0761
12	Lactation number		11.74		0.068
13	Rump width		9.19		0.0565
14	Rear udder		6.59		0.1591
15	SR42[2]		1.72		0.1902
16	PW[3]		5.01		0.2859
17		PW		4.97	0.2902

[1]SR21 = Submission rate at 21 days after the start of mating
[2]SR42 = Submission rate at 42 days after start of mating
[3]PW = Production worth
[*]Milking speed, SCS, SMFS, front teat placement, rear teat placement were removed in previous steps of the procedure

Table A7. Effect of explanatory variables on the survival of cows from Massey University Dairy 1

Effect	Wald Chi-Square	P-value
Breed	13.97	0.0009
Empty status	52.56	<.0001
Milk solids yield	11.75	0.0028
Milk yield	12.61	0.0018
Adaptability to milking	17.96	<.0001
Body capacity	15.33	0.0016
Legs	15.45	0.0015
Rump angle	21.05	0.0001
Udder support	13.04	0.0111
Rump width	6.38	0.1724