Phenotypic correlations between linear type conformation traits, production and fertility in a once-a-day milked dairy cattle herd

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

Master of Veterinary Science

At Massey University, Palmerston North, New Zealand.

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2015

ABSTRACT

There is widespread adoption of OAD milking of dairy cattle in New Zealand, and to maximize the benefits, selection of animals which function well on this system is necessary. Selection can be facilitated through the use of linear type trait scoring in the selection procedure and this study aimed to quantify the correlations between the linear type traits and economically important traits in an OAD milked herd. Jersey cows in this study had lower mean scores for the body type traits, milk and protein yield and lactation length, but similar udder type scores, somatic cell score, fat yield and fertility performance compared with Holstein-Friesian and crossbred cows. The phenotypic correlations between individual body type traits were positive and strong, and likewise between individual udder type traits, however, between the two groups, the phenotypic correlations were weak and negative as found in previous TAD studies. There were also indications of a more consistent association of highly curved legs in larger animals in this study. Reduced udder support was correlated with higher somatic cell scores, and greater body type scores were strongly associated with high yield, while higher yielding animals tended to have less desirable udders. The linear type traits were not correlated with lactation length except for a weak positive correlation with rump angle. Older animals with higher scores for stature, weight and body condition were submitted earlier, and the likelihood of early conception and pregnancy was most dependent on early calving and higher body condition score and was associated with reduced rump width. The suggestion was put forward that the number of linear type traits to be used in OAD systems can be reduced to include only one or two body type and one or two udder type traits, and the linear type traits to be considered for inclusion in the selection index for OAD milking systems are: stature/weight, udder support/fore udder attachment, body condition score, udder overall, and dairy conformation. Of these, udder support and stature appear to be the most suitable. In general, higher values for these traits would be desirable to improve yield and fertility in the case of the body type traits, and somatic cell score in the case of the udder type traits.

ACKNOWLEDGEMENTS

Firstly, I would like to thank my supervisors Professor Nicolas Villalobos-Lopez and Dr. Rebecca Hickson for their sound advice and guidance throughout this research. I would also like to thank Felipe Lembeye and Nick Sneddon who assisted in the data collection and recording process, and were extremely helpful in my understanding of the preliminary information. Mrs. Jolanda Amoore, farm manager at Massey Farms Dairy No. 1 was also of great assistance in the completion of this project, as she provided additional data and rapid responses to questions and queries I had.

Many thanks also, to my family and friends both in New Zealand, and in my home-country Jamaica, including my partner, O'Dane Daley. Your words of encouragement, love and support were much appreciated. Finally, I would like to thank God for His many blessing towards me throughout this year, and enabling me to accomplish this task.

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LIST OF ABBREVIATIONS

BCS	Body condition score
C21	Conception to Day 21
C42	Conception to Day 42
F	Holstein-Friesian cows
F x J	Crossbred cows
J	Jersey cows
LIC	Livestock Improvement Corporation (New Zealand)
LL	Lactation length
MS/cow	Milksolids production per cow
MS/ha	Milksolids production per hectare
OAD	Once-a-day milking
S21	Submission to Day 21
S42	Submission to Day 42
SBCO	Interval from start of breeding to conception
SBFS	Interval from start of breeding to first service
SCS	Somatic cell score
TAD	Twice-a-day milking
TOP	Traits other than production

Chapter 1: INTRODUCTION

In New Zealand, there has been a growing movement to adopt once-a-day milking in the dairy industry, motivated by various factors such as the health, welfare and management benefits to both farmers and their cows (Holmes & Hendrikse, 2014). There are, however, some disadvantages to the practice of once-a-day milking versus twice-a-day milking on dairy farms. These include: reductions in milk production per cow, reductions in lactation length, increases in milking time, increases in somatic cell count at various times during the lactation period, and problems associated with severely distended udders, as animals are required to carry a larger quantity of milk in the udders for a longer period of time (Dalley & Bateup, 2004; Gleeson *et al.*, 2007; O'Driscoll *et al.*, 2010; O'Driscoll *et al.*, 2012).

These issues can be addressed to a large extent by the identification of individual cows and breeds of dairy cattle which are suitable for once-a-day milking, as there are wide variations in responses of animals to once-a-day milking (Holmes & Hendrikse, 2014). Currently, farmers are selecting for animals which function well on once-a-day milking systems (Holmes & Hendrikse, 2014), and this suitability is partly related to their ability to store a large proportion of their total milk production in the udder cisternae (Knight & Dewhurst, 1994), and them having strong udder attachment to increase their ability to carry more milk (Holmes *et al.*, 2002). This informal selection has resulted in improvements in profitability and milksolids yield (fat and protein yield) on once-a-day milking farms in New Zealand over the past few years, with some farmers reporting milksolids yields of approximately 300-380 kg MS/cow and 900-1235 kg MS/ha in the 2013-2014 lactation season (Holmes & Hendrikse, 2014).

The finding of an association between particular udder traits (such as udder attachment) and suitability of animals for once-a-day milking, as well as the need for cows to be faster and easier to milk so as to reduce labour cost and increase milking efficiency, has spurred interest in the inclusion of linear type traits in a selection index for once-a-day milking systems. The linear type traits, otherwise called traits other than production (TOP), are objective descriptions of an individual animal's body, udder and leg conformation (*Advisory Committee on TOP*, 2011). Consequently, the objective of this study was to examine the phenotypic correlation between these linear type traits (TOP) and traits of economic importance affecting farm profitability, including production and fertility traits for cows on a once-a-day milking system. In doing so, the correlation between individual linear type traits for cows on once-a-day milking will be assessed in an effort to reduce the number of traits included, and then these will be related to production and fertility, in order to assist in the formulation of a model for their inclusion in a selection index for once-a-day dairy milking systems in New Zealand. The subsequent chapter will review existing literature on the variations in linear type scores between breeds on twice-a-day milking systems, the performance of animals on once-a-day milking compared to twice-a-day milking systems, and how this varies between breeds (particularly between Jersey and Holstein-Friesian cows). The literature review will also examine the phenotypic relationships found in previous studies between the linear type traits, production and fertility for cows on twice-a-day milking regimens.

Chapter 2: LITERATURE REVIEW

2.1 Once-a-day milking in New Zealand

Dairy production in New Zealand is a seasonal pasture-based system in which most cows are milked twice a day (TAD) (in the morning and evening) during the lactation period. In 2004, however, 130 farms were identified to be milking cows only once a day (OAD) for the majority of the lactation period, and by 2005 and 2006, this number had increased to 351 and 746 farms respectively (Bewsell *et al.*, 2008). In 2014, based on statistics from the Livestock Improvement Corporation (LIC), approximately 2-5% of cows in New Zealand were being milked OAD throughout the entire lactation season (Holmes & Hendrikse, 2014).

2.1.1 Motivation to adopt OAD milking

This growing movement to adopt OAD milking has been motivated by the many health, welfare, and management benefits of this practice (Holmes & Hendrikse, 2014). Firstly, an often quoted factor is the lifestyle/social benefit (Bewsell *et al.*, 2008). Many farmers adopt OAD milking so as to reduce personal labour input in an effort to have more family time, pursue other business and leisure interests, and better cope with health issues (Kolver, 2001; Bewsell *et al.*, 2008). The latter point is of particular significance in New Zealand since the average age of dairy farmers is increasing, with less young people entering this field (Bewsell *et al.*, 2008).

Another major benefit of OAD milking is the resultant improvement in the health and fertility of the dairy cows. With a reduction in the energy demand, there can be improvements in the body weight and body condition score (BCS) throughout lactation compared to traditional TAD milkers (a 0.5 to 1.0 unit increase in BCS was noted in the study by Dalley and Bateup (2004)), and this can in turn lead to improved pregnancy rates and heavier cull cows (Rémond *et al.*, 2004; Dalley & Bateup 2004; Lee, 2011). On one particular farm, Rakaia Island, switching from TAD to OAD milking resulted in a reduction in the empty rate from 14% to 6.5% at ten weeks after mating (Lee, 2011).

Other health benefits relate to lameness incidence, which tends to be lower for OAD milked cows, partly due to them spending less time walking to the milking parlour (O'Driscoll *et al.*, 2010). This also has the added benefit of reducing energy expenditure, and allowing for the incorporation of marginal land into the milking platform, as cows would otherwise have to walk extremely long distances twice per day to the milking parlour (Kolver, 2001; Lee, 2011). One study by O'Driscoll *et al.* (2010) found that OAD milked cows had better overall hoof health and locomotion ability, with less sole lesions and white line disease incidence compared to TAD milked cows. Also, with OAD milking, there is better maintenance of a functioning immune system in the peri-partum period, via a reduction in metabolic stress in these cows compared to those on TAD milking systems (O'Driscoll *et al.*, 2012). These differences all lead to lower veterinary costs, lower herd wastage and replacement rates, extra calves for sale, and more selection options for replacement in OAD milked herds (Dalley & Bateup, 2004). The improvements in health and fertility also indicate an improvement in animal welfare (Dalley & Bateup, 2004; O'Driscoll *et al.*, 2010; Lee, 2011; O'Driscoll *et al.*, 2012).

Many farms which adopt OAD milking for at least a portion of the lactation period, do so as a means of coping with reduced feed availability, particularly at the start and end of the season or during adverse climatic conditions (e.g. droughts in the summer) (Dalley & Bateup, 2004; Bewsell *et al.*, 2008). In practicing OAD milking, there is a smaller energy demand on the cows, therefore farmers can support the same number of cows on less feed, rather than reduce cow numbers or import expensive feed. Other management benefits include: a reduction in milking parlour expenses (less effluent and lower power, detergent, filter socks and teat spray costs), facilitation of farm expansion without straining current farm infrastructural and personnel resources, and better utilization of the milking plant as two farms can use one milking shed and a distribution of milking over a 24 hour period can be facilitated in large herds (Dalley & Bateup, 2004; Bewsell *et al.*, 2008).

2.1.2 OAD milking concerns

Despite the advantages of OAD milking discussed above, there are a few concerns and considerations which need to be addressed in the drive for widespread adoption of OAD milking in dairy cattle. The foremost of these is the reduction in total milk volume, fat and protein yield per cow which occurs (Carruthers *et al.*, 1993; Kolver, 2001; Rémond *et al.*, 2004; Dalley & Bateup, 2004). Also, OAD milked cows tend to have shorter lactation lengths due to cows reaching low levels of milk production sooner in late lactation and generally, the milking time of the whole herd is increased per session (Dalley & Bateup, 2004). In the study by Rémond *et al.* (2004), Holstein-Friesian cows being milked OAD produced 30% less milk volume, as well as 25% less fat and 26% less protein milksolids (though the fat and protein concentration in the milk was higher), and had a shorter lactation length than those milked TAD. Likewise in the study by Carruthers *et al.* (1993), Jersey and Holstein-Friesian cows milked OAD produced 10-28% less milk volume and total milk solids (including fat and protein) in early to mid-lactation, and 9-13% less milk volume in late lactation than similar cows milked TAD.

The reduction in farm milk production due to reduced per cow production can be addressed to some extent by increasing the stocking rate and managing pasture and supplementary feed more efficiently so as to improve production per hectare (Dalley & Bateup, 2004; Lee, 2011). In the review of the Rakaia Island farm, it was stated that feed quality and availability was improved, particularly in late lactation to prevent premature drying off, and the number of cows was increased by 52% (Lee, 2011). Issues associated with increasing the stocking rate so as to have comparable economic farm surplus (EFS/ha) include concerns such as: the maintenance of extra cows in the winter, costs associated with milking, herd testing and artificially inseminating more cows, as well as the risk of having a larger feed deficit if harsh seasonal conditions are encountered (Dalley & Bateup, 2004).

Another concern with OAD milking is the higher somatic cell count and problems with distended udders and mastitis, which frequently occur. This is however not consistently the case as, although some reports show higher somatic cell counts in OAD milked cows

(O'Driscoll *et al.,* 2012), others show increased somatic cell counts at certain periods during lactation, but similar mean somatic cell counts to that of TAD milked cows (Rémond *et al.*, 2004). Also, most times the somatic cell levels in OAD milked herds are below the limits above which penalties would occur (Dalley & Bateup, 2004). Nevertheless, problems of discomfort and udder lesions associated with severely distended udders or "udder blowout" occur more frequently with OAD milked cows, as they have to carry larger quantities of milk for longer periods (O'Driscoll *et al.*, 2010; Lee, 2011; Holmes & Hendrikse, 2014).

2.1.3 Improvements through selection for OAD milking

Both the issues of reduced per cow production and increased udder problems can be addressed by genetic selection for individuals and breeds suitable for OAD milking as opposed to TAD milking systems (Dalley & Bateup, 2004; Holmes & Hendrikse, 2014). Jersey cows have been found to be more suited to OAD milking, producing only 9% less milksolids on this system compared to TAD milking, while Holstein-Friesian cows produced 19% less on OAD milking compared to TAD milking at similar live weight per hectare as the Jersey cows (Tong *et al.,* 2002). Similar results were found in the study by Dalley and Bateup (2004) (*see Table 2.1)*. Currently, farmers are selecting for animals which function well on OAD milking systems (Lee, 2011; Holmes & Hendrikse, 2014), and this selection has already resulted in improvements in profitability and milksolids yield for OAD milking farms in New Zealand, with some farmers reporting milksolids yields of approximately 300-380 kg MS/cow and 900-1235 kg MS/ha in the 2013-2014 lactation season (Holmes & Hendrikse, 2014). Even so, there is a need for a more specific selection index for OAD milkers so that genetic progress can be made much more rapidly and the profitability of this practice maximized.

Table 2.1. Differences between Jersey and Friesian cows in production and fertility on once-a-day (OAD) versus twice-a-day (TAD) milking. Adapted from Dalley and Bateup, 2004

	FRIESIAN			JERSEY		
	TAD	OAD	Difference	TAD	OAD	Difference
Milksolids[1] (kg/cow)	333	237	*- 29%*	276	224	*-19%*
Milksolids[1] (kg/ha)	999	831	*-17%*	994	939	*-6%*
Lactation length (days)	244	226	*-7%*	242	228	*-6%*
Somatic cell count (10^{-3}/ml)	78	160	*+105%*	87	146	*+68%*
Submission rate (both breeds)	88.0%	98.7%	*+12%*			
Empty rate (both breeds)	7.6%	3%	*-61%*			

[1] Milksolids is the sum of fat and protein yield

2.2 Linear type traits

Linear type traits (also referred to as traits other than production (TOP)) give objective descriptions for a number of visual characteristics of an animal, ranking them between biological extremes, irrespective of what ranking is considered ideal (Berry *et al.*, 2004; *Advisory Committee on TOP*, 2011). This method of linear scoring was introduced in 1983 (Brotherstone, 1994) and includes inspector-scored traits relating to the conformation of the body, udder and legs of the animal, as well as farmer-scored traits related to management (Cue *et al.*, 1996). In New Zealand, the former are scored by a pool of trained inspectors under the supervision of the TOP Advisory Committee (*Advisory Committee on TOP*, 2011). These traits are of interest to breeders as they are associated with production, longevity and profitability of animals in the dairy system (Brotherstone, 1994; NZ Animal Evaluation Unit, 2009). Currently TOP are only included in breeding worth indices indirectly by their contribution to the residual survival trait (*Advisory Committee on TOP*, 2011) however, there may be some benefit to their direct inclusion since they have a major impact on survival of animals, especially for OAD systems, and they can be measured earlier. Their inclusion in an economic selection index would be dependent on their heritabilities, their relationship with, and importance to production and survival, and the degree to which they can be used to reduce the rates of involuntary culling and increase production efficiency. In general, the body type conformation traits have the largest heritabilities (0.19 - 0.37), followed by udder traits (0.20 - 0.28), while the heritability of the leg trait tends to be low (0.07). The heritabilities of the farmer scored traits are also low (0.13 - 0.21) (NZ Animal Evaluation Unit, 2009) (*see Table 2.2)*.

The specific linear type traits assessed vary between countries. In New Zealand, 14 traits are scored by inspectors and 4 traits are scored by farmers using a scale from 1 to 9 *(see Table 2.2)*. Body condition score, although not commonly considered a TOP, is used to assess energy reserves (*Advisory Committee on TOP*, 2011) and is strongly correlated with fertility (NZ Animal Evaluation Unit, 2009). Sound feet and legs are most important in grazing systems such as practiced in New Zealand, so as to provide superior locomotion to enable efficient grazing (Berry *et al.*, 2004).

Table 2.2. Linear type traits used in New Zealand dairy cattle. Adapted from NZ Animal Evaluation Unit (2009) and *Advisory Committee on Top* (2011)

Type	Trait	Description	Minimum (1)	Maximum (9)	Heritability
Farmer scored traits[1]	Milking adaptability	How soon the animal settles into the milking routine post-calving	slowly	quickly	0.13
	Shed temperament	Temperament in the dairy shed while being handled	nervous	placid	0.14
	Milking speed	Time between cup attachment and removal	slow	fast	0.21
	Overall opinion	Farmer's overall acceptance of the heifer as a herd member	undesirable	desirable	0.13
Body type	Stature	Height at the shoulder in 5 cm bands	<105 cm	>140 cm	0.37
	Weight	Estimated live-weight in 50 kg bands	<250 kg	>600 kg	0.30
	Capacity	Depth and width of chest/body in relation to physical size (side, front, rear views)	frail	capacious	0.22
	Rump angle	Angle of a line between hip centre and top of pins	high	low	0.25
	Rump width	Width of pins, hips and thurls relative to physical size	narrow	wide	0.19
	Body condition	Estimation of body fat reserves	skinny	obese	0.38[2]
	Legs	Curvature of hind-limbs (side-view) while walking	straight	very curved	0.07
Udder type	Udder support	Strength of suspensory ligament and udder depth relative to the hocks	weak	strong	0.20
	Front udder	Attachment of front udder to the body wall	loose	strong	0.20
	Rear udder	Height and width of the rear udder attachment	low	high	0.20
	Front teats	Placement of the front teats relative to the centre of the quarters (rear view)	wide	close	0.25
	Rear teats	Placement of the rear teats relative to the centre of the quarters (rear view)	wide	close	0.28
	Udder overall	All udder traits	undesirable	desirable	0.23
	Dairy conformation	All dairy conformation traits excluding udder traits	undesirable	desirable	0.19

[1] The 4 farmer-scored traits were not assessed in this study [2] Veerkamp *et al*., 2001

2.2.1 Linear-type traits: means and standard deviations

With these linear type traits being represented on a scale from 1 to 9 and treated as continuous data rather than categorical, the expected mean for each would be approximately 5, with a phenotypic standard deviation of 1.5, however, departures from these values frequently occurred in various studies, i.e. results are skewed and show kurtosis (Meyer *et al.,* 1987; Brotherstone *et al.,* 1990; Cue *et al.,* 1996; Berry *et al.,* 2004). This is due to differences between populations, but also is a reflection of the subjective nature of the linear scoring, which, with the exception of stature (and weight), is not based on actual measurements but rather, assessments (Brotherstone *et al.,* 1990).

In reviewing previous studies done in TAD milked herds using a 1-9 scale, the phenotypic standard deviations of the conformation linear type traits tend to be lower than the expected 1.5, with exceptions occurring for front udder attachment, udder depth and front teat placement in some studies, where the standard deviations are higher than 1.5 (*see Table 2.2.1)*. This could indicate reluctance by the inspectors to score animals at the extreme ends of the range for the different traits, or the presence of uniformity within the herds with most animals having scores within a narrow range close to the mean, possibly due to intensive selection occurring previously (Meyer *et al.,* 1987; Brotherstone *et al.,* 1990; Berry *et al.,* 2004). It is also possible that the 1 to 9 scale may be too wide for some traits (Meyer *et al.,* 1987). The higher than expected standard deviation for some of the udder type traits could indicate the presence of large variations in udder conformation or lack of selection on these traits in TAD milking systems.

The means for the body type traits from the various studies in TAD milked cows (namely, body condition score, rump angle, chest width (capacity), and stature) tend to be close to or slightly below the expected value of 5, while that of body depth (capacity) and rump width are above the expected mean (*see Table 2.2.1)*. An exception is the study by Cue *et al.* (1996) conducted in New Zealand Holstein cows, which found stature and rump angle to have means higher than normally found. In all the studies examined, the mean score for legs (hind-legs viewed from the side) was higher than the expected 5 with a very low standard deviation, thus indicating high curvature of the legs of dairy cows in most herds. Likewise, in all studies examined, the mean score for udder type traits was higher than the expected 5, except for front udder and rear udder attachment, which were close to the expected 5 in a few studies while higher in others; and front and rear teat placement which were below the expected 5 in some studies while greater than 5 in others. In the study by Meyer *et al.* (1987), for the second lactation, udder depth had a mean score close to 5. The overall udder score obtained from the study by Cue *et al.* (1996) in New Zealand Holstein cows was 4.76 (*see Table 2.2.1 for a summary of the findings*).

2.2.2 Difference in means and standard deviations between breeds

The means and standard deviations for the linear type traits can vary between breeds. In the study by Visscher and Goddard (1995), Jersey cows had higher means for dairy character, fore udder attachment, rear udder attachment, front teat placement, capacity, stature, and similar means for the legs trait compared to Holstein-Friesian cows. Likewise, in the study by Cue *et al.* (1996) in New Zealand, Jersey cows had higher mean values for dairy conformation, fore udder attachment, rear udder attachment and capacity, as well as rump width, udder support and overall udder score, but in this study they scored lower for stature and legs (and also weight, rump angle and rear teat placement) and similarly for front teat placement compared with Holstein-Friesian cows (*see Figure 2.2.2)*.

Table 2.2.1. A compilation of means (top value) and standard deviations (bottom value) of linear type traits in dairy herds using data from various studies

Reference	Country and Breed	S	W	CW	BD (C)	RA	RW	BCS	L	US	UD	FUA	RUW	RUH (RUA)	FTP	RTP	UO	DCo	DCh
Brotherstone *et al.*, 1990	UK	4.45		5.18	6.14	4.42	5.56		5.73	6.05	6.34	5.89	5.68			4.66			
	HF	1.33		1.34	1.38	1.22	1.27		1.16	1.38	1.64	1.59	1.40			1.41			
Brotherstone, 1994	UK	4.46		5.12	6.12	4.36	5.58		5.78	6.04	6.31	5.82				4.73			
	HF	1.36		1.24	1.29	1.22	1.26		1.08	1.35	1.62	1.57				1.35			
Lund *et al.*, 1994	Denmark									6.08	5.92	5.76		5.36	5.91				5.19
	Holstein									1.36	1.15	1.39		1.40	1.59				1.27
Berry *et al.*, 2004	Ireland	4.1		4.9	5.3	4.3	4.9	4.8	5.6	5.7	5.8	5.0		4.9		4.7			
	HF and XB	1.31		1.43	1.35	1.35	1.37	1.57	1.22	1.21	1.25	1.58		1.33		1.31			
Meyer *et al.*, 1987	UK HF	4.36		5.26	6.41	4.17	5.94		5.89	5.82	4.95	5.59	5.83		4.71				
		1.37		1.32	1.22	1.19	1.19		1.00	1.47	1.91	1.69	1.39		1.48				
Klassen *et al.*, 1992	Canada	5.7										5.0		5.0	5.5	6.9			
	Holstein	1.5										1.1		1.2	1.4	1.4			
Rupp and Boichard, 1999	France										6.3	5.2		5.1	5.2	3.8			
	Holstein										1.1	1.7		1.4	1.4	1.5			
Cue *et al.*, 1996	New Zealand	5.98	4.79		5.77	5.52	5.51		5.89	4.92		5.02		4.83	4.51	5.56	4.76	5.42	
	Holstein	1.01	0.97		0.89	0.85	0.87		0.95	0.95		0.99		0.91	0.89	0.93	0.93	0.99	

S: stature, W: weight, CW: chest width, BD: body depth, C: capacity, RA: rump angle, RW: rump width, BCS: body condition score, L:legs, US: udder support, UD: udder depth, FUA: fore udder attachment, RUW/H: rear udder height/width, RUA: rear udder attachment, FTP: front teat placement, RTP, rear teat placement, UO: udder overall, DCo: dairy conformation, DCh: dairy character, HF: Holstein-Friesian, XB: crossbred

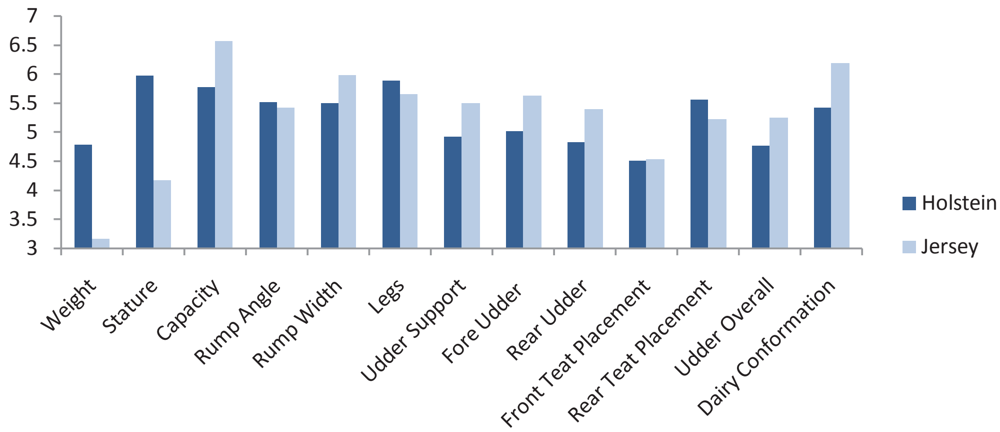

Figure 2.2.2. Comparison of mean scores for linear type traits in Holstein and Jersey cows. Adapted from Cue *et al.* (1996)

2.3 Phenotypic correlations between linear type traits

The following review includes studies of phenotypic correlations between the various linear type traits in TAD milked herds.

2.3.1 Correlations between body type traits

In general, the phenotypic correlations between the body type traits: stature, weight, capacity, body condition score, rump angle and rump width are moderate and positive (except those involving rump angle which are negative and low to insignificant) (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Harris *et al.*, 1992; Brotherstone, 1994; Cue *et al.*, 1996; DeGroot *et al.*, 2002; Berry *et al.*, 2004).

From previous studies, it is evident that stature is strongly and positively correlated with most other body type traits. The phenotypic correlation between stature and body depth is between 0.48 - 0.52 in most studies, and the correlation between stature and chest width usually occurs in the range of 0.25 - 0.38 (Brotherstone *et al.*, 1990; Harris *et al.*, 1992; Brotherstone, 1994; Berry *et al.*, 2004). Body depth and chest width are components of capacity, and the correlation between stature and capacity is also moderate at 0.24 (Cue *et al.*, 1996). Likewise, the phenotypic correlation between stature and rump width is moderate and positive, usually ranging from 0.23 - 0.31 (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Brotherstone, 1994; Cue *et al.*, 1996), however, between stature and rump angle, the correlation is insignificant (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004). One study also showed the correlation between stature and body condition score to be insignificant (Berry *et al.*, 2004).

As expected, since chest width and body depth are components of the same trait capacity, their phenotypic correlation is strong – approximately 0.54 (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Brotherstone, 1994; Berry *et al.*, 2004). They, along with the composite capacity trait, have negative and very weak or insignificant correlations with rump angle, however, they are moderately positively correlated with rump width usually ranging from 0.34 - 0.49 (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Brotherstone, 1994; Berry *et al.*, 2004).

The correlation between rump width and rump angle is negative and usually weak to insignificant (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004). In the study by Berry *et al*. (2004), it was found that body condition score was strongly correlated with chest width (0.58), moderately correlated with rump width (0.31), weakly correlated with body depth (0.11) and very weakly correlated with rump angle (0.08). In the study by Cue *et al.* (1996), weight was positively correlated with stature (0.78), capacity (0.38), rump width (0.24) and rump angle (0.02). Dairy conformation was found to be moderately to strongly positively correlated with the body type traits (Harris *et al.*, 1992; Cue *et al.*, 1996).

2.3.2 Correlations between body and leg traits

The leg type trait, rear legs curvature is not correlated with body type traits (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Harris *et al.*, 1992; Klassen *et al.*, 1992; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004) except with body condition score where the correlation coefficient is negative and low (-0.17) (Berry *et al.*, 2004), and in the study by Cue *et al.* (1996), rear legs was negatively and weakly but significantly correlated with capacity (-0.13). This suggests that higher body condition scores and more capacious animals have straighter legs. The correlation between legs and dairy conformation is also negative and weak (-0.19) (Cue *et al.*, 1996).

2.3.3 Correlations between udder type traits

The phenotypic correlations between udder type traits are all positive however they vary in significance and strength (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Klassen *et al.*, 1992; Brotherstone, 1994; Lund *et al.*, 1994; Cue *et al.*, 1996; Boettcher *et al.*, 1998; Berry *et al.*, 2004).

Fore and rear teat placement are generally strongly correlated with each other (Klassen *et al.*, 1992; Cue *et al.*, 1996; Boettcher *et al.*, 1998), and fore and rear udder attachment (measured by rear udder width and rear udder height) are moderately correlated (0.27 - 0.48) (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Klassen *et al.*, 1992; Lund *et al.*, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004). This means that wider front teats are usually associated with wider rear teats, and strong fore-udder attachment usually equates to strong rear udder attachment. Similarly, fore udder attachment is moderately correlated with fore teat placement (0.24 - 0.38) (Meyer *et al.*, 1987; Harris *et al.*, 1992; Klassen *et al.*, 1992; Lund *et al.*, 1994; Cue *et al.*, 1996; Boettcher *et al.*, 1998), while rear udder attachment is weakly correlated with rear teat placement (0.11 - 0.19) (Brotherstone *et al.*, 1990; Cue *et al.*, 1996; Boettcher *et al.*, 1998). In the study by Klassen *et al.* (1992), this correlation between rear udder attachment and rear teat placement was found to be moderate (0.35) and similarly, in the study by Berry *et al.* (2004), this correlation was also moderate at 0.29. The correlation between fore udder attachment and rear teat placement, or rear udder attachment and fore teat placement is weak to moderate (0.10 - 0.27) (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Harris *et al.*, 1992; Klassen *et al.*, 1992; Brotherstone, 1994; Lund *et al.*, 1994; Cue *et al.*, 1996; Boettcher *et al.*, 1998; Berry *et al.*, 2004).

Udder support is weakly to moderately correlated with the other udder traits (fore and rear udder attachment, fore and rear teat placement) with various studies giving ranges from 0.08 - 0.40 for udder attachment, and 0.14 - 0.36 for teat placement (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Harris *et al.*, 1992; Brotherstone, 1994; Lund *et al.*, 1994; Cue *et al.*, 1996; Boettcher *et al.*, 1998; Berry *et al.*, 2004). However, in the study by Cue *et al.* (1996), the correlation between udder support and fore udder attachment was found to be very strong (0.60) and also between udder support and rear udder attachment (0.61). Likewise, in the study by Berry *et al.* (2004) the correlation between udder support and rear udder attachment was moderately strong (0.45).

Of importance is the finding in most studies of a strong positive correlation between the overall udder score and the other udder type traits with the strongest correlations being with udder support (0.73) (Cue *et al.*, 1996) and front and rear udder attachment (0.53 -

0.71), and the lowest being the moderate correlations with front and rear teat placement (0.39 - 0.41 and 0.21 - 0.27 respectively) (Cue *et al.*, 1996; Boettcher *et al.*, 1998).

2.3.4 Correlations between udder and leg traits

The phenotypic correlations between the rear leg trait and udder type traits are very weak and insignificant in some cases (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Harris *et al.*, 1992; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004). The phenotypic correlations between legs and rear and fore udder attachment in most studies except the one by Klassen *et al.* (1992) are negative and weak and, between legs and udder support, rear and fore teat placement, the correlations are insignificant or non-existent (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Harris *et al.*, 1992; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004). Cue *et al.* (1996) however found a weak but significant negative correlation between legs and udder support. The correlation between legs and overall udder score is weak (-0.11) (Cue *et al.*, 1996).

2.3.5 Correlations between body and udder traits

The phenotypic correlations between the body type and udder type traits are weak and mostly insignificant. Udder support has no correlation with the body type traits except with body condition where the correlation is moderate and negative (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004), thus suggesting that higher body condition scores are associated with weaker udder support. Also, a weak positive correlation was seen with body depth in the study by Berry *et al.* (2004). Likewise, fore-udder attachment has weak and mostly insignificant correlations with the body type traits, though in some studies, a weak positive correlation was found between fore udder attachment and stature or capacity, and a weak negative correlation between fore udder attachment and rump angle or rump width (Harris *et al.*, 1992; Klassen *et al.*, 1992; Cue *et al.*, 1996; Berry *et al.*, 2004). The phenotypic correlation between rear udder attachment (measured by rear udder height and width) and stature is positive and weak, and similarly positive and weak between rear udder attachment and both body depth (capacity) and rump width, while with rump angle and body condition score, the correlation for rear udder attachment is negative and weak (Meyer *et al.*, 1987;

Brotherstone *et al.,* 1990; Cue *et al.,* 1996; Berry *et al.,* 2004). Fore and rear teat placement are not correlated with body type traits (Meyer *et al.,* 1987; Brotherstone *et al.,* 1990; Harris *et al.,* 1992; Klassen *et al.,* 1992; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004).

In the study by Cue *et al.* (1996), the overall udder score only showed a weak correlation with the body type traits: capacity (0.11), rump width (0.11) and rump angle (-0.16). Dairy conformation was moderately to strongly positively correlated with overall udder score, udder support and front and rear udder attachment, and weakly or insignificantly positively correlated with teat placement (Harris *et al.,* 1992; Cue *et al.,* 1996).

2.3.6 Summary (correlations between linear type traits)

The positive and moderately strong correlations between the body type traits in TAD milked cows indicate that high scores in one trait usually equate to high scores in the other traits, hence these traits can be combined to produce composite traits, thus reducing the number of body type traits necessary for analysis. Likewise, the positive and moderate to strong correlations between some udder traits indicate that it may not be necessary to use all these traits but rather, composite traits can be used or some traits omitted from analysis. For example, fore and rear teat placement, as well as fore and rear udder attachment are moderately to strongly correlated with each other, therefore, these four traits could be reduced to just traits for teat placement and udder attachment. Also, it should be noted that udder support was found in some studies to be strongly correlated with fore and rear udder attachment and thus could be used to incorporate all three of these traits. Given the high correlation coefficients obtained between the overall udder score and all other udder type traits, it may be feasible to use this trait to represent udder conformation in the dairy cow. The correlations between body and udder type traits are generally weak, hence at least one of each type trait is necessary. The absence of a significant correlation between leg and the body type or udder type traits could necessitate the inclusion of the leg score as a separate trait.

2.3.7 Difference between breeds in correlation between linear type traits

The phenotypic correlations between traits other than production in TAD milked herds show a considerable degree of consistency between Holstein-Friesian, Jersey and crossbred cows in some studies, however, when there are inconsistencies between breeds, this is usually associated with large standard errors and experimental biases such as those occurring when comparing registered versus non-registered herds, the latter of which usually have lower correlation results (Cue *et al.,* 1996; Visscher & Goddard, 1995).

2.4 Differences between OAD and TAD milking in production and fertility

Generally, when animals are placed on OAD milking routines there is a decrease in milk volume, fat, and protein production, as well as a decrease in lactation length (Carruthers *et al.*, 1993; Kolver, 2001; Rémond *et al.*, 2004; Dalley & Bateup, 2004). According to the literature, milk yield reductions vary widely from 10-50%, mainly due to variations in experimental conditions such as: trial duration, timing of switch in milking frequency (a sudden switch cause a more drastic decrease compared to milking OAD from the start of lactation post-calving), production level (losses are higher in primiparous cows and those with lower milksolids concentration), stage of lactation (losses are higher at the beginning of lactation) and feeding level (losses are more noted in high feed systems) (Rémond *et al.*, 2004). There is usually an increase in milk fat and protein concentration in the milk (Rémond *et al.*, 2004), however, this is not sufficient to counteract the overall reduction in milk fat and protein production. In the study by Carruthers *et al.* (1993), milk and fat yield reductions in OAD milked herds varied from 12-16% and 3-17% respectively, at various times in the lactation season. Likewise, in the study by Rémond *et al.* (2004), milk production for the OAD milked herd peaked in Week 4-5 at 8 kg/day lower than the peak yield for TAD herds, which occurred in Week 5-6. The OAD herd had overall decreases in milk, fat and protein volume of 30.2%, 25% and 26% respectively compared to the TAD herd (Rémond *et al.*, 2004). Also, lactation length in the OAD milked herd was 12 days shorter than in the TAD milked herd, however, the lactation curves after peak production, were similar in shape (similar persistency) (Rémond *et al.*, 2004).

Live-weight and body condition score, as well as fertility, are usually improved with OAD milking, while somatic cell score changes vary (Rémond *et al.*, 2004; Dalley & Bateup, 2004). In the study by Dalley and Bateup (2004), OAD milked cows were 0.5-1.0 condition score higher than the TAD milked cows, and in the study by Rémond *et al.* (2004), eight of nine OAD cows (89%) were pregnant by 102 days after calving compared to four of seven TAD cows (57%). An increase in somatic cell count, which occurs often, is dependent on the initial condition of the udder (Rémond *et al.*, 2004). In the study by

Rémond *et al.* (2004), the somatic cell count increased more rapidly in OAD milked cows after Week 29 of lactation and was significantly higher during much of the last 15 weeks of lactation, however, it was not significantly higher for the whole lactation period. It has been suggested that the higher somatic cell count in OAD milked cows later in lactation could be attributed to the lower milk yield towards the end of lactation, and the increased pregnancy rates as a result of improved fertility, compared to TAD milked herds (Rémond *et al.*, 2004). Because of these differences, somatic cell count is more economically important and fertility less so in the national breeding worth index for once-a-day compared to twice-a-day milking systems (Holmes & Hendrikse, 2014).

Nevertheless, it has been shown that proper selection of animals for once-a-day milking improves milk production so that the reduction is minimized, or does not occur. When a New Zealand OAD trial with randomly selected Jersey cows was done, stocking rates had to be increased by 17% over that of TAD milking so as to obtain almost equivalent milksolids yield per hectare (Canton, 2005). However, when the trial was repeated using animals selected for suitability for OAD milking (using LIC OAD Index), with only a 10% increase in stocking rate, the OAD herd produced similar milksolids per hectare to that obtained from the herd milked TAD (1142 kg MS/ha vs. 1190 kg MS/ha respectively) (Canton, 2005). These OAD milked cows had higher condition scores, longer lactation lengths, acceptable somatic cell scores, similar lactation curves and similarly low empty rates (4%) as the TAD milked herd (Canton, 2005).

2.4.1 Breed differences in performance on OAD vs. TAD milking

As mentioned previously, there are breed differences in suitability for OAD milking systems and these differences are reflected in the different production and fertility responses to OAD milking. The Jersey breed experiences less reductions in milksolids compared to the Holstein-Friesian (9% versus 19% in the study by Tong *et al.* (2002) with similar results given in Dalley and Bateup (2004)). In the study by Carruthers *et al.* (1993), it was found that high protein-producing Jersey cows had less reduction in milk protein yield in late lactation than Holstein-Friesian cows when milked OAD, however, although they had less reduction in fat and milk volume yield compared to Holstein-Friesian cows, this was not significant ($P>0.05$). Jersey cows also have a much smaller increase in somatic cell score than Holstein-Friesian cows when switched to OAD milking (68% versus 105% increase, Dalley & Bateup, 2004) and a smaller decrease in lactation length than Holstein-Friesians (6% vs. 7%, Dalley & Bateup, 2004; 9% versus 13%, Tacon, 2002).

Despite this apparent suitability of Jersey cows compared to Holstein-Friesian cows for OAD milking, based on information given by LIC (Holmes & Hendrikse, 2014), there is a wide variation in performance for Holstein-Friesian cows (wider than that of Jersey cows) on OAD milking systems. A 57% performance difference was found between top and bottom quartile Holstein-Friesian cows, therefore, breeding selection within the Holstein-Friesian breed for OAD can be practical (Holmes & Hendrikse, 2014). Also, the evidence so far seems to suggest that the improvement in fertility on OAD milking regimens is similar between Jersey and Holstein-Friesian cows (Dalley & Bateup, 2004).

2.5 Phenotypic correlations between linear type traits and production

Linear trait evaluation programmes have been used to aid in breeding decisions and recently there has been an increased diversification of selection indices worldwide to include non-production, functional traits (Berry *et al.*, 2004). However, due to the long time intervals required, and poor recording of some health and fertility functional traits, linear type traits, which are more easily measured, are highly heritable, and have correlations with and influence on the desired functional and productive traits, have been increasingly used (Brotherstone, 1994; Berry *et al.*, 2004). For example, studies have shown that the type traits and yield traits are independent predictors of herd-life (Foster *et al.*, 1989) and are correlated with survival (Brotherstone, 1994).

2.5.1 Influence of udder type traits on dairy system production

The importance of the linear type traits with regards to various aspects of dairy production has been highlighted previously in many studies. Many of these studies relate to the importance and correlation of the udder type traits with somatic cell count, mastitis and cow survival or longevity. Research has shown that selection for increased udder height/depth (udders higher off the ground), greater udder support and rear udder attachment, and more closely placed teats can help to reduce the incidence of mastitis (Seykora & McDaniel, 1985; Monardes *et al.*, 1990; deGroot *et al.*, 2002) and thus also improve survival and longevity.

In addition to the influence of udder type trait on the functional traits, they also impact production directly. The reduction in milk production (both in yield and lactation length) in OAD milked cows has been attributed to alveolar (secretory cells) milk accumulation (Carruthers *et al.*, 1993; Davis *et al.*, 1999) and the effect of an autocrine inhibitor of milk secretion produced in the mammary epithelial cells, which, when stored in the gland for some time due to less frequent milking, results in feedback inhibition (Wilde & Peaker, 1990). This inhibitor is active within the secretory tissue but not within the cisternae (non-secretory cells), thus large cisterned-cows, which store a greater proportion of their milk in the cisternae, tolerate infrequent milking much better, i.e. have less reduction in milk production (Knight & Dewhurst, 1994). On average Jersey cows have larger udder capacities (and cisternal storage) than Holstein-Friesian cows (Carruthers *et al.*, 1993) and this could partially explain their better suitability for OAD milking. Additionally, studies in ewes have shown positive correlations between udder measurements and milk yield, with udder circumference and teat diameter being good predictors of milk yield (Merkhan, 2014). It should however be noted that prediction based on udder capacity is difficult, as functional udder capacity (indirectly measured using udder type traits) is not representative of cisternal capacity, and even with excess udder capacity, cows still sometimes show unacceptably high losses in production on OAD milking (Carruthers *et al.*, 1993).

2.5.2 Influence of body, leg type traits and lameness on dairy system production

The body traits (particularly body condition score) are also related to production and fertility as they indicate, to some extent, energy availability to produce milk and reproduce. Additionally, leg traits have also been shown to be of importance in influencing production. Lameness produces economic losses through treatment costs and culling, as animals with bad legs will not have optimal access to feed, and thus will experience reductions in milk production and fertility (Warnick *et al.*, 2001). Lameness therefore impacts production, fertility and survival, and the linear type traits: foot angle and rear legs set, in addition to udder attachment and rump width, have all been found to be significantly correlated with clinical lameness and thus can provide an indication of susceptibility to locomotion diseases (Perez-Cabal *et al.*, 2006).

2.5.3 Influence of milking speed on dairy system production

Milking speed, a farmer-scored type trait, has also been theorized to be useful in improving milk production, especially as a means of reducing labour input (Sharaby *et al.*, 1979), and this may be applicable especially for OAD milking systems. However, increased milking speed has been reported to be associated with an undesirably high somatic cell count and can lead to an increase in mastitis incidence (Moore *et al.*, 1983; Rupp & Boichard, 1999). It is therefore important to evaluate the usefulness of selection for improved udder type traits and milking speed in reducing mastitis or slowing its increase in association with the increase in milk yield (Rogers *et al.,* 1991) particularly under OAD regimens.

2.5.4 Correlation of linear type traits with milk yield, fat yield, protein yield

Different studies from TAD milking systems conducted previously report significant phenotypic correlations between milk yield and the linear type traits: angularity (moderate and positive) (Meyer *et al.,* 1987; Klassen *et al.,* 1992; Brotherstone, 1994), chest width and body depth (capacity) (weak or insignificant) (Meyer *et al.,* 1987; Klassen *et al.,* 1992; Brotherstone, 1994), udder depth (moderate and negative) (Meyer *et al.,* 1987; Harris *et al.,* 1992; Brotherstone, 1994), fore udder attachment (weak and negative) (Meyer *et al.,* 1987; Harris *et al.,* 1992; Brotherstone, 1994), rear udder attachment (weak to moderate and positive) (Meyer *et al.,* 1987; Harris *et al.,* 1992; Klassen *et al.,* 1992), and dairy conformation (moderate to strong and positive) (Klassen *et al.,* 1992; Harris *et al.,* 1992; Visscher and Goddard, 1995). In the studies by Seykora and McDaniel (1985), and Batra and McAllister (1984), rather than a moderately positive correlation with rear udder attachment, the relation of udder height (a partial measure of rear udder attachment) with milk yield was weak and negative. Other traits also found to be significantly associated with milk yield in specific studies include the positive association of rump angle, stature (also in Harris *et al.,* 1992) and udder support in the study by Foster *et al.* (1989), using regression models for herd-mate deviation for milk. In another study by Veerkamp and Brotherstone (1997), weight and condition score were found to be moderately negatively correlated with milk yield, and similarly in the study by Kadarmideen (2004), body condition was weakly and negatively correlated with milk yield. In the study by Klassen *et al.* (1992), overall mammary system (udder overall) had a weak positive correlation with milk production. In all studies reporting on the traits rear legs side, rump width and teat placement, the correlations with milk yield were insignificant or zero (Meyer *et al.,* 1987; Harris *et al.,* 1992; Klassen *et al.,* 1992; Brotherstone, 1994).

Likewise, with fat and protein yield, the linear type traits showing significant phenotypic correlations are: angularity (moderate and positive), stature (weak and positive), chest width (weak and negative) and body depth (weak to moderate and positive) (capacity weak to insignificant and positive overall), fore udder attachment (weak and negative), udder depth (moderate and negative), rear udder attachment (moderate and positive), udder support (weak and positive), dairy character/conformation (moderate to strong and positive) (Meyer *et al.*, 1987; Klassen *et al.*, 1992; Harris *et al.*, 1992; Brotherstone, 1994), and weight and condition score (weak to moderate and negative) (Veerkamp & Brotherstone, 1997; Kadarmideen, 2004). All other linear type traits were not correlated with the yield traits, particularly rump angle, rump width, teat placement, and especially rear legs viewed from the side, whose coefficient was found to be close to or zero in most studies examined (Meyer *et al.*, 1987; Klassen *et al.*, 1992; Harris *et al.*, 1992; Brotherstone, 1994). Despite this, rear legs side view appears to be significantly associated with longevity of a cow since in the study by Foster *et al.* (1989), the regression coefficient was significant and indicated that straighter legs equated to a longer herd life.

As shown above, the correlation between milk yield and linear type traits is similar to that between protein yield or fat yield and the linear type traits. Overall, greater milk, fat and protein production is associated with lighter cows with lower weight, body condition score and chest width, but greater body depth, stature and angularity and similarly, using udder type traits, cows with greater udder support, tighter attachment of the rear udders but looser fore udder attachment and good overall dairy conformation seem to be better producers of milk, fat and protein. This is slightly contradictory, as yield is also negatively correlated with udder depth, thus indicating that udders with a tendency to be below the hocks are usually associated with greater production. Dairy conformation and udder depth were the most closely associated with the different variables of milk production and there are very large responses in yield to changes in these linear type traits (Foster *et al.*, 1989). An explanation given for the significant correlations between most body type traits and milk yield is the previous simultaneous selection on both increased milk yield and a particular body conformation (Berry *et al.*, 2004).

2.5.5 Correlation of linear type traits with lactation length

The study by Klassen *et al.* (1992) found that the correlations between the lactation length and linear type body and udder traits are non-significant (<0.10) except with angularity (0.18), rear udder attachment (0.14) and udder support (0.11), i.e. animals with greater angularity, rear udder attachment and udder support had longer lactation lengths. In the study by Perez-Cabal *et al.* (2006), rear legs set was not found to affect lactation length although it was statistically significantly correlated to dry days, as animals with intermediate scores tended to have longer dry periods.

2.5.6 Correlation of linear type traits with somatic cell score

The correlation between the linear type traits and somatic cell score (SCS) are of importance so that their usefulness in reducing the incidence of mastitis, or slowing the increase in mastitis incidence which is associated with increased milk yield, can be evaluated (Rogers *et al.,* 1991; Boettcher *et al.*, 1998). Despite the weak environmental correlation between SCS and clinical mastitis – indicating a limitation of SCS in detecting clinical mastitis, SCS is strongly genetically correlated with clinical mastitis incidence (0.72) thus selection for a reduction in one should decrease the other (Rupp & Boichard, 1999).

The phenotypic correlation between the body type traits and SCS were found to be mostly positive and all insignificant (P>0.05) (Rogers *et al.,* 1991; Kadarmideen, 2004) and similarly, the relationship between the rear legs trait and SCS was also very weak (0.01) (Rogers *et al.,* 1991). On the other hand, the phenotypic correlation coefficients between the udder type traits and SCS were negative and slightly higher, however, all were still insignificant (Rogers *et al.*, 1991; Lund *et al.*, 1994; Boettcher *et al*., 1998; Rupp & Boichard, 1999) except that with udder depth (~-0.10) (Rogers *et al.,* 1991; Lund *et al.,* 1994) and udder height – distance from udder floor to ground (-0.16) (Seykora & McDaniel, 1985). Using genetic correlations, the most significantly correlated with SCS are: fore udder attachment, teat placement and udder support (Lund *et al.* 1994; Boettcher *et al.* 1998; Kadarmideen, 2004; Berry *et al.*, 2004), which are all negative correlations except the positive correlation with udder support in the study by Berry *et al.* (2004).

The conclusion in most studies examined are similar in that, selection for greater udder attachment (higher udders) and support with more closely placed teats will be favourable for reducing SCS (Seykora & McDaniel, 1985; Rogers *et al.,* 1991; Lund *et al.,* 1994; Boettcher *et al.*, 1998; Rupp & Boichard, 1999; deGroot *et al.*, 2002; Kadarmideen, 2004). This may be due to higher udders and closer placed teats being less prone to injury and having reduced exposure to environmental pathogens. This is also supported by the finding that longer teats (usually closer to the ground) are associated with higher SCS (Rogers *et al.,* 1991; Lund *et al.,* 1994). It is also apparent that the non-udder type traits are not very important in reducing mastitis incidence or SCS in dairy cattle (Rogers *et al.*, 1991) and the obvious choices for inclusion in an udder health index for mastitis resistance would include udder attachment and udder depth/support (Rogers *et al.,* 1991; Boettcher *et al.,* 1998; Rupp & Boichard, 1999; Berry *et al.,* 2004) with udder depth seemingly the most important (Seykora & McDaniel, 1985; Rogers *et al.*, 1991; Boettcher *et al.*, 1998). Other teat traits such as: diameter, teat-end shape and lesion scores are also important for consideration in an index to reduce SCS, as highlighted in the study by Seykora and McDaniel (1985). It should be noted that selection for reduction in clinical mastitis incidence and reduced SCS can cause a reduction in production levels (e.g. milk yield) as these are positively correlated genetically with one another (Rupp & Boichard, 1999).

2.5.7 Differences in correlations between breeds

In the study by Visscher and Goddard (1995), when Holstein-Friesian and Jersey cows were compared, the linear type traits rear legs set and fore-udder attachment showed similar insignificant correlations with milk yield for the two breeds, while capacity, size, height and rear udder attachment showed significant but weak positive correlations with milk yield, which were similar for both breeds. On the other hand, the phenotypic correlations for dairy character with milk yield were different between Holstein-Friesians and Jersey cows (0.27 versus 0.34 respectively).

2.5.8 Summary (Correlations between linear type traits and production)

The linear type traits have generally weak or moderate phenotypic correlations with the production traits in TAD milking herd studies (Meyer *et al.,* 1987; Brotherstone *et al.,* 1990; Klassen *et al.,* 1992; Brotherstone, 1994; Visscher & Goddard, 1995; Cue *et al.,* 1996). This supports the belief that their value is mostly in their ability to indicate easier management (e.g. faster milking) and improve longevity (i.e. related to fertility, lameness and mastitis) (Brotherstone *et al.*, 1990; Cue *et al.*, 1996) rather than increase yield.

2.6 Phenotypic correlations between linear type traits and fertility

Fertility in dairy cattle breeding can be considered to have two components: 1) the timing of the onset of oestrus which affects the number of days to first service, and 2) the ability of the cow to conceive at each insemination thus affecting the non-return rate (Pryce *et al.,* 2000; Kadarmideen, 2004). As a result, in New Zealand's seasonal-based pastoral dairy system, the primary breeding objective is to have cows in the herd conceive as soon as possible after the start of breeding date (Grosshans *et al.,* 1997). In the study by Grosshans *et al.* (1997) conducted in New Zealand using TAD milked herds, the average intervals from the start of breeding to first service and to conception were 17.0 - 17.5 and 30.8 - 31.7 days respectively (for first and second lactations only), and the percentage of cows conceiving within the first 21 and 42 days after the start of breeding were found to be 48.5 - 50.0% and 74.7 - 76.5% respectively. It was also noted in this study that Jersey cows showed superiority in having shorter start of breeding to first service intervals (Grosshans *et al.,* 1997).

Practicing selection for improved fertility can be difficult due in part to the lower heritability and the age before which data is available for an individual animal, however, the possible existence of correlations between some of the linear type traits and various measures of fertility indicate their usefulness to indirectly select for improved fertility when included in a selection index (Berry *et al.,* 2004).

2.6.1 Body type traits

The general consensus is that body condition score is a trait indispensable in improving fertility, therefore this trait is most often used in analyses for improvement in dairy cow fertility. Body condition score is negatively correlated phenotypically with days to first service, positively correlated phenotypically with non-return rate or pregnancy rates, and negatively correlated with calving interval, although the strength of the correlations are generally weak (Pryce *et al.,* 2000; Veerkamp *et al.,* 2001; Wall *et al.,* 2003; Kadarmideen, 2004). For example, in the study by Veerkamp *et al.* (2001), the phenotypic correlations between body condition score and interval to first service, calving interval and number of services to conception were -0.15, -0.07 and -0.02 respectively. The genetic correlations have similar signs, however, the strength of correlations are usually slightly higher (Berry *et al.,* 2003). This therefore means that cows in better body condition have shorter intervals to insemination post-calving, less number of services and are more likely to conceive after insemination (Pryce *et al.,* 2000; Wall *et al.,* 2003; Kadarmideen, 2004). The shortened calving interval with higher body condition scores is accounted for, to some extent, by the relationship with production, since longer calving intervals are associated with higher milk yields and thus greater mobilization of body tissue (Pryce *et al.,* 2000). The favourable association between body condition and fertility traits, as well as its moderately high heritability compared to that of fertility traits suggests its utility in a selection index for improved fertility (Berry *et al.*, 2003; Kadarmideen, 2004).

It is important to note that the strength of correlation between body condition score and fertility traits does vary somewhat (although slight) depending on the time during lactation at which measurements are done. It was found to be most strongly correlated with fertility traits during mid to late lactation in the study by Berry *et al.* (2003), while in the studies by Veerkamp *et al*. (2001) and Pryce *et al.* (2000), it was most strongly correlated in early lactation, these differences possibly being due to the differences in parity of cows used in the studies.

The linear type trait weight has similar negative correlations with interval to first service, however its correlation with number of services is positive, and with pregnancy to Day 63 it is negative, thus suggesting that although heavier animals are inseminated earlier, they have poorer pregnancy rates by Day 63 and require more services (Berry *et al.,* 2003). When these correlations were adjusted for the body condition score (which accounts for a large percentage of variation in weight), the correlation with interval to first service became weaker and the others became stronger, indicating that independent of body condition, increases in body weight reduce overall fertility performance (Berry *et al.,* 2003).

The findings for dairy character or conformation are similarly unfavourable as this trait was found to be positively associated with days to first service (Kadarmideen, 2004), indicating that increased conformation scores are associated with longer intervals to first insemination. This occurs despite the moderate and positive correlation between weight and dairy conformation (Cue *et al.,* 1996).

Two studies examining the genetic correlations between the other body type traits and fertility indicate that taller, wider, deeper and more angular cows (higher scores for stature, capacity and angularity) have lower pregnancy rates to first service and longer calving intervals (Pryce *et al.,* 2000; Berry *et al.,* 2004). Despite this, the study by Kadarmideen (2004) found the regression coefficients for stature, capacity and rump to be positive with non-return, thus implying that higher scores equate to better ability to conceive per insemination.

Pregnancy rates are positively correlated genetically, and number of services negatively correlated with rump angle, while they are negatively and positively correlated with rump width, thus cows with higher pins and wider rumps require more services and have lower pregnancy rates (Berry *et al.,* 2004). Both rump angle and rump width are negatively correlated genetically with interval to first service (Berry *et al.,* 2004). High scores for rump width and rump angle indicate a predisposition to lower incidence of dystocia and thus the negative correlation between rump width or rump angle and interval to first service may be indicative of cows with easier calving (Berry *et al.,* 2004).

2.6.2 Leg trait

Studies show divergent results for the correlation between the leg trait and fertility. In the study by Perez-Cabal *et al.* (2006), this trait did not significantly affect the fertility measures: average number of inseminations per lactation, nor calving interval (especially when adjusted for production), while in the study by Pryce *et al.* (2000), it was found that rear legs set was positively genetically correlated with calving interval (indicating that straighter legs was more favourable), and in the study by Berry *et al.* (2004) legs was found to be negatively correlated genetically with interval to first service and positively correlated genetically with pregnancy rates to first service (indicating that straighter legs were less desirable) (Berry *et al.,* 2004).

2.6.3 Udder type traits

The udder type trait udder depth is negatively correlated genetically with interval to first service, pregnancy rate to first service and calving interval (Pryce *et al.,* 2000; Berry *et al.,* 2004). Udder support is negatively correlated genetically with pregnancy rate to first service and positively correlated with calving interval (Pryce *et al.,* 2000; Berry *et al.,* 2004), while teat placement is positively correlated with interval to first service and pregnancy to first service (Berry *et al.,* 2004). Therefore, cows with weaker udder support, less udder depth, and more closely placed teats seem to have better pregnancy rates to first service. Both fore and rear udder attachment are negatively correlated with pregnancy rates to first service, but fore udder attachment is negatively correlated to interval to first service, while rear udder attachment is positively correlated to interval to first service (Berry *et al.,* 2004). This indicates that cows with weaker rear and fore udder attachments have better pregnancy rates to first service. Despite this, in the study by Kadarmideen (2004), the general udder score was positively associated with non-return rate (from the regression coefficient) thus indicating that cows with better udder scores had better ability to conceive per insemination (Kadarmideen, 2004).

It should however be noted that in most studies, the phenotypic correlation between the linear type traits and the fertility traits were zero, or close to zero (Pryce *et al.,* 2000; Kadarmideen, 2004).

2.6.4 Logistic regression modelling of fertility

In the study by Kadarmideen (2004), when the linear type traits were modeled on to sire estimated breeding values for days to first service, most gave significant regression coefficients. For days to first service, body depth, dairy character and fore and rear teat position gave significant and positive coefficients while fore udder attachment and udder depth gave negative coefficients ($P<0.10$) (Kadarmideen, 2004). In the study by Royal *et al.* (2002b), udder depth was also found to have a negative and significant regression coefficient with interval to commencement of luteal activity along with foot angle, body condition score and chest width. Body condition score was also found to have a significant and negative coefficient with calving interval in the study by Pryce *et al.*, (2000). Unlike in the study by Kadarmideen (2004), where rump measures were found to be insignificant variables, in the study by Royal *et al*. (2002b), both rump width and rump angle had significant negative coefficients with interval to commencement of luteal activity. Angularity was also found to have a positive and significant regression coefficient (Royal *et al.*, 2002b). In all three studies, stature and rear legs side view were found to have insignificant coefficients (Pryce *et al.*, 1998; Royal *et al.*, 2002b; Kadarmideen, 2004) and in the former two studies, body depth, udder attachment, udder support and teat placement were also insignificant (Pryce *et al.*, 1998; Royal *et al.*, 2002b) in affecting the intervals.

These findings indicate that increases in the linear scores for: fore udder attachment, rump angle, rump width, udder depth and chest width, and decreases in body depth, angularity, dairy character and teat position will result in reductions in the days to first service or commencement of luteal activity. Using the trait body condition score, the regression coefficient on interval to commencement of luteal activity post-partum is negative, indicating that cows with one unit lower average body condition scores have approximately a six day extension in the interval (Royal *et al.*, 2002b).

For regression models on non return rate, none of the coefficients were significant in the study by Kadarmideen (2004), while in the study by Pryce *et al*. (1998) using genetic analysis, the only significant regression coefficient was for chest width in models for conception to first service, with a higher score being more desirable for increasing first service conception.

In all studies reporting on these traits, rear legs side view and rear udder attachment were not related to fertility traits (Pryce *et al.*, 1998; Royal *et al.*, 2002b; Kadarmideen, 2004).

In addition to the linear type traits, consideration must be made for the production type traits. Fat yield was found to have positive and significant regression coefficients on interval to luteal activity commencement (10kg increase in fat yield increased the interval by 1.6 day) while for milk and protein these were positive but not significant (Royal *et al.*, 2002a; Royal *et al.*, 2002b). Parity has also been found to significantly affect interval to luteal activity commencement with prolonged intervals for later lactations (Royal *et al.*, 2002a). Another important point to note is that the occurrence of health issues, e.g. uterine infections, during the previous or current breeding season can also affect the model as these were found to significantly impact the length of the interval to commencement of luteal activity, and therefore also affected interval to first service (Royal *et al.*, 2002a).

Breed affects fertility as in the study by Veerkamp *et al.* (2001) in TAD milked herds, purebred Holstein cows had a longer interval to first service (+ 4.7 days), longer calving interval (+7.2 days) and had a lower conception rate (-6.5%) than crossbred cows (50% Holstein). Likewise, in the study by Berry *et al.* (2005), the risk of involuntary culling (due to low fertility among other factors) increased as proportion of overseas Holstein-Friesian genes increased to 80%.

2.7 Phenotypic correlations between linear type traits and survival

An increase in the length of productive life within a herd directly affects profitability through reductions in replacement costs (costs of raising a replacement heifer), and increases in proportion of lactations from mature higher yielding cows (Brotherstone & Hill, 1991; Boettcher *et al.,* 1997; Sewalem *et al.,* 2004). Also, more voluntary culling for low production can be practised (Boettcher *et al.,* 1997). Estimates of the economic value of longevity range from 25-70% of that for production (Boettcher *et al.,* 1997), however, direct selection to reduce involuntary culling is limited, due to the low heritability and increased generation interval, as records are not available until after relatives have died or are culled (Rogers *et al.,* 1988; Boettcher *et al.,* 1997; Sewalem *et al.,* 2004). Thus selection on possibly correlated traits such as the linear type traits, which can be measured in the first lactation, can be used (Rogers *et al.,* 1988; Brotherstone & Hill, 1991; Boettcher *et al.,* 1997; Berry *et al.,* 2005).

The studies by Brotherstone and Hill (1991) and Cue *et al.* (1996) both found that the phenotypic correlation between the inspector-scored linear type traits and survival are very small and insignificant (less than 0.10) with the highest correlation coefficients being for teat placement (0.09-0.10) in the study by Brotherstone and Hill (1991), and dairy conformation (0.10-0.11), capacity (0.07-0.08) and udder overall (0.06-0.07) in the study by Cue *et al.* (1996). The farmer-scored traits, particularly farmer opinion, however, are more strongly correlated with longevity and thus give a good indication of survival (Cue *et al.,* 1996; Berry *et al.,* 2005).

On the other hand, when genetic correlations are examined, the type traits show significant correlations with longevity (Sewalem *et al.,* 2004) as is described in the following sections. Of the type traits, the composite traits, total/final score, mammary system, rear and fore-udders and feet and legs are the most important (Sewalem *et al.,* 2004; Berry *et al.,* 2005).

2.7.1 Body type traits

The genetic relationship between the body type traits and survival is generally very weak (Rogers *et al.*, 1989; Boettcher *et al.*, 1997; Sewalem *et al.*, 2004). Stature and capacity have positive correlations with survival (Sewalem *et al.*, 2004) while rump angle (Sewalem *et al.*, 2004; Berry *et al.*, 2005) and rump width (Berry *et al.*, 2005) show an intermediate optimum, thus indicating that taller more capacious animals with horizontally sloped rumps and intermediate rump widths are more desirable for survival. The study by Sewalem *et al.* (2004), however, found no relationship between rump width and culling risk, and the study by Boettcher *et al.* (1997) found that slightly narrower rump widths are more desirable as well as a decrease in body depth.

2.7.2 Leg trait

There appears to be almost no linear relationship, both genetically and phenotypically, between rear legs (viewed from the side) and survival/stayability (Rogers *et al.*, 1988; Berry *et al.*, 2005), and various studies examined reveal that an intermediate score for the rear legs set trait equates phenotypically and genetically to better longevity of cows in a herd (Boettcher *et al.*, 1997; Berry *et al.*, 2005; Perez-Cabal *et al.*, 2006), thus cows with extremely high or low scores have a higher risk of being culled (Berry *et al.*, 2005). In the study by Boettcher *et al. (*1997*)*, the regression coefficient for rear leg side view was slightly negative thus suggesting that the ideal legs for longevity is slightly straighter than the mean in that study (Boettcher *et al.*, 1997). It was also noted that this trait plays a much greater role in survival during the later stages of herd-life (Boettcher *et al.*, 1997).

2.7.3 Udder type traits

Of all the linear type traits, the udder type traits have the largest effect on functional longevity/survival, next to the composite traits: dairy conformation and overall udder score (Boettcher *et al.*, 1997; Sewalem *et al.*, 2004; Berry *et al.*, 2005) This may be due to the influence of udder type traits on susceptibility to mastitis and other infectious diseases (Sewalem *et al.*, 2004).

Teat placement (both fore and rear) has an intermediate optimum for survival (Sewalem *et al.,* 2004; Berry *et al.,* 2005), therefore, nearly central placement is most desirable. The other udder type traits, namely: udder attachment (fore and rear) and median suspensory/ udder support show a positive linear relationship with functional longevity/survival especially after adjustment for yield (Rogers *et al.,* 1989; Sewalem *et al.,* 2004; Berry *et al.,* 2005), thus increased udder attachment and support is ideal. In one study, udder depth was found to have an intermediate optima (Sewalem *et al.,* 2004), while in the studies by Rogers *et al.* (1988) and Rogers *et al.* (1989), udder depth was phenotypically positively associated with survival (along with teat placement) thus suggesting that increased udder depth and more closely placed teats are more desirable for improved cow survival.

2.7.4 Other influences and interactions

It should be noted that the relationship between the linear type traits and survival is affected by the production traits. In the study by Boettcher *et al.* (1997), the interaction between these traits and longevity was affected by production level since the type traits played a less important role in the longevity of low producing compared to average and high producing cows. In addition to the production traits such as deviation of fat and protein production, other non-linear type traits such as age at calving, are also associated with survival and thus can also affect this relationship (Boettcher *et al.,* 1997).

Another example of the effect of production on the interaction between the linear type traits and survival is the finding that good udder conformation is more important for medium and high producing cows than for low producers (Boettcher *et al.,* 1997), partly due to the increase in udder health problems in cows selected for increased production. This therefore means that the udder type traits are likely to have weak associations with herd-life amongst low producing cows which suffer from fewer udder health issues (Boettcher *et al.,* 1997), compared to high producers. Also, when dairy character is adjusted for milk yield, the relationship between it and longevity becomes negative (Boettcher *et al.,* 1997), and when the genetic correlations between the linear type traits, particularly body type and leg traits, are adjusted for milk yield, the relationship becomes weak or non-significant thus indicating little usefulness in reducing involuntary culling (Rogers *et al.*, 1989).

Another point of interest is that there are differences between registered and graded (or pedigree and commercial) populations in the association between linear type traits and survival/longevity (Rogers *et al.*, 1988; Berry *et al.*, 2005). Commercial farmers are more likely to cull slow milking cows with poor temperament (i.e. based off farmer-scored traits), while farmers of pedigree/registered herds place more emphasis on the conformation of the animal, which can result in a disadvantage to survival analysis as there can be an over-valuing of traits when animals are retained due to their score and not necessarily due to an innate survival ability or utility (Cue *et al.*, 1996; Berry *et al.*, 2005).

2.7.5 Logistic regression modelling of survival

Based on studies by Rogers *et al.* (1988) and Berry *et al.* (2005), in addition to the farmer-scored traits (farmer opinion and milking speed), the inspector-scored traits of greatest contribution to the regression equation on survival include: udder overall, dairy conformation, udder support, as well as fore udder attachment, teat placement, udder depth, angularity, rump width and stature to a lesser extent. Also, in the study by Boettcher *et al.* (1997), those most important in affecting survival were overall conformation, mammary system (udder overall), fore and rear udder attachment, rear teat placement and legs. When adjustment for production/milk yield is performed, there are not many changes except for some udder type and dairy conformation coefficients (Brotherstone & Hill, 1991; Berry *et al.*, 2005). In the study by Perez-Cabal *et al.* (2006), it was noted that linear type traits may be quadratically related to longevity, including productive days, number of lactations, and functional herd-life (productive days adjusted by production level).

2.8 Specific linear type traits for OAD selection indices

2.8.1 Milking speed

There has been a growing interest and consideration by OAD farmers and LIC in New Zealand for the inclusion of the trait milking speed in the selection index for OAD milking animals (Lopez-Villalobos, personal communication). Milking speed is one of the four management type linear traits scored by the dairy farmer in New Zealand dairy systems (Berry *et al.,* 2005), and may have a large influence on dairy production success (Blake & McDaniel, 1978; Moore *et al*., 1983; Batra & McAllister, 1984; Banos & Burnside, 1992; Boettcher *et al.,* 1998) since faster milking is associated with decreased electrical power cost, less wear on milking equipment, and decreased labour time, the last being a significant expense in milk harvesting (Blake & McDaniel, 1978; Batra & McAllister, 1984; Boettcher *et al*., 1998). As a result, milking speed is a criterion used in New Zealand for voluntary culling (Dorman, 2012).

Milking speed is correlated genetically to some extent with other farmer and inspector-scored traits. There is a positive genetic correlation with temperament- calmer cows are faster milkers (Lund *et al*., 1994; Visscher & Goddard, 1995; Berry *et al*., 2004) and negative genetic correlations with rear udder attachment and teat length (Boettcher *et al*., 1998). Milking ease also has weak positive phenotypic correlations with stature, body depth, udder support, teat placement and rear udder attachment, and a weak negative phenotypic correlation with body condition score (Berry *et al*., 2004). Despite this, milking speed is usually not significantly phenotypically correlated with the inspector-scored traits (Cue *et al*., 1996; Boettcher *et al*., 1998).

Milking speed has desirable and significant correlations with production and survival traits. Higher yielding Jersey cows tend to have faster milking speed (Visscher & Goddard, 1995), although overall the correlation with milk yield is weak (Boettcher *et al*., 1998). In a study done by Berry *et al*. (2005) in New Zealand, there was a trend for declining relative culling rate with an increase in milking speed score (milking speed accounting for 5% of the total change in log-likelihood of culling). Nevertheless, this trait had a very weak influence on the true longevity of a cow. Also, in the studies by Cue *et al*. (1996) and Dorman (2012) both conducted in New Zealand dairy herds, milking speed was not significantly correlated phenotypically nor genetically with survival to second and third lactation, but was significantly correlated genetically with survival to the fifth lactation (Dorman, 2012).

The heritability of milking speed has been estimated to be between 0.15 and 0.30 in most studies (Moore *et al*., 1983; Lund *et al*., 1994; Visscher & Goddard, 1995; Cue et al., 1996; Boettcher *et al*., 1998; Rupp & Boichard, 1999; Lopez-Villalobos *et al.*, 2014), and therefore genetic evaluation of bulls could be a means by which to select sires for daughters with improved milking speed (Banos & Burnside, 1992; Lund *et al*., 1994; Visscher & Goddard, 1995; Lopez-Villalobos *et al.*, 2014). Also, the finding of differences (although sometimes non-significant) in milking speed between: 1) breeds - Jerseys slightly faster milkers than Holstein-Friesians (Visscher & Goddard, 1995; Cue *et al*., 1996); 2) ages - older cows milk more slowly than younger cows (Boettcher *et al*., 1998); 3) nutrition levels – longer milking duration and higher flow rate with higher nutrition plane (Gleeson *et al*., 2007; Walsh *et al*., 2007), and the finding that OAD milked cows take slightly longer to milk than TAD milked cows at the morning milking ($P>0.05$) (Gleeson *et al*., 2007), suggest that selection and control of milking speed is practical.

Even so, a major consideration in including milking speed as a selection trait is the impact on udder health. A positive correlation (both genetic and phenotypic) between milking speed and SCS has been established in various studies, that is, faster milkers have higher somatic cell scores (Moore *et al*., 1983; Lund *et al*., 1994; Rupp & Boichard, 1995; Boettcher *et al*., 1998), however, the phenotypic relationship with clinical mastitis varies - insignificant (Rupp & Boichard, 1995; Boettcher *et al*., 1998) or positive and weak (Lund *et al*., 1994). Based on these inconclusive findings, rather than faster milkers having easier pathogen entry into udders due to decreased teat sphincter tension (Boettcher *et al*., 1998), the alternate explanation for higher SCS is a more complete drainage of the udders, with the last milk fraction having higher cell content (Rupp & Boichard, 1995) and therefore faster milking speed may not be a contributing factor to mastitis although an increase in

SCS may be observed. Consequently, although inclusion of milking speed in the selection index seems feasible, consideration must be made for the impact on SCS especially considering the higher scores sometimes associated with OAD milking. Further research in this area is therefore necessary.

2.8.2 Udder support and front teat placement

In addition to milking speed, the linear type traits: udder support and front teat placement are also being proposed to be included in an OAD selection index in New Zealand (Lopez-Villalobos, personal communication). The trait front teat placement could be especially useful in aiding easier and faster milking, especially with automated milking machines as optimal teat placement should facilitate quicker and more secure cup attachment. This is particularly important for OAD milking as milking times are usually slightly prolonged due to a greater yield at each milking session (Dalley & Bateup, 2004; Gleeson *et al.*, 2007). Udder support could be of great importance due to the unique problem of severe udder distention which occurs more frequently in animals on OAD milking regimens (O'Driscoll *et al.*, 2010; Lee, 2011). This is due to the larger volume of milk that animals are required to carry in the udders over a longer period of time, therefore, strong udder support as well as strong fore and rear udder attachment, are indispensable. Since front teat placement is strongly correlated with rear teat placement, measurement of only the former should be sufficient in accounting for overall teat placement, and likewise, udder support measures will account for attachment as well, since they are well correlated (Cue *et al.*, 1996; Berry *et al.*, 2004).

These traits are also relevant to an OAD selection index since they are the most strongly correlated linear type traits to somatic cell score and mastitis, and are also correlated to overall cow longevity/survival. Somatic cell scores tend to be higher in OAD milked cows and therefore by increasing udder support and front teat placement (more closely placed teats), the SCS to some extent, and mastitis incidence can be reduced (Seykora & McDaniel, 1985; Rogers *et al.*, 1991; Lund *et al.*, 1994; Boettcher *et al.*, 1998; Rupp and Boichard, 1999; deGroot *et al.*, 2002; Kadarmideen, 2004), which would be particularly important if faster milking is to be selected for, since this is associated with increases in somatic cell count (Moore *et al*., 1983; Lund *et al*., 1994; Rupp & Boichard, 1995; Boettcher *et al*., 1998).

2.9 Summary and research questions (literature review)

Approximately 2-5% of the New Zealand national herd was being milked once-a-day in 2014, with motivation behind this drive being the many benefits of the practice including: improvements in the health, fertility and welfare of the cows; reductions in milking parlour expenses and better coping ability during feed shortages; and the lifestyle and social benefits to the farmers. However, the concerns associated with OAD milking include: reductions in per cow yields, shortened lactations, increased milking time, higher somatic cell counts and problems with udder injuries and diseases due to the requirement to carry larger quantities of milk for longer. Nevertheless, by selecting animals and breeds suitable for OAD milking, performance can be improved. Jersey cows generally perform better than Holstein-Friesian cows on OAD-milking regimens.

The linear type traits are of possible value in the selection of animals suitable for OAD milking as they are strongly correlated with certain productivity and profitability measures. These traits objectively describe the conformation of the body, udder and legs of an animal using a linear scoring system. TAD herds usually show small standard deviations for the body and leg type traits, probably indicating uniformity of these traits, while the udder type traits vary widely. Linear type traits within groups generally show strong correlations with one another (e.g. body type traits are moderately to strongly correlated with one another, and most udder type traits are moderately to strongly correlated with one another, though not highly correlated with body type traits). It is therefore possible to combine body type traits into a composite trait, and likewise the udder type traits into a composite trait (or several composite traits) thus reducing the number of traits required for analysis. It is suggested that at least one body type, one udder type and the leg trait be used.

The linear type/conformation traits which seem to be strongly correlated with dairy cow performance based on TAD studies, and would most likely be effective in addressing some of the issues associated with OAD milking (longer milking time, higher somatic cell score and lower yields), in addition to improving fertility include: udder support, body condition score, weight and stature. In addition to these inspector-scored traits, the farmer-scored trait milking speed should also be beneficial for inclusion in a selection index for OAD milking. None of the linear type traits seem to be strongly correlated with lactation length, therefore, other means of minimizing the reduction in lactation length which occurs in OAD milking would need to be explored.

Overall, the linear type traits of importance to survival in TAD herds, besides the farmer-scored traits, include mainly the udder type traits. However, this relationship is affected by production level as good udder conformation is more important for higher producing cows, partly due to the increase in udder health problems in cows selected for increased production.

The main aim of this research was therefore to identify linear type traits that could be appropriate for inclusion in a selection index for OAD milking. This was done by analyzing the relationship among the individual linear type traits in an OAD milked herd, and identifying appropriate traits which are strongly correlated with better production and fertility performance on OAD milking. Models with these correlated traits were also designed so as to further analyze the extent of the influence of these linear type traits on animal performance within an OAD milking regimen. This research is especially important as these analyses have usually been done in TAD herds and findings extrapolated to OAD milked herds, however, differences may exist between the two systems.

Chapter 3: MATERIALS AND METHOD

3.1 Data collection

3.1.1 Animals

Data were collected from the dairy cattle herd at Massey University Dairy No. 1 during the 2013-2014 milking season. The herd consists of both spring and autumn calving cows of which only the spring calving cows were used in this research. The farm is located 35 m above sea level, with average annual rainfall of approximately 980 mm. The stocking rate is approximately 2.4 cows/ha, and production and breeding worth using a TAD milking system is 90/47 and 103/68. Animals on the farm were switched from TAD milking to OAD milking at the beginning of the 2013-2014 milking season, and thus previous selection for suitability for this system was minimal in this herd.

The sample size was 167 dairy cattle in their first to ninth lactation, of which 40 were Holstein-Friesian (F), 42 Jersey (J), and 85 cross-bred (crosses mainly between Holstein-Friesian, Jersey and Guernsey) (F×J). Breed was recorded in 16^{th} fractions such that a cow consisting of 14/16 or more of either breed was considered a pure-bred Holstein-Friesian or Jersey.

3.1.2 Linear type traits

Fourteen linear type conformation traits (TOP) were scored in all 167 animals by a Livestock Improvement Corporation inspector on the 4^{th} December, 2013 using a scale of 1 - 9. These traits were: stature, weight, capacity, rump angle, rump width, body condition score, legs, udder support, front udder attachment, rear udder attachment, front teat placement, rear teat placement, udder overall and dairy conformation. A description of these traits is given in Table 2.2 and *Appendix Diagram A.1*.

3.1.3 Production

Production data were based on monthly herd testing during the 2013-2014 milking season and included the following: lactation length (days), total milk yield (kg), total fat yield (kg), total protein yield (kg), and average somatic cell score (SCS). Other production data collected, that were used in the analyses include: 2013 calving date, deviation of individual calving dates from the planned start of calving date for the herd, as well as milk, fat and protein yields and SCS for each cow on Day 1, 60, 120, 180 and 240 of the lactation period, each estimated from the herd testing results closest to those days. The lactation length was calculated as the number of days between calving and drying-off and the total milk, fat and protein were derived from a test-day model implemented in the recording system MINDA (Livestock Improvement Corporation). The average SCS was calculated as the mean SCS for Days 1, 60, 120, 180 and 240. The SCS was derived from the somatic cell count (SCC, cells/ml) for each individual using the formula:

$$\mathrm{SCS} = \log_2 (\mathrm{SCC} \div 1000)$$

3.1.4 Fertility

The fertility measures were obtained during the 2013 breeding season (mid-October to early December) and the 2014 calving season (late July to September). The data collected included: all artificial insemination (A.I.) service dates, expected calving date (calculated as 282 days from the last service to conception or from veterinary pregnancy diagnosis), and actual calving date. From these records, the following variables typical of a spring calving herd were derived and used in the analyses (Grosshans *et al.*, 1997): interval from start of breeding to first service (SBFS), submission to Day 21 and Day 42 after the official start of mating (S21 and S42 respectively), interval from start of breeding to conception (SBCO), conception to Day 21 and Day 42 after the official start of mating (C21 and C42 respectively), and pregnancy at the end of the mating period. Conception dates were determined primarily using correspondence between ultrasound pregnancy diagnosis and the last recorded A.I. service dates, however, the conception dates for a few animals were uncertain, and were then calculated as the service date corresponding best to the actual calving date minus a normal gestation length. Two cows aborted after pregnancy confirmation and twenty cows were culled at the end of the 2013-2014 season due to non-reproductive issues including low production, lameness and mastitis. These twenty-two animals were counted as having conceived. In total, only thirteen cows failed to become pregnant.

3.2 Statistical analysis

All analyses were conducted using SAS 9.3 (SAS Institute Inc., Cary, NC, USA).

3.2.1 Preliminary data analysis

Preliminary analysis of the individual linear type trait data revealed a deviation from normal distribution for all traits examined (P<0.01) with some skewness and kurtosis, thus Snell transformation (Snell, 1964) was applied to readjust the scores and reduce the departure from normality. After subsequent rescaling, all TOP were still non-normally distributed (P<0.01) and there was very little improvement, if any, in the skewness and kurtosis of the TOP data [*see Appendix Table A.1*]. This possibly occurred due to the data set not being large enough (Tong *et al.*, 1977), the presence of irregularities in the data beyond tolerance in some cases, or the requirement for there to be relatively few observations in the extreme scale scores (Snell, 1964) not being met, since a large proportion of animals scored as 8 or 9 for some traits.

Other studies done previously did not find substantial differences in the results obtained using statistical analysis of raw data compared with analyses using Snell transformed data (Carta *et al.*, 1999; Abdel-Azim & Berger, 1999; Serrano *et al.*, 2002). In the studies by Fernando (1981), Huang and Shanks (1995), and Serrano *et al.* (2002), when the original untransformed score data and Snell transformed score data were used to calculate heritabilities for frame scores in beef cattle, feet and leg traits in dairy cattle, and udder traits in ewes respectively, there were no appreciable differences in the results, and in some cases, the transformation did not result in a decrease in departure from normality or reduction in skewness and kurtosis (Serrano *et al.*, 2002). Hence Snell transformation of data may not affect variance component estimation and may be unnecessary in its application (Serrano *et al.*, 2002). Consequently, in the current study, the categorical nature of the TOP data was ignored (i.e. traits were treated as continuous data) and the untransformed data set was used, as was also done in many other previous studies on linear type scoring of traits (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Harris *et al.*, 1992;

Brotherstone, 1994; Veerkamp & Brotherstone, 1997; Rupp & Boichard, 1999; Berry *et al.*, 2004; Casu *et al.*, 2006).

The mean, median, range and standard deviation of each linear type trait was found and this was also done for each of the production and fertility traits. The same inspector was used to score all animals, and all animals were scored simultaneously, therefore, there was no need to account for inter-inspector or lactation stage variation.

3.2.2 Analysis by breeds

Variations between the three breed categories (F, J and F×J) in the linear type trait scores, as well as production and fertility traits were also analyzed. The following model was used for these analyses:

$$y_{ijk} = \mu + P_i + B_j + b_1 C_k + e_{ijk};$$

where y_{ijk} is the value for the individual linear type, production or fertility trait; μ is the intercept; P_i is the fixed effect of the i^{th} parity; B_j is the fixed effect of the j^{th} breed; b is the regression coefficient of calving deviation C_k and e_{ijk} is the random residual error. The least square means, standard error and p-values were recorded for each breed for each of the traits mentioned.

3.2.3 Phenotypic correlation analysis between linear type traits

Phenotypic correlations (Pearson's linear correlation coefficients: *r*) between individual body type traits were calculated using the correlation procedure (PROC CORR) of SAS 9.3. The procedure was repeated for all udder type traits and then also correlations were made between leg and body type traits, between leg and udder type traits, and finally between body and udder type traits. Phenotypic correlations between linear type traits was also analyzed within breeds using animals in the third to fifth parity only, so as to eliminate biases due to the significant difference in parity between breeds. There were 20 Holstein-Friesian, 20 Jersey and 36 cross-bred animals which met this criterion and these were used in the within breed analysis.

3.2.4 Phenotypic correlation analysis between linear type, production and fertility traits

Phenotypic correlations (Pearson's linear correlation coefficient: *r*) between the different individual production traits, between individual fertility traits and also between production and fertility traits were calculated using the correlation procedure (PROC CORR) of SAS 9.3.

Following this, phenotypic correlations (Pearson's linear correlation coefficient: *r*) between each of the 14 linear type traits and the production and fertility traits were analyzed. Phenotypic correlations were also done within breeds, using animals in the third to fifth parity only - 20 Holstein-Friesian, 20 Jersey and 36 cross-bred animals.

3.2.5 Regression modelling of linear type on production and fertility traits

Linear regression models for the production and fertility traits were created using the linear type traits as independent variables. These dependent production and fertility variables included: lactation length, milk yield, fat yield, protein yield, somatic cell score (SCS), interval from start of breeding to first service (SBFS), interval from start of breeding to conception (SBCO), submission to 21 days (S21), submission to 42 days (S42), conception to 21 days (C21), conception to 42 days (C42) and pregnancy. The model used was as follows:

$$\mathrm{y}_{\mathrm{ijkm}} = \mu + \mathrm{P}_{\mathrm{i}} + \mathrm{B}_{\mathrm{j}} + b_1\mathrm{C}_{\mathrm{k}} + b_l\mathrm{X}_{\mathrm{lm}} + e_{ijkm};$$

where $\mathrm{y}_{\mathrm{ijkm}}$ is the value for lactation length, milk yield, fat yield, protein yield, SCS, SBFS, SBCO, S21, S42, C21, C42 or pregnancy; μ is the overall mean/intercept; P_{i} is the fixed effect of the i^{th} parity; B_{j} is the fixed effect of the j^{th} breed; b_1 is the regression coefficient of calving deviation C_{k}; b_l is the coefficient of the l^{th} linear type trait; X_{lm} is the linear score for the l^{th} linear type trait on the m^{th} individual and e_{ijkm} is the random residual error.

The regression coefficients obtained for each linear type trait when modeled with each production and fertility trait were recorded, along with the standard errors and p-values. In the case of the binomially distributed traits: S21, S42, C21, C42 and Pregnancy, the p-values were recorded from the logistic regression models created using the generalized linear mixed model procedure (PROC GLIMMIX).

Chapter 4: RESULTS

Animal Preliminary Details

Total Number of Animals = 167

Number in each breed: J = 42 (**25%**), F = 40 (**24%**), F×J = 85 (**51%**)

4.1 Preliminary data analysis

4.1.1 Linear type traits

Table 4.1.1. Descriptive statistics for the linear type traits in the once-a-day milked herd

Linear type traits	Mean	SD	Median	Range
Stature	6.41	1.393	7	4 - 9
Weight	5.27	1.503	5	3 - 9
Capacity	6.97	0.764	7	5 - 9
Rump angle	4.03	0.825	4	2 - 7
Rump width	6.38	0.660	6	3 - 8
Body condition score	4.38	0.248	4.5	4 - 5
Legs	6.37	0.586	6	5 - 8
Udder support	5.80	1.054	6	2 - 8
Fore udder attachment	5.79	1.046	6	3 - 8
Rear udder attachment	6.13	0.699	6	4 - 8
Fore teat placement	4.69	0.559	5	2 - 6
Rear teat placement	6.29	0.879	6	4 - 9
Udder overall	5.75	1.044	6	2 - 8
Dairy conformation	6.95	0.642	7	4 - 8

With the linear type traits in this study being represented on a scale from 1 to 9 and treated as continuous data rather than categorical/discrete, using the normality tests (Kolmogorov-Smirnov, Cramer-von Mises and Anderson-Darling), the null hypothesis of normality was rejected ($P<0.05$) and the conclusion was made that the linear type traits data were not from a normally distributed population and had high levels of skewness and kurtosis. Transformation of the data using Snell's method was, however, not undertaken in this study as the benefits to be gained were minimal (*see Chapter 3.2.1*).

4.1.2 Production traits

Table 4.1.2. Descriptive statistics for the production traits in the once-a-day milked herd

Production traits	N	Mean	SD	Min - Max	Skewness	Kurtosis	H_0: Normally distributed
Lactation length (days)	166	251.5	24.4	190 - 305	-0.200	-0.599	>0.05*
Milk yield (kg)	166	3636.7	805.8	2005 - 5476	0.225	-0.480	>0.05*
Fat yield (kg)	166	189.8	32.1	118.0 - 284.1	0.272	-0.301	>0.05*
Protein yield (kg)	166	145.4	27.7	85.8 - 221.4	0.145	-0.258	>0.05*
Somatic cell score[1]	166	6.22	1.05	4.42 - 10.67	0.946	1.636	<0.01

[1]SCS $=\log_2$ (Somatic cell count÷1000) * The null hypothesis of normality was not rejected at a critical value of 0.05 using three tests (Shapiro-Wilk, Cramer-von Mises and Anderson-Darling) therefore these data were taken from a normal distribution

Preliminary investigation showed that there was one cow outlier which had a total number of lactation days of 148. This animal was omitted from all production analyses, resulting in 166 being the total number of cows analyzed. The lactation number varied between 1st and 9th lactation with a mean and median of the 3rd lactation, since the most frequent parities were the first and second (45% of all cows).

4.1.3 Fertility traits

Table 4.1.3. Descriptive statistics for the fertility traits in the once-a-day milked herd (N=167)

Fertility traits	Mean	SD
Interval from start of breeding to first service (days)	11.1	7.6
Interval from start of breeding to conception (days)	19.2	14.9
Submission rate (21 days)	96.4%	18.7
Submission rate (42 days)	98.8%	10.9
Conception rate (21 days)	65.9%	47.6
Conception rate (42 days)	82.0%	38.5
Pregnancy rate	92.2%	26.9

The mean number of days from the start of breeding to the first service (SBFS), depending on when the animals begun to display signs of oestrus, was 11 days (standard deviation: 7.6 days). By Day 21 (three weeks after the start of breeding), the submission rate was 96.4% and by Day 42 (six weeks later), all except two animals had been submitted for servicing (98.8%).

The mean number of days from the start of breeding to conception (in those animals that did conceive) (SBCO) was 19 days, with a standard deviation of 14.9 days. By Day 21, 65.9% of the cows had conceived and by Day 42, 82.0% had conceived. 17 animals conceived after Day 42 resulting in an overall pregnancy rate of 92.2%, with 13 animals not becoming pregnant (empty rate: 7.8%) in the 2013-2014 breeding season.

4.2 Difference between breeds in linear type traits, production and fertility

4.2.1 Linear type trait variations between breeds

Table 4.2.1. Least square means (LSM) and standard errors (SE) for the linear type traits in Holstein-Friesian (F), Jersey (J), and crossbred (F×J) cows in the once-a-day milked herd

Linear type traits	F (n=40)		F×J (n=85)		J (n=42)		P
	LSM	SE	LSM	SE	LSM	SE	
Stature	7.77[a]	0.174	7.20[b]	0.156	5.16[c]	0.181	<0.0001
Weight	6.76[a]	0.186	6.14[b]	0.166	4.13[c]	0.193	<0.0001
Capacity	7.67[a]	0.148	7.26[b]	0.133	7.33[b]	0.154	0.013
Rump angle	3.71	0.180	3.93	0.161	3.75	0.188	0.299
Rump width	6.90[a]	0.143	6.66[a]	0.127	6.20[b]	0.148	<0.0001
Body condition score	4.39	0.056	4.38	0.050	4.27	0.059	0.051
Legs	6.54[a]	0.134	6.42[a]	0.120	6.16[b]	0.140	0.017
Udder support	5.65[a]	0.233	5.19[b]	0.208	5.56[ab]	0.242	0.049
Fore udder attachment	5.92[a]	0.243	5.45[b]	0.217	6.00[a]	0.253	0.014
Rear udder attachment	6.04	0.164	6.08	0.146	6.23	0.170	0.448
Fore teat placement	4.76	0.128	4.60	0.115	4.73	0.134	0.308
Rear teat placement	6.50	0.204	6.59	0.182	6.27	0.212	0.191
Udder overall	5.62	0.238	5.33	0.212	5.81	0.247	0.051
Dairy conformation	7.30	0.141	7.17	0.126	7.39	0.147	0.182

[a,b] Values with different superscripts in a row indicate significant differences in least square mean values (P<0.05)

Using the model with breed, parity and calving deviation as given in Section 3.2.2, the results in Table 4.2.1 were obtained. In general, the standard errors for the linear type traits were smaller for F compared with J, and the standard errors for F×J were lower than for J and F. For the body type traits: stature and weight, the least square mean values for J was lowest, F highest, and F×J intermediate, while for capacity, although F had the highest mean, there was no difference between J and F×J, and for rump width, J had the lowest mean but there was no difference between F and F×J (P>0.05). For rump angle, body condition score and dairy conformation, there were no differences between the three breeds (P>0.05). The leg score was similar to the body type traits with J having the lowest scores (straightest legs).

In examining the udder type traits, there were no differences between the three breed categories in mean scores for rear udder attachment, fore and rear teat placement and udder overall, however, for udder support, F×J had significantly lower scores than F, and for fore udder attachment, F×J had significantly lower scores than F and J.

4.2.2 Production and fertility trait variations between breeds

Table 4.2.2. Least square means (LSM) and standard errors (SE) for the production and fertility traits in Holstein-Friesian (F), Jersey (J) and crossbred (F×J) cows in the once-a-day milked herd

Traits	F (n=40)		F×J (n=85)		J (n=42)		P
	LSM	SE	LSM	SE	LSM	SE	
Lactation length (days)	251.7[a]	3.07	249.2[a]	2.74	240.1[b]	3.19	0.0004
Milk yield (kg)	4216.6[a]	114.2	3893.4[b]	102.1	3177.8[c]	118.8	<0.0001
Fat yield (kg)	194.3[b]	5.11	206.6[a]	4.57	186.7[b]	5.32	<0.0001
Protein yield (kg)	155.4[a]	4.12	154.7[a]	3.69	134.3[b]	4.29	<0.0001
Somatic cell score	6.568	0.242	6.464	0.217	6.684	0.252	0.560
SBFS[1] (days)	9.94	1.78	11.06	1.59	12.10	1.86	0.507
SBCO[2] (days)	17.15	3.07	19.05	2.83	15.98	3.37	0.581
Submission rate Day 21	100%	4.43	96.2%	3.96	97.2%	4.61	0.659
Submission rate Day 42	100%	2.60	98.5%	2.30	98.4%	2.68	0.673
Conception rate Day 21	69.7%	10.88	62.4%	9.73	72.2%	11.33	0.519
Conception rate Day 42	82.0%	8.71	76.3%	7.78	71.6%	9.07	0.524
Pregnancy rate	87.1%	6.08	83.4%	5.44	76.2%	6.33	0.197

[1]SBFS - interval from start of breeding to first service [2]SBCO - interval from start of breeding to conception [a,b] Values with different superscripts in a row indicate significant differences in least square mean values ($P<0.05$)

The parity of F was significantly higher than that of J and F×J (4.025, 2.595 and 2.821 respectively). Using the model with breed, parity and calving deviation as given in Section 3.2.2, the results in Table 4.2.2 were obtained. Milk yield was highest in F, lowest in J and intermediate in F×J. Both protein yield and the number of lactation days was significantly lower in J than in the other two breeds, while for fat yield, although F×J had significantly higher fat yields, there was no difference between F and J. There were no significant difference between breeds in any of the fertility traits ($P>0.05$).

4.3 Phenotypic correlations amongst linear type traits in OAD milked cows

Table 4.3. Phenotypic correlations amongst all linear type traits across the three breed groups –Holstein-Friesian, Jersey and crossbred cows

	Stature	W	C	RA	RW	BCS	L	US	FU	RU	FT	RT	UO
Weight (W)	**0.946** <0.0001												
Capacity (C)	**0.442** <0.0001	**0.532** <0.0001											
Rump angle (RA)	**-0.215** 0.0052	**-0.264** 0.0006	**-0.238** 0.0020										
Rump width (RW)	**0.464** <0.0001	**0.477** <0.0001	**0.248** 0.0012	-0.076 0.3306									
Body condition score (BCS)	**0.259** 0.0007	**0.315** <0.0001	**0.362** <0.0001	0.047 0.5423	0.118 0.1284								
Legs (L)	**0.249** 0.0012	**0.255** 0.0009	-0.002 0.9802	0.052 0.5072	**0.242** 0.0017	-0.037 0.6366							
Udder support (US)	**-0.216** 0.0051	**-0.229** 0.0030	**-0.179** 0.0203	0.028 0.723	-0.031 0.6951	-0.036 0.6470	**-0.427** <0.0001						
Fore udder attachment (FU)	-0.127 0.1017	-0.109 0.1590	0.015 0.8503	-0.090 0.2450	-0.042 0.5936	-0.007 0.9297	**-0.295** 0.0001	**0.612** <0.0001					
Rear udder attachment (RU)	-0.062 0.4291	-0.057 0.4649	-0.015 0.8461	-0.111 0.1517	-0.017 0.8288	-0.010 0.8940	**-0.253** 0.0010	**0.551** <0.0001	**0.590** <0.0001				
Fore teat placement (FT)	-0.030 0.7040	-0.043 0.5814	-0.008 0.9197	-0.032 0.6819	-0.039 0.6196	0.049 0.5337	**-0.289** 0.0002	**0.437** <0.0001	**0.290** 0.0001	**0.229** 0.0029			
Rear teat placement (RT)	0.145 0.0617	0.146 0.0593	0.040 0.6094	**-0.162** 0.0369	0.061 0.4350	-0.044 0.5690	-0.056 0.4691	0.133 0.0861	0.125 0.1078	**0.154** 0.0473	**0.502** <0.0001		
Udder overall (UO)	**-0.204** 0.0081	**-0.215** 0.0053	-0.085 0.2758	-0.026 0.7349	-0.048 0.5373	-0.012 0.8738	**-0.421** <0.0001	**0.886** <0.0001	**0.785** <0.0001	**0.672** <0.0001	**0.436** <0.0001	0.130 0.0943	
Dairy conformation (DC)	**0.166** 0.0321	**0.227** 0.0031	**0.377** <0.0001	-0.020 0.8007	0.104 0.1794	0.109 0.1596	-0.123 0.1146	0.073 0.3476	**0.162** 0.0361	0.096 0.2153	0.070 0.3656	-0.004 0.9549	0.088 0.2585

Bottom numbers are P-values and values in bold indicate significant correlations (P<0.05)

4.3.1 Correlation between body type traits

All phenotypic correlations between body type traits were significant except between body condition score, rump angle and rump width, and all were positive except between rump angle and the other body type traits. Stature and weight were almost equivalent with a phenotypic correlation of 0.95. Capacity was strongly correlated with stature and weight (0.44 and 0.53 respectively) and likewise, rump width with stature and weight (0.46 and 0.48 respectively). Rump width and capacity were moderately correlated (0.25) and also body condition score was moderately correlated with stature, weight and capacity (0.26, 0.32 and 0.36 respectively). Dairy conformation was also positively correlated with stature, weight and capacity and the relationships were weak to moderate (0.17, 0.23 and 0.38 respectively). Rump angle was negative and moderately correlated with stature, weight and capacity (-0.22, -0.26, and -0.24 respectively).

In comparing the correlations by breed, the difference in average parities between breeds was taken into account. In all, 20 Holstein-Friesian, 20 Jersey and 36 cross-bred animals were used and the complete results can be found in Appendix Tables A.2, A.3 and A.4 for F, J and F×J cows respectively. Between the breeds, stature and weight were similarly correlated, however, F and F×J had significant positive correlations between other body type traits while for J, all other body type traits were not significantly correlated, except between dairy conformation and rump angle where the correlation was positive.

4.3.2 Correlation between body and leg traits

The leg trait was positively and moderately correlated with stature, weight and rump width (0.25, 0.26 and 0.24 respectively) but was not correlated with capacity, rump angle, body condition score and dairy conformation.

There were no correlations between the leg trait and any other trait for J cows while for F, leg was positively correlated to rump angle and in F×J , legs was negatively correlated with capacity [*see Appendix Tables A.2, A.3 and A.4*].

4.3.3 Correlation between udder type traits

All udder type traits were positively correlated, however, the significance and strength of the correlations varied. Udder support was very strongly correlated with the overall udder score (0.89), fore udder attachment (0.61) and rear udder attachment (0.55), and strongly correlated with front teat placement (0.44), but not significantly correlated with rear teat placement (0.13, P>0.05). Likewise fore and rear udder attachment were very strongly correlated with the overall udder score (0.79 and 0.67 respectively) and moderately correlated with front teat placement (0.29 and 0.23 respectively). Front teat placement was strongly correlated to overall udder score (0.44) while rear teat placement was not correlated with the overall udder score (0.13, P>0.05). The correlation between fore udder attachment and rear teat placement was insignificant (P>0.05), however the correlation between rear udder attachment and rear teat placement was weak but significant (0.15). Fore udder attachment and rear udder attachment were strongly correlated (0.59) and similarly there was a strong correlation between front teat and rear teat placement (0.50).

In comparing the breeds, there were similarly strong correlation between udder type traits for the three breeds, however, J had a much stronger correlation between rear udder and overall udder score than F (0.92 vs. 0.64), while fore udder was more strongly correlated to udder overall in F than in J (0.80 vs. 0.53). F×J generally had a greater number of correlations, especially between rear teat placement and the other udder type traits [*see Appendix Tables A.2, A.3 and A.4*].

4.3.4 Correlation between udder and leg type traits

Legs was negatively and significantly correlated with all udder traits except rear teat placement (-0.06, P>0.05). The correlation coefficient was highest with udder support and udder overall score (-0.43 and -0.42 respectively), and moderate with rear udder attachment, fore udder attachment and front teat placement (-0.25, -0.30 and -0.29 respectively).

Both F and F×J showed negative correlations between the leg trait and udder type traits while J had no significant correlations between these traits [*see Appendix Tables A.2, A.3 and A.4*].

4.3.5 Correlation between body and udder type traits

There was very little correlation between the body type and udder type traits and where correlations were present, they were negative. Fore udder attachment, rear udder attachment and front teat placement showed no correlation with the body type traits (P>0.05). Rear teat placement was very weakly correlated to rump angle (-0.16, P<0.05), and udder support was weakly to moderately correlated with stature, weight and capacity (-0.22, -0.23, and -0.18 respectively), while showing no correlation with rump angle, rump width and body condition score (P>0.05). Udder overall was also negatively and moderately correlated with stature and weight (-0.20 and -0.22 respectively). Dairy conformation did not show significant correlation with any of the udder type traits (P>0.0.5) except for a weak but significant positive correlation with fore udder attachment (0.16).

The only correlation found within breeds was in J, between body condition score and fore udder attachment (0.49) and between fore teat placement and rump angle (-0.54), while both F and F×J showed no significant correlations between body and udder type traits [*see Appendix Tables A.2, A.3 and A.4*].

4.4 Phenotypic correlations between linear type, production & fertility traits in OAD milked cows

4.4.1 Correlation between the production traits

Milk yield, fat yield and protein yield were very strongly positively correlated with one another (0.75 - 0.93), and also strongly positively correlated with lactation number (0.59, 0.49 and 0.59 respectively). Milk yield was not found to be correlated with lactation length, however, fat and protein yield were correlated to lactation length moderately (0.25) and weakly (0.17) respectively. Calving deviation had a very strong negative correlation with lactation length (-0.83) – as calving deviation increased (i.e. cows calving later), the lactation length decreased. There was a moderate positive correlation between calving deviation and parity. Milk yield on Days 1, 60, 120, 180 and 240 were very strongly correlated with each other (0.52-0.97) and with overall milk yield (0.79-0.97), fat yield (0.50-0.69) and protein yield (0.70-0.89). Somatic cell score (SCS) was not correlated with any other production trait except for a weak positive correlation with parity (0.20).

4.4.2 Correlation between the fertility traits

All fertility traits were significantly correlated with one another ($P<0.05$). There were strong correlations between submission to 21 (S21) and to 42 days (S42) (0.57) and between conception to 21 (C21) and to 42 days (C42) (0.65). The interval to conception (SBCO) had very strong negative correlations with C21 and C42 (-0.87 and -0.75) and similarly, the interval to first service (SBFS) had strong negative correlations with S21 and S42 (-0.59 and -0.52).

The correlation between SBFS and SBCO was moderate (0.34). The correlations between S21 and C21 or C42 were moderately weak (0.27 and 0.16 respectively), and similarly the correlation between S42 and C42 days was also moderately weak (0.24). SBFS was weakly negatively correlated with C21 and C42 (-0.22 and -0.16 respectively) and SBCO was weakly negatively correlated with S21 and S42 (-0.17 for both).

The correlations between S21 and S42 with pregnancy were also weak (0.18 and 0.17 respectively), while the correlations between C21 and C42 with pregnancy were strong (0.40 and 0.62 respectively). SBFS was weakly negatively correlated with pregnancy occurrence (-0.18), while a correlation between SBCO and pregnancy rate was not applicable since all animals which had a value for SBCO would be recorded as pregnant.

4.4.3 Correlation between the production and fertility traits

Table 4.4.3. Phenotypic correlations between production and fertility[1] traits in the once-a-day milked herd

Traits	SBFS	SBCO	S21	S42	C21	C42	Pregnancy
Lactation length	0.006 0.941	-0.110 0.174	-0.001 0.994	-0.037 0.635	**0.153** 0.048	**0.198** 0.010	**0.222** 0.004
Parity	**-0.199** 0.010	-0.103 0.202	0.119 0.124	0.068 0.382	0.075 0.338	0.015 0.849	-0.043 0.579
Milk yield	-0.128 0.099	0.014 0.862	**0.154** 0.047	0.039 0.615	-0.013 0.869	-0.040 0.608	-0.042 0.594
Fat yield	-0.085 0.275	-0.020 0.809	0.115 0.139	-0.006 0.943	0.014 0.861	-0.009 0.905	0.005 0.946
Protein yield	-0.111 0.153	-0.008 0.921	0.131 0.091	0.032 0.680	0.019 0.803	-0.015 0.851	-0.005 0.949
Somatic cell score	**-0.154** 0.047	0.091 0.263	0.120 0.124	0.125 0.108	-0.083 0.288	-0.018 0.818	0.041 0.597
Calving deviation	-0.043 0.582	**0.169** 0.036	0.055 0.484	0.030 0.699	**-0.198** 0.011	**-0.196** 0.011	**-0.156** 0.044

[1]SBFS:- start of breeding to first service, SBCO:- start of breeding to conception; S21, S42, C21, C42:- submission and conception to 21 and 42 days
Bottom numbers are P-values and values in bold indicate significant correlations (P<0.05)

Submission for mating (including the variables: SBFS, S21 and S42) was not significantly correlated with the calving deviation (and subsequent lactation length), or yields of fat and protein in the current season (P>0.05), however, the total milk yield was found to be weakly positively correlated with submission rate to Day 21 (0.15), and SCS and parity were weakly negatively correlated with SBFS (-0.15 and -0.20).

Neither yield traits, nor parity and SCS were significantly correlated with SBCO, C21 and C42 (P>0.05), but calving deviation was weakly positively correlated to SBCO (0.17) and negatively correlated with C21 and C42 (-0.20 for both). Likewise lactation length was weakly positively correlated with C21 and C42 (0.15 and 0.20 respectively). Similarly, neither yield traits nor parity and SCS were significantly correlated with the occurrence of pregnancy but calving deviation and lactation length were weakly negatively and positively correlated with pregnancy (-0.16 and 0.22 respectively).

Difference between breeds

Complete results for the comparisons between breeds can be found in Appendix Tables A.5a, A.5b and A.5c for F, J and F×J cows respectively. In J, SBFS was positively correlated with lactation length, milk yield and protein yield, and in F, SBFS was negatively correlated to parity, while submission was not correlated to production in F×J. Conception was not correlated to production in F and F×J , however in J, C21 and C42 were negatively correlated to calving deviation and SBCO positively correlated to calving deviation, i.e. delays in calving increase the interval to conception and decrease likelihood of conception by 21 and 42 days in Jersey cows. Parity was also positively correlated with C21 in Jersey cows. Pregnancy was negatively correlated with yield in F, negatively correlated with yield and positively correlated with SCS in J, and positively correlated to lactation length in F×J.

4.4.4 Correlation between linear type traits with production and fertility traits

Table 4.4.4. Phenotypic correlations between linear type[1] with production and fertility[2] traits in the once-a-day milked herd

Traits	Calving deviation	Lactation length	Parity	Milk yield	Fat yield	Protein yield	Somatic cell score	SBFS	SBCO	S21	S42	C21	C42	Pregnancy
S	**0.298**	-0.110	**0.502**	**0.659**	**0.361**	**0.536**	0.038	**-0.208**	-0.004	0.126	0.072	-0.007	0.036	0.037
	<0.0001	0.158	<0.0001	<0.0001	<0.0001	<0.0001	0.629	0.007	0.958	0.105	0.356	0.927	0.643	0.636
W	**0.251**	-0.066	**0.584**	**0.679**	**0.411**	**0.577**	0.077	**-0.257**	-0.022	**0.164**	0.093	0.003	0.043	0.037
	0.001	0.401	<0.0001	<0.0001	<0.0001	<0.0001	0.324	0.001	0.784	0.035	0.231	0.969	0.585	0.632
C	**0.218**	-0.086	**0.544**	**0.349**	**0.260**	**0.345**	0.056	-0.150	-0.029	0.035	-0.004	0.038	0.002	-0.011
	0.005	0.272	<0.0001	<0.0001	0.001	<0.0001	0.471	0.053	0.721	0.657	0.956	0.626	0.979	0.884
RA	-0.099	**0.154**	**-0.395**	**-0.235**	**-0.172**	**-0.207**	-0.047	0.008	0.104	-0.071	0.004	-0.081	-0.021	0.064
	0.206	0.048	<0.0001	0.002	0.027	0.007	0.549	0.919	0.197	0.360	0.959	0.296	0.789	0.404
RW	0.118	-0.026	**0.200**	**0.259**	0.106	**0.196**	-0.010	-0.027	0.144	0.061	0.063	-0.143	**-0.157**	-0.104
	0.131	0.742	0.010	0.001	0.176	0.011	0.902	0.726	0.076	0.431	0.421	0.065	0.042	0.179
BCS	-0.014	0.134	**0.172**	0.080	0.094	0.100	**0.174**	**-0.259**	-0.140	0.099	0.057	0.128	**0.178**	0.127
	0.861	0.084	0.027	0.304	0.227	0.198	0.025	0.001	0.083	0.202	0.468	0.100	0.022	0.103
L	0.119	-0.008	**0.161**	**0.298**	0.130	**0.265**	0.028	-0.025	0.079	0.068	-0.024	-0.0830	-0.103	-0.045
	0.127	0.915	0.038	<0.0001	0.096	0.001	0.725	0.7441	0.328	0.385	0.756	0.286	0.185	0.565
US	-0.111	0.082	**-0.349**	**-0.322**	**-0.302**	**-0.356**	**-0.168**	**0.179**	0.023	-0.098	-0.073	-0.0152	0.046	0.030
	0.153	0.295	<0.0001	<0.0001	<0.0001	<0.0001	0.030	0.020	0.777	0.210	0.348	0.846	0.559	0.696
FU	-0.038	-0.014	-0.075	**-0.169**	**-0.157**	**-0.177**	-0.068	0.111	-0.021	-0.069	-0.075	0.037	0.026	0.027
	0.629	0.856	0.339	0.029	0.043	0.023	0.386	0.154	0.794	0.371	0.336	0.635	0.743	0.726
RU	-0.017	-0.019	-0.072	-0.125	-0.067	**-0.160**	0.045	0.070	0.034	-0.010	-0.058	-0.009	-0.001	0.055
	0.832	0.811	0.359	0.109	0.390	0.039	0.561	0.371	0.674	0.901	0.455	0.909	0.989	0.481
FT	**-0.229**	0.109	-0.033	-0.010	0.012	-0.007	-0.019	0.057	-0.044	-0.050	-0.062	0.006	0.018	-0.042
	0.003	0.163	0.676	0.903	0.873	0.933	0.803	0.464	0.590	0.520	0.429	0.942	0.813	0.590
RT	0.033	-0.041	**0.158**	0.149	0.021	0.110	0.021	0.082	0.079	-0.010	-0.090	-0.038	-0.114	-0.058
	0.674	0.596	0.042	0.056	0.788	0.157	0.786	0.294	0.333	0.897	0.250	0.628	0.144	0.459
UO	-0.093	0.031	**-0.253**	**-0.291**	**-0.228**	**-0.303**	-0.135	**0.181**	-0.020	-0.107	-0.079	0.024	0.039	0.017
	0.235	0.691	0.001	0.0001	0.003	<0.0001	0.083	0.019	0.810	0.167	0.311	0.755	0.612	0.824
DC	0.046	0.002	**0.352**	**0.282**	**0.262**	**0.264**	0.066	-0.084	-0.092	0.034	-0.009	-0.001	-0.015	-0.129
	0.558	0.975	<0.0001	0.0002	0.001	0.001	0.396	0.279	0.254	0.663	0.905	0.986	0.847	0.096

[1]Stature (S), Weight (W), Capacity (C), Rear angle (RA), Rear width (RW), Legs (L), Udder support (US), Fore udder (FU), Rear udder (RU), Fore teats (FT), Rear teats (RT), Udder overall (UO), Dairy conformation (DC) Body condition score (BCS) [2]SBFS:- interval from start of breeding to first service; SBCO:- interval from start of breeding to conception; S21, S42, C21, C42:- submission and conception to 21 and 42 days. Bottom numbers are P-values and values in bold indicate significant correlations ($P<0.05$)

None of the linear type traits were significantly correlated with lactation length in this study (P>0.05) except a weak positive correlation with rump angle.

All body type traits were significantly correlated with milk yield, fat yield and protein yield, except for body condition score with all yield traits, and rump width with fat yield. Stature, capacity and weight were moderately to strongly positively correlated with the yield traits, rump angle was weakly to moderately negatively correlated with the yield traits, and rump width moderately positively correlated with milk and protein yield. Dairy conformation also showed moderate positive correlations with all three yield traits. Legs was moderately positively correlated with milk and protein yield (0.30 and 0.27 respectively) but showed no correlation with fat yield (P>0.05). Of the udder type traits, those showing significant correlations with milk, fat and protein yield respectively were: udder support (-0.32, -0.30, -0.36), fore udder attachment (-0.17, -0.16, -0.18), and udder overall (-0.29, -0.23, -0.30). Rear udder attachment was also weakly correlated with protein yield (-0.16).

The only linear type traits that had a significant correlation with SCS were udder support (-0.17) and body condition score (0.17). These correlations indicate that animals with greater body condition scores and less udder support had higher somatic cell scores.

Fertility

Of the body type traits, the only ones displaying significant phenotypic correlations with the fertility traits were: stature - negative correlation with SBFS (-0.21); weight - negative and positive correlation with SBFS and S21 respectively (-0.26 and 0.16); rump width - negative correlation with C42 (-0.16); and body condition score - negative and positive correlation with SBFS and C42 respectively (-0.26 and 0.18). This indicates that taller, heavier animals with higher body condition scores at time of scoring had shorter intervals to first service, heavier animals had a greater likelihood of being submitted by Day 21, and animals with higher condition scores and narrower rumps were more likely to conceive by Day 42. The leg trait was not significantly correlated to the fertility traits. Of the udder type traits, only udder support and udder overall were significantly correlated to

SBFS and the correlation coefficient was low and positive (0.18 for both), thus indicating that cows with more desirable udders with greater udder support had longer intervals to first service.

Differences between breeds

After repetition of the correlation analysis by breed using only animals of third to fifth parity (20 J, 20 F and 35 F×J), significant differences between breeds in the correlation between production and linear type traits were observed [*see Appendix Tables A.6, A.7 and A.8*]. Generally, F and F×J had stronger phenotypic correlations and a greater number of correlations with the linear type traits than J. For J, the only significant correlations with yield were between dairy conformation and milk yield (positive), and body condition score and fat yield (negative), while for F, stature, rump width, legs, and rear udder were all correlated to yield. Stature, weight, body condition score, legs, udder support and udder overall were correlated with yield in F×J. No linear type trait was correlated to SCS in J, while udder support was correlated with SCS for F (negative), and rear udder was correlated with SCS (positive) for F×J. There was not sufficient data available to analyze the difference between breeds in correlations between linear type and fertility traits.

4.5 Regression of linear type traits on production and fertility

4.5.1 Regression model of linear type traits on production traits

Table 4.5.1. Regression coefficients (*b*) and standard errors (SE) for each linear type trait when used to predict milk, fat and protein production, somatic cell score and lactation length

Traits	Lactation length (days)			Milk yield (kg)			Fat yield (kg)			Protein yield (kg)			Somatic Cell Score[1]		
	b	SE	P	*b*	SE	P	*b*	SE	P	*b*	SE	P	*b*	SE	P
Stature	1.02	1.41	0.472	**171.55**	50.79	0.001	**4.76**	2.33	0.042	**5.27**	1.85	0.005	-0.051	0.112	0.649
Weight	1.27	1.32	0.340	**129.28**	48.28	0.008	4.07	2.19	0.065	**4.40**	1.75	0.013	0.005	0.105	0.964
Capacity	**3.59**	1.65	0.031	-2.92	62.19	0.963	0.486	2.78	0.862	1.17	2.24	0.601	-0.082	0.132	0.536
Rump angle	**2.93**	1.34	0.031	12.05	50.82	0.813	0.301	2.28	0.895	1.10	1.83	0.548	0.057	0.108	0.595
Rump width	0.596	1.73	0.731	-19.03	64.43	0.768	-2.38	2.88	0.409	-0.520	2.33	0.823	-0.041	0.137	0.767
Body condition score	7.94	4.31	0.068	**-431.67**	158.60	0.007	-11.34	7.21	0.118	**-12.38**	5.77	0.034	**0.806**	0.338	0.018
Legs	2.07	1.83	0.261	**161.89**	67.26	0.017	3.16	3.06	0.303	**6.44**	2.42	0.009	0.003	0.145	0.983
Udder support	0.326	1.06	0.758	**-108.63**	38.41	0.005	**-4.06**	1.73	0.020	**-4.66**	1.37	0.001	-0.126	0.083	0.132
Fore udder attachment	-0.288	1.02	0.778	**-78.82**	37.46	0.037	-2.77	1.69	0.102	**-2.95**	1.35	0.031	-0.071	0.080	0.378
Rear udder attachment	-0.314	1.50	0.835	-95.48	55.51	0.087	-1.28	2.51	0.611	**-5.03**	1.98	0.012	0.106	0.119	0.372
Fore teat placement	-3.17	1.90	0.098	-50.04	71.45	0.485	-3.75	3.19	0.242	-3.06	2.57	0.236	-0.002	0.152	0.991
Rear teat placement	-0.810	1.21	0.503	-1.31	44.96	0.977	**-4.01**	1.99	0.045	-1.06	1.62	0.515	0.012	0.095	0.904
Udder overall	-0.210	1.04	0.840	**-98.67**	37.74	0.010	-3.27	1.71	0.057	**-4.15**	1.35	0.003	-0.098	0.081	0.233
Dairy conformation	3.36	1.75	0.057	**152.88**	64.73	0.019	**5.83**	2.91	0.047	3.72	2.36	0.117	-0.012	0.140	0.930

[1]Somatic cell score $=\log_2$ (Somatic cell count÷1000)   Values in bold indicate significant correlations (P<0.05)

Lactation Length

With lactation length (LL) as the dependent variable, and including the effects of breed, parity and calving deviation, when regression models were fitted individually using each of the linear type traits as independent variables, none were found to be significant in affecting the models except capacity and rump angle with regression coefficients indicating an increase in lactation length by 3.6 and 2.9 days with each unit increase in capacity or rump angle score (*see Table 4.5.1)*.

Yield

Modelling with the effects of breed, parity and calving deviation, when regression models were fitted individually for milk yield using each of the linear type trait as independent variables, those significantly affecting the models were: stature, weight, body condition score, legs, udder support, fore udder attachment, udder overall and dairy conformation. Likewise, for protein yield, the significant traits were: stature, weight, body condition score, legs, udder support, fore udder attachment and udder overall as well as rear udder attachment, while for fat yield only the regression coefficients for stature, udder support, rear teat placement and dairy conformation were significant ($P<0.05$).

Somatic Cell Score

The individual linear type trait models for SCS using individual TOP, breed, parity and calving deviation, reveal only the coefficient of body condition score to be significant ($P<0.05$). The results indicate an increase in the somatic cell score by 0.81 for every unit increase in the body condition score.

4.5.2 Regression model of linear type traits on fertility traits

Table 4.5.2. Regression coefficients (*b*) and standard errors (SE) for each linear type trait[1] when used to predict fertility[2]:-interval to first service and conception, submission and conception to 21 and 42 days, and pregnancy

Traits	SBFS (days)			SBCO (days)			S21			S42			C21			C42			Pregnant		
	b	SE	P	*b*	SE	P	*b*	SE	P	*b*	SE	P	*b*	SE	P	*b*	SE	P	*b*	SE	P
S	-1.08	0.819	0.191	-1.23	1.61	0.447	0.025	0.020	0.396	0.004	0.012	0.897	0.037	0.050	0.657	0.016	0.040	0.986	-0.005	0.028	0.765
W	**-1.67**	0.761	0.030	-0.731	1.51	0.629	0.035	0.019	0.097	0.006	0.011	0.668	0.013	0.047	0.917	0.001	0.038	0.915	-0.010	0.026	0.774
C	-0.502	0.965	0.604	0.188	1.91	0.922	-0.017	0.024	0.517	-0.014	0.014	0.441	0.013	0.059	0.904	0.001	0.047	0.981	0.013	0.033	0.887
RA	-0.856	0.792	0.282	1.31	1.60	0.413	-0.003	0.020	0.802	0.007	0.011	0.622	-0.026	0.048	0.517	-0.002	0.039	0.844	0.026	0.027	0.428
RW	0.352	1.00	0.727	3.12	2.00	0.122	0.005	0.025	0.712	0.004	0.014	0.610	-0.104	0.061	0.062	**-0.122**	0.048	0.013	-0.064	0.034	0.061
BCS	**-6.79**	2.48	0.007	-8.28	5.08	0.105	0.062	0.063	0.356	0.011	0.037	0.689	0.245	0.154	0.130	**0.234**	0.122	0.042	0.114	0.086	0.125
L	0.376	1.07	0.725	1.75	2.13	0.412	0.012	0.026	0.578	-0.011	0.015	0.458	-0.066	0.065	0.338	-0.081	0.052	0.564	-0.036	0.036	0.297
US	0.903	0.612	0.142	0.019	1.23	0.988	-0.014	0.015	0.278	-0.006	0.009	0.389	-0.003	0.038	0.995	0.019	0.030	0.421	0.001	0.021	0.749
FU	0.756	0.586	0.199	-0.216	1.19	0.856	-0.012	0.015	0.352	-0.006	0.008	0.349	0.016	0.036	0.690	0.020	0.029	0.639	0.014	0.020	0.650
RU	0.518	0.875	0.555	0.276	1.77	0.876	-0.002	0.022	0.957	-0.006	0.013	0.491	0.007	0.053	0.913	0.011	0.043	0.914	0.031	0.030	0.430
FT	0.852	1.11	0.445	-0.283	2.22	0.899	-0.015	0.028	0.431	-0.009	0.016	0.390	-0.027	0.068	0.535	-0.003	0.054	0.809	-0.029	0.038	0.350
RT	1.21	0.696	0.083	1.49	1.38	0.280	-0.003	0.017	0.640	-0.010	0.010	0.138	-0.014	0.043	0.555	-0.044	0.034	0.079	-0.010	0.024	0.276
UO	0.972	0.598	0.106	-0.580	1.21	0.632	-0.016	0.015	0.202	-0.006	0.009	0.355	0.017	0.037	0.685	0.023	0.029	0.467	0.006	0.021	0.778
DC	-0.466	1.02	0.647	-1.18	2.06	0.568	0.0004	0.025	0.879	-0.002	0.015	0.698	-0.029	0.062	0.499	-0.005	0.050	0.767	-0.048	0.034	0.110

[1]Stature (S), Weight (W), Capacity (C), Rear angle (RA), Rear width (RW), Legs (L), Udder support (US), Fore udder (FU), Rear udder (RU), Fore teats (FT), Rear teats (RT), Udder overall (UO), Dairy conformation (DC) Body condition score (BCS), [2]SBFS-start of breeding to first service, SBCO-start of breeding to conception, S21, S42, C21 and C42- submission or conception to 21 and 42 days Values in bold indicate significant correlations ($P<0.05$)

For interval to first service, using the model with breed, parity and calving deviation along with each linear type trait individually, the regression coefficients for body condition score and weight were significant ($P<0.05$), indicating a decrease in the interval to first service by 1.7 and 6.8 days for every unit increase in the weight and body condition score respectively. For interval to conception, all regression coefficients were non-significant ($P>0.05$).

The models for submission to 21 and 42 days had all TOP regression coefficients as non-significant ($P>0.05$) and similarly, the models for conception to 21 days and pregnancy had all regression coefficients as non-significant ($P>0.05$). In the model for conception to 42 days, however, both the regression coefficient for rump width and body condition score were significant ($P<0.05$), indicating an increase in conception likelihood by Day 42, with an increase in body condition score and decrease in rump width.

Chapter 5: DISCUSSION

The main aim of this research was to identify linear type traits appropriate for inclusion in a selection index for OAD milking, based on their phenotypic correlations with each other, and with the economically important production and fertility traits. Differences in these correlations between breeds were also investigated. This research was of particular value since, in the past, these correlation studies were done using TAD milked herds, and discussions are currently taking place with regards to the inclusion of linear type traits in the selection index specifically for OAD herds in New Zealand. The results obtained in this study, using the OAD milked herd at Massey Dairy No.1 farm, indicate that there are strong positive correlations between the individual body type traits and between the individual udder type traits, however, correlations between body and udder type traits are generally negative and weak. The traits: stature, weight, body condition score, dairy conformation, udder support, fore udder attachment, and udder overall in particular, showed moderate to strong correlations with production and fertility, and models also indicated significant associations between these traits and production and fertility. Generally, across breeds, increased stature and weight, less desirable udders, and higher body condition and dairy conformation scores were associated with improved production and fertility.

5.1 Preliminary data analysis

In most cases, in addition to being below the expected value of 1.5, the standard deviations of the linear type traits were also significantly less than that found in other studies using TAD herds (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Klassen *et al.*, 1992; Lund *et al.*, 1994; Brotherstone, 1994; Rupp & Boichard, 1999; Berry *et al.*, 2004). The low standard deviation for BCS is expected as the Dairy No. 1 herd is managed so as to have uniformity, i.e. ideal and similar conditions at specific times during the year. The low standard deviations for the other linear type traits also indicate high levels of uniformity (low variation) and it is possible that indirect selection for these traits has occurred within the herd. It is also possible that there was reluctance by the inspector to score at extreme ends of the range, or that this reflects greater uniformity of cows when on OAD systems.

The mean value obtained for the rear legs trait in this study was significantly higher than that of other TAD studies (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004), thus indicating higher levels of leg curvature in the Massey Dairy No. 1 cows. Likewise, the means of body traits: stature, weight, capacity and rump width were higher than those obtained in other studies (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Klassen *et al.*, 1992; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004) suggesting that the OAD-milked cows in the current study were taller, heavier, and wider at the rump and chest, and had greater body depth. The mean rump angle in the current study, however, was much lower than that obtained in other studies (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Brotherstone, 1994; Berry *et al.*, 2004). These findings could be attributed to the fact that the animals used in the previous studies were all TOP-scored in their first lactation or as heifers, whilst the mean parity for the animals at TOP-scoring in the present study was three. Older cows are usually larger in body size, score higher for stature, capacity and rump width, have greater leg curvature, and have lower rump angle scores than primiparous cows (Hayes & Mao, 1987). The mean BCS obtained in this study using OAD milked cows was unexpectedly lower than that of Berry *et al.* (2004) conducted in TAD milked herds, but this may be partly due to a difference in the time at which BCS was measured in both studies, as measurements were taken later in lactation (Day 51 - 223) in that study, when animals would have started regaining condition.

The mean score obtained for udder support tended to be similar to that in some previous studies (Meyer *et al.*, 1987; Berry *et al.*, 2004) and similarly for front udder attachment (Brotherstone *et al.*, 1990; Brotherstone, 1994; Lund *et al.*, 1994), however, the mean values for rear teat placement and rear udder attachment tended to be higher in the present study (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Brotherstone, 1994; Lund *et al.*, 1994; Rupp & Boichard, 1999; Berry *et al.*, 2004), and front teat placement lower than that found in the literature (Klassen *et al.*, 1992; Lund *et al.*, 1994; Rupp & Boichard, 1999). The mean value for front teat placement was however similar to that of the studies by Meyer *et al.* (1987) and Cue *et al.*, (1996). Both udder overall and dairy conformation mean scores were higher than that found in the study by Cue *et al.* (1996) also conducted in New Zealand using similar breeds. This finding could be indicative of an improvement in the overall udder and dairy conformation of present day dairy cattle compared to two decades ago, however, it is worth noting that the study by Cue *et al.* (1996) was conducted using the overall national dairy population, which includes low breeding value dairy animals, while the current study was done using cows of generally higher breeding value.

The lactation length varied widely in this study but the mean obtained is only moderately lower than the national average of 266 days for the 2013-2014 season, which includes mostly TAD-milked animals (LIC, 2014). The average total milk, fat and protein yields recorded in this study are similar to that being produced currently by other high-performing New Zealand OAD milked cows (Holmes & Hendrikse, 2014), however, they are lower - approximately 15%, 9% and 9% lower for milk volume, fat and protein respectively - than the national/regional averages for mostly TAD-milked New Zealand commercial dairy systems in the same milking season (LIC, 2014). The SCS varied widely between cows, and the mean of 6.22, which equates to approximately 75 000 cells/ml, was much lower than that of other TAD-milked herds in the Manawatu region at herd-testing (average approximately 7.8 [223 000 cells/ml]) (LIC, 2014), and also lower than that of other OAD-milked herds in New Zealand (Holmes & Hendrikse, 2014). This herd is therefore a good example that ideal SCS can be achieved on OAD milking regimens.

The submission rate to 21 days recorded in this study is much better than the national average of 79.9% in the 2013-2014 season (LIC, 2014), and the conception rate to 42 days, likewise, is higher than the national average of 65.6% for a similar period, with only 10% of all herds having rates above 71% (LIC, 2014). The conception rate is, however, similar to that of other high-performing OAD-milking farms in New Zealand during the 2013-2014 season, with conception rate to 42 days ranging between 80-87%, and the empty rate is also comparable to other OAD-milking herds (Holmes & Hendrikse, 2014). The higher reproductive performance of this herd compared to previously on TAD-milking, as well as compared to the national top performing herds, is expected as fertility traits are improved in cows on OAD-milking regimens (Rémond *et al.*, 2004; Dalley & Bateup 2004; Bewsell *et al.*, 2008; Lee, 2011).

5.2 Difference between breeds in linear type traits, production and fertility

The lower mean values for the body type traits in Jersey cows compared with Holstein-Friesian and crossbred cows are expected as Jersey cows are smaller in size (height, width and weight) than Holstein-Friesian cows (Cunningham & Syrstad, 1987). The study conducted by Cue *et al.* (1996) in New Zealand found similar results to this study with Holstein-Friesian cows scoring higher for weight, stature and legs and Jersey cows scoring similarly with Holstein-Friesian cows for rump angle, however, unlike in the current analysis, Jersey cows in that study scored higher for capacity and rump width (Cue *et al.*, 1996). The absence of differences between Jersey and Holstein-Friesian cows in udder type traits is different from the results found in previous TAD studies where Jersey cows generally have higher udder scores (Visscher & Goddard, 1995; Cue *et al.*, 1996). This is also inconsistent with the belief among New Zealand OAD farmers, that Jersey cows have better udders (e.g. udder support) than Holstein-Friesian cows under OAD milking systems (Holmes & Hendrikse, 2014), but it is possible that the results may differ if analyses are conducted after a longer time on OAD milking (the study herd had only been milked OAD for one season).

The greater milk and protein yield of Holstein-Friesian cows compared to Jersey cows, and the finding of no differences in fat yield between these two breeds have been demonstrated and established in many previous studies in OAD and TAD-milked herds (Mackle *et al.*, 1996; Gale, 2004; Palladino *et al.*, 2010; Prendiville *et al.*, 2010). The absence of a difference in fat yield could be due to the much higher milk fat content/percentage produced by Jersey cows, thus making up for the reduction in milk volume so that very little reduction in overall fat yield occurs. The significantly higher fat yield in crossbred animals may be due to hybrid vigour.

In agreement with the present study, SCS was found to be similar between Jersey and Holstein-Friesian cows in the studies by Washburn *et al.* (2002) and Prendiville *et al.* (2010), also conducted using small sample sizes similar to the present study (<200 animals), however, it is possible that with a larger sample size, the difference would be significant (i.e. Jersey cows having significantly higher SCS), as was the case in the study by Berry *et al.* (2007) done in New Zealand using 2635 records. After adjustment for calving deviation, the Jersey breed was found to have a significantly shorter lactation length than Holstein-Friesian and cross-bred cows ($P<0.05$) which was also found in the study by Mackle *et al.* (1996). The milk, fat and protein yield for Holstein-Friesian and Jersey cows on this OAD milking system are similar to the national breed averages, however, the cross-bred animals in this study produced far less milk yield than the national average (LIC, 2014) although having similar breed make-up.

The national herd statistics show that Jersey cows have the highest breeding value for fertility, followed by cross-bred animals and then Holstein-Friesian cows (LIC, 2014). Several studies using TAD milked animals have also shown a resultant improvement in fertility traits in Holstein-Friesian-Jersey crossed cows compared to purebred Holstein-Friesians (Auldist *et al.*, 2007; Heins *et al.*, 2012), and shorter intervals to first service in Jersey compared to Holstein-Friesian cows (Grosshans *et al.*, 1997). This is in direct contrast to the findings of the present study, where the trend was for better fertility performance in the Holstein-Friesian cows compared to cross-bred and Jersey animals although not significant ($P>0.05$). It should be noted, however, that there is evidence elsewhere to suggest that the fertility performance on OAD milking regimens is similar between Jersey and Holstein-Friesian cows (Dalley & Bateup, 2004) and therefore our results could indicate that with OAD milking, there is no difference in fertility performance between the breeds.

5.3 Phenotypic correlations amongst linear type traits

The findings in this study indicate that high scores in most body type traits will accompany high scores in other body type traits, with the exception of rump angle since taller, heavier and more capacious animals will have higher pins (i.e. lower rump angle scores). Since stature and weight were almost equivalent, it is likely that the type trait weight is scored linearly based on the “tallness” of the animal rather than the actual perception of the animal’s estimated weight. The necessity of including measurement for the trait weight can therefore be argued against, and similarly, it is possible to omit measures for capacity and rump width as these are also strongly correlated with stature.

The results for the body type traits are comparable to previous studies done in TAD milked herds. Most phenotypic correlations were similar, except for the finding of no correlation between stature and rump angle, capacity and rump angle and stature and body condition score in the studies by Meyer *et al.* (1987); Brotherstone *et al*. (1990); Brotherstone (1994); Berry *et al*. (2004); and Cue *et al.* (1996). Incidentally, the correlations between these traits were some of the lowest found in the current study. Also, the correlation between weight and the other body type traits found in the study by Cue *et al.* (1996) were similar to our findings, but values were generally lower in that study.

The results for correlations between udder type traits were very similar to previous TAD studies (Meyer *et al*., 1987; Brotherstone *et al*., 1990; Harris *et al.*, 1992; Klassen *et al*., 1992; Brotherstone, 1994; Lund *et al.*, 1994; Cue *et al.*, 1996; Boettcher *et al.*, 1998; Berry *et al.*, 2004), especially compared with that of Cue *et al.* (1996) where, in many cases, the phenotypic correlations between udder type traits were almost identical to those found in the present study. The strong correlation between front and rear teat placement and between fore and rear udder attachment implies that by measuring either front or rear teat placement, and fore or rear udder attachment, the unmeasured trait can be predicted with a fair amount of accuracy. Furthermore, based on the strong correlations between the overall udder score or udder support and all other udder type traits ($r > 0.44$) except rear teat placement, it is suggested that the number of udder traits measured could be reduced from six to two- namely udder overall or udder support and rear teat placement.

The finding in this study that taller, heavier and wider-rump animals have greater hind leg curvature could be due to a change in conformation through selection over the past few decades, resulting in the larger modern cows consistently having greater hind leg curvature compared to the greater variation in leg curvature with different body sizes in the past. This speculation is substantiated by earlier studies, where the leg trait was found to be uncorrelated with body type traits (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Harris *et al.*, 1992; Klassen *et al.*, 1992; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004). The results of correlation analyses between the leg trait and udder traits indicate that animals having better udder scores - that is, greater udder support, fore and rear udder attachment, closer front teat placement and more desirable overall udder scores, tend to have straighter hind limbs when viewed from the side. This is also corroborated by the negative correlations found in previous studies (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Harris *et al.*, 1992; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004) which is expected, as it follows the positive correlation of legs with body type traits, and as discussed subsequently, body and udder type traits are negatively correlated.

The results indicating that taller, heavier, more capacious animals tend to have weaker udder support and lower overall udder score – i.e. have less desirable udders, are somewhat similar to those of previous studies, with the finding of weak negative or no correlations between most body and udder type traits (Meyer *et al.*, 1987; Brotherstone *et al.*, 1990; Harris *et al.*, 1992; Brotherstone, 1994; Cue *et al.*, 1996; Berry *et al.*, 2004). Dairy conformation, however, showed a marked difference from previous studies as it was previously found to be moderately or strongly correlated with all udder traits excepting teat placement (Harris *et al.*, 1992; Cue *et al.*, 1996). These findings of very little correlations therefore necessitates the use of at least some body type traits to accompany the measurement of udder type traits, since the correlation between these two groups of traits is weak in both TAD and OAD systems.

In summary, the occurrence of strong correlations within groups indicates that the number of traits measured for body type and udder type can be reduced, while the correlation findings between body and udder type traits have two consequences. Firstly, the lack of significant correlations between most of these two group traits suggests that traits in either group are not good representations of traits in the other group and thus both groups are needed independently. Also, the occurrence of mostly negative correlations indicates that the selection for animals with smaller body size as is currently practiced in New Zealand (negative economic value for live-weight in the TAD selection index for breeding worth) may also be favourable for improving udders in OAD milked herds, although this has the disadvantage of reducing yield as discussed later (*see Section 5.4*).

The lower incidence of correlations between linear type traits in Jersey cows compared to Holstein-Friesians differs from the studies by Cue *et al.* (1996) and Visscher and Goddard (1995), in which the correlations were similar between breeds. Any inferences made from these breed differences in this study, nevertheless, must be done with caution as the sample size may have been too small.

5.4 Phenotypic correlations between linear type, production and fertility traits

The results of phenotypic correlations between the production traits found in this study are comparable to the study by Harris *et al.* (1992), where the phenotypic correlations between milk, fat and protein yield were similarly strong (0.86 - 0.94), however, the result for SCS differs from that of other TAD studies, which found SCS or CMT (California Mastitis Test score) to be negatively and weakly correlated with milk, fat and protein yield (Batra & McAllister, 1984; Seykora & McDaniel, 1985; Rupp & Boichard, 1999). Overall the results presented here indicate that there is higher milk production as parity increases, and later calving for older animals, which is expected since heifers were mated to calve early in their first calving season. The absence of a correlation between milk yield and lactation length in this study indicates that some cows were able to produce adequate milk volumes on the OAD system, despite having a shorter lactation.

The significant correlations between fertility traits were also found in Grosshans *et al* (1997) and are as would be expected - that animals with shorter intervals to submission or conception were more likely to be submitted or conceived by 21 and 42 days and animals which had been submitted/conceived by 21 days were also submitted/ conceived by 42 days. The correlation between SBFS and SBCO was forced to be positive due to the part-whole relationship between these two variables, as interval to first service is part of or partially determines the interval to conception, as was also highlighted in the study by Grosshans *et al.* (1997). The moderate to low correlation coefficients between submission and conception found in the current study indicate that earlier submissions were not necessarily equivalent to earlier conceptions. This could suggest that animals were being submitted while not in oestrus, thus there was possibly an issue with oestrus detection on this farm. Submission for mating was not affected by the time of calving, but, as expected, cows which calved later in the season and had a subsequently shorter lactation, were less likely to become pregnant or conceive by Day 21 and 42 after the start of mating.

The correlation analyses between production and fertility also indicate that cows which were submitted by Day 21 subsequently produced higher milk yields, and older cows with higher somatic cell scores seem to have a shorter interval to first service. Other studies have also found that submission rates tend to be better in older cows (Fulkerson, 1984; Darwash *et al.*, 1994) although in the study by Royal *et al.* (2002b) longer intervals to commencement of luteal activity were observed in animals over four years. The quicker submission in cows with higher SCS during the season may just be because older animals had higher SCS (correlation between these was positive). Alternatively, the relationship between SCS and SBFS may be due to their dependency on body condition score, since animals with higher SCS may produce less milk, lose less condition and have better fertility (the correlation between SCS and BCS was positive and between BCS and SBFS negative- *see Table 4.4.4*), but this is dependent on the assumption that animals with higher SCS had similarly higher SCS the previous season. This theory is supported by the moderate and positive phenotypic correlation between SCS in the first, second and third lactations found in the TAD study by Boettcher *et al.* (1998). The study by Wall *et al.* (2003) using genetic correlations also found higher SCS to be associated with better fertility.

The reason behind why animals which submitted by 21 days had higher milk yields could not be ascertained, as this finding differs from that of most previous studies where milk, fat and protein yield were not significantly correlated with any fertility trait (including SBFS, SBCO, C21, C42 and pregnancy) (Grosshans *et al.*, 1997; Pryce *et al.*, 1998; Royal *et al.*, 2002a; Wall *et al*., 2003). Even more contrasting, is the finding in the study by Veerkamp *et al*. (2001) of weak positive correlations between milk yield (and fat and protein yield) and SBFS, suggesting higher milk yields are less desirable for improving fertility. The findings in the present study may be spurious, however, since early submission was not strongly associated with early conception and therefore the early submission in higher yielding cows may not be an indicator of improved fertility, but rather, a result of human error - submission of high yielding cows which had not resumed cycling.

Other studies done in TAD milking systems which also found similar results to the current study for the linear type and yield traits include that for: stature (Foster *et al.*, 1989; Harris *et al.*, 1992), capacity (Meyer *et al.*, 1987; Klassen *et al.*, 1992; Brotherstone, 1994), weight, rump angle, udder depth/support (Meyer *et al.*, 1987; Harris *et al.*, 1992; Brotherstone, 1994), fore udder attachment (Meyer *et al.*, 1987; Harris *et al.*, 1992; Brotherstone, 1994), udder height (a component of rear udder attachment) (Batra & McAllister, 1984; Seykora & McDaniel, 1985), and dairy conformation (Klassen *et al.*, 1992; Harris *et al.*, 1992; Visscher & Goddard, 1995). In contrast, the results from the studies by Klassen *et al.* (1992) and Veerkamp and Brotherstone (1997) for weight, rump angle, and udder overall had different signs from that found here, and the legs trait is usually found to have a correlation close to zero when related to milk, fat and protein yields (Meyer *et al.*, 1987; Harris *et al.*, 1992; Klassen *et al.*, 1992; Brotherstone, 1994). This difference could be due to the greater association between increased leg curvature and higher body type scores, and thus, also higher yielding modern cows. The findings in this study support the belief that higher-producing cows, even on OAD milking systems, have less desirable udders (weakened udder support and udder attachment). These high-producers also tend to have better dairy conformation scores and are taller, heavier, more capacious, wider- and higher-rumped, and have greater leg curvature. The greater number of associations between linear type traits and yield traits in Holstein-Friesian cows compared to Jersey cows on OAD milking regimens had also been noted in the study by Gale (2004).

The correlations between udder support and BCS with SCS indicate that animals with greater body condition scores and less udder support had higher somatic cell scores, while other traits were insignificantly correlated with SCS. Similarly, the studies by Rogers *et al.* (1991) and Kadarmideen (2004) also found insignificant correlations between SCS and the body and leg traits, and studies by Rogers *et al.* (1991), Lund *et al.* (1994) and Rupp and Boichard (1999) found insignificant correlations with the udder type traits, except for weak negative correlations with udder depth and udder height (similar traits to udder support). Less udder support may result in the udders being more prone to ground contact and environmental contamination. Body condition score and SCS could be indirectly related to each other, as cows with high somatic cell scores usually have a reduction in production/yield (as indicated by the negative though insignificant correlation found between SCS and milk, fat and protein yield), which will, due to a reduced energy demand, result in higher body condition scores.

The general lack of correlations between lactation length and linear type traits was also found in the study by Perez-Cabal *et al.* (2006) where rear legs was not found to be significantly correlated with days in milk, and in the study by Klassen *et al.* (1992) where all traits were found to be insignificantly or very weakly correlated with days in milk (<0.15), except angularity, which was not measured in the present study.

The results from this study indicate that taller, heavier animals with higher body condition scores at time of scoring had had shorter intervals to first service, heavier animals had been more likely to be submitted by Day 21, and animals with higher condition scores and narrower rumps were more likely to conceive by Day 42. These conclusions are also corroborated by the findings for SBCO, S42 and C21 although the correlations with body type traits were insignificant. This finding of improved fertility in animals with better body condition is also supported in the study by Veerkamp *et al.* (2001) which found similar negative phenotypic correlations with interval to first service, and the study by Kadarmideen (2004) which found positive though very weak phenotypic correlations with pregnancy rates. Likewise, the findings for weight are also corroborated by the study by Berry *et al.* (2003), which also found a negative correlation with interval to first service. In that study, however, the phenotypic correlations between the fertility traits and stature or rump width were all insignificant (Berry *et al.*, 2003). A negative correlation between rump width and conception was, however, found in the genetic study by Berry *et al.* (2004). Similar to the current study, Perez-Cabal *et al.* (2006) found the leg trait to be uncorrelated to fertility, and the conflicting relationship between improved udders and reduced fertility was also found in previous studies using genetic correlations (Pryce *et al.*, 2000; Berry *et al.*, 2004). A possible explanation for this is the reduction in udder support and overall udder score in taller and heavier animals (and those with higher BCS though insignificant), which as pointed out above, tend to have better fertility.

5.5 Regression of linear type traits on production and fertility

The models for lactation length indicate that one unit increases in capacity and rump angle scores can increase the number of days in milk for the OAD cows by 3 - 4 days. Likewise, increases in the stature, weight, leg curvature and dairy conformation of the OAD milked cows have profound and favourable effects on yield. For example, for every 1 unit increase in the stature, there is an increase in milk, fat and protein yield by approximately 172 kg, 5 kg and 5 kg respectively. The models for yield also indicate a decrease in yield with higher scores for udder support, udder attachment, udder overall and body condition score, however, decreased udder desirability and body condition score is more likely to be the effect of increased yield rather than cows with inherently less udder support and body condition being higher producers. The study by Gale (2004) also found the regression coefficients for dairy conformation and legs to be significant in affecting yields in OAD milked cows, and the study by Foster *et al.*, (1989) also found the traits dairyness (dairy character), udder/support, stature and legs to be important in affecting herdmate deviation of fat and milk (in addition to other traits), with similar signs for these traits as found in the present study, except for udder support where the regression coefficient was positive. BCS was not assessed in either of these two studies.

In this study, regression coefficients of the linear type traits with SCS were all non-significant except BCS indicating an increase in SCS by 0.81 for every unit increase in

BCS, however, as explained previously, higher SCS is more likely to lead to higher BCS indirectly. Unlike in this study where no udder type traits had significant regression coefficients in the model for SCS, the study by Seykora and McDaniel (1985) demonstrated an appropriate regression model for SCS in TAD herds using the traits parity, fat yield, udder height, milking speed and teat end shape, and in the study by Boettcher *et al.* (1998), udder health indices were developed to reduce SCS, using udder conformation traits, particularly udder depth and udder attachment. Likewise, Pryce *et al.*, (1998) showed regression coefficients for the udder traits: udder support and rear udder attachment, in addition to rump angle and rump width, to be significant in the model for SCS. The inability to design suitable regression models for SCS with linear type traits in this study may be related to the small sample size, and the generally low SCS of the animals, as less than 2% had SCS season average above the threshold for penalties.

From the regression models for fertility traits, as well as correlation analyses, it can be seen that the main linear type trait seeming to affect submission and conception is body condition score. For example, an increase in BCS by one unit increases the probability of conception by Day 42 by 23% and reduces the interval to first service by 6.8 days. In the study by Royal *et al.* (2002a), the regression coefficient of BCS also indicated a decrease of 6 days in the interval to commencement of luteal activity post-partum for every one unit increase in BCS, however, that study also had rump width, fat yield and chest width having significant coefficients. Weight had a significant negative coefficient indicating reduced intervals to first service with increased weight, but it is possible that when adjusted for body condition score, the relationship will become positive (i.e. increased weight is unfavourably associated with fertility) as was demonstrated in the study by Berry *et al.* (2003). Rump width was also found to significantly affect the probability of conception by 42 days, with an increase in probability of conception at 42 days by 12%, for every unit decrease in rump width. For all other fertility traits examined, including pregnancy, none of the linear type traits had significant regression coefficients. In the study by Kadarmideen (2004), most linear type traits analyzed had significant regression coefficients for non-return rate (or pregnancy), however, that study was done using genetic relationships.

The results for the correlation and regression models for the fertility traits suggest that, for the most part, animal conformation traits and production/yield are not good indicators of early submission or conception ability in dairy cattle, but that the ability to conceive early is dependent mainly on early calving in the breeding season and cows being in good body condition.

5.6 Summary and implications

Most body type traits showed strong correlations and significant coefficients when modeled with yield, and similarly for the udder type traits: udder support, udder overall, and fore udder attachment, thus, it can be concluded that an increase in most body type scores (particularly stature and weight) and dairy conformation, as well as a decrease in body condition score and udder type traits, is associated with increased yield. Therefore, selection for higher body type scores should be beneficial for increasing yield in OAD milked herds. On the other hand, selection based on the findings for the udder type traits and body condition score is not recommended as reduced udder support, udder attachment and body condition score is most likely an effect of higher milk production rather than a cause.

Somatic cell score was found to be independent of most production and linear type traits as indicated by the absence of correlations in most cases, and the inability to formulate an adequate model with the individual linear type traits ($P>0.05$). Despite this, the correlation and modelling findings indicate a preference for greater udder support to reduce SCS, and also indicate an increase in body condition score in cows with high somatic cell scores possibly due to the associated lower production.

Earlier submission of cows to artificial insemination in this OAD-milked herd was associated with older cows, and it was found that earlier calving and higher body conditions scores, and to a lesser extent, lower rump width, were desirable for improving fertility. Although breed did not significantly impact fertility in this study, previous studies on TAD herds showed a significant influence of breed on the models for fertility and on correlations between fertility and the linear type and production traits (Veerkamp *et al.*, 2001; Berry *et al.*, 2005).

Generally, the results found in this study using an OAD-milked herd, showed correlations between the udder type traits, and between the body and udder type traits that are similar to previous studies done in TAD-milked cows. It is however difficult to conclude whether the stronger correlations between the body type traits, the body type and leg traits, and the udder type and leg traits in this study, could be due to a difference between OAD and TAD milking, the result of genetic selection over the past few decades, or a difference in research methodologies. This requires further investigation.

Based on these findings, it is suggested that at least one of the body type traits (e.g. stature) and dairy conformation be included in the selection index for increasing milk production in once-a-day milked herds. It is also suggested that increased udder support be included in selection practices, since, although the relationship with yield appears unfavourable, it is important in reducing the somatic cell score of dairy cows. Somatic cell scores can be especially high in OAD milkers, although in this study the SCS was within the acceptable limit. With regards to fertility, the suggestion to include BCS in the selection index for improving conception and pregnancy rates in OAD milked cows has also been made elsewhere for both OAD and TAD herds. It is however important to note that the ability of body condition score to accurately predict phenotypic fertility is best maximized by recording this trait multiple times throughout a lactation season (Veerkamp *et al.*, 2001) since a single measurement is not sufficient.

5.7 Limitations and future research

Despite attempts to minimize errors in this study, a few limitations and sources of possible biases were identified. The main concern was related to the sample population used, as the sample size of 167 was very small and unbalanced in age/parity between breeds (Holstein-Friesians were significantly older). The small sample size, along with the relatively high performance of this herd resulted in issues such as: 1) an insufficient number of, and variation between animals within the different breeds for an accurate between breed comparison, especially for fertility, where in some cases, correlation measurements were impossible due to 100% submission; 2) high levels of uniformity, skewness and kurtosis in the linear type trait data resulting in a non-normal distribution (for many traits, no animal scored below 4 on the 1 - 9 scale); and 3) overall low SCS thus possibly diminishing the correlation results for SCS with other traits. In addition to this, there were indications that there may have been a problem with oestrus detection on this farm therefore affecting some fertility results.

It is recommended that further studies be done on a larger scale using a cross-section of farms and conditions in New Zealand, so as to have a better sample representation of the OAD-milked dairy population and so that the skewness of linear type trait data can be minimized. Also, conduction of this study over multiple seasons of OAD milking may improve the validity of the findings. It is also proposed that the producer-scored traits – particularly milking speed, be included in further analyses, and multiple measures of BCS be assessed throughout the season. The conformation traits: stature, weight, body condition score, dairy conformation, udder support, fore udder attachment and udder overall warrant further investigation into their suitability for inclusion in a selection index for OAD milking.

CHAPTER 6: CONCLUSIONS

There is currently widespread adoption of OAD milking of dairy cattle in New Zealand, and to maximize the benefits of this practice, selection for animals which function well on this system is necessary. This selection can be facilitated through the use of linear type trait scoring in the selection procedure, however, although exhaustive literature exists for the extent to which these traits are associated with production and fertility in TAD herds, their association in OAD herds has not been fully explored. This study therefore aimed to look at the correlations between the linear type traits and economically important traits in an OAD milked herd.

The standard deviation of the linear type traits, found in this study are generally lower than expected, and lower than those found in previous studies in TAD herds. This may be due to greater uniformity in the herd resulting from selection over time, reluctance by inspectors to score animals in the extreme categories, or may reflect greater uniformity of animals under OAD milking regimens. The mean values for the linear type traits are similar to those in TAD herds, but where they differ, it is theorized to be as a result of differences in timing of scoring, i.e. ages of animals, stages in the lactation, or different years of analysis. Jerseys generally have lower mean scores for the body type traits than Holstein-Friesians and cross-bred cows. The production and fertility trait averages found are similar to that of other high-producing OAD herds, with lower yields and somatic cell scores, and higher fertility performance than national averages for TAD herds. The variations in yield between breeds are as expected, with Jerseys producing lower milk and protein yields and having shorter lactations by 10 days after adjusting for late calving. There are no differences between breeds in fertility performance in this OAD study.

The phenotypic correlations between different body type traits are positive and strong, and likewise between different udder type traits, however, between the two groups, the phenotypic correlations are weak and negative as found in previous studies. This indicates that the number of body and udder type traits can be reduced but both groups need to be included. The leg trait shows greater correlation with the other type traits in this study compared to previous studies, indicating a more consistent association of highly curved legs in larger animals. Overall, phenotypic correlations among linear type traits in this OAD herd are similar to those of TAD herds, except for larger correlations between body traits or legs with other traits.

The main conclusions from the production and fertility phenotypic correlation and regression analyses are: 1) some cows are able to produce well on OAD milking regimens despite having shorter lactations; 2) somatic cell scores are not affected by overall yield but are higher in older animals and animals with less udder support; 3) greater body type scores are strongly associated with high yield, while higher yielding animals tend to have less desirable udders; 4) the linear type traits generally do not affect lactation length; 5) older animals with higher scores for stature, weight and body condition are submitted earlier and 6) the likelihood of early conception and pregnancy is most dependent on early calving and animals having higher BCS and reduced rump width. Although a positive correlation was found in this study between somatic cell score and body condition, this is hypothesized to be due to higher SCS resulting in yield reductions which lead to higher BCS. Likewise, although undesirable udders are associated with early submission, this is possibly an indirect relationship modulated by their relationship with the body type traits.

The suggestion is therefore put forward that the number of linear type traits to be used in OAD systems can be reduced to include only one or two body type and one or two udder type traits. Based on the results of all correlation and regression analyses between linear type traits, production and fertility, linear type traits to be considered for inclusion in the selection index for OAD milking systems are: stature/weight, udder support/fore udder attachment, body condition score, udder overall, and dairy conformation. Of these, the most suitable are stature and udder support. In general, higher values for these traits would be desirable (and an optima for BCS at various times throughout the season), however a compromise will have to be made relative to improved udder scores, as this is associated with lower yields. Consideration can also be made for the inclusion of rump width as it relates to fertility.

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APPENDIX

Table A.1. Results of normality tests on the linear type trait[1] data

	Traits	Skewness (Raw)	Skewness (Transformed)	Kurtosis (Raw)	Kurtosis (Transformed)	H_0: Normally distributed*
BODY TYPE	S	-0.192	-1.036	-0.956	0.652	<0.01
	W	0.026	-1.636	-0.891	1.064	<0.01
	C	0.133	-0.639	0.278	2.106	<0.01
	RA	0.075	-4.003	1.372	17.34	<0.01
	RW	-0.351	0.055	3.380	2.413	<0.01
	BCS	-0.417	NA	-0.245	NA	<0.01
	L	1.152	1.268	0.618	0.948	<0.01
UDDER TYPE	US	-0.876	-4.437	1.206	30.14	<0.01
	FU	-0.656	-0.395	0.645	0.603	<0.01
	RU	-0.401	-0.085	0.486	0.098	<0.01
	FT	-1.418	-8.357	2.958	90.896	<0.01
	RT	0.534	-0.728	0.682	4.049	<0.01
	UO	-0.746	-3.835	0.479	30.638	<0.01
	DC	-0.641	-0.279	2.290	1.183	<0.01

*The normality tests (Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises and Anderson-Darling) results were identical for both raw and transformed data sets.

[1]Stature (S), Weight (W), Capacity (C), Rear angle (RA), Rear width (RW), Legs (L), Udder support (US), Fore udder (FU), Rear udder (RU), Fore teats (FT), Rear teats (RT), Udder overall (UO), Dairy conformation (DC) and Body condition score (BCS).

Table A.2. Phenotypic correlation amongst all the linear type traits[1] in Holstein-Friesian cows (20 animals) (Bottom numbers are the P-values)

	S	W	C	RA	RW	L	US	FU	RU	FT	RT	UO	DC
W	**0.89812**												
	<.0001												
C	**0.62718**	**0.75139**											
	0.0031	0.0001											
RA	-0.39960	-0.33316	-0.17250										
	0.0809	0.1512	0.4671										
RW	0.41340	0.42786	**0.56430**	0.03783									
	0.0700	0.0598	0.0095	0.8742									
L	-0.20294	-0.06345	-0.04617	**0.61334**	0.03122								
	0.3908	0.7904	0.8467	0.0040	0.8960								
US	0.08991	0.10881	0.20191	-0.18728	0.22487	**-0.48274**							
	0.7062	0.6479	0.3933	0.4291	0.3405	0.0311							
FU	0.13283	0.15737	0.18131	-0.35249	0.10325	**-0.52056**	**0.74046**						
	0.5767	0.5076	0.4443	0.1274	0.6649	0.0186	0.0002						
RU	-0.12830	-0.17828	0.08432	-0.33206	0.05263	**-0.49951**	0.41762	**0.54204**					
	0.5899	0.4521	0.7238	0.1526	0.8256	0.0249	0.0669	0.0136					
FT	0.06091	0.06529	-0.15440	-0.31556	-0.09637	-0.41922	**0.54248**	**0.74046**	0.31054				
	0.7987	0.7845	0.5157	0.1753	0.6861	0.0658	0.0135	0.0002	0.1827				
RT	-0.29936	-0.24959	-0.27891	-0.29843	-0.40351	-0.43707	0.33195	0.31834	0.11111	0.43904			
	0.1998	0.2886	0.2337	0.2012	0.0777	0.0540	0.1528	0.1713	0.6410	0.0528			
UO	0.10863	0.13586	0.23067	-0.28829	0.28968	**-0.56835**	**0.91578**	**0.79773**	**0.63877**	**0.59843**	0.17826		
	0.6485	0.5679	0.3278	0.2177	0.2154	0.0089	<.0001	<.0001	0.0024	0.0053	0.4521		
DC	0.05797	0.11864	0.22302	0.31236	0.40863	0.04617	-0.08314	0.00954	-0.14918	-0.20191	-0.04540	-0.06591	
	0.8082	0.6184	0.3446	0.1800	0.0736	0.8467	0.7275	0.9681	0.5302	0.3933	0.8493	0.7825	
BCS	0.06091	0.19587	0.32068	0.30017	**0.54612**	-0.03811	0.28105	-0.04726	-0.11779	-0.17647	0.01071	0.19041	**0.51071**
	0.7987	0.4079	0.1680	0.1985	0.0127	0.8733	0.2300	0.8431	0.6209	0.4567	0.9643	0.4213	0.0214

[1]Stature (S), Weight (W), Capacity (C), Rear angle (RA), Rear width (RW), Legs (L), Udder support (US), Fore udder (FU), Rear udder (RU), Fore teats (FT), Rear teats (RT), Udder overall (UO), Dairy conformation (DC) Body condition score (BCS) Bottom numbers are P-values and values in bold indicate significant correlations (P<0.05)

Table A.3. Phenotypic correlation amongst all the linear type traits in Jersey cows (20 animals)

	S	W	C	RA	RW	L	US	FU	RU	FT	RT	UO	DC
W	**0.88615**												
	<.0001												
C	0.15891	0.17703											
	0.5034	0.4553											
RA	-0.21369	-0.20559	-0.27845										
	0.3657	0.3845	0.2345										
RW	0.00000	0.02085	-0.27477	0.34310									
	1.0000	0.9305	0.2410	0.1386									
L	0.00000	0.05338	0.30151	-0.24777	-0.04340								
	1.0000	0.8232	0.1964	0.2922	0.8558								
US	0.00000	0.11566	-0.37508	-0.00813	-0.01567	-0.44141							
	1.0000	0.6273	0.1032	0.9728	0.9477	0.0514							
FU	0.00000	0.05223	-0.29503	-0.02204	-0.04246	-0.10872	0.43192						
	1.0000	0.8269	0.2067	0.9265	0.8589	0.6482	0.0572						
RU	-0.14199	-0.05752	-0.41517	0.08496	-0.07015	-0.17961	**0.80001**	**0.52723**					
	0.5504	0.8097	0.0687	0.7218	0.7689	0.4486	<.0001	0.0169					
FT	0.44281	0.38118	0.32369	**-0.53935**	-0.30991	-0.32673	0.05057	-0.04567	-0.27665				
	0.0506	0.0973	0.1639	0.0141	0.1836	0.1597	0.8323	0.8484	0.2377				
RT	0.44042	0.32709	-0.01866	-0.26351	-0.02418	-0.06190	0.08942	0.06057	-0.10006	**0.59806**			
	0.0520	0.1592	0.9378	0.2616	0.9194	0.7954	0.7077	0.7998	0.6747	0.0053			
UO	-0.09535	0.04828	-0.27273	-0.10187	-0.19627	-0.30151	**0.90744**	**0.53105**	**0.92060**	-0.04222	-0.05599		
	0.6893	0.8398	0.2447	0.6691	0.4069	0.1964	<.0001	0.0160	<.0001	0.8597	0.8146		
DC	0.00000	0.03307	-0.15914	**0.73036**	0.33162	-0.29832	0.05801	0.02245	-0.11128	-0.10604	0.08949	-0.14530	
	1.0000	0.8899	0.5028	0.0003	0.1532	0.2014	0.8080	0.9251	0.6404	0.6564	0.7075	0.5411	
BCS	0.39528	0.32026	0.30151	-0.13515	0.06509	0.16667	-0.09029	**0.48925**	0.04490	0.14003	0.09285	0.00000	-0.06884
	0.0845	0.1686	0.1964	0.5700	0.7851	0.4825	0.7050	0.0286	0.8509	0.5560	0.6970	1.0000	0.7730

[1]Stature (S), Weight (W), Capacity (C), Rear angle (RA), Rear width (RW), Legs (L), Udder support (US), Fore udder (FU), Rear udder (RU), Fore teats (FT), Rear teats (RT), Udder overall (UO), Dairy conformation (DC) Body condition score (BCS) Bottom numbers are P-values and values in bold indicate significant correlations ($P<0.05$)

Table A.4. Phenotypic correlation amongst all the linear type traits in crossbred cows (36 animals)

	S	W	C	RA	RW	L	US	FU	RU	FT	RT	UO	DC
W	**0.83280**												
	<.0001												
C	0.24921	**0.41672**											
	0.1427	0.0115											
RA	-0.11709	-0.16520	0.04250										
	0.4965	0.3356	0.8056										
RW	0.27241	**0.37524**	0.11686	0.13093									
	0.1080	0.0241	0.4973	0.4466									
L	0.03003	0.02395	**-0.48184**	0.05293	0.09701								
	0.8620	0.8897	0.0029	0.7592	0.5735								
US	-0.03228	0.01692	0.15754	-0.11214	0.04022	**-0.69908**							
	0.8518	0.9220	0.3588	0.5149	0.8158	<.0001							
FU	-0.01566	0.06771	0.06924	-0.29200	-0.03595	**-0.39236**	**0.65644**						
	0.9278	0.6948	0.6882	0.0840	0.8351	0.0179	<.0001						
RU	0.11541	0.13693	0.15674	-0.28276	-0.12276	**-0.34736**	**0.61411**	**0.57889**					
	0.5027	0.4258	0.3613	0.0947	0.4757	0.0379	<.0001	0.0002					
FT	-0.09202	-0.03669	-0.03800	0.06082	0.08361	**-0.35486**	**0.61960**	0.29779	**0.38964**				
	0.5935	0.8317	0.8259	0.7246	0.6278	0.0337	<.0001	0.0777	0.0188				
RT	-0.20691	-0.09706	-0.09190	-0.22522	0.14744	-0.17880	**0.42828**	0.20024	**0.38211**	**0.62664**			
	0.2260	0.5733	0.5940	0.1866	0.3908	0.2968	0.0092	0.2416	0.0215	<.0001			
UO	-0.06820	-0.01813	0.10728	-0.22703	-0.03672	**-0.60856**	**0.90660**	**0.83970**	**0.68867**	**0.61401**	**0.45117**		
	0.6927	0.9164	0.5334	0.1830	0.8316	<.0001	<.0001	<.0001	<.0001	<.0001	0.0057		
DC	0.11266	0.23829	0.27276	0.05180	-0.07121	-0.17270	0.20949	0.23939	0.06475	0.00827	-0.22748	0.15252	
	0.5130	0.1617	0.1075	0.7642	0.6798	0.3138	0.2201	0.1597	0.7075	0.9618	0.1821	0.3745	
BCS	0.14560	0.27221	**0.46182**	0.16406	0.10410	-0.21039	0.27782	0.06353	0.05127	0.05641	-0.11938	0.13803	0.21276
	0.3968	0.1083	0.0046	0.3390	0.5457	0.2181	0.1009	0.7128	0.7665	0.7438	0.4880	0.4221	0.2128

[1]Stature (S), Weight (W), Capacity (C), Rear angle (RA), Rear width (RW), Legs (L), Udder support (US), Fore udder (FU), Rear udder (RU), Fore teats (FT), Rear teats (RT), Udder overall (UO), Dairy conformation (DC) Body condition score (BCS) Bottom numbers are P-values and values in bold indicate significant correlations (P<0.05)

Tables A.5. Phenotypic correlation between production and fertility traits in Holstein-Friesian, Jersey and Crossbred cows

a. Holstein-Friesian

	Calv Dev	LL	Parity	MY	FY	PY	SCS
SBFS	-0.09093	-0.12355	**-0.46621**	0.14824	-0.35658	-0.00972	-0.06001
	0.7030	0.6038	0.0383	0.5328	0.1228	0.9675	0.8016
SBCO	0.34786	-0.22372	-0.35724	-0.06011	-0.16433	-0.08420	0.17567
	0.1445	0.3572	0.1332	0.8069	0.5014	0.7318	0.4719
S21*	-	-	-	-	-	-	-
S42*	-	-	-	-	-	-	-
C21	-0.31240	0.09182	0.02425	-0.10748	-0.16128	-0.15833	-0.31015
	0.1799	0.7002	0.9192	0.6520	0.4970	0.5050	0.1833
C42	-0.15344	-0.00199	-0.11111	-0.11019	-0.35911	-0.11467	0.14442
	0.5184	0.9933	0.6410	0.6437	0.1199	0.6302	0.5435
Pregnant	0.12650	-0.18437	-0.33138	**-0.48019**	**-0.53959**	**-0.46372**	0.10916
	0.5951	0.4365	0.1535	0.0321	0.0141	0.0395	0.6469

SBFS:- interval from start of breeding to first service; SBCO:- interval from start of breeding to conception; S21, S42, C21, C42:- submission and conception to 21 and 42 days. Lactation length (LL), Milk yield (MY), Fat yield (FY), Protein yield (PY), Somatic cell score (SCS), Calving deviation (Calv Dev)

Bottom numbers are P-values and values in bold indicate significant correlations (P<0.05)

*Missing data indicate inability to compute correlations since 100% submission rates noted

b. Jersey

	Calv Dev	LL	Parity	MY	FY	PY	SCS
SBFS	-0.32056	**0.51928**	-0.06917	**0.50920**	0.37095	**0.45654**	-0.30238
	0.1682	0.0190	0.7720	0.0218	0.1074	0.0430	0.1950
SBCO	**0.52888**	-0.36259	-0.42286	-0.18071	-0.13549	-0.16145	0.14979
	0.0240	0.1392	0.0804	0.4730	0.5919	0.5222	0.5530
S21*	-	-	-	-	-	-	-
S42*	-	-	-	-	-	-	-
C21	**-0.58008**	0.35641	**0.49707**	-0.15888	-0.11946	0.00211	0.17158
	0.0073	0.1230	0.0258	0.5035	0.6159	0.9930	0.4695
C42	**-0.58662**	**0.51232**	0.41762	-0.17503	-0.14347	-0.06387	0.31703
	0.0066	0.0209	0.0669	0.4605	0.5462	0.7891	0.1732
Pregnant	-0.32455	0.18130	0.33138	**-0.45807**	-0.34446	-0.27627	**0.48294**
	0.1627	0.4443	0.1535	0.0422	0.1370	0.2384	0.0310

SBFS:- interval from start of breeding to first service; SBCO:- interval from start of breeding to conception; S21, S42, C21, C42:- submission and conception to 21 and 42 days. Lactation length (LL), Milk yield (MY), Fat yield (FY), Protein yield (PY), Somatic cell score (SCS), Calving deviation (Calv Dev)

Bottom numbers are P-values and values in bold indicate significant correlations (P<0.05)

*Missing data indicate inability to compute correlations since 100% submission rates noted

c. Crossbred

	Calv Dev	LL	Parity	MY	FY	PY	SCS
SBFS	-0.01781	-0.05401	-0.12209	-0.09493	-0.02538	-0.06709	-0.12244
	0.9179	0.7544	0.4781	0.5818	0.8832	0.6975	0.4768
SBCO	0.14698	-0.11633	-0.19712	-0.05505	-0.10859	-0.10536	0.03798
	0.4068	0.5124	0.2638	0.7571	0.5410	0.5532	0.8311
S21	-0.18559	0.16002	0.00588	0.22046	0.19765	0.14585	-0.09823
	0.2785	0.3512	0.9729	0.1963	0.2479	0.3960	0.5687
S42*	-	-	-	-	-	-	-
C21	-0.14210	0.18178	0.24104	0.09875	0.23304	0.16707	-0.03117
	0.4084	0.2887	0.1567	0.5666	0.1714	0.3301	0.8568
C42	-0.30704	0.31048	-0.06506	-0.01886	0.18722	0.09837	0.03218
	0.0685	0.0653	0.7062	0.9131	0.2742	0.5682	0.8522
Pregnant	-0.29169	**0.49291**	0.00843	0.00689	0.32620	0.16859	0.02613
	0.0843	0.0023	0.9611	0.9682	0.0522	0.3257	0.8798

SBFS:- interval from start of breeding to first service; SBCO:- interval from start of breeding to conception; S21, S42, C21, C42:- submission and conception to 21 and 42 days. Lactation length (LL), Milk yield (MY), Fat yield (FY), Protein yield (PY), Somatic cell score (SCS), Calving deviation (Calv Dev)

Bottom numbers are P-values and values in bold indicate significant correlations ($P<0.05$)

*Missing data indicate inability to compute correlations since 100% submission rates noted

Table A.6. Phenotypic correlation between linear type[1] and production[2] traits in Holstein-Friesian cows

	LL	Parity	MY	FY	PY	SCS	Calv Dev
S	0.11487	**0.53162**	0.14109	**0.51224**	0.17634	-0.04333	-0.11033
	0.6296	0.0158	0.5530	0.0209	0.4571	0.8561	0.6433
W	0.13668	**0.51806**	0.10370	0.39903	0.17468	-0.04035	-0.12500
	0.5656	0.0193	0.6635	0.0814	0.4614	0.8659	0.5995
C	-0.06309	**0.63143**	-0.13539	0.27791	-0.09708	0.00903	0.12829
	0.7916	0.0028	0.5693	0.2355	0.6839	0.9699	0.5899
RA	0.07004	-0.12825	0.11778	-0.26848	0.07658	0.01132	0.12317
	0.7692	0.5900	0.6209	0.2524	0.7483	0.9622	0.6049
RW	0.28228	0.43334	0.03545	**0.52929**	0.13644	0.03109	-0.31450
	0.2279	0.0563	0.8821	0.0164	0.5662	0.8965	0.1769
L	-0.04668	0.04536	0.36067	-0.15286	**0.45395**	-0.19039	0.11083
	0.8451	0.8494	0.1182	0.5200	0.0444	0.4214	0.6418
US	0.30000	-0.03630	-0.17580	-0.01345	-0.13314	**-0.46033**	-0.22171
	0.1988	0.8792	0.4585	0.9551	0.5758	0.0411	0.3475
FU	0.40319	-0.03750	-0.05477	0.16547	-0.07147	-0.15216	-0.35628
	0.0779	0.8753	0.8186	0.4857	0.7646	0.5219	0.1231
RU	-0.07488	-0.26340	-0.31680	-0.13829	**-0.46318**	0.01287	0.03598
	0.7537	0.2618	0.1735	0.5609	0.0397	0.9571	0.8803
FT	**0.55598**	-0.29561	0.20070	0.22229	0.17014	-0.39184	**-0.51213**
	0.0109	0.2057	0.3962	0.3462	0.4733	0.0875	0.0210
RT	0.15570	-0.24641	-0.19362	-0.32322	-0.17785	-0.14538	-0.01277
	0.5121	0.2950	0.4134	0.1645	0.4532	0.5408	0.9574
UO	0.24289	-0.11871	-0.15837	0.06721	-0.21456	-0.35264	-0.25648
	0.3021	0.6181	0.5049	0.7783	0.3637	0.1273	0.2750
DC	0.09861	0.31100	0.29401	0.12953	0.16006	0.38401	0.05192
	0.6791	0.1820	0.2083	0.5862	0.5002	0.0946	0.8279
BCS	0.11477	0.01556	-0.31595	-0.01104	-0.16973	0.11538	0.02621
	0.6299	0.9481	0.1748	0.9632	0.4744	0.6281	0.9127

[1]Stature (S), Weight (W), Capacity (C), Rear angle (RA), Rear width (RW), Legs (L), Udder support (US), Fore udder (FU), Rear udder (RU), Fore teats (FT), Rear teats (RT), Udder overall (UO), Dairy conformation (DC), Body condition score (BCS) [2]Lactation length (LL), Milk yield (MY), Fat yield (FY), Protein yield (PY), Somatic cell score (SCS), Calving deviation (Calv Dev)

Bottom numbers are P-values and values in bold indicate significant correlations ($P<0.05$)

Table A.7. Phenotypic correlation between linear type[1] and production[2] traits in Jersey cows

	LL	Parity	MY	FY	PY	SCS	Calv Dev
S	0.14956	0.36274	0.08844	-0.14225	-0.02456	0.13214	-0.27722
	0.5291	0.1160	0.7108	0.5497	0.9181	0.5786	0.2367
W	0.14660	0.28164	0.16437	-0.18311	0.09772	0.04736	-0.14993
	0.5374	0.2290	0.4886	0.4397	0.6819	0.8428	0.5281
C	-0.05466	**0.66866**	-0.04313	-0.18865	-0.09339	0.02435	0.19533
	0.8189	0.0013	0.8567	0.4257	0.6953	0.9188	0.4092
RA	-0.06415	-0.27388	-0.01250	-0.08120	-0.07542	0.19159	0.27754
	0.7882	0.2426	0.9583	0.7336	0.7520	0.4184	0.2361
RW	-0.28192	**-0.52766**	-0.13070	-0.21287	-0.18851	-0.21350	0.01020
	0.2285	0.0168	0.5828	0.3675	0.4261	0.3661	0.9660
L	-0.13626	0.17843	0.17736	-0.02264	0.16843	-0.08776	-0.04850
	0.5668	0.4516	0.4544	0.9245	0.4778	0.7129	0.8391
US	0.36156	-0.21174	-0.17035	-0.19294	-0.19699	-0.20647	-0.02650
	0.1173	0.3702	0.4727	0.4151	0.4052	0.3825	0.9117
FU	0.21928	-0.02494	-0.11863	-0.23937	-0.03784	0.17542	-0.18373
	0.3530	0.9169	0.6184	0.3094	0.8741	0.4594	0.4381
RU	0.30763	-0.39831	-0.29717	-0.27059	-0.27413	-0.11146	0.00201
	0.1870	0.0820	0.2032	0.2485	0.2422	0.6399	0.9933
FT	0.35148	0.41762	0.08096	0.16342	0.15664	-0.10132	-0.40901
	0.1286	0.0669	0.7344	0.4912	0.5096	0.6708	0.0733
RT	0.22521	0.24141	0.16540	0.17908	0.15855	-0.25977	**-0.57427**
	0.3397	0.3052	0.4859	0.4500	0.5044	0.2687	0.0081
UO	0.34123	-0.20751	-0.23217	-0.22851	-0.19428	-0.13826	0.00562
	0.1409	0.3800	0.3246	0.3325	0.4118	0.5610	0.9812
DC	0.12954	-0.10003	**0.45929**	0.31950	0.30027	0.04171	0.11890
	0.5862	0.6748	0.0416	0.1697	0.1983	0.8614	0.6176
BCS	0.02703	0.30589	-0.32873	**-0.51210**	-0.37813	0.36314	-0.21637
	0.9099	0.1897	0.1570	0.0210	0.1002	0.1156	0.3595

[1]Stature (S), Weight (W), Capacity (C), Rear angle (RA), Rear width (RW), Legs (L), Udder support (US), Fore udder (FU), Rear udder (RU), Fore teats (FT), Rear teats (RT), Udder overall (UO), Dairy conformation (DC) Body condition score (BCS) [2]Lactation length (LL), Milk yield (MY), Fat yield (FY), Protein yield (PY), Somatic cell score (SCS), Calving deviation (Calv Dev)

Bottom numbers are P-values and values in bold indicate significant correlations (P<0.05)

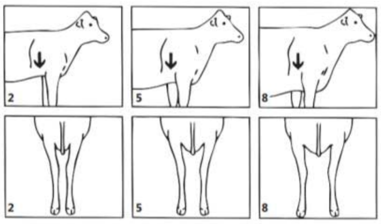
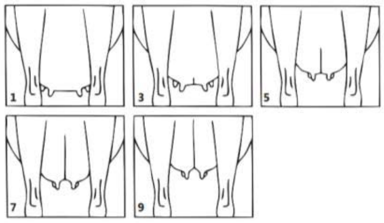
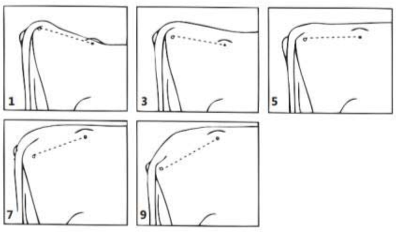
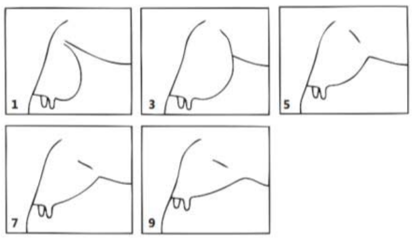
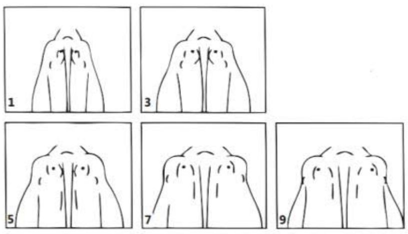
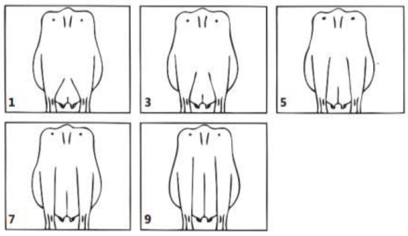
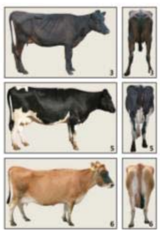
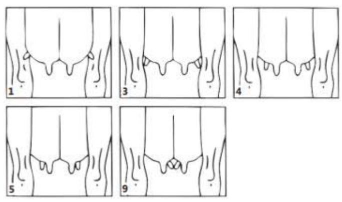
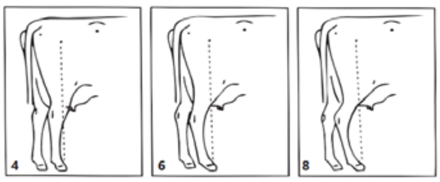
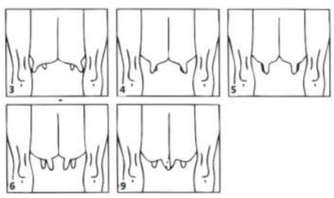
Table A.8. Phenotypic correlation between linear type[1] and production[2] traits in crossbred cows

	LL	Parity	MY	FY	PY	SCS	Calv Dev
S	0.02961	0.03783	**0.42122**	0.15955	**0.37211**	-0.01081	0.06347
	0.8659	0.8292	0.0117	0.3599	0.0277	0.9509	0.7172
W	0.22947	0.15209	**0.34666**	0.16038	0.32448	0.06915	-0.14884
	0.1848	0.3831	0.0413	0.3574	0.0572	0.6930	0.3935
C	0.27573	-0.12156	-0.03722	0.01657	0.07848	-0.07247	-0.19959
	0.1089	0.4866	0.8319	0.9247	0.6540	0.6791	0.2503
RA	0.09018	-0.21738	-0.18496	-0.02818	-0.04945	-0.06690	-0.09453
	0.6064	0.2097	0.2875	0.8723	0.7779	0.7026	0.5891
RW	0.19309	-0.08717	0.06665	-0.03291	0.08743	-0.00320	-0.16968
	0.2664	0.6185	0.7036	0.8511	0.6175	0.9854	0.3298
L	0.12563	0.10597	0.28755	**0.39093**	0.30193	-0.07398	-0.14430
	0.4721	0.5446	0.0939	0.0202	0.0779	0.6728	0.4082
US	-0.07910	-0.15404	-0.32250	**-0.49005**	**-0.38115**	0.10492	0.00518
	0.6515	0.3770	0.0588	0.0028	0.0239	0.5486	0.9764
FU	-0.03982	0.19595	-0.17099	-0.23788	-0.17597	-0.01633	0.03231
	0.8203	0.2593	0.3260	0.1688	0.3119	0.9258	0.8538
RU	0.00366	-0.16995	-0.07635	-0.11985	-0.16431	**0.38558**	-0.05949
	0.9834	0.3290	0.6629	0.4929	0.3456	0.0222	0.7343
FT	0.06775	-0.00385	-0.14294	-0.27111	-0.19004	0.16676	-0.29257
	0.6990	0.9825	0.4127	0.1152	0.2742	0.3383	0.0881
RT	-0.10090	0.16770	-0.12546	-0.32116	-0.25887	0.24204	-0.06277
	0.5641	0.3356	0.4727	0.0599	0.1332	0.1613	0.7202
UO	-0.06439	-0.03829	-0.25846	**-0.40243**	-0.30123	0.06709	-0.03117
	0.7133	0.8271	0.1338	0.0165	0.0787	0.7018	0.8589
DC	0.32169	0.09643	0.24779	0.17915	0.29797	-0.02754	-0.25944
	0.0595	0.5816	0.1512	0.3031	0.0821	0.8752	0.1323
BCS	0.26628	-0.05304	**-0.44340**	**-0.33517**	**-0.36535**	0.00559	-0.21046
	0.1221	0.7622	0.0076	0.0490	0.0309	0.9746	0.2249

[1]Stature (S), Weight (W), Capacity (C), Rear angle (RA), Rear width (RW), Legs (L), Udder support (US), Fore udder (FU), Rear udder (RU), Fore teats (FT), Rear teats (RT), Udder overall (UO), Dairy conformation (DC) Body condition score (BCS) [2]Lactation length (LL), Milk yield (MY), Fat yield (FY), Protein yield (PY), Somatic cell score (SCS), Calving deviation (Calv Dev)

Bottom numbers are P-values and values in bold indicate significant correlations ($P<0.05$)

Appendix Diagram A.1. Diagrammatic illustration of selected linear type traits measured in New Zealand dairy herds. Adapted from Advisory Committee on TOP, 2011

CAPACITY  frail → intermediate → capacious	**UDDER SUPPORT**  Weak →→ Strong
RUMP ANGLE  Pins high (1)→ level (5)→Pins low (9)	**FORE UDDER ATTACHMENT**  Loose →→ Strong
RUMP WIDTH  Narrow (1)→Intermediate (5)→ Wide (9)	**REAR UDDER ATTACHMENT**  Low →→ High
BODY CONDITION SCORE 	**FRONT TEAT PLACEMENT**  Wide →→Close
LEGS  Straight legs→ Sickle/curved	**REAR TEAT PLACEMENT**  Wide →→ Close