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# **A Genetic and Economic Evaluation of Lactose in the New Zealand Dairy Industry**

A thesis presented in partial fulfilment of the requirements

for the degree of

**Doctor of Philosophy**

in

Animal Science



**Nicholas William Sneddon**

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## **Abstract**

**Sneddon (2016). A Genetic and Economic Evaluation of Lactose in the New Zealand Dairy Industry.**

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Milk composition in New Zealand is heavily influenced by the selection for Breeding Worth (BW) and the breed composition of the national herd. Under selection for BW a greater emphasis is placed upon protein (39% of emphasis) than fat yield (13% of emphasis) with a penalty on milk volume (14% of emphasis). The export orientated product portfolio influences the development of economic values for fat and protein in the BW, to date lactose has not been considered despite its importance in the manufacture of whole milk powder (WMP). The milk produced on farm is in deficit for lactose based on the current export product portfolio. This thesis evaluated the potential of altering New Zealand milk through the modification of the selection objective around milk lactose selection. Genetic parameters were estimated including lactose yield to construct selection objectives and indices to evaluate the effect on lactose production under a number of different product portfolio scenarios. Genetic parameters were estimated from daily and total milk records with moderate heritabilities found for both lactose yield and lactose content. The genetic correlations between lactose yield and milk volume was estimated to be 0.98, which is a potential problem as this correlation effectively gives lactose a negative economic value due to the negative value on milk volume. Using an existing industry milk processing model, the lactose deficit was estimated to be 129,000 tonnes in 2012 which is consistent with industry records. A genetic gains model developed from this thesis, combined with an existing industry model estimated that the deficit in lactose would increase by 60%, to 204,000 tonnes by

2022 if no changes were made to the current selection objective and index. Including lactose yield in the selection objective with an economic value of \$2.04, 14.7% relative emphasis within the objective, would reduce the lactose deficit by 8.7% to 194,000 tonnes. Overall the results of this thesis indicate that including lactose yield in the selection objective has the potential to modify the composition of milk to make it more suitable for the production of WMP and increase the potential for profit in the industry.

## **Declarations**

This thesis contains no material that has been accepted for a degree or diploma by the University or any other institution. To the best of my knowledge no material previously published or written by another person has been used, except where due acknowledgement has been made in text.

This thesis has been written with chapters formatted as papers for publication. Therefore there is some repetition of chapter introductions or methods, each chapter contains a full discussion, with the final general discussion chapter providing a succinct discussion of key findings of this thesis. Each chapter has been formatted for the New Zealand Journal of Agricultural Science and each has a complete list of references. The submitted manuscripts include supervisors as co-authors, however, for each chapter I planned the study, undertook the analysis and wrote the manuscripts with directions of those co-authors.

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“The presence of those seeking the truth is infinitely to be preferred to the presence of those who think they've found it.”

Sir Terry Pratchett, *Monstrous Regiment*

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## List of Abbreviations

P:P+L = Protein-to-protein-plus-lactose ratio  
P:F = Protein-to-fat ratio  
TMY = Total lactation milk yield  
MY = Daily milk yield  
TFY = Total lactation fat yield  
FY = Daily fat yield  
TPY = Total lactation protein yield  
PY = Daily protein yield  
TLY = Total lactation lactose yield  
LY = Daily lactose yield  
MS = Milk solids  
MSY = Milk solids yield  
FP = Fat percentage  
PP = Protein percentage  
LP = Lactose percentage  
SCS = Somatic cell score calculated as  $\text{Log}_2(\text{somatic cell count})$   
DIM = Days in milk  
F = Holstein-Friesian  
J = Jersey  
OT = Other breeds (Ayrshire, Brown Swiss, Guernsey, Milking Shorthorn.)  
FxJ = Holstein-FriesianxJersey crossbred cows  
BW = Breeding Worth  
EBV = Estimated breeding values  
WMP = Whole milk powder  
SMP = Skim milk powder  
WP = Whey powder  
BMP = Butter milk powder  
MPC(90) = Milk protein concentrate (90% protein)  
MPSM = Moorepark processing sector model  
DM = Dry matter

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## **Chapter 1**

### **General introduction**



Currently the export product portfolio of the New Zealand dairy industry is in a state of lactose deficit (Fonterra 2014). This is caused by two factors, the high concentration of protein, relative to lactose, in the milk of New Zealand dairy cows (LIC & DairyNZ 2014; Sneddon et al. 2014) and the high proportion of milk used for whole milk powder (WMP) (Fonterra 2014). The standardisation of milk for particular products requires the three main milk components (fat, protein and lactose) to meet specified levels. In the production of WMP, the minimum standard is 26.5% fat, 25.1% protein and 39.8% lactose (Garrick & Lopez-Villalobos 2000; Geary et al. 2010; codex standard 207-1999 WHO & FAO 2011). However, if the milk from the average New Zealand cow was manufactured without standardisation, the WMP produced would have a composition of 36.9% fat, 28.3% protein and 34.8% lactose, which is higher in fat and protein but lower in lactose than standard (Sneddon et al. 2014). The current Fonterra strategy is to purchase lactose to fill this lactose deficit to fully utilise the available protein. This has been a preferred strategy, compared with the alternative, which is removal of excess fat and protein from WMP to produce butter and milk protein concentrates.

A balance between the composition of the milk supplied and the composition required for the product mix, minimises the cost of milk standardization using separation and ultrafiltration while at the same time minimising the requirement for ingredient purchase to maximise the value of milk.

In the 2013-2014 dairy season the lactose deficit was around 310,000 tonnes per year (Fonterra 2014), however, this includes lactose ‘purchased’ from within Fonterra’s own processing system. After accounting for the internal transfer from the manufacturing of other products, the deficit was estimated to be around 150,000 tonnes in 2010 (Sneddon

et al. 2014). This deficit is dependent on the lactose concentration in the milk, but lactose percentage is not published or publically available for milk collected in New Zealand.

The breed composition of the national herd has a large influence on milk composition. However, in New Zealand there is no direct control of the breed composition of the herd because each farmer has individual breed preferences and breeding goals. Crossbred cows increased from 19% of the national herd in 1997-1998 dairy season to 42.6% of the national herd in the 2013-2014 dairy season (LIC 1999; LIC & DairyNZ 2014) as farmers have identified the potential of the crossbred cow to convert pasture to profit (Lopez-Villalobos et al. 2000).

The selection objective of the New Zealand dairy industry is created with the aim to improve the genetic capability of a cow to convert feed into profit. To achieve this objective, a selection index called breeding worth (BW) was developed to express predicted profit per 5 tonnes of dry matter. Breeding Worth is calculated as:

$$BW = \sum_{i=1}^7 EBV_i \times EV_i$$

Where  $EBV_i$  is the estimate breeding value for trait  $i$  and  $EV_i$  is the corresponding economic value. The traits considered in BW are lactation yields of milk, fat and protein, mature live weight, fertility, somatic cell score calculated as  $\text{Log}_2(\text{somatic cell count})$  and residual survival. The economic values in 2015 were  $-\$0.097/\text{L}$  for milk volume,  $\$1.81/\text{kg}$  for fat,  $\$8.18/\text{kg}$  for protein,  $-\$1.63/\text{kg}$  for mature live weight,  $\$7.23/\%$  for fertility,  $-\$38.61/\text{unit}$  for SCS and  $\$0.140/\text{day}$  for residual survival. In 2013

protein received a relative emphasis of 39.3% of the index (NZAEL 2013). The negative weighting placed upon milk volume (14.5% of relative emphasis) and the positive value on fat (12.3% of relative emphasis) and protein (NZAEL 2013; 2015) creates the expectation of increasing the concentrations of protein and fat in milk, with protein expected to increase at a greater rate than fat. Milk volume and lactose yield have a high genetic correlation (0.92-0.98; Welper & Freeman 1992; Johnson et al. 2000; Miglior et al. 2007), meaning that lactose yield is being restricted relative to increasing fat and protein yields. The high genetic correlation effectively creates an implied weighting placed on lactose yield that is the same as that placed upon milk volume.

Lactose is one of the three major components of milk, along with fat and protein. It is a disaccharide of glucose and galactose produced in the epithelial cells lining the mammary alveoli. Lactose has never been included in the selection objective; however, the herd-testing procedure which records milk, fat and protein yields has the capability to also record lactose. Nationally, milk lactose content is recorded during the herd-testing although the data are not always returned to the farmer. Nevertheless, from these records, genetic parameters may be estimated and breeding values developed making it feasible to include lactose in the selection objective.

The economic values used in the BW are based upon a product mix given by the Fonterra co-operative in the production of the farm gate milk price (Fonterra 2014). However, the farm gate milk prices for fat, protein and milk volume are determined from only the values of WMP, SMP, butter and anhydrous milkfat and excludes cheese and casein (as the other two main milk products). Despite its importance in the

production of WMP and SMP, lactose has not been included into a payment system or the selection objective.

There is currently no publication of lactose concentrations within the milk of New Zealand cows. Furthermore, no studies have investigated the future size of the lactose deficit. Therefore, the general objective of this thesis was to evaluate the possibility of changing the composition of milk in New Zealand to better suit the expected product mix through the modification of the selection objective. To meet this goal, four specific objectives were developed:

- 1 To produce genetic parameter estimations for yields of milk, fat, protein and lactose and fat, protein and lactose percentages and the ratio of protein-to-protein-plus-lactose (P:P+L).
- 2 To quantify the current lactose deficit in terms of both financial and physical size.
- 3 To produce estimates of the lactose deficit in terms of financial and physical size for a range of future product portfolios and future projections of milk, fat, protein and lactose production.
- 4 To incorporate lactose yield, percentage or P:P+L into a selection objective and investigate the effects of these changes on the lactose deficit and industry income after 10 years of selection.

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## **Chapter 2**

### **Literature review**

Published in part in: Sneddon NW, Lopez-Villalobos N, Hickson RE, Shalloo L 2013.

Review of milk payment systems to identify the component value of lactose.

Proceedings of the New Zealand Society of Animal Production 73: 33-36.



## **Introduction**

The concentrations of lactose (LP), fat (FP) and protein (PP) in bovine milk vary with animal, breed and diet. In general, Holstein-Friesian (F) cattle have lower component concentrations relative to other dairy breeds, notably Jersey (J) cattle (Erb & Ashworth 1963; Olori et al. 1997; Roman et al. 2000; Miglior et al. 2007; Wickramasinghe et al. 2011; Loker et al. 2012).

Feed types and composition have the potential to alter the composition of milk (FP, PP and LP). However, the degree of change in FP and PP is usually larger than the change in LP (Davidson et al. 1990; Tesfa et al. 1995). Cow age and health are also important influences on the composition of milk, with older cows or mastitic cows having a tendency towards a lower LP in the milk (Welper & Freeman 1992; Auldist et al. 1995; Oliszewski et al. 2002; Migilor et al. 2007; Bleck et al. 2009; Hossein-Zadeh & Ardalan 2011; Hussain et al. 2012; Malek dos Reis et al. 2013).

Many studies have reported the estimation of genetic parameters for daily or total lactation milk, fat and protein yields, FP, PP and somatic cell score (Spelman & Garrick 1997; Roman et al. 1999; 2000; Johnson et al. 2000; Pryce & Harris 2006, Miglior et al. 2007; Stoop et al. 2008; Battagin et al. 2013). There is, however, a lack of data regarding genetic parameters for lactose yield, LP and the ratios between milk components. The scarcity of these estimations may be due, in part, to a relatively low value for lactose.

Lactose percentage has the least genetic and phenotypic variation, FP the greatest and PP intermediate between the two (Vos & Groen 1998; Roman et al. 2000; Sneddon et

al. 2012). With this small amount of genetic variation in LP, genetic gain will be limited and it appears that the variation within breed is greater than the variation among different breeds. Lactose was traditionally considered as a waste product in milk processing which had little value. However advances in processing now present opportunities to transfer lactose and other milk components from one area of processing to another which create opportunities around maximising processing efficiency.

Milk from New Zealand's dairy herd in the year 2012-2013 had a composition of 4.77% fat, 3.80% protein and 4.76% lactose (LIC & DairyNZ 2013). This milk, if processed directly into whole milk powder (WMP), without standardisation with lactose, would produce WMP with a composition of 35.7% fat, 28.5% protein and 35.7% lactose. This does not comply to the required international standard with a composition of 26.5% fat, 25.1% protein and 39.8% lactose (Geary et al. 2010). In order to standardise this milk, either lactose must be added or fat and protein must be removed through separation and ultra-filtration. This adds costs to the overall processing, reduces product yield and reduces milk value. The alternative situation knowing the deficit in lactose exists when producing WMP to the international standards previously mentioned would be to produce a WMP with greater fat and protein content. This milk powder while not strictly WMP could meet minimum requirements or charge a premium for a milk with a greater protein content.

New Zealand's export profile for milk products is dominated by milk powders (Fonterra 2014). The milk components associated with New Zealand milk creates a situation where either, both milk protein and fat must be removed from milk or lactose added in order to balance the milk to meet international powder standards. New Zealand milk has

high PP and FP leading to differences in the component ratios between the raw and final products. The price of lactose for import is set by an international auction of milk products, in the same manner as milk fat, protein and various milk products. This system has seen lactose go from a value of around US\$700/t in 2007 to US\$2000/t in October 2012 (Global Dairy Trade 2012). However, these auctions do not appear to set the price for lactose used in the pharmaceutical industry.

Therefore, the shift in focus in New Zealand's export dairy product mix towards the production of WMP has resulted in a deficit in milk lactose across the overall industry. Currently the deficit in lactose is filled using imported lactose. The cost of importing lactose has been reported to be NZ\$ 300 million per year (Fonterra 2011). The importation of lactose into New Zealand may not be sustainable in the long term in relation to the value of WMP and the cost importing lactose and other strategies to reduce the deficit of lactose within New Zealand need be explored. Farmers will respond to signals through milk payments by feeding and breeding, if there is an economic benefit from doing so.

Milk payment strategies differ across the world as the markets, product portfolios, consumer and farmer preferences change. These can be from single-component pricing systems such as per litre of milk (Australia, Denmark), per kilogram (kg) of milk solids (MS) (fat + protein) (New Zealand; Fonterra) or per kg of total milk solids (TMS) (fat + protein + lactose + minerals) (New Zealand; Synlait), to multiple-component pricing systems (MCP) (Ireland, Netherlands, UK, USA) (Emmons et al. 1990). A MCP is defined as the pricing of milk on the basis of more than one component, each rewarded differently. For example, a fixed price per litre of milk with a different premium or

penalty for each percentage unit fat and protein above or below a base concentration (Emmons et al. 1990). The primary objective of MCP is that the prices paid or received for milk reflect as accurately as possible the amount and value of products that can be made from it (Emmons et al. 1990; Garrick & Lopez-Villalobos 2000) as well as the costs associated with processing that milk. The payment system should also suit the market being supplied, as using an incorrect system would lead to a greater cost to the processor and reduced returns to the farmer (Emmons et al. 1990) through incentivising sub-optimal responses from farmers. Currently only one milk processor (Synlait) in New Zealand includes an economic value of lactose in its payment to dairy farmers, this is partly due to the product mix of this company requiring large amounts of lactose to produce milk powder to required standards for export. However, processors in Europe have now included lactose into their payment systems with the end of the European quotas such as FrieslandCampina.

### **Biochemical description of lactose**

Lactose is a disaccharide of glucose and galactose, however, in most testing procedures additional oligosaccharides in milk will be included into the determination for lactose. In a study of gene expression in animals for the production of oligosaccharides (Wickramasinghe et al. 2011) it was shown that there are many more oligosaccharides in bovine milk than just lactose. These include lactose derivatives, precursors and analogues. However, as lactose makes up the majority of the oligosaccharides present, the other products have very little quantitative significance on the characteristics of milk (between 10% to 20% of oligosaccharides present in milk). In standard herd testing analysis in New Zealand lactose is determined by mid-infrared spectroscopy (FOSS

machine) and as such is calibrated against lactose monohydrate level (lactose plus one water molecule).

### **Synthesis of lactose**

The amount of lactose produced is affected by the concentration of precursor glucose in the blood, but is also affected by breed of the animal and days in milk (Erb & Ashworth 1963; Olori et al. 1997; Roman et al. 2000; Miglior et al. 2007; Wickramasinghe et al. 2011; Loker et al. 2012). These animal and production effects are covered later in this chapter.

Lactose synthesis occurs in the Golgi apparatus of epithelial cells lining the mammary alveoli, this is the same location as all other major aqueous components (Jones 1977). The final stage of lactose synthesis undergoes the following reaction;



The reaction can be described as one typical of those involving the synthesis of glycosidic bonds in the presence of a nucleotide derivative to shift the equilibrium in favour of synthesis (Jones 1977) The reaction is therefore totally dependent on the glucose supply, with lactose production utilising between 60% to 98% of the glucose entering the blood stream in dairy cattle (Bickerstaffe et al. 1974; Dijkstra et al. 2005).

The two main protein subunits of this reaction are  $\alpha$ -lactalbumin and galactosyltransferase (Jones 1977).  $\alpha$ -lactalbumin is a whey protein, which in bovines

comprises between 2-5% of total milk protein (Jones 1977).  $\alpha$ -lactalbumin acts as the regulatory subunit of lactose synthase, as it changes the affinity of galactosyltransferase for glucose to catalyse the lactose synthesis reaction. Galactosyltransferase is membrane bound in the Golgi apparatus of the epithelial cells in the mammary gland (Jones 1977; Kuhn et al. 1980). These two proteins combine to make the heterodimer known as lactose synthase, this dimer catalysing the reaction for the production of lactose from glucose and galactose-UDP (Jones 1977; Kuhn et al. 1980).

As glucose is the major precursor in lactose synthesis and its supply is a limiting factor in the synthesis reaction, it can be expected that glucose availability has a significant effect around the control of lactose synthesis (Davis and Collier 1985; Liu et al. 2002; Rigout et al. 2002; Shahbazkia et al. 2010). A rise in glucose concentration was hypothesised to elicit a proportionally greater rise in the rate of lactose synthesis (Kuhn et al. 1980). This theory was demonstrated with increases in plasma glucose leading to increases in milk yield and therefore lactose yield (Davis & Collier 1985; Rigout et al. 2002). However glucose concentrations in blood below 60mg/dl are associated with decreased milk secretion (Kronfeld et al. 1963)

### **Effect of lactose on human health**

Lactose is hydrolysed into glucose and galactose by an enzyme called lactase-phlorizin hydrolase (also known as lactase) encoded by a gene called LCT (Tishkoff et al. 2007). Lactase is synthesised and secreted into the small intestine of young mammals, including humans. In humans lactase is synthesised by infants up to 3-4 years of age but some individuals lactase synthesis declines until they become lactose intolerant

(Swallow 2003). The ability to digest lactose as an infant is important as human breast milk contains around 7% lactose (Fox & McSweeney 1998) and represents around 40% of the energy value of human milk (Koletzko et al. 2005). The codex standards, however, allow for greater lactose content in milk (9%) contributing up to 56% of the energy value of milk (Koletzko et al. 2005) this can reduce the protein and lipid content of the infant formula.

Lactose intolerance is characterised by an inability to digest lactose, causing abdominal pain and diarrhoea due to fermentation of undigested lactose in the colon. Lactose intolerance is the ancestral genotype, with 2 SNP changes identified in European populations which are associated with lactose tolerance, allowing for LCT gene expression in adulthood (Tishkoff et al. 2007; Ingram et al. 2009). These changes C/T-13910 and G/A-22018 are located 14kb and 22kb upstream of LCT, respectively (Tishkoff et al. 2007), however C/T-13910 is proposed as the causative change (Tishkoff et al. 2007; Ingram et al. 2009). Both of these SNPs are associated with lactose tolerance which is inherited as a dominant Mendelian trait in Europeans (Swallow 2003; Tishkoff et al. 2007), as enzyme activity from a single active copy of LCT in adulthood is capable of transferring lactose tolerance (Swallow 2003).

In African populations lactose tolerance is also a dominant Mendelian trait, however, the associated SNPs are still being identified (G/C-14010, T/G-13915 and C/G-13907) (Tishkoff et al. 2007). The characterisation of lactose tolerance as a genetic trait was largely identified through large familial studies in Scandinavia in the 1970's when lactose intolerance was thought to be the anomaly (Swallow 2003); however, it was found that lactose tolerance was the anomaly (Sahi et al. 1983; Swallow 2003).

Lactase intolerance has a frequency of less than 10% in northern European (Denmark and Sweden) populations, 50% in southern European (Spanish and French) and Middle Eastern (pastoralist Arab) populations, 90-95% in West African populations and around 98% in Chinese populations (Tishkoff et al. 2007).

Notably, lactose intolerance is less common in pastoralist populations from Africa than in other populations from Africa with frequencies between 10 and 50% (Tishkoff et al. 2007), this could be linked positive selection pressure from the greater dairy intakes of these African populations (Tishkoff et al. 2007).

Lactose intolerance is an issue of particular and growing importance to the New Zealand dairy industry. The fastest growing markets for New Zealand dairy exports are the Asian markets, where the majority of potential consumer base are lactose intolerant. This can be overcome by the production of milks with low to no lactose content through the addition of lactase to milk prior/during processing so that the carbohydrate content is unaltered but the lactose is converted into glucose and galactose (Fox & McSweeney 1998). Lactose can be removed through ultrafiltration; however, this would also remove minerals from the milk so is not advised (Fox & McSweeney 1998).

### **Factors affecting concentration of lactose in milk**

The concentration of lactose in milk is affected by several factors from dietary effects (feeding types and frequencies) to genetic effects. Different feeds and feed additives can be used to modify the LP in dairy cattle; physiological stresses also influence the LP. The heritability of LP is moderate to high (0.32-0.72; Roman et al. 1999; 2000; Roman

& Wilcox 2000; Miglior et al. 2007; Hossein-Zadeh & Ardalan 2011; Loker et al. 2012; Sneddon 2012). The moderate to high heritability of both lactose yield and LP will allow genetic selection on populations to increase the concentration and yield of lactose.

### *Feed type and feeding frequency*

Feed type and feeding frequency have the potential to alter the lactose yield of a cow, with greater available glucose allowing for greater lactose synthesis. Direct infusion of glucose into the abomasum causes an increase in plasma glucose levels, increasing milk production (Frobish & Davis 1977). However this infusion was associated with a depression of milk fat production and a reduction in C18:0 and short chain fatty acid concentration within in the milk (Frobish & Davis 1977), inclusion of acetate in the infusion prevented the decline in fat production. In contrast intravenous infusion of glucose only increased milk yield in animals that were fasting, however this increase did not match the production of milk from fed animals (Davis & Collier 1985). In real life situations, delivery of glucose directly to the abomasum would be impractical, however, it could be possible to increase the proportion of sugar in the diet by providing by-pass starches which can enhance glucose supply. This can be done easily when feeding a total mixed ration, but it is more difficult and would require in shed feeding under New Zealand's pastoral farming system potentially increasing capital costs.

Supplementation of various feeds to a pasture based diet has shown some potential to alter the lactose content or milk yield. Tesfa et al. (1995) fed 4 different supplements to a group of cows grazing pasture (meadow fescue, timothy and red clover) and found that there was a small but significant effect on concentrations of lactose, milk urea

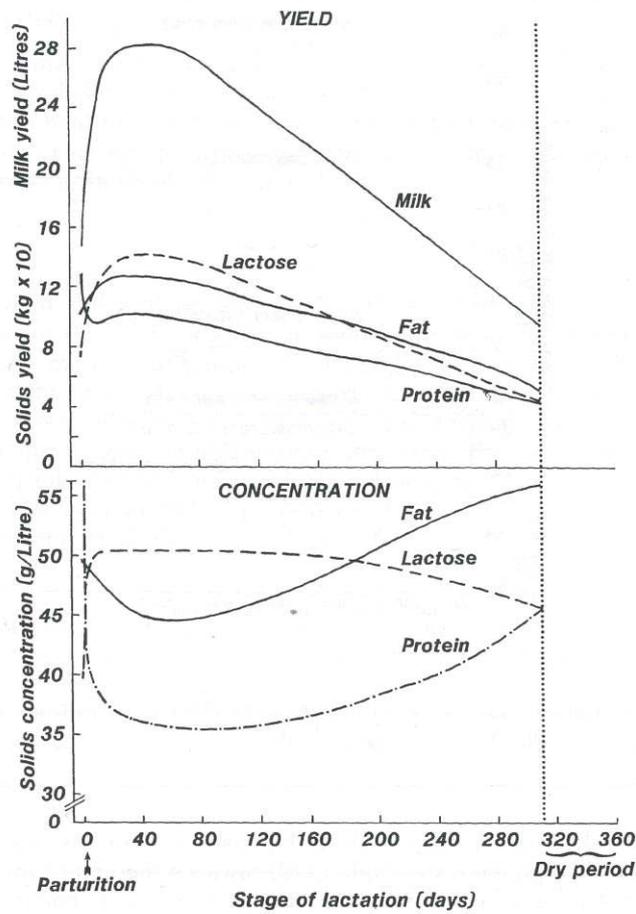
nitrogen and protein from the different feed types. Supplement with a “basic dairy concentrate (BDC)” decreased the LP of the milk relative to the other supplementation strategies including BDC plus 0.9% urea, BDC plus 12% rapeseed meal and heat treated BDC plus 12% rapeseed meal (Tesfa et al. 1995). Despite these effects on the concentrations of milk components there was no significant effect on the total yields of milk or milk components. Davidson et al. (1990) fed cows on pasture with supplementation of bone meal and reported a decreased lactose yield for cows fed with meat and blood meal. Conversely, Davidson et al. (1990) reported an increase in LP when supplemented with bone meal on legume pastures. However, it is not reported as to whether these differences were statistically significant (Davison et al. 1990).

A 5% supplementation (as a proportion of total offered feed) of sodium fumarate resulted in an increase in LP from 4.84% to 4.96%, with those fed sodium fumarate having a greater lactose concentration with no change in other milk components (Kolver & Aspin 2006). The supplementation of fumarate therefore has the potential to increase LP without negative impacts on FP or PP.

In total mixed ratio feeding trials, where cattle are fed at different times during the day or at different frequencies (once, twice, five times a day), there has been little difference in LP reported (Robinson & McQueen 1994; Shabi et al. 1999; Dhiman et al. 2002; Mantysaari et al. 2006). However, the trial of Shabi et al. (1999) reported differences in LP which were numerically different by feeding frequency and near significant ( $P=0.07$ ), the yield of lactose was significantly different for the method of grain processing used in this trial.

*Age of cow and stage of lactation*

Miglior et al. (2007) reported a decreasing LP with increasing age, however, the difference in LP was not investigated in the paper. Miglior et al. (2007) also reported an increase in somatic cell count with age, which was negatively associated with LP (Welper & Freeman 1992; Miglior et al. 2007; Hossein-Zadeh & Ardalan 2011). This was also shown in Bleck et al. (2009) who reported a negative linear correlation between LP and lactation number.



**Figure 2.1.** Idealised diagram showing the changes in milk, fat, protein and lactose yields as well as the changes in the concentrations of fat, protein and lactose over the lactation adapted from Holmes et al. (2007).

In Figure 2.1 it can be seen that LP is more consistent over the lactation when compared with FP and PP. The curve followed by LP is also of the opposite sign to that of FP and PP with a slow decrease over the lactation while FP and PP peak at the end of the lactation (Holmes et al. 2007).

A lactation study by Olori et al. (1997) showed no significant change in LP due to pregnancy requirements during lactation. However, they did indicate that, along with milk, fat and protein yields, lactose yield did decrease as pregnancy continued. By the 3rd month of gestation Olori et al. (1997) found that pregnant cows produced an accumulated 1.4 kg of lactose less than non-pregnant animals and by month 8 this difference was an accumulated total of 10.7.kg for the lactation. There was a similar interaction between days in milk and LP in that study (Bleck et al. 2009). However, a twin study evaluating the effect of pregnancy on milk production in New Zealand (Roche 2003) showed no differences for milk, fat, protein or lactose yields between pregnant and non-pregnant cows.

### ***Health status of the cow***

Mastitis is one of the most common and economically significant diseases for the dairy industry (National Mastitis Advisory Committee 2006; Geary et al. 2013a; 2013b). Not only does mastitis reduce the total yield of milk and milk components, but it also impacts the FP, PP and LP (Auldist et al. 1995; Oliszewski et al. 2002; Hussain et al. 2012; Malek dos Reis et al. 2013).

An increased somatic cell count is associated with a decrease in the LP of milk (Bleck et al. 2009). This association could explain some of the extreme low LP sometimes seen in animal records. As somatic cell count increases in milk, a significant decrease in milk proteins and calcium concentrations occurs during clinical or subclinical mastitis (Hussain et al. 2012). The inflammatory cells and damaged epithelial cells release various products such as lactate dehydrogenase and  $\beta$ -galactosidase (Oliszewski et al.

2002). As well as potentially decreasing lactose content of milk, mastitis can also decrease the FP and PP (Auldist et al. 1995; Hussain et al. 2012; Malek dos Reis et al. 2013). Casein is degraded in milk by the release of plasmin (Auldist et al. 1995). Free radicals produced by leukocytes during the response to microbial infection cause damage to the mammary epithelial cells resulting in decreased milk production (Barbano et al. 2006) this damage will also decrease the lactose secretion in to the luminal space in the udder. Hussain et al. (2012) reported a decrease from 4.7 to 3.9% lactose in milk of cows with mastitis infection compared to healthy cows, as well as reductions in FP from 5.5 to 4.2% and PP reductions from 4.5 to 3.7%. While the volume of milk from both the healthy and mastitic cows was low, the difference between these two groups was significant. Malek dos Reis et al. (2013) reported lower LP in mastitic compared with healthy Gyr cows, but an increase in FP and PP. Auldist et al. (1995) reported significantly lower LP in mastitic cows at all points of the lactation compared with healthy cows. Mastitis could cause the decreased LP through damage to the alveolar epithelial cells potentially reducing the capacity of the mammary gland to synthesise lactose (Ali et al. 1980), it could also be due to epithelial damage allowing lactose to leak down a concentration gradient between alveolar lumina and extracellular fluid (Auldist et al. 1995). This is evidenced by increased urine concentrations of lactose in mastitic cows (Wiesner 1985). Additionally pathogens which cause mastitis are also capable of digesting lactose which could lower the concentration in milk (Merchant & Packer 1971). The impact of mastitis on milk composition is also seen in milk product processing (Auldist et al. 1995).

## Heritability

Heritability is an estimation of the proportion of a population's variance for a trait which can be attributed to the genetic variance between the individuals. The equation used to estimate heritability is the following:

$$h^2 = \sigma_a^2 / (\sigma_a^2 + \sigma_e^2)$$

where  $\sigma_a^2$  is the additive animal genetic variance,  $\sigma_e^2$  is the residual variance. When there are repeated measures on the same cow, heritability is estimated as

$$h^2 = \sigma_a^2 / (\sigma_a^2 + \sigma_c^2 + \sigma_e^2)$$

where  $\sigma_a^2$  is the additive animal genetic variance,  $\sigma_c^2$  is the permanent cow variance and  $\sigma_e^2$  is the residual variance. These estimates are required to determine the potential effects that breeding may have on milk production traits and components such as lactose.

Estimates of heritabilities show considerable variation for lactose yield with estimates ranging from 0.25 to 0.53 (Welper & Freeman 1992; Miglior et al. 2007). Similar studies using New Zealand data have returned estimates of 0.26 (Johnson et al. 2000) and 0.49 (Sneddon et al. 2012). This range can be in part explained by the nature of heritability estimates being population specific.

The estimations of heritabilities for LP also have a range in reported values from 0.32 (Hosseini-Zadeh & Ardalan 2011) to 0.72 (Vos & Groen 1998). There is a tendency of

estimates of heritability for FP, PP and LP to be greater than those of milk, fat, protein and lactose yields. This can result in a greater rate of progress with concentration rather than yield if genetic variance is equal, with the same level of selection pressure.

A summary of previously reported genetic parameters including heritabilities, genetic and phenotypic correlations is shown in Table 2.1. While there is limited reporting of the heritabilities for both lactose yield and LP in the literature, there is a consistency in reported values. There are also similar ranges in the heritabilities reported for other yield and concentration traits such as 0.22 to 0.57 for milk yield or 0.28 to 0.50 for fat yield (Vos & Groen 1998; Miglior et al. 2007), PP from 0.25 to 0.83 (Vos & Groen 1998; Hossein-Zadeh & Ardalan 2011) or FP from 0.23 to 0.79 (Vos & Groen 1998; Miglior et al. 2007).

**Table 2.1.** Genetic and phenotypic correlations between milk components.

Trait <sup>1</sup>	MY	FY	PY	LY	FP	PP	LP	SCS	F:P	Study
MY	<b>0.47</b>	0.86	0.96	0.98	-0.27	-0.39	0.18	-0.23		<b>1</b>
	<b>0.22</b>				0.72	0.85	0.55	0.17		<b>2</b>
	<b>0.29</b>	0.71	0.93	0.92	-0.40	-0.47	-0.30	0.15		<b>3</b>
	<b>0.57</b>				-0.52	-0.61	-0.13		0.18	<b>4</b>
	<b>0.50</b>	0.79	0.92	0.99	-0.14	-0.32	-0.06	-0.18	-0.08	<b>5</b>
FY	0.57	<b>0.36</b>	0.89					-0.24		<b>1</b>
										<b>2</b>
	0.81	<b>0.28</b>	0.79	0.68	0.35	-0.04	-0.16	0.12		<b>3</b>
		<b>0.50</b>								<b>4</b>
	0.83	<b>0.25</b>	0.80	0.77	0.46	-0.11	-0.15	-0.13	-0.54	<b>5</b>
PY	0.89	0.68	<b>0.41</b>					-0.22		<b>1</b>
										<b>2</b>
	0.96	0.85	<b>0.25</b>	0.89	-0.21	-0.12	-0.21	0.18		<b>3</b>
			<b>0.36</b>							<b>4</b>
	0.97	0.81	<b>0.56</b>	0.90	-0.05	0.05	-0.09	-0.15	0.03	<b>5</b>
LY	0.98			<b>0.48</b>				-0.02		<b>1</b>
										<b>2</b>
	0.96	0.79	0.94	<b>0.25</b>	-0.35	-0.37	0.10	0.13		<b>3</b>
										<b>4</b>
	0.99	0.81	0.97	<b>0.49</b>	-0.17	-0.34	0.09	-0.19	-0.06	<b>5</b>
FP	-0.49				<b>0.54</b>	0.59	0.01	-0.01		<b>1</b>
	0.47				<b>0.23</b>	0.54	0.50	-0.08		<b>2</b>
	-0.34	0.27	-0.20	-0.30	<b>0.51</b>	0.59	0.16	-0.06		<b>3</b>
	-0.64				<b>0.79</b>	0.57	0.00		-0.78	<b>4</b>
	-0.19	-0.26	-0.55	-0.65	<b>0.33</b>	0.28	-0.19	0.06	-0.82	<b>5</b>
PP	-0.54				0.66	<b>0.57</b>	0.08	0.17		<b>1</b>
	0.33				0.38	<b>0.25</b>	0.58	0.03		<b>2</b>
	-0.36	-0.06	-0.09	-0.27	0.51	<b>0.45</b>	0.29	0.01		<b>3</b>
	-0.16				0.56	<b>0.83</b>	0.00		0.05	<b>4</b>
	-0.84	-0.87	-0.83	-0.87	0.41	<b>0.58</b>	-0.12	0.09	0.28	<b>5</b>
LP	0.10				0.06	0.02	<b>0.50</b>	-0.31		<b>1</b>
	0.05				-0.14	-0.07	<b>0.32</b>	-0.19		<b>2</b>
	-0.08	-0.02	0.01	0.20	0.11	0.29	<b>0.48</b>	-0.11		<b>3</b>
	-0.16				-0.01	0.03	<b>0.72</b>		-0.01	<b>4</b>
	-0.12	-0.31	-0.09	0.02	-0.17	0.02	<b>0.64</b>	-0.07	0.14	<b>5</b>
SCS	0.00	-0.05	0.01	-0.02	-0.11	0.01	-0.20	<b>0.27</b>		<b>1</b>
	0.11				0.04	0.08	-0.16	<b>0.24</b>		<b>2</b>
	-0.04	-0.07	-0.04	-0.08	-0.06	-0.01	-0.15	<b>0.13</b>		<b>3</b>
										<b>4</b>
	-0.39	-0.42	-0.47	-0.36	0.19	0.16	0.16	<b>0.33</b>	0.03	<b>5</b>
F:P										<b>1</b>
										<b>2</b>
										<b>3</b>
	0.18				-0.77	0.10	0.02		<b>0.79</b>	<b>4</b>
	-0.07	-0.53	0.09	0.01	-0.61	0.21	0.47	0.05	<b>0.24</b>	<b>5</b>

<sup>1</sup>MY = milk yield; FY = fat yield; PY = protein yield; LY = lactose yield; FP = fat percentage; PP = protein percentage; LP = lactose percentage; ratio; SCS = somatic cell score calculated as Log<sub>2</sub>(somatic cell count); F:P = fat-to-protein.

Study 1 = Miglior et al. 2007; 2 = Hossein-Zadeh & Ardalan 2011; 3 = Welper & Freeman 1992; 4 = Vos & Groen 1998; 5 = Sneddon et al. 2012. Heritability's in bold on the diagonal with phenotypic correlation above the diagonal and genetic correlations below the diagonal.

### ***Breed***

Lactose percentages from F, J and crossbred (FxJ) cows from several studies are presented in Table 2.2 the LP (measured as lactose monohydrate) in dairy cattle has been reported between 4.5 and 5.6% (Brown et al. 1936; Cerbulis & Farrell 1975; Welper & Freeman 1992; Miglior et al. 2007; Loker et al. 2012; Sneddon et al. 2012). However, this range of concentrations can be exceeded (higher and lower lactose percentages are possible) (Hussain et al. 2012).

Despite the greater lactose yields of the F cow compared with the J, the F cow has lower LP than the J cow, similar to what is seen in fat and protein (Cerbulis & Farrell 1975). This difference can be seen in Table 2.2 where the average of the reported concentrations are 4.73 for HF and 4.81 for JE. These values are smaller than most values reported from New Zealand data (Mackle et al. 1996; Sneddon et al. 2012). This is, however, a reflection of the limited data reported around LP in the New Zealand dairy industry and other countries.

**Table 2.2.** Reported lactose monohydrate concentrations (g/100 ml milk) for differing breeds.

Study	Country/Feeding	Holstein-Friesian	Crossbred	Jersey
Aikman et al. (2008) <sup>1</sup>	USA/TMR	4.68	-	4.76
Erb & Ashworth (1963) <sup>2</sup>		4.72	-	4.85
Barnes et al. (1989) <sup>1</sup>		5.05	-	5.05
Cerbulis & Farrell (1975) <sup>3</sup>		4.93*	-	4.99*
Prendiville et al. (2010) <sup>1</sup>	IRE/Pasture	4.45	4.56*	4.48
White et al. (2001) <sup>1</sup>	USA/TMR	4.81	-	4.86
White et al. (2001) <sup>1</sup>	USA/Pasture	4.61	-	4.79
Mackle et al. (1996) <sup>1</sup>	NZ/Pasture	4.80	-	4.94
Average		4.73	-	4.81

\*Denotes difference in study between breed concentrations  $p < 0.05$ .

<sup>1</sup>Monohydrate.FOSS determined; <sup>2</sup>Monohydrate picric method; <sup>3</sup>Monohydrate (Marier & Boulet 1959).

### *Genetic correlation of lactose with other milk components*

Many studies estimating the genetic components of traits of interest in dairy cattle have been reported, however, these do not always contain an estimate of the genetic contributions to LP or lactose yield. This gap in the knowledge can reduce the development of breeding objectives and selection indices including lactose, as well as the prediction of correlated responses to selection pressures.

Most genetic correlations between LP and other yield traits show a small positive relationship to a small negative effect (LP to milk, fat, protein or lactose yields) (Welper & Freeman 1992; Sneddon et al. 2012). The genetic correlations between traits are important as it determines the effects that selection for increasing lactose percentage will have on the current rates of genetic gain in other traits in the dairy industry. The reported correlations between lactose yield and LP appear to be low and positive, meaning that LP would be unlikely to change with selection on only lactose yield.

Large datasets provide the most accurate estimations of genetic parameters however, most studies reporting lactose use small datasets, either through experimental design or limited animal records such as in Roman & Wilcox (2000) or Sneddon et al. (2012). While estimation of genetic parameters is possible, the associated standard error on these calculations is greater. This can create an issue with the functionality of the animal model, if there is insufficient data to allow convergence of the equation, or to account for all known sources of variation.

A summary of genetic correlations and heritabilities can be seen in Table 2.1; this table shows the variation in the estimates of milk trait correlations and heritabilities. It is notable, though, that while few papers report the correlation of LP with milk yield, for those that do, these estimations are generally negative or close to zero (Welper & Freeman 1992; Vos & Groen 1998; Miglior et al. 2007; Hossein-Zadeh & Ardalan 2011; Sneddon et al. 2012). This is the case with the genetic correlation between milk yield and LP, where reported values ranged from -0.16 (Vos & Groen 1998) to 0.10 (Miglior et al. 2007). With the gaps in reported knowledge and estimations (Table 2.2) it is, therefore, important to weigh the estimation of these values by the size of the datasets used and the size of the standard error of the mean. This consideration will lead to the identification of a range in which values most likely lie. For example using the milk yield and LP correlations in Miglior et al. (2007) while the estimation is 0.10 it could truly lie between -0.01 and 0.21 (using largest reported SE of 0.11).

Lactose yield appears to have great genetic and phenotypic correlations with milk and protein yield this is most likely due to the osmotic effects of lactose within the mammary gland. However, correlation between lactose and fat show less consistency as

this is based only on 2 reports, with total yield correlations being great (0.79 and 0.81) and percentage correlations crossing zero (-0.17 to 0.11). The genetic correlation between milk yield and lactose yield is very high (0.95-0.99; Welper & Freeman 1992; Johnson et al. 2000; Miglior et al. 2007). The phenotypic correlation is also close to one (Welper & Freeman 1992; Johnson et al. 2000; Miglior et al. 2007), this does highlight the osmotic role of lactose within milk as the milk volume increases so does the lactose yield.

### **Lactose use in the dairy industry**

Lactose has many uses in the dairy industry as well as outside of it; in the dairy industry it is used to aid standardisation of milk products to maximise the return on particular milk components. Outside the dairy industry lactose is used in the pharmaceutical and confectionary industries, it is used in bakery, animal feeds and industrial fermentation (Yang & Silva 1995), for pharmaceuticals lactose is used in the production of tablets as a filler or drug carrier (Yang & Silva 1995). Lactose is used in bakery goods as it does not undergo fermentation by bakers yeast, it can be used as a flavour carrier such as in instant coffee (Yang & Silva 1995).

### ***Value of lactose***

The value of lactose, while subject to change with the changes in the demand for milk products, has been increasing in recent years (Global Dairy Trade 2014). This has mainly been driven by the demand from Asia for powders and the decision taking by New Zealand processors to add lactose to standardise their milk to meet standardisation

requirements. The addition of lactose is required as milk powder requires a specific ratio of protein-to-solids-not-fat (P:SNF), rather than protein-to-fat. The difference in P:SNF is more pronounced in J cows which have greater PP relative to LP when compared with F cows. The codex standard for WMP, (CODEX STAN 207-1999 WHO & FAO 2011), requires WMP to contain a minimum of 26% but less than 42% fat and a minimum of 34% protein in solids-not-fat (25.1% protein). However, WMP is generally specified as 26.5% fat, 25.1% protein and 39.8% lactose (Geary et al. 2010). The milk produced by New Zealand cows generally has a P:SNF of around 0.42 (LIC & DairyNZ 2013) compared to the international standard level of 0.39 (Geary et al. 2010) for WMP. As lactose is cheaper than milk protein the standardisation of the milk is undertaken by the removal of the fat component of milk and the addition of lactose from other milk processing sectors. The values at June 5th 2012 Global Dairy Trade were US\$3,011, US\$2,763, US\$3,096 and US\$1,992 per tonne for WMP, SMP, anhydrous fat and lactose, respectively. As can be seen from the values of lactose and fat, the small addition of lactose can be balanced against the sale of excess fat, however, this is only the case whilst the value of lactose is low and the increase in the value of lactose makes this method less appealing as the profit differential decreases.

The standards are set by the World Health Organisation and the Food and Agriculture Organisation of the United Nations, which is a set of voluntary reference standards, which have become the industry minimum standards for international trade. These minimum standards do allow the possibility to produce altered WMP, but the markets willingness to accept these would have to be investigated before altering the product composition.

Many companies in New Zealand have been using this method of milk standardisation as it allows them to increase the amount of saleable product from the milk collected. However, this method carries a risk for the brands because the majority of lactose used to standardise the milk is imported from outside of New Zealand. This importation can risk the brand as this calls into question how much of the product is “New Zealand Made”. This is certainly a problem if the price achieved for milk products is partly due to the “clean and green” brand image of New Zealand.

There is, however, also an increasing demand for lactose in the confectionary industry (Nutria Ingredients 2012; Global Industry Analysts Inc 2014), which has the potential to further increase demand and influencing the price of lactose. The increase in demand from the dairy, confectionary and pharmaceutical industries is increasing the value of food grade lactose.

### **Milk payments in other countries**

Table 2.3 shows the milk payment systems and the average price paid per litre of milk in different countries for the dairy seasons 2005-2006. In the formation of Table 2.3, all values are for 2006 and are expressed in NZD values, using conversion rates of 1.54, 1.16, 1.94, 2.84 and 0.26 for NZD to American dollars, Australian dollars, Euros, British pounds and Danish Kroner, respectively (NZForex 2013) Countries in Table 2.3 were selected to compare with New Zealand as they are similar-sized countries by population (Denmark and Ireland), similar-sized dairy industries (Australia, Netherlands and Britain) or market competitors (USA).

**Table 2.3.** Comparison of milk payment systems in different countries (adapted from International Dairy Federation 2006) with all values expressed as New Zealand dollars.

Compositional criteria	New Zealand (Fonterra Co- operative Group)	Australia	USA	Ireland	United Kingdom	Netherlands	Denmark
Fat	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total protein (Nitrogen x 6.38)	Yes	No	No	Yes	Yes	Yes	Yes
True protein ((Nitrogen – Non- protein nitrogen) x 6.38)	No	Yes	Yes	No	No	No	No
Lactose	No	No	No	No	No	No	No
Lactose and other solids	No	No	Yes	No	No	No	No
Total milk solids	No	No	Yes	No	No	No	No
Solids-not-fat	No	No	Yes	No	No	No	No
Other (specified)	Volume penalty for cartage and drying	No	Somatic cell count	No	Milk volume	No	No
Payment system	A+B-C expressed per Kilogram of milk solids	Litres of milk	Hundredweight of milk	Litres milk with premium on concentration	Litres of milk with premium on concentration	Kilograms of milk with premium on concentration	Kilograms of milk
Value of an average litre of milk in payout excluding any levy or premium	0.36/L	0.32/L	0.43/L	0.51/L	0.51/L	0.62/L	0.64/L
Value of a kg of fat in payout	2.36	2.61	4.10	-	5.32	6.09	-
Value of a kg of protein in payout	6.76	6.55	8.06	-	9.37	10.09	-
Cartage and drying charge based on volume	-0.04						
Government subsidy	No	No	Yes	Yes	Yes	Yes	Yes

In order to identify the components which could best reward farmers for the milk they produce, all payment systems must be considered. Some payment systems in the USA follow a hundredweight of milk plus fat or protein component, fat plus solids-not-fat (SNF), fat only, TMS, or volume of milk. The payment in the USA appears to be commonly expressed as a price per hundredweight of milk; this price is determined through the quantities of fat and SNF in the milk. This payment system is complicated by a classification system, where each class has a different value (Jesse & Cropp 2004). Class I milk is milk used for beverage products. This includes “white” whole, low-fat and skim milk in all container sizes; chocolate and other flavoured milks; liquid buttermilk and eggnog. Class II milk is milk used for soft manufactured products such as ice cream and other frozen dairy desserts, cottage cheese and creams such as sour cream, aerosol whipped cream and whipping cream, half and half and coffee cream. Class III milk is milk used to manufacture cream cheese and hard cheese. Class IV milk is milk used to make butter and dry milk products, principally non-fat dry milk (Jesse & Cropp 2004). As the final value of milk to the farmer is a composite of these classes, as well as federal dairy product price-support programs, such as the milk income loss contract (MILC) (Chang & Mishra 2011), the determination of the value of independent milk components is more complicated than those reported for the New Zealand dairy industry. In Table 2.3, it can be seen that almost all of the component criteria are included in the payment system in the USA market as a result of the differing classes used in the USA market. The MILC system in America allows a subsidy on up to 2.4 million pounds (1,088,600 kg of milk equivalent to approximately 74,000 kg MS at 6.8% MS) of the milk produced (Chang & Mishra 2011) per farm and equates to a subsidy of US dollars (USD) 400,000 per farm (USD16.94 per hundredweight of milk).

Amies (1984) outlined the previous payment system for the British dairy industry as a payment on fat and SNF. The existing system pricing was shown to value a kg of fat versus a kg of SNF at 1.67 British pounds (UK£) and 0.96 UK£, respectively. Amies (1984) proposed a system of payment based on fat, protein and lactose. The system proposed values of UK£2.02, £1.77 and £0.28 per kg of fat, protein and lactose, respectively. However, this payment system was never introduced, probably due to the introduction of the European Union milk quota system which was introduced on 2 April 1984.

The Irish dairy industry uses a similar payment system to New Zealand, the 'A+B-C' payment system, where A and B are the values per kg of fat and protein and C represents a volume-related processing cost per litre of milk volume. However, in the case of Ireland, for some processors, there is a penalty when lactose is below a certain percentage (Dairygold Co-operative Society Ltd. 2011). The LP penalty is -€0.10, -€0.05 and -€0.025 for percentages below 4% and between 4.001-4.100% and 4.101-4.200%, respectively. Lactose percentage in Ireland is used as a proxy for milk processing ability, the ease at which milk can be processed into differing milk products. Of the 30 payment systems outlined by the International Dairy Federation (2006), 17 paid on a litre of milk basis, 10 on a kg of milk basis and two (New Zealand and Canada) on a kg of MS basis. The exception was the USA, where payment was on a hundred weight of milk basis and was also based on a complicated collection of class payments. The authors expect that there has been significant change since 2006, such as in Ireland.

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### *Current milk payments in New Zealand*

All milk payment systems in New Zealand are based on a form of MCP. The prominent milk payment system in New Zealand is the 'A+B-C' formula used by the Fonterra Co-operative Group. Farmers supplying the Fonterra Co-operative Group are required to hold shares in the company in proportion to the supplied quantity of MS, in addition to payment per kg of MS supplied. Farmers receive a share dividend based on the number of shares they hold. This was around NZD 0.40/share in the 2011-2012 production season. This is not included in companies which do not require farmers to have shares to supply, such as Open Country Dairy Ltd. currently the second largest dairy processor in New Zealand. Open Country Dairy Ltd. uses a similar pricing structure to the Fonterra Co-operative Group.

One exception of the 'A+B-C' payment system in New Zealand is the payment system used by Synlait Milk Ltd. Synlait Milk Ltd. is a small- to medium-sized milk processor, processing approximately 500 million litres per year, that operates in the South Island of New Zealand. Most of the suppliers are within 80 kilometres of the factory. Synlait Milk Ltd. produces a range of milk powder products, including infant, whole milk, skim milk and colostrum powders. Synlait Milk Ltd. pays farmers on amounts of fat, protein and, lactose with a negative value on milk volume.

### *Alternative payment systems that include lactose for New Zealand dairy farmers*

Encouraging farmers to increase the production of lactose could be implemented through the inclusion of lactose into the payment system. Synlait Milk Ltd. is already

paying suppliers with a MCP system that includes lactose. This system is known as 'F+P+L-V', where F, P, L and V are the component values for fat, protein, lactose and milk volume processing charge. The values used for the season 2010-2011 were 4.24, 10.34, 1.84 and - 0.0324 NZD per kg of fat, protein, lactose and litre of milk volume respectively. These component values were derived from a model proposed by Garrick & Lopez-Villalobos (2000). Holmes et al. (2007) when comparing two pricing systems: 'A+B-C' and 'F+P+L-V' demonstrated that the inclusion of lactose in the payment systems reduced the values of fat and protein by between 7% and 9%, with the value per kg of lactose ranging from -0.416 to 2.00 NZD depending on the product portfolio of the milk and breeds examined.

Brog (1969) examined the accuracy of different MCP systems, in terms of the value returned to farmers compared to an ideal 100% and found a payment system based on 'fat + protein' had a correlation of 99.93%, relative to a payment system based on 'fat + protein + lactose'. The analysis showed that the value for lactose was small and negative, at around 4% of the value of fat or protein, which is similar to the negative weighting on milk volume of the 'A+B-C' schedule, noted by (Emmons et al. 1990). This 'fat + protein' system was noted by Brog (1969) as a highly efficient system for returning value of the components to the farmer, as well as avoiding overpayment incurring a loss to the processor. A full review of the milk payment system is required as the product portfolio of New Zealand has moved from a butter and cheese producer to a milk powder producer. Holmes et al. (2007) showed that a payment system based on 'F+P+L-V' had a smaller difference from the true value of the milk for differing breeds, milk compositions and product mixes than the 'A+B-C' system. The true value

was defined as the income from the sale of dairy products minus milk collection, processing, storage, distribution and marketing costs.

Overall with the large range of methods for payment of milk, the most efficient system for indicating the value of milk components to New Zealand farmers would be a  $F + P + L - V$ . This would only require a small change to the current payment system and would not require the complicated methods as those of the class system implemented in America.

### **Implications of including lactose in the breeding objective of New Zealand dairy cattle**

The national breeding objective of the New Zealand dairy industry is called breeding worth (BW). The calculation of BW contains the traits in decreasing order of trait emphasis, of protein, milk volume, live weight, fat, fertility, somatic cell score and residual survival (Bryant 2012). The economic values and correlated responses are shown in Table 2.4. This Table demonstrates the importance of being able to calculate the response of a trait to selection pressure. Selection response estimations are required for either lactose yield or LP before it can be incorporated into BW, given the effect this would also have on the other traits. Without an estimate of the change in response rates, the implications of introducing a new trait into the BW objective cannot be known. Farmers could be encouraged to adopt management and breeding strategies to increase lactose production through the introduction of payment systems incorporating lactose. While this has not been demonstrated on an industry scale, breeding experiments have shown this to be theoretically possible (Vos & Groen 1998).

**Table 2.4.** Economic values and expected response in milk traits achieved through selection based on Breeding Worth. NZD= New Zealand dollars.

Trait	Economic value (NZD)	Annual genetic change
Fat	1.79/kg	2.22 kg
Protein	8.63/kg	1.84 kg
Milk volume	-0.09/L	44 L
Live weight	-1.52/kg	-0.04 kg
Residual survival	0.15/day above average herd age	13.3 days
Fertility	7.35/% increase in calving rate in first 42 days	0.30%
Somatic cell score	-38.57/unit of somatic cell score	-0.01 units of somatic cell score

If lactose is included in the breeding objective, the payment system can be changed from ‘A+B-C’ to ‘F+P+L-V’. The component value of lactose in the MCP should be estimated under a different mixes of dairy products, accounting for processing cost and prices of dairy products.

The economic value of lactose to be used in the calculation of BW needs to be estimated using a farm model to account for feed costs and other farms costs and discounted gene expressions.

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## Chapter 3

### **Genetic parameters for milk components including lactose from test day records in the New Zealand dairy herd**

NW Sneddon<sup>a\*</sup>, N Lopez-Villalobos<sup>a</sup>, SR Davis<sup>b</sup>, RE Hickson<sup>a</sup> and L.Shalloo<sup>c</sup>

<sup>a</sup>Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Private Bag 11-222, Palmerston North, New Zealand

<sup>b</sup>Livestock Improvement Corporation, Private Bag 3016, Hamilton 3240, New Zealand

<sup>c</sup>Dairy Production Department, Teagasc, Moorepark Production Research Centre, Fermoy, Co. Cork, Cork, Ireland

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**Abstract**

There are currently few published estimates of genetic parameters for lactose yield or lactose percentage for dairy cows. Recent trends in milk standardisation for whole milk powder have resulted in whole milk being standardised with the ratio of protein-to-protein-plus-lactose of at least 0.39. Currently whole milk powder produced from New Zealand milk has a protein-to-protein-plus-lactose ratio of 0.43, thus requiring additional lactose to be imported to maximise the return from the current product portfolio. Estimates of genetic parameters were obtained using 15,366 test day records from 4,378 first-lactation cows in the Livestock Improvement Corporation sire proving scheme in the 2011-2012 dairy season, distributed across 70 herds. These data included milk, fat, protein and lactose yields, fat, protein and lactose percentages, somatic cell count, days in milk and the protein-to-fat ratio and protein-to-protein-plus-lactose ratio. Mean milk yield was 13.8 L/day, containing 5.16% fat, 3.93% protein and 5.12% lactose. Heritability estimates were 0.22, 0.35, 0.32 and 0.25 for milk yield, fat, protein and lactose percentages, respectively, which were lower than those reported in the literature but enough to allow for selection of lactose percentage.

***Keywords:***

Lactose; genetic parameters; milk processing

**Introduction**

Many studies have reported the estimation of genetic parameters for daily milk yields (MY), fat yield (FY), protein yield (PY), percentages of fat (FP) and protein (PP) and

somatic cell score (SCS; calculated as  $\text{Log}_2(\text{somatic cell count})$ ) (Roman et al. 1999; 2000; Johnson et al. 2000; Pryce & Harris 2006; Miglior et al. 2007; Battagin et al. 2013). There is, however, a scarcity of estimations of genetic parameters for lactose yield (LY), lactose percentage (LP) and the ratios between milk components. The scarcity of estimations may be due in part to a relatively low value for lactose. Few production records containing lactose data may also be limiting the publication of genetic parameter estimations.

Whole milk powder (WMP) has international codex specifications (CODEX STAN 207-1999, WHO & FAO 2011) which require a specific range of component ratios, with the narrowest range being that of protein-to-protein-plus-lactose (P:P+L). Codex standards for WMP are that it contains 26.5% Fat, 25.1% protein and 39.8% lactose. These standards were set based on a historical product portfolio that allowed the incorporation of surplus lactose resulting from cheese production into WMP, however, the product portfolio has changed in response to changing market demands so that the majority of milk in New Zealand is now processed into WMP. The milk of an average New Zealand cow (4.99% fat, 3.82% protein and 4.70% lactose (anhydrate)) (LIC & DairyNZ 2012; Sneddon et al. 2014a) would make a milk powder of 36.9% fat, 28.3% protein and 34.8% lactose if processed directly without standardisation. The New Zealand cow's milk fails to meet the specification with a rich fat and protein content relative to its lactose content and this deficit can no longer be filled by surplus lactose removed during cheese production (Sneddon et al. 2014a). In New Zealand this has led to a situation where there is a demand for additional lactose to be incorporated into milk to produce WMP in order to maximise the returns from WMP while maximising the lactose component of WMP. In WMP production, standardisation of P:P+L to

approximately 0.39 meets product specifications and optimises lactose use for WMP production (Geary et al. 2010) through the purchase of milk lactose. In order to identify the optimum milk for the New Zealand dairy industry with its given product portfolio it is important to determine the ideal composition of that milk with current and future product portfolio projections in order to generate genetic parameters and allow the estimation of genetic response to various genetic selection programmes.

The aim of this study is to provide genetic parameter estimations for milk traits including lactose based on data collected as part of the national sire proving scheme throughout New Zealand from 70 multi-breed herds.

## **Materials and methods**

### *Data*

Test day information from 4,378 first-lactation cows in the Livestock Improvement Corporation (LIC) sire proving scheme herds was used in this analysis, similar to the methodology of Johnson et al. (2000). From these 4,378 cows there were a total of 15,366 test day records, averaging 3.5 tests per animal. These test day records provided morning and evening milk yields as well as mean daily FP, PP and LP, days in milk (DIM) and somatic cell count (SCC). Daily MY were calculated as the sum of the morning and evening yields and daily FY, PY and LY were calculated by multiplication of MY by the respective percentages. Somatic cell count was transformed to  $\text{Log}_2$  to produce a SCS. Days in milk on test day ranged from day 74 to 297 with a mean mid lactation test at day 135.

All cows used in this analysis were born in 2009 and had their first lactation in the 2011-2012 New Zealand dairy season. Calving month (defined as the month in which the cow calved) was condensed into 3 calving periods, to maintain balanced group sizes. June and July were combined into early-calving, August and September were combined into middle-of-calving and October, November and December were combined into late-calving. This gave three calving periods (June-July (early-calving), August-September (middle-of-calving) and October-November-December (late-calving)) for analysis with an average of 1,460 cows per calving period. This was done to obtain a consistent number of cows per herd in each calving period. Cows with fewer than 3 herd tests in the season were removed from the dataset, as well as animals with no lactose production information or for which sire or dam was unknown to ensure complete records for both ancestry and production. Herds with fewer than 25 first-lactation cows in the dataset were also removed to maintain contemporary group sizes. From a total of 128 herds this gave a sample 70 herds with an average of 62 first-lactation cows per herd and standard deviation of 29 first-lactation cows and a range of 27-157 first-lactation cows. These first-lactation animals represented a subset of the whole herd; most herd removals resulted from no lactose information.

Breed proportions were calculated using pedigree information and were grouped into proportions Holstein-Friesian (F), Jersey (J) and other (OT; Ayrshire, Guernsey, Brown Swiss, Milking Shorthorn, other). Coefficients of specific heterosis and recombination were calculated between any pair of the F, J and OT breeds using the following identities (Dickerson 1973):  $h_{ij} = \alpha_{si}\alpha_{dj} + \alpha_{sj}\alpha_{di}$  and  $r_{ij} = \alpha_{si}\alpha_{sj} + \alpha_{dj}\alpha_{di}$  where  $h_{ij}$  and  $r_{ij}$  are the coefficient of expected heterosis and recombination between fractions of breeds  $i$

and  $j$  in the progeny,  $\alpha_{si}$  and  $\alpha_{sj}$  are proportions of breeds  $i$  and  $j$  in the sire, respectively and  $\alpha_{di}$  and  $\alpha_{dj}$  are proportions of breed  $i$  and  $j$  in the dam, respectively. The total of 4,378 cows was comprised of 811 purebred F, 578 purebred J, 2,556 F×J crossbreds and 433 other breeds and crossbreds.

### *Data analysis*

A single-trait animal model was used for the estimation of heritability and repeatability and a bivariate animal model was used for the estimation of genetic and phenotypic correlations. In matrix notation, the bivariate model can be represented as:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} \mathbf{X}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_2 \end{bmatrix} \begin{bmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \end{bmatrix} + \begin{bmatrix} \mathbf{Z}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{Z}_2 \end{bmatrix} \begin{bmatrix} \mathbf{u}_1 \\ \mathbf{u}_2 \end{bmatrix} + \begin{bmatrix} \mathbf{C}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{C}_2 \end{bmatrix} \begin{bmatrix} \mathbf{p}_1 \\ \mathbf{p}_2 \end{bmatrix} + \begin{bmatrix} \mathbf{e}_1 \\ \mathbf{e}_2 \end{bmatrix}$$

where  $\mathbf{y}_1$  and  $\mathbf{y}_2$  are the vectors of phenotypic measures for two traits under study;  $\mathbf{X}_1$  and  $\mathbf{X}_2$  and  $\mathbf{Z}_1$  and  $\mathbf{Z}_2$  are design matrices relating the fixed and additive genetic effects to the phenotypes, respectively;  $\mathbf{C}_1$  and  $\mathbf{C}_2$  are incidence matrices relating the records to the permanent environmental effects on the animal,  $\mathbf{b}_1$  and  $\mathbf{b}_2$  are the vectors of fixed effects of herd-test-day (day of herd-testing), month of calving, days in milk fitted as a 3<sup>rd</sup> degree Legendre polynomial, the proportion of J or OT, heterosis coefficients of F×J, F×OT and J×OT and the recombination coefficients of F×J, F×OT and J×OT;  $\mathbf{u}_1$  and  $\mathbf{u}_2$  are the vectors of random effects of animal for each trait;  $\mathbf{p}_1$  and  $\mathbf{p}_2$  are the vectors of permanent environmental effects for cow for each trait; and  $\mathbf{e}_1$  and  $\mathbf{e}_2$  are vectors of residual errors not accounted for by the fixed and random effects. The distributional properties of the elements in the model with  $\mathbf{E}$  and  $\mathbf{V}$  indicating the expectation and variance were as follows:

$$\mathbf{E} \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} \mathbf{X}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_2 \end{bmatrix} \begin{bmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \end{bmatrix}$$

and

$$\mathbf{V} \begin{bmatrix} \mathbf{u}_1 \\ \mathbf{u}_2 \\ \mathbf{c}_1 \\ \mathbf{c}_2 \\ \mathbf{e}_1 \\ \mathbf{e}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{A}\sigma_{a1}^2 & \mathbf{A}\sigma_{a12} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{A}\sigma_{a12} & \mathbf{A}\sigma_{a2}^2 & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{I}_1\sigma_{c1}^2 & \mathbf{I}_1\sigma_{c12} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{I}_1\sigma_{c12} & \mathbf{I}_1\sigma_{c2}^2 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{I}_2\sigma_{e1}^2 & \mathbf{I}_2\sigma_{e12} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{I}_2\sigma_{e12} & \mathbf{I}_2\sigma_{e2}^2 \end{bmatrix}$$

where  $\mathbf{A}$  is the numerator relationship matrix of size 9,014, the total number of animals in the pedigree file;  $\sigma_{a1}^2$ ,  $\sigma_{a2}^2$  and  $\sigma_{a12}$  are the animal (co)variance components for the traits under consideration;  $\mathbf{I}_1$  is an identity matrix of size 4,378, the number of cows with records;  $\sigma_{c1}^2$ ,  $\sigma_{c2}^2$  and  $\sigma_{c12}$  are the cow permanent environmental (co)variance components for traits being considered;  $\mathbf{I}_2$  is an identity matrix of size 15,366, the number of herd-test records;  $\sigma_{e1}^2$ ,  $\sigma_{e2}^2$  and  $\sigma_{e12}$  are the residual (co)variance components for the traits. Estimates of (co)variance components were obtained using the Restricted Maximal Likelihood procedure in ASReml package (Gilmour et al. 2009) of VSN International Ltd.

Heritability ( $h^2$ ) of a trait was calculated as:

$$h^2 = \sigma_a^2 / (\sigma_a^2 + \sigma_c^2 + \sigma_e^2)$$

Repeatability (rep) of a trait was calculated as:

$$\text{rep} = (\sigma_a^2 + \sigma_c^2) / (\sigma_a^2 + \sigma_c^2 + \sigma_e^2)$$

Genetic correlations ( $r_g$ ) were estimated as:

$$r_g = \frac{\sigma_{g12}}{\sigma_{g1} \times \sigma_{g2}}$$

where:

$\sigma_{g12}$  = genetic covariance between trait 1 and trait 2, equivalent to  $\sigma_{a12}$ ;

$\sigma_{g1}$  = genetic additive standard deviation for trait 1, equivalent to  $\sqrt{\sigma_{a1}^2}$ ;

$\sigma_{g2}$  = genetic additive standard deviation for trait 2, equivalent to  $\sqrt{\sigma_{a2}^2}$ ;

and phenotypic correlations ( $r_p$ ) as:

$$r_p = \frac{\sigma_{p12}}{\sigma_{p1} \times \sigma_{p2}}$$

where:

$\sigma_{p12}$  = phenotypic covariance between trait 1 and trait 2, equivalent to  $\sigma_{a12} + \sigma_{c12} + \sigma_{e12}$ ;

$\sigma_{p1}$  = phenotypic standard deviation for trait 1, equivalent to  $\sqrt{\sigma_{a1}^2 + \sigma_{c1}^2 + \sigma_{e1}^2}$ ;

$\sigma_{p2}$  = phenotypic standard deviation for trait 2, equivalent to  $\sqrt{\sigma_{a2}^2 + \sigma_{c2}^2 + \sigma_{e2}^2}$ .

Estimated breeding values (EBV) for daily MY, LY, LP and P:P+L were calculated by the addition of relative proportions of the breed effects plus the individual animal effects. Correlations between MY EBV and LY EBV, MY EBV and LP EBV and MY EBV and P:P+L EBV were represented graphically in Figure 3.1.

A milk income merit index (MI) was calculated using the EBV for MY, FY PY and SCS from this dataset and their respective economic values under breeding worth (Bryant 2012) of  $-\$0.091$ ,  $\$1.79$ ,  $\$8.63$  and  $-\$38.57$ , respectively. Phenotypic response to selection in milk traits EBV was estimated by selection of the top 10% of cows for; highest EBV for MY, FY, PY, LY, LP and PP and lowest EBV for P:P+L and PP, as well as the top 10% of animals sorted on their estimated MI. This resulted in 9 groups of 430 animals, some animals were selected in more than one selection scheme, allowing for a comparison between different selection criteria.

## **Results**

Descriptive statistics for milk production traits are shown in Table 3.1. The means for FP, PP and LP were 5.16%, 3.93% and 5.12%, respectively and the mean ratios of protein-to-fat (P:F) and protein-to-protein-plus-lactose (P:P+L) were 0.78 and 0.43, respectively.

**Table 3.1.** Mean, standard deviations (SD), minimum and maximum for milk traits per day.

Trait <sup>1</sup>	Mean	SD	Minimum	Maximum
Milk yield (kg)	13.83	4.29	2.70	39.50
Fat yield (kg)	0.69	0.18	0.10	1.79
Protein yield (kg)	0.53	0.14	0.12	1.50
Lactose yield (kg)	0.71	0.23	0.12	2.12
Fat percentage	5.16	0.92	1.84	11.32
Protein percentage	3.93	0.41	2.76	6.77
Lactose percentage	5.12	0.18	4.30	5.60
P:F	0.78	0.10	0.32	2.16
P:P+L	0.43	0.03	0.33	0.60
Milk solids yield (kg)	1.23	0.32	0.23	3.27
SCS	5.83	1.30	2.59	13.48

<sup>1</sup>P:F = protein-to-fat ratio; P:P+L = protein-to-protein-plus-lactose ratio; SCS = somatic cell score calculated as  $\text{Log}_2(\text{somatic cell count})$ .

Heritabilities are shown in Table 3.2 and were similar between bivariate and univariate analyses, although there was a tendency for the heritabilities to be greater in the bivariate model for MY, FY and PY. Fat yield had heritabilities of 0.12 and 0.19 for univariate and bivariate, respectively. Milk and protein yield heritability estimates were 0.19 and 0.13, respectively in the univariate estimates vs 0.22 and 0.16, respectively in the bivariate. The P:P+L had a moderate estimated heritability of 0.32 ( $\pm 0.04$ ).

**Table 3.2.** Estimates of variance components and heritabilities ( $h^2$ ) and repeatabilities (rep) with their associated standard errors of the mean for milk production traits.

Trait <sup>1</sup>	Univariate						Bivariate		
	$\sigma_a^2$	$\sigma_p^2$	$\sigma_e^2$	$\sigma_{total}^2$	$h^2$	rep	$h^2$	rep	rep
MY	1.1117	1.903	2.9774	5.9921	0.19±0.03	0.50±0.01	0.22±0.04	0.51±0.01	0.51±0.01
FY	0.0018	0.0044	0.0083	0.0144	0.12±0.02	0.42±0.01	0.19±0.03	0.43±0.01	0.43±0.01
PY	0.001	0.0025	0.0042	0.0076	0.13±0.03	0.45±0.01	0.16±0.03	0.46±0.01	0.46±0.01
LY	0.0028	0.0051	0.0083	0.0162	0.18±0.03	0.49±0.01	0.18±0.03	0.49±0.01	0.49±0.01
FP	0.1402	0.1125	0.1491	0.4019	0.35±0.05	0.63±0.01	0.35±0.05	0.63±0.01	0.63±0.01
PP	0.0237	0.023	0.0265	0.0732	0.32±0.05	0.64±0.01	0.32±0.05	0.64±0.01	0.64±0.01
LP	0.0052	0.0072	0.0081	0.0205	0.25±0.04	0.60±0.01	0.25±0.04	0.60±0.01	0.60±0.01
P:F	0.0019	0.0014	0.0038	0.0071	0.27±0.04	0.46±0.01	0.27±0.04	0.46±0.01	0.46±0.01
P:P+L	0.0001	0.0001	0.0001	0.0003	0.32±0.04	0.60±0.01	0.32±0.04	0.60±0.01	0.60±0.01
MSY	0.0042	0.0127	0.0222	0.039	0.11±0.02	0.43±0.01	0.11±0.02	0.43±0.01	0.43±0.01
SCS	0.1193	0.6827	0.6879	1.4898	0.08±0.02	0.54±0.01	0.08±0.02	0.54±0.01	0.54±0.01

<sup>1</sup>MY = milk yield; FY = fat yield; PY = protein yield; LY = lactose yield; MSY = milk solids yield (fat plus protein); FP = fat percentage; PP = protein percentage; P:F = protein-to-fat ratio; P:P+L = protein-to-protein-plus-lactose ratio; SCS = somatic cell score calculated as  $\text{Log}_2(\text{somatic cell count})$ ;  $\sigma_a^2$  = animal additive genetic variance;  $\sigma_p^2$  = cow permanent environment variance;  $\sigma_e^2$  = residual error variance;  $\sigma_{total}^2$  = sum of all variances.

There were strong ( $r > 0.7$ ) genetic and phenotypic correlations between MY, FY, PY and LY (Table 3.3). The genetic correlation between MY and LY was almost 1 and the genetic correlation between LY and PY was strong and positive. The genetic correlation between MY and LP was low and negative at  $-0.11 \pm 0.12$ , however this does overlap with 0. The estimated genetic correlation between P:P+L and PP was found to be highly positive ( $0.94 \pm 0.01$ ) and P:P+L and LP was moderately negative ( $-0.45 \pm 0.09$ ).

**Table 3.3.** Estimates of genetic and phenotypic correlations<sup>1</sup> with standard errors of the mean for milk production traits.

Trait <sup>2</sup>	MY	FY	PY	LY	FP	PP	LP	P:F	P:P+L	MS	SCS
MY	0.75±0.01	0.92±0.01	0.99±0.01	-0.35±0.01	-0.36±0.10	0.01±0.01 <sup>ns</sup>	0.15±0.01	0.15±0.01	-0.33±0.01	0.86±0.01	-0.10±0.01
FY	0.70±0.06	0.81±0.05	0.73±0.01	0.30±0.01	-0.01±0.01 <sup>ns</sup>	-0.02±0.01 <sup>ns</sup>	-0.40±0.01	-0.40±0.01	0.03±0.01	0.97±0.01	-0.05±0.01
PY	0.87±0.03	0.82±0.04	0.90±0.01	-0.17±0.01	-0.01±0.01 <sup>ns</sup>	-0.01±0.01 <sup>ns</sup>	0.17±0.01	0.17±0.01	0.00±0.01 <sup>ns</sup>	0.93±0.01	-0.08±0.01
LY	0.98±0.01	0.40±0.11	0.83±0.04	-0.35±0.01	-0.37±0.01	0.16±0.01	0.15±0.01	0.15±0.01	-0.39±0.01	0.85±0.01	-0.13±0.01
FP	-0.67±0.07	0.37±0.11	-0.42±0.11	-0.68±0.07	0.56±0.01	-0.10±0.01	-0.79±0.01	-0.79±0.01	0.53±0.01	0.11±0.01	0.08±0.01
PP	-0.67±0.07	-0.04±0.12	-0.22±0.12	-0.70±0.07	0.68±0.06	-0.11±0.01	0.01±0.01 <sup>ns</sup>	0.01±0.01 <sup>ns</sup>	0.93±0.01	-0.01±0.01 <sup>ns</sup>	0.09±0.01
LP	-0.11±0.12	-0.14±0.12	-0.24±0.12	0.07±0.12	-0.05±0.11	-0.14±0.11	0.02±0.01 <sup>ns</sup>	0.02±0.01 <sup>ns</sup>	-0.46±0.01	-0.02±0.01 <sup>ns</sup>	-0.19±0.01
P:F	0.42±0.10	-0.53±0.09	0.41±0.11	0.41±0.10	-0.85±0.03	-0.20±0.10	-0.06±0.11	-0.06±0.11	0.00±0.01 <sup>ns</sup>	-0.17±0.01	-0.03±0.01
P:P+L	-0.57±0.08	0.01±0.12 <sup>ns</sup>	-0.13±0.12	-0.66±0.07	0.63±0.06	0.94±0.01	-0.45±0.09	-0.17±0.10	0.00±0.01 <sup>ns</sup>	0.00±0.01 <sup>ns</sup>	0.15±0.01
MSY	0.69±0.07	0.92±0.02	0.84±0.04	0.66±0.07	0.04±0.13	-0.14±0.13	-0.21±0.13	-0.15±0.13	-0.06±0.13	-0.06±0.13	-0.07±0.01
SCS	-0.16±0.15	0.13±0.16	-0.12±0.16	-0.17±0.15	0.22±0.14	0.11±0.14	-0.07±0.14	-0.21±0.14	0.12±0.14	0.03±0.17	

<sup>1</sup>Genetic correlations shown below the diagonal and phenotypic above, along with the associated standard errors.

<sup>2</sup>MY = milk yield; FY = fat yield; PY = protein yield; LY = lactose yield; MSY = milk solids yield (fat plus protein); FP = fat percentage; PP = protein percentage; LP = lactose percentage; P:F = protein-to-fat ratio; P:P+L = protein-to-protein-plus-lactose ratio; SCS = somatic cell score calculated as Log<sub>2</sub>(somatic cell count).  
ns= non-significant correlations P<0.05.

The genetic correlation between MY and P:P+L was  $-0.57 (\pm 0.08)$  which indicates that selection for increased MY would decrease the P:P+L ratio, this is also a reflection of the dataset where the greater volume-producing F animals have less concentrated milk components than J animals. Lactose percentage is less variable in F cows, P:P+L ratio is also lower in F than J or F×J crossbred animals (Table 3.4).

**Table 3.4.** Mean, regression coefficients of Jersey (relative to Holstein-Friesian) and heterosis Holstein-Friesian×Jersey (Het F×J) for milk traits.

Trait <sup>1</sup>	Mean	SE	Jersey	SE	P	Het F×J	SE	P
MY (kg)	15.3	0.48	-2.93	0.19	< 0.001	0.45	0.14	< 0.001
FY (kg)	0.76	0.02	-0.01	0.01	0.456	0.05	0.01	< 0.001
PY (kg)	0.57	0.02	-0.06	0.01	< 0.001	0.03	0.01	< 0.001
LY (kg)	0.78	0.03	-0.14	0.01	< 0.001	0.02	0.01	< 0.001
FP	5.10	0.13	1.08	0.05	< 0.001	0.15	0.04	< 0.001
PP	3.84	0.06	0.38	0.02	< 0.001	0.06	0.02	< 0.001
LP	5.09	0.03	0.05	0.01	< 0.001	0.01	0.01	0.401
P:F	0.76	0.02	-0.09	0.01	< 0.001	-0.01	0.01	0.003
P:P+L	0.43	0.01	0.02	0.01	< 0.001	0.01	0.01	< 0.001
MSY (kg)	1.33	0.04	-0.06	0.01	< 0.001	0.08	0.11	0.229

<sup>1</sup>MY = milk yield; FY = fat yield, PY = protein yield, LY = lactose yield; MSY = milk solids yield (fat plus protein); FP = fat percentage; PP = protein percentage; LP = lactose percentage; P:F = protein-to-fat ratio; P:P+L = protein-to-protein-plus-lactose ratio; SCS = somatic cell score calculated as Log<sub>2</sub>(somatic cell count).

The mean phenotypic performance of the top 10% of animals selected for the highest EBV for MY, LY, PY, PP and LP and the lowest EBV for PP and P:P+L are shown in Table 3.5. Phenotypic responses to selection for MY or LY EBV were the same for all traits, except for the LP which was estimated to be greater under selection for LY EBV compared with MY EBV 4.88 vs 4.86 ( $P < 0.05$ ). Selection for low P:P+L EBV resulted in a low phenotypic mean for P:P+L ( $P < 0.05$ ) compared with the base mean (0.404 vs 0.434). Selection on MY, LY and PY EBV lead to the greatest increases in MY, however, selection for LP and high PP lead to the greatest decreases in MY. Selection on MI lead to differences for FY, FP, LP, P:P+L SCS and MI compared with the base population.

Selection for PP EBV lead to a large number of J cows being selected, this also resulted in the greatest P:P+L and the lowest MI. Selection on MY, PY, LY, low P:P+L and low PP EBV lead to a mostly F animals ( $n = 299-351$  out of 430) selected and no J cows selected. In contrast, selection for high PP EBV selected mostly J with the balance as F×J animals. Selection on LP EBV had similar numbers of J and F×J animals selected (187 and 204, respectively). The selection of the top 10% of animals on their EBV for each trait also led to differences in the proportion of breeds in the selected animals, with significant differences in the proportions of F, J and OT between MY, FY, LP, high PP, low PP and MI EBV selection.

All selection schemes led to significantly different breed compositions compared with the mean of the population ( $P < 0.05$ ). Selection on MI had the fewest deviations from the base population mean, with selection based on MI also causing a significant

decrease in SCS. Selection for high PP and high LP resulted in a significant decrease in mean MY, FY, PY and LY compared with the base population.

**Table 3.5.** Phenotypic responses in milk traits and breed composition to selection of top 10% of cows (n=430) for different estimated breeding values (EBV).

Trait <sup>1</sup>	Selection on											MI <sup>3</sup>	SEM <sup>4</sup>
	Base Mean	MY EBV	FY EBV	PY EBV	LY EBV	LP EBV	Low P:P+L EBV	High PP EBV	Low PP EBV				
MY (kg)	13.80	17.37 <sup>ax</sup>	16.18 <sup>bx</sup>	17.21 <sup>ax</sup>	17.31 <sup>ax</sup>	12.62 <sup>dx</sup>	15.82 <sup>bx</sup>	11.09 <sup>ex</sup>	15.95 <sup>bx</sup>	13.74 <sup>c</sup>	0.14		
FY (kg)	0.69	0.74 <sup>cx</sup>	0.85 <sup>ax</sup>	0.76 <sup>bx</sup>	0.74 <sup>cx</sup>	0.67 <sup>dx</sup>	0.67 <sup>dx</sup>	0.66 <sup>dx</sup>	0.67 <sup>dx</sup>	0.68 <sup>dx</sup>	0.01		
PY (kg)	0.53	0.63 <sup>abx</sup>	0.63 <sup>abx</sup>	0.64 <sup>ax</sup>	0.62 <sup>bx</sup>	0.50 <sup>ex</sup>	0.55 <sup>cx</sup>	0.48 <sup>fx</sup>	0.55 <sup>cx</sup>	0.53 <sup>d</sup>	0.01		
LY (kg)	0.71	0.89 <sup>ax</sup>	0.83 <sup>bx</sup>	0.88 <sup>ax</sup>	0.89 <sup>ax</sup>	0.67 <sup>dx</sup>	0.82 <sup>bx</sup>	0.57 <sup>ex</sup>	0.82 <sup>bx</sup>	0.71 <sup>c</sup>	0.01		
FP	5.08	4.27 <sup>ex</sup>	5.31 <sup>bx</sup>	4.43 <sup>dx</sup>	4.29 <sup>ex</sup>	5.33 <sup>bx</sup>	4.26 <sup>ex</sup>	5.99 <sup>ax</sup>	4.24 <sup>ex</sup>	4.98 <sup>ex</sup>	0.03		
PP	3.89	3.60 <sup>ex</sup>	3.89 <sup>c</sup>	3.71 <sup>dx</sup>	3.60 <sup>ex</sup>	3.97 <sup>bx</sup>	3.48 <sup>fx</sup>	4.33 <sup>ax</sup>	3.48 <sup>fx</sup>	3.86 <sup>c</sup>	0.01		
LP	4.88	4.86 <sup>ex</sup>	4.86 <sup>ex</sup>	4.86 <sup>ex</sup>	4.88 <sup>d</sup>	5.04 <sup>ax</sup>	4.91 <sup>bx</sup>	4.89 <sup>cd</sup>	4.86 <sup>ex</sup>	4.90 <sup>bcx</sup>	0.01		
P:P+L	0.433	0.415 <sup>ex</sup>	0.434 <sup>b</sup>	0.423 <sup>dx</sup>	0.414 <sup>ex</sup>	0.429 <sup>ex</sup>	0.404 <sup>gx</sup>	0.459 <sup>ax</sup>	0.406 <sup>fx</sup>	0.430 <sup>ex</sup>	0.01		
SCS	5.83	5.91 <sup>ab</sup>	5.84 <sup>b</sup>	5.89 <sup>ab</sup>	5.88 <sup>ab</sup>	5.64 <sup>cx</sup>	5.81 <sup>b</sup>	6.00 <sup>ax</sup>	5.85 <sup>b</sup>	5.13 <sup>dx</sup>	0.05		
MI, \$	0.84	1.13 <sup>bc</sup>	0.46 <sup>c</sup>	0.83 <sup>c</sup>	1.27 <sup>bc</sup>	0.96 <sup>c</sup>	1.81 <sup>bx</sup>	-0.93 <sup>dx</sup>	1.92 <sup>bx</sup>	12.30 <sup>ax</sup>	0.30		
Number of selected cows by breed <sup>2</sup>													
F		351	130	323	347	39	317	0	299	89			
J		0	59	0	0	187	0	304	0	41			
FxJ		78	241	107	82	204	110	126	129	297			
OT		1	0	0	1	0	3	0	2	3			
Breed proportion of selected cows													
F	0.53	0.91 <sup>ax</sup>	0.60 <sup>dx</sup>	0.90 <sup>abx</sup>	0.91 <sup>ax</sup>	0.28 <sup>fx</sup>	0.86 <sup>bcx</sup>	0.11 <sup>gx</sup>	0.88 <sup>bcx</sup>	0.48 <sup>ex</sup>	0.01		
J	0.44	0.06 <sup>ex</sup>	0.39 <sup>cx</sup>	0.08 <sup>dex</sup>	0.06 <sup>ex</sup>	0.70 <sup>bx</sup>	0.09 <sup>dx</sup>	0.88 <sup>ax</sup>	0.07 <sup>dex</sup>	0.37 <sup>cx</sup>	0.01		
OT	0.03	0.03 <sup>c</sup>	0.01 <sup>dex</sup>	0.02 <sup>cd</sup>	0.03 <sup>c</sup>	0.02 <sup>dex</sup>	0.05 <sup>bx</sup>	0.01 <sup>ex</sup>	0.06 <sup>bcx</sup>	0.15 <sup>ax</sup>	0.01		

<sup>1</sup>MY = milk yield; FY = fat yield; PY = protein yield; LY = lactose yield; FP = fat percentage; PP = protein percentage; LP = lactose percentage; SCS = somatic cell score calculated as  $\text{Log}_2(\text{somatic cell count})$ ; P:P+L = protein-to-protein-plus-lactose ratio.

<sup>2</sup>F = Holstein-Friesian; J = Jersey; FxJ = Holstein-Friesian x Jersey crossbreed; OT = other breed.

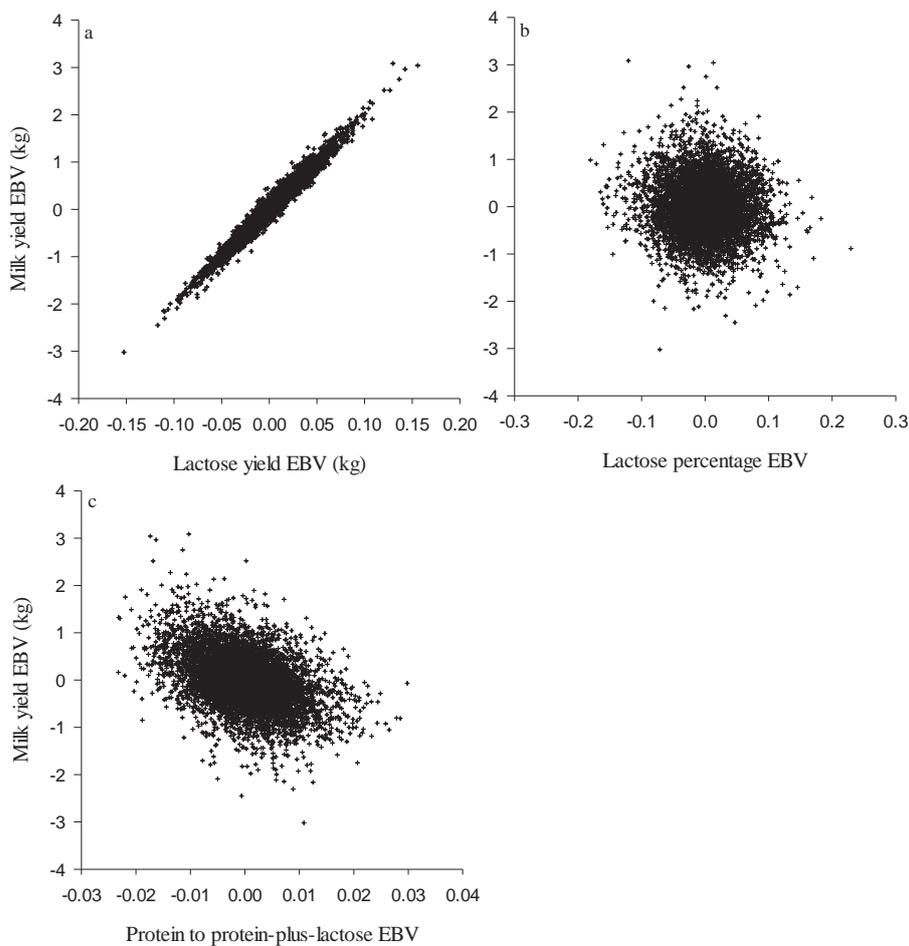
<sup>3</sup>MI = milk income merit calculated as  $(\text{MY EBV} \times 0.091) + (\text{FY EBV} \times 1.79) + (\text{PY EBV} \times 8.63) + (\text{SCS EBV} \times -38.57)$ .

<sup>4</sup>Standard error of the mean.

<sup>a,b,c,d,e,f,g</sup> Means with different letters denote significant differences ( $P < 0.05$ ).

<sup>x</sup> Denotes significant difference between mean of selected animals and mean of the population ( $P < 0.05$ ).

The correlations of LY EBV, LP EBV, P:P+L EBV with MY EBV are shown in Figure 3.1. The correlation coefficients were 0.99, -0.38 and -0.76, which agree with the estimates of genetic correlations shown in Table 3.3.



**Figure 3.1.** Correlation between (a) daily milk yield estimated breeding values (EBV) and daily lactose yield EBV; (b) daily milk yield EBV and daily lactose percentage EBV; (c) daily milk yield EBV and daily protein-to-protein-plus-lactose ratio EBV from first lactation cows in the 2011-2012 dairy season.

## Discussion

The mean MY, FY and PY were similar to the national average for first lactation cows in New Zealand (LIC & DairyNZ 2012). Mean LP (5.12%) was slightly higher in this study than that reported in literature (4.49% - 5.09%, Welper & Freeman 1992; White et al. 2001; Prendiville et al. 2009; Sneddon et al. 2012).

The heritabilities for MY, FY, PY and LY were less than those reported in literature (Welper & Freeman 1992; Roman et al. 2000; Pryce & Harris 2006) while PY was similar to that reported by Stoop et al. (2008). The heritabilities for LP ( $0.25 \pm 0.04$ ) and PP ( $0.32 \pm 0.05$ ) were much less than that expected from previous studies, but the estimate obtained for FP ( $0.35 \pm 0.05$ ) was similar (Welper & Freeman 1992; Roman et al. 2000; Sneddon et al. 2012). Heritabilities were similar to Battagin et al. (2013.) Repeatabilities were high for all traits which indicates consistency within cow throughout the year. The low heritability estimates are unlikely to be a dataset size issue because the number of records used for this study was intermediate compared with those used in previous studies. This study, however, used only one season of first lactation animals, similar to Johnson et al. (2000), compared with most other studies, which used either multiparous animals (Sneddon et al. 2012) or several seasons of data (Welper & Freeman 1992; Vos & Groen 1998; Roman et al. 2000; Roman & Wilcox 2000; Pryce & Harris 2006). The dataset size was, nevertheless, intermediate in size at 4,378 animals, compared with 374-169,661 first lactation cow records (Welper & Freeman 1992; Vos & Groen 1998; Johnson et al. 2000; Roman et al. 2000; Roman & Wilcox 2000; Pryce & Harris 2006; Stoop et al. 2008; Battagin et al. 2013). The use of

primiparous animals allowed for relatively large cohort groups compared with what would have been achieved with multiparous animals.

Daily milk production traits (MY, FY, PY and LY) were all within the reported ranges from literature (Welper & Freeman 1992; Mackle et al. 1996; Vos & Groen 1998; Johnson et al. 2000; Pryce & Harris 2006; Stoop et al. 2008; Prendiville et al. 2009; Sneddon et al. 2012). Lactose percentage, however, showed a greater-than-expected range from 4.3 to 5.6% from previous literature (Welper & Freeman 1992; Mackle et al. 1996; Vos & Groen 1998; Prendiville et al. 2009). A promising amount of variation was also seen in P:P+L which ranged from 0.33 - 0.60. While most of this range is greater than the current optimum ratio for WMP production, it again showed the possibility to select for milk in a different fashion in the future.

There were some very high P:F ratio values in the dataset but these were from early in lactation or samples with high somatic cell counts, which were accounted for in the model. There were no cows that had a consistently high P:F ratio (a P:F over 1.6), indicating that these high P:F values were the result of short-term effects on the cows. This was reflected in the lesser repeatability for P:F ratio compared with P:P+L ratio (0.46 vs 0.60 for P:F and P:P+L, respectively). This could be explained by the greater variation in FP than PP. Breeding experiments have shown it is possible to breed for either a greater or lesser P:F (Vos & Groen 1998). Heritability estimates from this study indicate that it may be possible to breed for an altered P:P+L ratio over time in a similar manner as achieved for P:F in Vos & Groen (1998), however, genetic variation is the limitation in P:P+L improvement with less variation in this trait compared with all the others considered.

The genetic correlation between P:P+L and PY was estimated to be  $-0.13 (\pm 0.12)$  which indicates that selection on PY may not lead to the lesser P:P+L shown in Table 3.5, conversely selection for P:P+L selects low PP animals. The genetic correlation between P:P+L and LY ( $-0.66 \pm 0.07$ ) as well as the phenotypic correlation ( $-0.39 \pm 0.01$ ) indicates that selection on LY would decrease the P:P+L, as shown in Table 3.5. Selection on LY would lead to an increase in MY; however, that would necessitate extra storage capacity and processing to produce the same amount of WMP due to the decreased concentration of milk components in the milk.

The strong positive correlation between MY EBV and LY EBV is similar to those reported in the literature (Johnson et al. 2000; Miglior et al. 2007; Sneddon et al. 2012) and strongly indicates that LY EBV can be directly derived from MY EBV data. Lactose percentage EBV and MY EBV were not strongly correlated which was shown by the clustered distribution in Figure 3.1, indicating that LP EBV could not be directly derived from MY EBV.

There can be difficulties in selecting on ratios, due to differences in heritability between the nominator and denominator, so any selection index would either have to deal with these difficulties or use the selection of multiple traits to have the same effect as selection on the ratio. This could be done by positive selection on LY with a negative weight on MY, similar to the current selection on protein and milk, so as to allow for some increase in volume but a proportionally greater increase in LY or to select directly on LP, such as done in the current New Zealand selection objective where fat and protein yields have positive economic values and milk volume has a negative economic

value (Bryant 2012). Selection on LP resulted in a small but significant decrease in the P:P+L which is supported by the genetic correlation obtained within this study.

Current selection pressure in the New Zealand dairy industry (currently selected on breeding worth, a selection index including 7 traits; annual milk yield, fat yield, protein yield, SCS, fertility, mature live weight and survival, with the greatest proportional economic weighting on protein yield) could be expected to increase the P:P+L ratio as this index aims to restrict liquid volume of milk while increasing the yield of protein. The effect of this is to increase PP which is positively correlated to P:P+L ( $0.94 \pm 0.01$ ). Selection for a greater PP EBV can increase P:P+L as indicated by this study. Selection on MI as a proxy for the production traits within breeding worth resulted in a mean P:P+L of 0.43 which was not significantly different from the mean of the dataset. Selection on MY or LY achieved equal changes in all traits excluding LP. Further research using selection theory is undertaken in chapter 7 to determine the correlated response of the selection objective traits if either LY or LP is included in the selection objective. The economic value for either LY or LP can be estimated using a processing sector model in combination with a farm model (Sneddon et al. 2014b).

Changes within the dairy industry must be led, however, by the farmers and this requires economic signals regarding the value of the milk. To alter the selection index by inclusion of any trait requires an economic value to be estimated using economic modelling which is yet to be undertaken by NZAEL. The future of the selection indices depend on the direction in which the milk product portfolio moves and the demands for lactose under these different processing methods. As there is a lag period in between breeding scheme changes and selected animals entering the milking herd, any volatile

changes in the potential future scenarios can have dramatic effects on the suitability of these animals for the products being produced. This is potentially what has happened in the New Zealand dairy industry with regard to lactose demands, with a dramatic increase in WMP and SMP in the past 10 years (687,000 to 2,353,000 tonnes from 2002 to 2012) (Fonterra 2003; 2012) this increase has led to greater protein use for WMP, but it has also created a lactose deficit.

### **Conclusion**

Estimates of heritability for yield traits reported in this study were less than previous estimates and the heritabilities of the concentration (FP, PP and LP) traits were much less than expected; the reason for this has not yet been identified. Bivariate and univariate estimations of heritability were similar. Genetic and phenotypic correlations among all traits were similar to previous estimates. The dataset used in this study had a P:P+L ratio greater than that considered economically optimal without alteration for the production of whole milk powder. Reducing P:P+L to the optimal level for protein utilisation in WMP production would occur with selection for either increased LY or MY, but not to the extent that selection directly on P:P+L or for a low PP EBV could achieve. Selection on LP could decrease the P:P+L given results of this study. The weighting on PY would also have to be reduced to achieve the target P:P+L as the current selection index is increasing PP which can increase the P:P+L ratio.

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## Chapter 4

### **Lactose demand in New Zealand and Ireland under different simulated milk product portfolios**

N.W. Sneddon<sup>a\*</sup>, N. Lopez-Villalobos<sup>a</sup>, R.E. Hickson<sup>a</sup>, S.R. Davis<sup>b</sup>, L. Shalloo<sup>c</sup>, D.J.

Garrick<sup>a</sup> and U. Geary<sup>c</sup>

<sup>a</sup>Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Private Bag 11-222, Palmerston North, New Zealand;

<sup>b</sup>Livestock Improvement Corporation, Private Bag 3016, Hamilton 3240, New Zealand;

<sup>c</sup>Dairy Production Department, Teagasc, Moorepark Production Research Centre, Fermoy, Co. Cork, Cork, Ireland



**Abstract**

Maximising dairy industry profitability involves maximising product returns for a specific set of costs or to minimise costs for a certain level of output. A strategy currently utilised by the New Zealand dairy industry to optimise the value of exports is to incorporate imported lactose along with local milk to maximise the production of whole milk powder (WMP) while complying with the codex standards and increasing the exported product for every litre of milk. This study investigated the impact of different product portfolio strategies on lactose requirements for the Irish and New Zealand dairy industries for current and predicted 2020 milk output projections. A mass balance processing-sector model that accounts for all inputs, outputs and losses involved in dairy processing was used to simulate the processing of milk into WMP, skim milk powder (SMP), cheese, butter and fluid milk of different proportions. All scenarios investigated projected an increase in production and revenue from 2012 to 2020. Higher cheese production reduced industry lactose demand through whey processing, while scenarios reliant on an increase in the proportion of WMP were associated with increased lactose deficits.

***Keywords:***

Lactose demand; New Zealand; Ireland; processing model

## **Introduction**

The dairy industries of both New Zealand and Ireland are limited by land area available for dairy expansion where cows can access feed within a reasonable walking distance from a milking shed. These limits of land area come from geographical (such as topography and soil types) and climatic factors as well as social and political restrictions. The New Zealand dairy industry is reaching its limit for pastoral dairying, with 15% of land originally classified as arable farm land now in dairying (LIC & DairyNZ 2014; World Bank 2014) and is facing increased feed costs with imported feeds increasing as a proportion of the total diet, while reducing the resilience of the overall dairy industry. The EU milk quota regime ceased for the EU and Irish dairy industry on 31st March 2015 with potential for expansion at farm level now for the first time in a generation for many. Dairy farm profitability will be determined by the most limiting resource which, on most farms, will be land area.

Profitability at dairy industry level is maximised when the output of the most profitable products is prioritised across a supply profile that balances costs at farm and at processor level. The optimisation process centres on maximising product returns (including by-products) after accounting for costs and making the most of the available local resources. The purchase of additional milk components as ingredients beyond raw milk, such as lactose, may increase manufactured product yields. The associated increases in ingredient costs are only justified if they are less than the increased value of the final product after accounting for the processing costs. In any scenario, the composition of manufactured dairy products must remain within market requirements and codex standards.

In New Zealand, in the past, milk was standardised by removing excess fat and protein and selling it separately, while over the past 10 years there is an increasing trend of importing lactose to extend the yield of WMP. There is a requirement to meet a set of international codex requirements (codex standard 207-1999 WHO & FAO 2011). Milk from the New Zealand herd is deficient in lactose relative to fat and protein when manufactured into WMP, which limits complete utilisation of fat and protein during the manufacture of WMP (Sneddon et al. 2014). Processors can either purchase lactose, utilise excess protein and/or fat in the form of less valuable products, or change their product portfolio. Currently New Zealand's dairy processors purchase milk lactose from international markets, maximising the amount of WMP produced and exported. In Ireland, this has not occurred because lactose has not been in deficit. However, it is anticipated that post-quota, there will be dairy expansion and much of the additional milk will be processed into WMP which may create situations where lactose is limited. The objective of this study was to investigate the impact of different product portfolios for Irish and New Zealand dairy industries in terms of lactose demand given current and anticipated milk constituents and current and future product portfolios across a range of input costs and output prices.

## **Materials and methods**

### *Model description*

A more detailed description of the model functionality and methodology is available in Geary et al. (2010). This mass balance processing-sector model accounts for all inputs, outputs and losses involved in dairy processing (Geary et al. 2010). The model of Geary et al. (2010) was used in this study to simulate the standardisation and processing of WMP, SMP, cheese, butter and fluid milk from milk purchased from farm. Key inputs for the model were volume and composition of milk and product portfolio and its composition. The quantities of products and by-products that can be produced from the available milk pool by balancing inputs of fat and protein are calculated (Geary et al. 2010). The model balanced fat and protein, to identify lactose deficits or surpluses when producing product to current codex standards.

For the purposes of this study, additional economic calculations were completed using model outputs. These were the calculation of gross income, as product yields multiplied by product values and net revenue, as gross income minus processing costs of each product. Values for each product were estimated from the Global Dairy Trade (Global Dairy Trade 2013) historic data for the 2011-2012 dairy season for the current and future scenarios while manufacturing costs were utilised from Geary et al. (2010).

***Processor returns***

Gross revenues were calculated as the sum of all product outputs multiplied by their respective market values. Lactose costs were calculated as the price of lactose multiplied by the size of the lactose processing deficit in tonnes. Net revenues were the sum of gross revenue of each product minus the collective processing costs and cost to purchase additional lactose as an ingredient.

Economic calculations were based on outputs from the Moorepark processing sector model (MPSM) and dairy product prices in USD for WMP, SMP, cheese, butter, butter milk powder (BMP), casein and milk protein concentrate (MPC) 70 (used as a proxy for MPC90) from the Global Dairy Trade auction from June 1st 2011 to May 15th 2012 (Global Dairy Trade 2013). The price for whey powder (WP) was not available from the GDT so was based on the average price for 2012 of €917.5 per tonne (Productschap Zuivel 2013), converted to USD 1241.54 per tonne using the average 2012 exchange rate of USD 1.35 per euro (NZForex 2013). All values in Table 4.1 are in USD as this is the common currency of Global Dairy Trade all values were converted to USD based on this exchange rate.

**Table 4.1.** 2011/2012 economic values (USD) of products in the model simulation and 2010 and 2011 product values used in sensitivity analysis and production cost per product used for all years of economic calculation.

Year	USD/ Tonne of product <sup>1</sup>									
	WMP	SMP	Cheese	Butter	Casein	MPC90	WP	BMP	Lactose	
2012	3355.39	3292.63	3454.51	3994	8185.59	5549.36	1241.54	3133.1	1979.27	
2011	3605	3321	4168	4344	10519	6148	157.35	3133.1	-	
2010	3215	3953	3679	3539	8782	5197	922.73	3042	-	
Production cost	496.95	465.75	449.5	441.25	572.05	572.05	572.05	429.3	286	

<sup>1</sup>WMP = whole milk powder; SMP= skim milk powder; MPC90 = milk protein concentrate 90% protein; WP = whey powder; BMP = butter milk powder. USD = American dollar.

### *Costs*

Costs for production of each tonne of product are shown in Table 4.1. These costs were converted to USD from those in Geary et al. (2010) using the same conversion factor as for product prices. Costs for MPC90 and Casein were assumed to be equal to the cost of manufacture of WP due to similarities in processing requirements and lactose recovery was assumed to be equal to half the cost of WP production due to a lower drying requirement. Costs were calculated per product (with the addition of lactose ingredient costs included) and summed to estimate total costs.

### **Data**

Product composition were assumed to be based on the international codex standards as in Geary et al. (2010) and Table 4.2. Milk production (total litres) and composition (milk fat, protein and lactose concentrations) for both Ireland and New Zealand is shown in Table 4.3. In order to complete current and future scenarios, a range of scenarios were taken based on current national situations and projected future 2020 milk output circumstances for Ireland and New Zealand accounting for expected gains in these two dairy industries.

**Table 4.2.** Composition of dairy products in g/100g of final product.

Component	Product <sup>1</sup>							
	WMP	SMP	Cheese	Butter	Casein	MPC90	WP	BMP
Fat	26.50	1.00	35.00	84.00	0.00	0.00	1.00	8.30
Protein	25.10	33.00	24.50	0.59	89.00	90.50	15.15	41.72
Lactose	39.80	54.00	1.39	0.79	0.56	Trace	77.15	40.32
Minerals	5.90	8.00	2.15	0.12	0.80	Trace	4.32	4.66
Water	2.70	4.00	35.26	14.50	9.64	9.50	2.38	5.00

<sup>1</sup>WMP = whole milk powder; SMP = skim milk Powder; MPC90 = milk protein concentrate 90% protein; WP = whey powder; BMP = butter milk powder.

**Table 4.3.** Baseline 2012 dairy industry production (LIC & DairyNZ 2012; CSO 2013; DCANZ 2013) and estimated future production (based on current rate of expansion for New Zealand (LIC & DairyNZ 2012) and Irish expansion post-quota) figures for Ireland and New Zealand.

Country	Milk (Litres, billions)	Fat (%) <sup>1</sup>	Protein (%) <sup>1</sup>	Lactose (%) <sup>1</sup>
Ireland 2012	5.376	3.94	3.37	4.61
Ireland 2020	7.500	4.08	3.43	4.61
New Zealand 2012	19.742	4.96	3.90	4.95
New Zealand 2020	26.220	5.03	3.98	4.95

<sup>1</sup>percentage as g/100g of milk, lactose concentration measured as lactose monohydrate.

### ***Irish scenarios***

Data for the Irish baseline was obtained from the Central Statistics Office (CSO) (2013), Geary et al. (2012) and Geary et al. (2014) which provided milk volume (Litres) and concentrations of milk fat, protein and lactose. These were average concentrations per month for the 2012 season; the weighted annual average was calculated for use in the MPSM. For Ireland, the production in 2020 was estimated based on an increase in milk output by 50% from averages between 2007 and 2009 periods, equating to approximately 7.5 billion litres of milk (Shalloo 2013 per comm). Milk fat and protein concentration were assumed to increase at 0.016% and 0.008% per year, respectively

based on historical changes, while lactose concentration was assumed to remain stable. Production for 2012 and estimated 2020 seasons are shown in Table 4.3.

Product mixes used for each of the scenarios for both Ireland and New Zealand are shown in Table 4.4. Product mixes were chosen to reflect 5 possible product portfolios. In the Irish base line scenario (Scenario 1), the milk production and product mix from 2012 was assumed, Irish Scenarios 2-6 reflect using 100%, 75%, 50%, 25% and 0% of the additional milk available in 2020 in the production of WMP with the balance processed into cheese. In scenarios where there was excess protein from the production of SMP this was processed into MPC90. Where the model had excess protein in the formation of SMP this was processed into casein products.

**Table 4.4.** Proportion (%) of total milk to each product stream in initial modelling.

Scenario <sup>2</sup>	Product <sup>1</sup>				
	WMP	SMP	Cheese	Butter	Casein
Irish Base	13.0	17.5	38.0	31.5	-
Irish Scenario 2	37.65	12.5	25.25	22.6	-
Irish Scenario 3	30.5	12.5	34.4	22.6	-
Irish Scenario 4	23.5	12.5	41.4	22.6	-
Irish Scenario 5	16.4	12.5	48.5	22.6	-
Irish Scenario 6	9.3	12.5	55.6	22.6	-
New Zealand (NZ) Base	60.0	23.5	14.0	0.5	2.0
NZ Scenario 2, 3 and 5	60.0	23.5	14.0	0.5	2.0
NZ Scenario 4	69.5	18.0	10.5	0.5	1.5
NZ Scenario 6	13.95	5.46	80.0	0.11	0.48

<sup>1</sup>WMP = whole milk powder; SMP = skim milk powder.

<sup>2</sup>Irish base line is 2012 season milk and product mix; Irish Scenario 2 is 100% of post quota milk into WMP; Irish Scenario 3 is 75% of post quota milk into WMP with 25% into cheese; Irish Scenario 4 is 50% of post quota milk into both WMP and cheese; Irish Scenario 5 is 25% of post quota milk into WMP with 75% into cheese; Irish Scenario 6 is 100% of post quota milk into cheese.

New Zealand (NZ) base is 2012 season milk and estimated product mix; NZ Scenarios 2, 3 and 5 have the same initial product mix as base with 2020 estimated milk production; Scenario 2 is 2020 production with 2012 portfolio; Scenario 3 is back calculated to have no lactose deficit with excess fat and protein going into butter and casein, respectively; Scenario 4 is 100% of increased milk production into WMP; Scenario 5 is back calculated to recover 80% of lactose from cheese whey to be incorporated into WMP; Scenario 6 is 80% of total milk production into cheese.

### *New Zealand scenarios*

Data for the New Zealand baseline scenario was from DCANZ 2013, in milk volume (litres) for each month of the 2011-2012 dairy season. Milk fat and protein production was obtained from New Zealand dairy statistics (LIC & DairyNZ 2012). Lactose percentage was estimated from a national dataset obtained from LIC (unpublished data). The weighted annual average concentrations were calculated from these monthly average figures for use in the MPSM. For the estimation of the 2020 milk production it was assumed milk production would continue to increase at 4% per year as estimated using data from NZ dairy statistics (LIC & DairyNZ 2012) with milk fat and protein concentration increasing at 0.006% and 0.008% per year respectively (LIC & DairyNZ 2012). Production parameters for the current base and predicted 2020 are shown in

Table 4.3. The product portfolios were estimated from several sources including the Fonterra annual report 2012 (Fonterra 2012a), Fonterra farm gate milk price statement (Fonterra 2012b) and Fonterra milk price – the facts (Fonterra 2012c). All of which were used to compile an estimated product portfolio.

The product mix for each scenario is shown in Table 4.4. The New Zealand current production (Scenario 1) was based on the 2011-2012 dairy season data (DCANZ 2013). Scenario 2 simulates the impact of using 2020 milk production with the actual 2012 product portfolio. In Scenario 3 the production of WMP was adjusted to balance available lactose, with excess fat and protein used for butter and casein production respectively, complying with Codex standards without importing lactose. Scenario 4 used all the predicted increase in milk production to produce WMP with imported lactose. Scenario 5 achieved lactose recovery of 80% from whey by ultrafiltration at efficiencies similar to levels reported in industry publications (Archer 1998; Mollea et al. 2013) with MPC being produced from the remaining WP. Scenario 6 assumed that 80% of the additional milk was converted into cheese with the remaining increase converted to WP production.

- Scenario 1. Actual 2012 milk production with 2012 product portfolio
- Scenario 2. Predicted 2020 milk production with 2012 product portfolio
- Scenario 3. Predicted 2020 milk production, no external lactose incorporated, excess fat and protein incorporated into butter and MPC
- Scenario 4. Predicted 2020 milk production, increased milk production towards WMP with imported lactose

- Scenario 5. Predicted 2020 milk production with 2012 product portfolio with lactose recovery from WP with deficit filled with imported lactose
- Scenario 6. Predicted 2020 milk production, 80% of milk towards cheese production

The model was run with the same product portfolios for scenarios 2, 3 and 5. From the resulting model outputs in Scenario 3, fat and protein were removed until the balance was achieved for lactose (giving no imported lactose), excess fat was incorporated into butter and excess protein was incorporated into MPC90. In Scenario 5 (lactose recovery from WP) it was assumed that ultra-filtration of whey would yield 80% (Archer 1998; Mollea et al. 2013) of the total lactose content as lactose powder with the remainder being incorporated into the WP production process. The recovered lactose was subtracted from the lactose deficit from WMP to reduce the total lactose deficit in the system.

### *Sensitivity*

To analyse effects of product prices on net revenues, average product prices from 2010, 2011 and 2012 were utilised (Fonterra 2012b; CLAL 2013; DairyCo 2013a; 2013b; Global Dairy Trade 2013; Productschap Zuivel 2013). These values are shown in Table 4.1. These numbers were used to compare between 3 different pricing scenarios in which the value of cheese and WMP differentiated.

## Results

Product outputs for the Irish scenarios are shown in Table 4.5 and the New Zealand scenarios in Table 4.6. Milk output and product outputs are greater in New Zealand than in the Irish scenarios due to the significant differences in the size of the industries in each country. In order to complete comparisons between the two industries they were compared on key traits common to both industries. Based on 2012 production levels, New Zealand proportionally made four and a half times as much of its milk (54.2%) into WMP compared with Ireland (11.7%), whereas Ireland produced almost twice as much milk into SMP and cheese and made almost three times as much WP.

**Table 4.5.** Tonnes (,000) of product produced from modelling alternative scenarios for Ireland.

Scenario <sup>2</sup>	Product <sup>1</sup>							Lactose Deficit
	WMP	SMP	Cheese	Butter	MPC90	WP	BMP	
1	93 (11.7)	212 (26.4)	227 (28.4)	124 (15.6)	15.1 (1.9)	114 (14.3)	14 (1.7)	-5
2	383 (34.4)	211 (19.0)	231 (20.8)	141 (12.7)	16.7 (1.5)	114 (10.3)	14 (1.3)	-23
3	310 (27.5)	211 (18.7)	292 (25.9)	138 (12.3)	16.7 (1.5)	144 (12.8)	16 (1.4)	-19
4	239 (20.9)	211 (18.5)	351 (30.8)	135 (11.9)	16.7 (1.5)	174 (15.2)	14 (1.2)	-14
5	166 (14.4)	211 (18.2)	411 (35.6)	132 (11.4)	16.7 (1.5)	204 (17.6)	15 (1.3)	-10
6	95 (8.1)	211 (18.0)	472 (40.3)	129 (11.0)	16.7 (1.4)	234 (20.0)	15 (1.2)	-6

Values in brackets are the contribution (%) of that product to the national product portfolios.

<sup>1</sup>WMP = whole milk powder; SMP= skim milk powder; MPC90 = milk protein concentrate 90% protein; WP = whey powder; BMP = butter milk powder.

<sup>2</sup>Scenario 1 is 2012 season milk and product mix; Scenario 2 is 100% of post quota milk into WMP; Scenario 3 is 75% of post quota milk into WMP with 25% into cheese; Scenario 4 is 50% of post quota milk into both WMP and cheese; Scenario 5 is 25% of post quota milk into WMP with 75% into cheese; Scenario 6 is 100% of post quota milk into cheese.

**Table 4.6.** Tonnes (,000) of product produced from modelling alternative scenarios for New Zealand.

Scenario <sup>2</sup>	Product <sup>1</sup>								
	WMP	SMP	Cheese	Butter	Casein	MPC90	WP	BMP	Lactose Deficit
1	1,774 (54.2)	494 (15.1)	347 (10.6)	429 (13.1)	12 (0.4)	-	165 (5.0)	54 (1.6)	-129
2	2,400 (54.5)	666 (15.1)	469 (10.6)	566 (12.8)	17 (0.4)	-	219 (5.0)	71 (1.6)	-271
3	1,926 (47.6)	532 (13.2)	469 (11.6)	691 (17.1)	-	136 (3.4)	219 (5.4)	71 (1.8)	0
4	2,780 (63.3)	513 (11.7)	352 (8.0)	507 (11.5)	13 (0.3)	-	164 (3.7)	64 (1.5)	-282
5	2,400 (56.1)	666 (15.6)	469 (11.0)	565 (13.2)	17 (0.4)	-	913 (2.1)	71 (1.7)	-131
6	558 (11.5)	155 (3.2)	2,682 (55.2)	184 (3.8)	4 (0.1)	-	1,251 (25.8)	21 (0.4)	-43

Values in parenthesis are contributions (%) of that product to the national product portfolio.

<sup>1</sup>WMP = whole milk powder; SMP = skim milk powder; MPC90 = milk protein concentrate, 90% protein; WP = whey powder, BMP = butter milk powder.

WP has 80% of lactose removed making it (13.6% fat, 30.1% protein, 38.5% lactose, 13.1% minerals and 4.6% water.

<sup>2</sup>Scenario 1 is 2012 season milk and estimated product mix; Scenarios 2,3 and 5 have the same initial product milk as base with 2020 estimated production; Scenario 2 is 2020 production with 2012 portfolio; Scenario 3 is back calculated to have no lactose deficit with excess fat and protein going into butter and casein, respectively; Scenario 4 is 100% of increased milk production into WMP; Scenario 5 is back calculated to recover 80% of lactose from cheese whey to be incorporated into WMP; Scenario 6 is 80% of total milk production into cheese.

It was predicted that by 2020 milk production in New Zealand will rise to 26.2 billion litres based on a compound growth of 4% per year, with milk fat and protein concentrations increasing to 5.03% and 3.98% respectively. For Ireland, post quota the industry goal is a 50% increase in milk volume taking Irish milk production to approximately 7.5 billion litres of milk with milk fat and protein concentrations increasing to 4.08% and 3.43% respectively.

When evaluated on the total yields of products SMP, butter, MPC90 and BMP did not vary much between the Irish scenarios. However, the volumes of WMP, cheese and WP varied from scenarios 2 to 6 as the use of post-quota milk shifted from WMP to cheese. Cheese and WP production was similar to base line in scenario 2 and WMP was similar to baseline in Scenario 6.

Gross revenue from model outputs for Ireland are presented in Table 4.7. Based on expected 2020 milk production and average 2012 (Global Dairy Trade 2013; Productschap Zuivel 2013) product price assumptions for Ireland, the greatest gross revenue would be achieved with 100% of post-quota milk going into WMP production. This would see the production of 290,000 more tonnes of WMP compared with 2012 and an increase of 1.1 billion USD in gross revenue. The difference in gross revenue between scenarios of 100% of additional milk going into WMP compared with 100% into cheese was estimated to be approximately 37 million USD (USD 3,622,508,000 vs USD 3,585,139,000).

**Table 4.7.** Gross revenue (millions USD) from model outputs for Irish scenarios.

Scenario <sup>2</sup>	Product <sup>1</sup>							Gross Revenue
	WMP	SMP	Cheese	Butter	MPC90	WP	BMP	
1	313	694	785	497	84	142	43	2,558
2	1,285	694	799	565	93	142	45	3,623
3	1,041	694	1,008	552	93	179	49	3,616
4	802	694	1,213	540	93	216	44	3,602
5	560	694	1,421	528	93	253	47	3,596
6	317	694	1,629	516	93	290	46	3,585

<sup>1</sup>WMP = whole milk powder; SMP= skim milk powder; MPC90 = milk protein concentrate; WP = whey powder; BMP = butter milk powder.

<sup>2</sup>Scenario 1 is 2012 season milk and product mix; Scenario 2 is 100% of post quota milk into WMP; Scenario 3 is 75% of post quota milk into WMP with 25% into cheese; Scenario 4 is 50% of post quota milk into both WMP and cheese; Scenario 5 is 25% of post quota milk into WMP with 75% into cheese; Scenario 6 is 100% of post quota milk into cheese

Under New Zealand product scenarios WMP production was maximised in Scenario 4 (all increased milk to WMP) and minimised in Scenario 6 (80% of additional milk processed into cheese). Cheese production was greatest in Scenario 6, but similar among Scenarios 2, 3 and 5 and among Scenarios 1 and 4.

Gross revenue from the model outputs for New Zealand are presented in Table 4.8. Using the New Zealand 2020 production estimations with baseline 2012 economic product returns, it was estimated the greatest gross revenue would be generated under the scenario all extra milk was used for WMP. This reflects the current strategy used in the New Zealand dairy industry. The least gross revenue would be generated when no lactose was imported. The difference in gross revenue between these two scenarios (3 (no imported lactose) and 6 (80% of milk used for cheese production)) is approximately 920 million USD. Due to the restriction in New Zealand Scenario 3 on importation of lactose for use in WMP, there is only an increase in WMP production of 152,000 tonnes (8% increase) between the baseline 2012 scenario and 2020 no lactose imported scenario, despite a 32% increase in total milk volume.

**Table 4.8.** Gross revenue (millions USD) from model outputs for New Zealand scenarios.

Scenario <sup>2</sup>	Product <sup>1</sup>						WP	BMP	Gross Revenue
	WMP	SMP	Cheese	Butter	Casein	MPC90			
1	5,952	1,625	1,198	1,711	101		204	168	10,961
2	8,054	2,193	1,622	2,259	137		272	223	14,760
3	6,463	1,752	1,622	2,761		753	272	223	13,846
4	9,329	1,690	1,216	2,023	103		204	200	14,766
5	8,054	2,193	1,622	2,259	137		112	223	14,601
6	1,873	509	9,266	734	33		1,553	66	14,034

<sup>1</sup>WMP = whole milk powder; SMP= skim milk powder; MPC90 = milk protein concentrate; WP = whey powder; BMP = butter milk powder.

<sup>2</sup>Scenario 1 is 2012 season milk and estimated product mix; Scenarios 2, 3 and 5 have the same initial product mix as base with 2020 estimated milk production; Scenario 2 is 2020 production with 2012 portfolio; Scenario 3 is back calculated to have no lactose deficit with excess fat and protein going into butter and casein, respectively; Scenario 4 is 100% of increased milk production into WMP; Scenario 5 is back calculated to recover 80% of lactose from cheese whey to be incorporated into WMP; Scenario 6 is 80% of total milk production into cheese.

The cost to produce each product was estimated using production costs of Geary et al.

(2010) to estimate financial differences between scenarios for Ireland and New Zealand.

Processing costs, lactose costs and net revenues are shown in Table 4.9.

**Table 4.9.** Costs and net revenue (millions USD) for each scenario after accounting for manufacturing costs.

Scenario (Ireland) <sup>1</sup>	Production Cost	Lactose costs	Net revenue	Scenario (NZ) <sup>2</sup>	Production Cost	Lactose costs	Net revenue
1	382	-9.8	2,168	1	1,581	-275.1	9,105
2	536	-43.5	3,041	2	2,129	-536.0	12,257
3	543	-37.6	3,035	3	1,955		11,892
4	550	-27.7	3,025	4	2,131	-558.2	12,076
5	557	-19.8	3,019	5	2,096	-259.2	12,246
6	564	-11.9	3,010	6	2,363	-85.1	11,586

<sup>1</sup>Ireland Scenario 1 is 2012 season milk and product mix; Irish Scenario 2 is 100% of post quota milk into WMP; Irish Scenario 3 is 75% of post quota milk into WMP with 25% into cheese; Irish Scenario 4 is 50% of post quota milk into both WMP and cheese; Irish Scenario 5 is 25% of post quota milk into WMP with 75% into cheese; Irish Scenario 6 is 100% of post quota milk into cheese.

<sup>2</sup>New Zealand scenario 1 is 2012 season milk and estimated product mix; NZ Scenarios 2, 3 and 5 have the same initial product mix as base with 2020 estimated milk production; NZ Scenario 2 is 2020 production with 2012 portfolio; NZ Scenario 3 is back calculated to have no lactose deficit with excess fat and protein going into butter and casein, respectively; NZ Scenario 4 is 100% of increased milk production into WMP; NZ Scenario 5 is back calculated to recover 80% of lactose from cheese whey to be incorporated into WMP; NZ Scenario 6 is 80% of total milk production into cheese.

The difference in net revenue between the highest and lowest gross revenue scenarios (scenario 2 vs scenario 6) was 31 million USD (USD 3,040,953,000 vs USD 3,009,604,000) for Ireland. This difference is despite a lactose cost difference of 32 million USD between the scenarios. This can be linked to the increased cost of processing cheese and WP relative to WMP. Sensitivity analyses are presented in Table 4.10. When individual dairy season prices of 2010, 2011 were included in the analysis, Irish Scenario 6 (55.6% to cheese) became the more profitable option for the dairy industry in 2010 and 2011 compared to Irish Scenario 2 (37.7% to WMP) which was the most profitable under 2012 prices. This is due to a greater difference in the values of cheese and WMP in these individual years (Shown in Table 4.1).

**Table 4.10.** Effect of yearly variation on net revenue (millions USD) of each scenario.

Scenario (Ireland) <sup>1</sup>	2012	2011	2010	Scenario (NZ) <sup>2</sup>	2012	2011	2010
1	2,168	2,404	2,246	1	9,105	9,980	9,015
2	3,041	3,359	3,070	2	12,095	13,274	11,979
3	3,036	3,375	3,081	3	11,639	13,035	11,892
4	3,025	3,385	3,085	4	12,076	13,236	11,823
5	3,019	3,401	3,095	5	12,286	13,476	12,211
6	3,010	3,419	3,101	6	11,586	13,614	11,730

All prices are relative to 2012 USD. Values are net revenue, costs were assumed to remain the same across years.

<sup>1</sup>Ireland Scenario 1 is 2012 season milk and product mix; Irish Scenario 2 is 100% of post quota milk into WMP; Irish Scenario 3 is 75% of post quota milk into WMP with 25% into cheese; Irish Scenario 4 is 50% of post quota milk into both WMP and cheese; Irish Scenario 5 is 25% of post quota milk into WMP with 75% into cheese; Irish Scenario 6 is 100% of post quota milk into cheese.

<sup>2</sup>New Zealand scenario 1 is 2012 season milk and estimated product mix; NZ Scenarios 2, 3 and 5 have the same initial product mix as base with 2020 estimated milk production; NZ Scenario 2 is 2020 production with 2012 portfolio; NZ Scenario 3 is back calculated to have no lactose deficit with excess fat and protein going into butter and casein, respectively; NZ Scenario 4 is 100% of increased milk production into WMP; NZ Scenario 5 is back calculated to recover 80% of lactose from cheese whey to be incorporated into WMP; NZ Scenario 6 is 80% of total milk production into cheese.

After incorporating production and lactose costs the maximum difference in net revenue between scenarios in New Zealand (2 and 6) was 687 million USD. This represents the increase in costs associated with cheese production and whey powder processing; which were greater than the costs to process WMP even when lactose purchase costs are included in the analysis.

When the 2010, 2011 and 2012 prices were used in the New Zealand scenario the lowest net revenue occurred in Scenario 6 in 2010 and 2012 and Scenario 3 in 2011. Scenario 5 was the most profitable scenario in 2010 and 2012, with scenario 6 most profitable in 2011. The difference between best and worst New Zealand scenarios being 481, 579 and 700 million USD for 2010, 2011 and 2012 respectively or 5.2%, 6.3% and 7.7% of 2012 net revenue. However, this study did not investigate the effect of increased product supply/demand balance on product value, as increased supply would most likely lead to a decrease in product values, and vice versa.

## Discussion

Milk production is projected to increase by 47% between 2015 and 2020 in Ireland as a result of the lifting of the European milk quotas (Laepplé & Hennessy 2012). In terms of total world supply, this increase would not be expected to be significant, with total Irish production accounting for only 0.87% of global milk production, whereas in New Zealand milk production is expected to continue to increase at historic rates. The increased production will bring Irish output close to 7.5 billion litres and New Zealand to 26.2 billion litres.

The scenarios outlined for the Irish industry used a base production situation where the post-quota milk was directed towards either WMP or cheese production. This leads to a decrease in the proportion of milk used for SMP and butter (decreases of 5 and 8.9%, respectively). While the quantity of milk partitioned towards these products did not decrease, the amount of butter produced decreased from 141,000 tonnes under Scenario 2 to 129,000 tonnes under Scenario 6. This change in butter production was due to the fact that there is a larger requirement for fat to balance cheese standards than there is for WMP.

Whole milk powder under the Irish scenario was closely aligned to the proportions outlined in the model inputs, with WMP making up 34.4% of the product portfolio in Scenario 2 and 8.1% in Scenario 6. The quantities of milk products in Scenario 1 matched current Irish industry product portfolios. The gross revenue for Ireland is projected to increase significantly between the current and 2020 scenarios irrespective

of product portfolio, worth around 870 million USD, however, between the best and worst 2020 scenarios the difference is in the region of 37 million USD (1.46% of 2012 gross revenue) and similar in net revenue at 31 million USD (1.45% of 2012 net revenue). However, this analysis very much centres on the production of commodity products and does not include depreciation or capital costs to alter available facilities to produce the altered portfolio, such as building new cheese processing capabilities. There is scope to add value through development of speciality products for specific markets. This can only be justified if all associated costs (including any capital development costs) are lower than the value of the additional returns.

For future New Zealand scenarios a series of differing mixes was used, from 80% of all milk processed as cheese to 80% lactose recovery from whey powder and 100% of future milk into WMP production. This gave a diverse range of possible future scenarios. The availability and usage of imported lactose in the system had one of the largest effects on net returns. When imported lactose was removed from the system in Scenario 3 the increase in milk production was greater than the increase in WMP production (32% vs 8.5%, respectively), this highlights the relatively high proportion of lactose that is currently being purchased by the New Zealand dairy industry. When 80% of all New Zealand milk was processed towards cheese, WMP production decreased to 11.5% of total exports with cheese making up 55.2% of exports.

Between 2012 and 2020 New Zealand scenarios gross revenue increased by 2-3 billion USD. The differences in gross revenue between top and bottom 2020 scenarios resulted from a difference of 300,000 tonnes of export product. The difference in gross revenue can be attributed to different product mixes and values of the products produced. This

indicates that processing decisions in New Zealand scenarios will have significant impacts on farmer income. Obviously markets will ultimately decide directions and product portfolios. The analysis completed in this study does not take external market considerations into account such as market requirement for 100% country of origin products.

Costs in both systems were greatest in scenarios where cheese was the predominant product produced; this was caused by the combined costs of producing cheese and processing whey powders. In the Irish scenarios an increase of 1% in cheese production as part of total exported products increased costs by 1.4 million USD, excluding costs required to build processing capability. In the New Zealand system this is not easy to calculate due to the diversity of scenarios investigated, however it can be seen that the scenario where 80% of milk is used for cheese production has costs that are \$200 million greater than the next most costly scenario (Scenario 4; predicted 2020 production milk with increased milk production towards WMP).

Yearly difference was greatest between 2011 and 2012 for Irish scenarios with the 100% cheese scenario experiencing the greatest difference. Under 2011 prices it was the most profitable, but in 2012 it was the least profitable. In contrast the difference in New Zealand scenarios was greatest between 2010 and 2011, except for the 80% of milk to cheese scenario and no lactose import scenarios where it was greatest between 2011 and 2012. Similar to Ireland, the high cheese scenario was the second most profitable in 2012 but least in 2010 and 2011. The results of modelling yearly variations indicates some of the logistical considerations required for product portfolio development as a decision made under 2011 prices may negatively impact returns if the future markets are

more like those in 2012. This study has clearly shown that the addition of flexibility into processing, by the processing sector, will be key to ensure maximum returns can be achieved across variation in component prices. While additional capacity may have cost implications it will facilitate significant flexibility within the overall system.

### **Conclusion**

For New Zealand the manufacture of WMP was associated with the highest lactose costs, due to the need to purchase foreign lactose for incorporation into WMP. When the costs associated with the alternative milk processing capabilities are excluded, net revenue is greatest for Irish Scenario 2 (100% of post quota milk into WMP production) and greatest in New Zealand Scenario 2 (2020 production with 2012 portfolio). If cheese value was to increase at a greater rate than WMP value the results would change in this analysis with cheese dominant portfolios returning greater net revenue. It is unlikely that either Irish or New Zealand dairy industries will dramatically alter their product portfolios in this short term time horizon; there will most likely continue to be slight annual modifications as have occurred over the last 20 years. This will allow for optimal usage of existing facilities as well as development of new capacity for altering total portfolio output similar to Scenarios 2-5 investigated for Ireland.

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## Chapter 5

### **Predicted Dairy Product Yields and Deficits of Lactose for Manufacturing under Differing Selection and Manufacturing Scenarios in New Zealand**

NW Sneddon<sup>a\*</sup>, N Lopez-Villalobos<sup>a</sup>, RE Hickson<sup>a</sup>, L Shalloo<sup>c</sup>, SR Davis<sup>b</sup>, DJ Garrick<sup>a</sup>  
and U Geary<sup>c</sup>

<sup>a</sup>Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Private  
Bag 11-222, Palmerston North, New Zealand;

<sup>b</sup>Livestock Improvement Corporation, Private Bag 3016, Hamilton 3240, New Zealand;

<sup>c</sup>Dairy Production Department, Teagasc, Moorepark Production Research Centre,  
Fermoy, Co. Cork, Cork, Ireland



**Abstract**

The New Zealand dairy industry is pasture based and over 90% of milk products are exported. The breeding goal of the breeding program of New Zealand dairy cattle is to improve the capability of the cow to convert feed into farmer profit. The breeding objective rewards yields of protein and fat but penalizes milk volume and ignores lactose, despite it being an important component of milk powders. With the industry currently in deficit for lactose, this study investigated the expected response to selection over the next 10 years and its impact on the annual industry production of milk, its components and yields of dairy products based on expected cow performance, number of cows and a fixed area for dairying. After 10 years of selection (with no increase in herbage production), there was a 5% increase in milk production per hectare. Total milk exports increased by 5.9% and the lactose deficit increased by 14% when 60% of milk was processed into whole milk powder.

***Keywords:***

Lactose; breeding objective; milk processing; New Zealand

**Introduction**

The majority of the New Zealand dairy industry feed supply is pasture and more than 90% of milk products are exported. The national herd is composed of 3 main breed groups; Holstein-Friesian (F) (37%), Jersey (J) (11.7%) and their crosses (FxJ) (42.6%), the remainder are Ayrshire (0.7%) and other (8%: comprising Milking Shorthorn, Guernsey, Brown Swiss and their crosses) (LIC & DairyNZ 2013). The current

breeding goal is to improve the capability of the cow to convert feed into farmer profit. The breeding objective is called breeding worth (BW) and reflects net farm profit per 5 tonnes of feed dry matter. It includes 7 traits; whole lactation milk volume, fat yield, protein yield, live weight, fertility, somatic cell score and residual survival. The selection index estimates of BW are based on estimated breeding values of the traits in the breeding objective multiplied by their relative economic values, but selection of dams of bulls includes constraints on breeding values for type traits. Lactose is not currently included as a trait in this national breeding objective. Estimated changes in lactose can be inferred from its genetic correlation with milk yield.

Breeding for altered milk composition has been proposed in several articles over the years (Gibson 1987; 1989; 1991; Karatzas & Turner 1997; Garrick & Lopez-Villalobos 2000). It was shown by Vos & Groen (1998) that it was possible to breed for altered protein-to-fat ratios. In that experiment there was a small change in lactose concentrations between high and low selection lines of cattle (Vos & Groen 1998). This small change may indicate that lactose concentration can be altered through breeding, but the change will happen much slower than that of protein or fat due to the smaller genetic variation (Gibson 1987; 1989; Vos & Groen 1998). Altering breed composition of the dairy industry can also be used to alter the composition of milk (ratios and concentrations of protein, fat and lactose) which can be used in conjunction with breed improvement (Gibson 1987; 1989; 1991; Karatzas & Turner 1997; Lopez-Villalobos et al. 2000).

Several methods can be used to model dairy industries, from simulating the processing of known industry milk production (Geary et al. 2010), to investigating differences in

seasonality of milk supply (Geary et al. 2012), to milk processing of a simulated dairy industry from the animal perspective (Lopez-Villalobos et al. 2000). Processing level simulation allows for an overall view of an industry, which can quantify total revenue and effects of changing the manufacturing product mix. In comparison, a simulated dairy industry from the animal perspective allows investigation of the effect of changes at farm level that result from genetic gain or changes in breed composition.

Codex standards dictate the minimum yields of milk components that are required in particular dairy products including whole milk powder (WMP). Over the past 3 years the New Zealand dairy industry has imported lactose (Fonterra 2012a); this has been a reaction to world prices for dairy products that have caused a rapid increase in the proportion of milk used for WMP production. The ratio of protein-to-protein-plus-lactose (P:P+L) can be used as a proxy for the ratio of protein-to-solids-not-fat and reflects the suitability of milk for production of WMP (Geary et al. 2010; Sneddon et al. 2014a; 2014b). The P:P+L of WMP is approximately 0.38 (Geary et al. 2010) whereas in the milk of New Zealand cows P:P+L is 0.44. This study aims to investigate the effect of 10 years of selection on BW on industry production of milk components, yields of dairy products, P:P+L ratio and the need for lactose imports in New Zealand for varying industry emphasis on production of WMP.

### **Materials and methods**

An industry model was developed to estimate annual production of milk and its components based on expected cow performance, number of cows and a fixed area for dairying as described in Lopez-Villalobos et al. (2000). An industry processing model

(Geary et al. 2010) was then used to simulate the processing of that milk into dairy products.

### ***Breeding objective***

Breeding worth (BW) is the national breeding objective of New Zealand and includes 7 traits (milk, fat, protein, live weight, somatic cell score (SCS calculated as  $\text{Log}_2(\text{somatic cell count})$ ), fertility and residual survival). The economic values used in 2013 were NZ\$-0.091 per L milk, \$1.79 per kg fat, \$8.63 per kg protein, \$-1.52 per kg mature cow live weight, \$-38.57 per unit of SCS, \$7.35 per 1% fertility (proportion calving in the first 42 days of calving) and \$0.148 per day of residual survival (herd life after accounting for genetic effects of the other 6 traits on herd survival) (NZAEL 2013). The negative value for milk yield represents the associated costs of transporting, storing, evaporating and drying liquid milk and the feeding cost of the cow to produce 1 L of milk without increasing production of milk solids.

### ***Genetic gains and expected cow performance***

The selection scheme was modelled on four pathways of selection, using progeny testing as the main method to evaluate bulls. This selection scheme had selection intensities of 0, 3.0, 2.2 and 2.6 for cows to breed cows, cows to breed bulls, bulls to breed cows and bulls to breed bulls respectively (Spelman & Garrick 1997) Genomic selection of young bulls now competes with progeny testing and is leading to an increase in the number of bull mothers, thus potentially increasing genetic diversity. The expected phenotypic performance of cows of average genetic merit (base cows)

under grazing conditions was the production of the average cow in the 2012-2013 dairy season (LIC & DairyNZ 2013) as shown in Table 5.1. The expected performance changed according to predicted genetic gain each year of the simulation. Genetic gain per year was predicted to remain as published by NZAEL (2013) at 44 L of milk, 2.22 kg fat, 1.82 kg protein and -0.039 kg live weight for the 2013/2014 dairy season. Genetic gain in lactose concentration was assumed to be unchanged by selection on BW, this was assumed from the very high genetic correlation (0.98-0.99 between milk and lactose yields) (Welper & Freeman 1992; Miglior et al. 2007; Hossein-Zadeh & Ardalan 2011; Sneddon et al. 2012; 2015), which resulted in lactose yield gains of 2.07 kg per year, which is 4.70% of the 44 L gain in milk yield. Improvement of productive performance caused by better feeding, supplementary feeding or management was not considered in the simulation.

**Table 5.1.** Production per cow, per hectare and across the industry for the base and after 10 years of selection for breeding worth.

Trait <sup>1</sup>	Base	Year 10	Change (%)
Average production per cow			
Milk (L)	3,953	4,351	10.07
Fat (kg)	195.9	216.1	10.30
Protein (kg)	149.5	165.9	10.97
Lactose (kg)	185.8	204.5	10.06
Live weight (kg)	420.6	420.3	-0.07
DM requirements per cow (kg)	4,225	4,421	4.64
Stocking rate, cows/hectare	2.86	2.73	-4.64
Production per hectare			
Milk (kg)	11,314	11,899	5.17
Fat (kg)	560.9	590.9	5.35
Protein (kg)	427.8	453.8	6.08
Lactose (kg)	531.8	559.3	5.17
Industry			
No. of cows (millions)	4.800	4.586	-4.46
Total hectares (millions)	1.677	1.677	-
Milk (billions L)	18.974	19.955	5.17
Fat percentage	4.96	4.97	0.20
Protein percentage	3.78	3.82	1.06
Lactose percentage	4.70	4.70	-
P:P+L	0.446	0.448	0.45

<sup>1</sup>DM = dry matter; P:P+L = protein-to-protein-plus-lactose ratio.

### *Production per hectare and stocking rate*

Pasture growth in the model was assumed to be 15,110 kg DM per hectare with 80% feed utilization corresponding to an intake of 12,090 kg DM per hectare. This allowed a stocking rate in the base year of 2.86 cows per hectare. To maintain this intake, stocking rates were decreased annually to account for the increasing feed demand of improved cows. This was done by reducing cow numbers until annual feed demand per ha equalled 12,090 kg DM. Stocking rates were decreased as the genetic potential of the cows increased in line with industry recommendations to account for greater feed demand per cow while maintaining high pasture utilisation (Penno 1999).

### *Industry production of milk components*

Production of milk components was estimated using the expected performance per cow and number of cows, accounting for the age structure of the national herd. Production for each age group was calculated using the number of animals in that age group multiplied by their production. Those values were then summed across all age groups. The number of hectares used to estimate industry production was the effective area from the 2012-2013 season of 1.677 million ha (LIC & DairyNZ 2013). The number of cows used to estimate industry production and stocking rates was rounded up to 4.8 million cows (LIC & DairyNZ 2013) from 2012-2013 numbers.

The age structure of the national herd was similar that reported by Lopez-Villalobos et al. (2000) comprising 22% 2-year-old, 19% 3-year-old, 16% 4-year-old, 13.5% 5-year-old, 11.3% 6-year-old, 9% 7-year-old, 6% 8-year-old and 3.2% at least 9-year-old. The breed composition was 37% F, 11.7% J and 42.6% FxJ crossbred animals. This was assumed to remain static over the simulated time period to avoid confounding factors of altered breed composition. Maturity weighting factors were used to adjust for animal age. The weighting factors were, 75% of mature equivalent for 2-year-old, 88% for 3-year-old, 95% for 4-year-old, 100% for 5-7-year-old, 90% for 8+ year-old. Replacements were 26% of calves born, with slight losses by 1-year-old (Lopez-Villalobos et al. 2000).

The phenotypic production of milk, fat and protein and live weight of cows were updated each year of the simulation accounting for the genetic gains of these traits. Feed requirements for each age class were based on requirements of metabolisable energy for

maintenance, milk production and for the growing of replacements, according to AFRC (1993) and Holmes et al. (2007). The total feed demand of the national herd was calculated as the multiplication of feed demand for each age class and the number of animals in age class. Then the number of cows was modified to match the feed available from the total national area used for dairying.

### ***Industry production of dairy products***

The Moorepark processing sector model (Geary et al. 2010) was used to estimate yields of dairy products. Four scenarios were evaluated in this study. The base New Zealand product portfolio was obtained by combining data available in the Fonterra 2012 annual report (Fonterra 2012b), Fonterra farm gate milk price statement (Fonterra 2012a) and Fonterra milk price – the facts (Fonterra 2012c). The product portfolios used in this study are summarised in Table 5.2 and included a current product mix (60% WMP) (60%) from Fonterra (2012a), a historical mix (30% WMP) (30%) from Fonterra (2003), an extreme high mix (80% WMP) (80%) and an extreme low mix (10% WMP) (10%) to represent situations where the industry produces almost all milk into WMP or very little milk into WMP. Volume of whey protein concentrate (WPC) was estimated by this model by removing 75% of the lactose from whey which was then reincorporated into WMP and SMP; this allowed for a recycling of lactose from a lower value by-product into WMP. A conservative value of 75% was chosen (Archer 1998; Mollea et al. 2013).

**Table 5.2.** Proportions of milk used for each product under the four investigated product portfolios in study as input values for the Moorepark processing sector model (Geary et al. 2010).

Product <sup>1</sup>	80% WMP	Base (60% WMP)	30% WMP	10% WMP
WMP	80.0	60.0	30.0	10.0
SMP	10.0	23.5	30.0	10.0
Cheese	8.0	14.0	30.0	75.0
Butter	0.5	0.5	6.0	2.5
Casein	1.5	2.0	4.0	2.5

<sup>1</sup>WMP = whole milk powder; SMP = skim milk Powder.

The processing model of Geary et al. (2010) is a mass balance milk processing model, which simulates the production of milk products with the composition outlined in Table 5.3. It is assumed that imported lactose is used to fill the deficit of lactose in both WMP and SMP.

**Table 5.3.** Composition of dairy products in g/100g of final product.

Component	Product <sup>1</sup>							
	WMP	SMP	Cheese	Butter	Casein	MPC	WP	BMP
Fat	26.50	1.00	35.00	84.00	0.00	0.00	1.00	8.30
Protein	25.10	33.00	24.50	0.59	89.00	90.50	15.15	41.72
Lactose	39.80	54.00	1.39	0.79	0.56	Trace	77.15	40.32
Minerals	5.90	8.00	2.15	0.12	0.80	Trace	4.32	4.66
Water	2.70	4.00	35.26	14.50	9.64	9.50	2.38	5.00

<sup>1</sup>WMP = whole milk powder; SMP = skim milk powder; MPC = milk protein concentrate; WP = whey powder; BMP = butter milk powder.

## **Results**

### ***Production per cow***

Response to selection was estimated over 10 years to increase average milk production per cow from 3,953 L to 4,351 L, an increase of 10.07% (Table 5.1). Similar percentages were estimated for fat and lactose yield (10.30% and 10.06% respectively). The increase in protein production was slightly greater at 10.97%, reflecting its greater emphasis in BW. In BW, more than 30% of emphasis is on protein yield (Bryant 2012), compared with 11% for milk volume and 9% for fat yield, while lactose yield has no direct economic value. Average feed demand per cow increased from 4,225 kg DM to 4,421 kg DM per cow per year, a 4.64% increase. Live weights of animals exhibited little change, decreasing by only 0.07%.

### ***Production per hectare with adjustment of stocking rate***

Per hectare changes are summarized in Table 5.1. Total feed supply was held constant, necessitating a 4.76% decrease in stocking rate over 10 years from 2.86 cows/hectare to 2.73 cows/ha. Milk production per ha increased from 11,314 to 11,899 kg (5.17%), protein production increased 6.08% per ha, while lactose production increased 5.17% per ha. This was in spite of the decrease in number of cows farmed, representing an increase in the efficiency of production, with cows producing more from the same amount of feed per ha.

### *Industry production of milk components and P:P+L ratio*

Changes in industry production are shown in Table 5.1. Assuming a fixed area for dairying with a constant pasture production, the total number of cows decreased from 4.800 million to 4.586 million to maintain a constant feed demand of 12,090kg per ha. Total milk production increased from 18.974 billion L to 19.954 billion L (5.17% increase) over the 10 year period due to gains in production per cow being greater than decreases in stocking rate. The base year had a similar total production to the 2012/2013 dairy season (LIC & DairyNZ 2013): 18.954 billion L vs 18.883 billion L. The greater genetic gain in protein relative to lactose meant P:P+L was estimated to further increase from 0.446 to 0.448 (0.45% increase).

### *Yield of dairy products from different scenarios*

Yields of dairy product are shown in Table 5.4. Between the base and the 10-year scenario using 60% milk for WMP, there was on average a 6.3% increase in dairy product yields with a 6.41% and 6.21% increase in WMP and SMP respectively. There was a 41.87% increase in WMP production between base and 10-year 80% scenario, a 46.8% decrease between base and 10-year 30% scenario and an 82.27% decrease between the base and the 10-year 10% scenario. The proportion of WMP produced was close to the amount set in the model due to the production of by-products, in the base scenario 55.86% of the product portfolio was WMP, compared with 74.84%, 56.04%, 29.14% and 9.89% in the 80%, 60%, 30% and 10% 10-year scenarios respectively. Butter and its by-product butter milk powder (BMP) had the smallest increase of 4.14% and 4%, respectively between the base and the 10-year 60% scenarios. Casein had the

smallest increase in terms of yield with 1700 tonnes, but the highest proportional increase at 11.11%. In all scenarios, casein makes up less than 1% of total exports. Skim milk production was highest in the 30% scenario at 22.84% of total exports. Total export quantity was highest in the 10-year 60% scenario at 3,201,000 tonnes, but only slightly higher than the 80% scenario at 3,196,000 tonnes.

**Table 5.4.** Industry production of dairy products ( $\times 10^3$  ton) from milk produced in the base and after 10 years of selection for breeding worth under four possible future product portfolios and change from base.

Product <sup>1</sup>	Base year	80% WMP		60% WMP		30% WMP		10% WMP	
		Production	Change (%)						
WMP	1,686	2392	41.87	1794	6.41	897	-46.8	299	-82.27
SMP	467	206	-55.89	496	6.21	703	50.54	244	-47.75
Cheese	329	200	-39.21	351	6.69	751	128.27	1879	471.12
Butter	413	316	-23.49	430	4.12	507	22.76	213	-48.43
Casein	11.7	9.3	-20.51	13	11.11	25	113.68	16	36.75
WPC	61.5	37	-39.84	65	5.69	139	126.02	347	464.23
BMP	50	35	-30	52	4	56	12	24	-52
Total	3,018	3196	5.9	3201	6.06	3078	1.99	3022	0.13
Lactose	-117	-186	58.97	-134	14.53	20	-117.09	444	-479.49

<sup>1</sup>WMP = whole milk powder; SMP = skim milk powder; WPC = whey protein concentrate; BMP = butter milk powder.

### ***Lactose imports***

The requirements for imported lactose increased to 134,000 tonnes (a 14.5% increase) during the 10 simulated years, when 60% of milk was processed into WMP. However, when 80% of milk was processed into WMP, the requirement was 186,000 tonnes, an increase of 58.9%, compared with a 20,000 tonne surplus in the 30% scenario and a 444,000 tonne surplus in the 10% scenario. Lactose made up 5.82%, 4.19%, 0.65% and 14.69% of exports in the 80%, 60%, 30% and 10% scenarios, respectively. Lactose imports as a proportion of the exported milk products increased from 3.88% to 4.19% in the 10-year 60% scenario.

### **Discussion**

The modelled increase in milk production per cow was greater than that historically shown from 10 years of industry data (LIC & DairyNZ 2013); from 2003-2004 dairy season to the 2012-2013 season there were increases of 5.62%, 6.52% and 8.70% in milk, fat and protein yields respectively (LIC & DairyNZ 2013). This anomaly may be due to drought conditions in the 2012-2013. The increase in the 10 years between the 2002-2003 and 2011-2012 dairy seasons, was 10.46%, 11.95% and 14.49% for milk, fat and protein yields, respectively (LIC & DairyNZ 2013). This was closer to that modelled in this study where increases were 10.07%, 10.30%, 10.97% and 10.06% for milk, fat, protein and lactose yields, respectively. While these increases are similar, when considered in terms of the increase in the concentration of the milk components, protein percent increased 1.06% whereas there was only a 0.20% increase for fat percent. With an increase of 1.06% in protein percentage and no change in lactose

percentage, the P:P+L increased by 0.45% from 0.446 to 0.448. Industry data between 2002-2003 and 2012-2013 indicated an increase of 1.61% in P:P+L from 0.441 to 0.447. The differences between 2011-2012 and 2012-2013 showed the impact of year-to-year environmental effects on cow production but still highlighted the fact that selection on BW increased protein yields faster than fat or milk yield and proportionally faster than that modelled in this study and as such will be increasing the P:P+L away from a processing optimum. The change in P:P+L may also be due in part to the change in breed composition of the national herd.

It is hard to compare the changes per hectare within this model with historical industry data, because the industry has expanded land area and increased brought-in-feed in the past 10 years while the model used in this study held land area static and limited feed to pasture grown. In the past 10 years (2002-2003 to 2011-2012 dairy seasons) milk production per hectare has increased by 22.3% (9,534 L to 11,664 L) and stocking rate has increased by 10.5% (2.56 to 2.83 cows/hectare) (LIC & DairyNZ 2013), whereas production per hectare in the model increased by 5.17% and the stocking rate decreased 4.64% due to the restrictions in feed supply. If the production per hectare in 2002-2003 is lifted to have an equal stocking rate to 2012-2013 the increase is 6.17% which is similar to that found in these simulations.

Change in P:P+L cannot be compared with historical values because the breed composition of the national herd influences this value as well as genetic gain. The current P:P+L of 0.44 is in the national herd with a breed split of 37%, 11.7% and 42.6% for F, J and FxJ cows respectively (LIC & DairyNZ 2013). However if the current trends continue and F and J reduce in proportion compared with crossbred

animals, the ratio could increase to 0.448 if the breed composition was 28% F, 8% J and 60% FxJ using breed effects from Sneddon et al. (2015).

The modelled increase in P:P+L was small, but it has a large impact when considering the high volumes of product dealt with in the New Zealand dairy industry. The 0.45% increase in P:P+L results in a 14.5% increase in requirements for lactose, if the product mix remains unchanged with around 60% of milk processed into WMP. If, however, the product mix continues to increase powder production as it has over the past 10 years (Fonterra 2003; 2012c) where the mix has gone from 44% milk powders in 2003 to almost 75% milk powders in 2012, requirements for lactose could increase even more. With 80% of milk used to produce WMP lactose requirements would increase by 58.9% to 186,000 tonnes (averaging US\$ 1,679 in 2014, Global Dairy Trade 2014); although some of this is caused by the 41.9% increase in WMP production, other factors also affect lactose supply. The decrease of 39.8% in cheese production when WMP uses 80% of milk reduces the amount of internal lactose available to the production of WMP; this effect is evident in the 39.8% decrease in WPC, as whey is no longer available for lactose recovery.

This paper is limited by the assumptions in the setting up of the models used, which in particular include fixed area of land, with fixed feed supply, where feed demand is matched to feed supply by reducing stock numbers. This industry model also does not account for any changes in the breed composition of the herd, as an increased F proportion would lead to greater milk volumes compared with a static breed make up. The model also only advances at the rate of genetic gain, it does not consider the effects from environment gains (improved management, imported feed, etc.). The processing

model assumes that some products can only be made as by-products, not individual product lines for example BMP and WPC. The results of this study indicate that the effects including of lactose into the breeding objective should be investigated to mitigate increasing lactose deficit.

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## Chapter 6

### **Estimates of genetic and crossbreeding parameters for milk components and potential yield of dairy products from New Zealand dairy cattle**

NW Sneddon<sup>a\*</sup>, N Lopez-Villalobos<sup>a</sup>, RE Hickson<sup>a</sup>, L Shalloo<sup>c</sup>, SR Davis<sup>b</sup> and DJ  
Garrick<sup>a</sup>

<sup>a</sup>Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Private  
Bag 11-222, Palmerston North, New Zealand

<sup>b</sup>Livestock Improvement Corporation, Private Bag 3016, Hamilton 3240, New Zealand

<sup>c</sup>Dairy Production Department, Teagasc, Moorepark Production Research Centre,  
Fermoy, Co. Cork, Cork, Ireland

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**Abstract**

Milk composition can vary significantly among individual cows and breeds, the dairy products that can be made from that milk are limited by available milk components. The objective of this research was to estimate genetic and crossbreeding parameters for lactation yields of milk, fat, protein and lactose and use these to determine potential yields of dairy products from New Zealand dairy cattle. A mass-balance milk-processing model was used to estimate yields of milk products for 4310 first lactation heifers that produced milk in the 2010-2011 dairy season. Estimates of heritability for yields of whole and skim milk powders were moderate (0.31). Heterosis effects for product yield per lactation was significant only for cheese and butter production ( $P < 0.05$ ). The use of genetic parameters and correlations for dairy product yield could increase the rate of gain for specific product yields, but have to be evaluated in conjunction with other traits of interest in breeding worth.

***Keywords:***

Lactose; genetic parameters; milk processing

**Introduction**

Milk fat and protein content varies significantly among individual cows and breeds (Cerbulis & Farrell 1975; Aikman et al. 2008; Bleck et al. 2009) and milk lactose content is also variable within and across breeds but generally with a lower coefficient of variation than fat or protein (Cerbulis & Farrell 1975; Prendiville et al. 2010; Sneddon et al. 2015a). Lactose is an important milk component in the standardisation of

milk products, as well as an energy source in milk. New Zealand has selected breeding animals using a selection index known as breeding worth, that has resulted in cows that produce relatively more protein and fat than lactose (Sneddon et al. 2014), leading to a situation where lactose yield is in deficit and local production cannot meet the requirements for the current product portfolio in New Zealand.

Dairy products traded internationally must meet international codex specification (CODEX STAN 207-1999, WHO & FAO 2011) in relation to the different components in the final products with these specifications required for whole milk powder (WMP), skim milk powder (SMP), cheddar cheese and butter. Whole milk powder is the largest dairy export from New Zealand making up almost 70% of dairy products (Fonterra 2014). This has been a relatively recent change in the dairy industry, with butter dominating the product mix until the 1970's and WMP not appearing until the 1980's.

In the New Zealand dairy industry estimates of genetic parameters from total lactations are required for use in the national breeding objective projections (Spelman & Garrick 1997; Pryce & Harris 2006). Previous studies have either lacked estimates for lactose and lactose related traits (Spelman & Garrick 1997; Pryce & Harris 2006; Stoop et al. 2008; Battagin et al. 2013) or use test day records (Johnson et al. 2000; Roman et al. 2000; Miglior et al. 2007; Sneddon et al. 2015a).

The breed composition of the dairy industry has changed with the move from Jersey (J) or J-type cows to Holstein-Friesian (F) or F-type crossbred cows through crossbreeding (LIC 1999; LIC & DairyNZ 2014). Breed differences in milk composition lead to differences in the yields of products. Breed changes over the past 30 years have,

incidentally, produced an average cow whose milk is better suited to WMP. Simulation studies (Garrick & Lopez-Villalobos 2000; Geary et al. 2010) have reported breed differences for yields of dairy products and value of milk using representative milk yield and composition for each of the breeds. For example, J can produce more cheese per 1000 litres of milk than F (Auld et al. 2004; Capper & Cady 2012; Sneddon et al. 2015b).

Some studies have reported heritability for cheese yields for samples of milk in dairy cattle (Bittante et al. 2013; 2014) and estimated total yields of mozzarella in buffalo (Rosati & Van Vleck 2002; Aspilcueta-Borquis et al. 2010). However, breed effects and heritabilities for total yields of WMP, SMP, cheese and butter have not been reported. This study aimed to produce the first estimates of genetic parameters and heterosis effects for total milk and component yields including lactose, along with milk product potential, using a New Zealand data set.

## **Materials and methods**

A milk-processing model developed at Massey University (Garrick & Lopez-Villalobos 2000) which uses a mass balance approach based on available fat, protein and lactose, was used to estimate yields of milk products for individual cows. Four scenarios were investigated representing different product portfolios; these were 100% of milk produced by the cow towards either WMP, SMP, cheese or butter. The model produced the maximal amount of the desired product with available components, with excess protein or fat being used for the production of “by-products” which depending on the scenario were SMP, butter, butter milk powder (BMP), casein and whey powder (WP),

determined by milk component availability and product value (Garrick & Lopez-Villalobos 2000). Depending on the context, this could result in butter production in SMP and cheese scenarios and SMP production in the cheese scenario, etc.

### ***Data***

Herd-test records for milk, fat, protein and lactose (as monohydrate, back calculated to anhydrate) were available from 4310 mixed-breed Livestock Improvement Corporation Sire Proving Scheme heifers from the 2010-2011 dairy season (Sneddon et al. 2015a). The data comprised 1067 F, 717 J and 2526 FxJ cows. Lactation yields of milk (TMY), fat (TFY), protein (TPY) and lactose (TLY) were calculated from herd-test records which were used to model individual lactation curves of milk, fat, protein lactose and somatic cell score (SCS; calculated as  $\text{Log}_2(\text{somatic cell count})$ ) using a 5<sup>th</sup> order Legendre polynomial with ASReml of VSN International Ltd (Gilmour et al. 2009).

### ***Breed and heterosis effects***

Least squares means for estimates of breed average were obtained using a linear model in SAS version 9.3 (SAS Institute Inc., Cary NC, USA) with fixed effects of breed, month of calving and herd. Heterosis and breed effects were estimated with another linear model that included the fixed effects of month of calving and herd as class effects and proportion of J, proportion of other breed (OT; grouped as other, including Ayrshire, Shorthorn, Brown Swiss) to avoid losing crossbred animals from the dataset and heterosis between F and J fitted as covariates.

*Genetic parameters*

Single-trait animal models were used for estimation of heritabilities and bivariate animal models were used for estimation of genetic and phenotypic correlations. In matrix notation, the bivariate models can be represented as:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} \mathbf{X}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_2 \end{bmatrix} \begin{bmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \end{bmatrix} + \begin{bmatrix} \mathbf{Z}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{Z}_2 \end{bmatrix} \begin{bmatrix} \mathbf{u}_1 \\ \mathbf{u}_2 \end{bmatrix} + \begin{bmatrix} \mathbf{e}_1 \\ \mathbf{e}_2 \end{bmatrix}$$

where  $\mathbf{y}_1$  and  $\mathbf{y}_2$  are the vectors of phenotypic measures for two traits under study,  $\mathbf{X}_1$  and  $\mathbf{X}_2$  and  $\mathbf{Z}_1$  and  $\mathbf{Z}_2$  are design matrices relating the fixed and additive genetic effects to the phenotypes respectively,  $\mathbf{b}_1$  and  $\mathbf{b}_2$  are the vectors of fixed effects of herd, deviation from mean calving date (per herd), the proportion of J or OT and heterosis coefficients of F×J, F×OT and J×OT,  $\mathbf{u}_1$  and  $\mathbf{u}_2$  are the vectors of random effects of animal for each trait,  $\mathbf{e}_1$  and  $\mathbf{e}_2$  are vectors of residual errors not accounted for by the fixed and random effects. The distributional properties of the elements in the model with  $\mathbf{E}$  and  $\mathbf{V}$  indicating the expectation and variance were as follows:

$$\mathbf{E} \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} \mathbf{X}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_2 \end{bmatrix} \begin{bmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \end{bmatrix}$$

and

$$\mathbf{V} \begin{bmatrix} \mathbf{u}_1 \\ \mathbf{u}_2 \\ \mathbf{e}_1 \\ \mathbf{e}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{A}\sigma_{a1}^2 & \mathbf{A}\sigma_{a12} & \mathbf{0} & \mathbf{0} \\ \mathbf{A}\sigma_{a12} & \mathbf{A}\sigma_{a2}^2 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{I}_1\sigma_{e1}^2 & \mathbf{I}_1\sigma_{e12} \\ \mathbf{0} & \mathbf{0} & \mathbf{I}_1\sigma_{e12} & \mathbf{I}_1\sigma_{e2}^2 \end{bmatrix}$$

where  $\mathbf{A}$  is the numerator relationship matrix of size 8,884, the total number of animals in the pedigree file;  $\sigma_{a1}^2$ ,  $\sigma_{a2}^2$  and  $\sigma_{a12}$  are the animal (co)variance components for the traits under consideration;  $\mathbf{I}_1$  is an identity matrix of size 4,310, the number of lactation records;  $\sigma_{e1}^2$ ,  $\sigma_{e2}^2$  and  $\sigma_{e12}$  are the residual (co)variance components for the traits.

Estimates of (co)variance components were obtained using the Restricted Maximal Likelihood procedure in ASReml package (Gilmour et al. 2009) of VSN international Ltd.

Heritability ( $h^2$ ) of a trait was calculated as:

$$h^2 = \sigma_a^2 / (\sigma_a^2 + \sigma_e^2).$$

Genetic correlations ( $r_g$ ) were estimated as:

$$r_g = \frac{\sigma_{g12}}{\sigma_{g1} \times \sigma_{g2}}$$

where:

$\sigma_{g12}$  = genetic covariance between trait 1 and trait 2, equivalent to  $\sigma_{a12}$ ,

$\sigma_{g1}$  = genetic additive standard deviation for trait 1, equivalent to  $\sqrt{\sigma_{a1}^2}$ ,

$\sigma_{g2}$  = genetic additive standard deviation for trait 2, equivalent to  $\sqrt{\sigma_{a2}^2}$ ,

and phenotypic correlations ( $r_p$ ) as:

$$r_p = \frac{\sigma_{p12}}{\sigma_{p1} \times \sigma_{p2}}$$

where:

$\sigma_{p12}$  = phenotypic covariance between trait 1 and trait 2, equivalent to  $\sigma_{a12} + \sigma_{e12}$ ,

$\sigma_{p1}$  = phenotypic standard deviation for trait 1, equivalent to  $\sqrt{\sigma_{a1}^2 + \sigma_{e1}^2}$ ,

$\sigma_{p2}$  = phenotypic standard deviation for trait 2, equivalent to  $\sqrt{\sigma_{a2}^2 + \sigma_{e2}^2}$ .

## Results

Least squares means and standard errors for lactation yields of milk components for the three breed groups are shown in Table 6.1. Lactation length was similar for the three breed groups. Holstein-Friesian cows had the greatest ( $P < 0.05$ ) TMY and TLY, whereas for TPY there was no difference ( $P > 0.05$ ) between F and FxJ, J cows had the greatest fat (FP), protein (PP) and lactose percentages (LP). Holstein-Friesian cows had the lowest protein-to-protein-plus-lactose ratio (P:P+L), whilst J had the greatest and FxJ intermediate ( $P < 0.05$ ). Somatic cell score was not different ( $P > 0.05$ ) among the breeds.

Estimates of breed and heterosis effects for milk traits and yields of dairy products are also shown in Table 6.1. Breed differences between F and J cows were estimated to be

greatest for TMY and TLY ( $P < 0.05$ ), whereas there was no difference in TFY between breeds. Jersey cows had lower TMY, TPY, TLY but higher FP, PP and LP and P:P+L than the F cows ( $P < 0.05$ ). Estimates of heterosis were positive for all traits except for days in milk, LP and SCS which were not different to zero ( $P > 0.05$ ). Heterosis effects (as a proportion of parent average) were greatest for TFY (8.26%) followed by TPY (5.30%). Heterosis effects for TMY and TLY were similar when compared as a percentage of parent average. Heterosis for product yield per lactation was significant only for cheese and butter production scenarios ( $P < 0.05$ ) (14.32% and 4.31% respectively). Breed effects between F and J were significant in all products except cheese ( $P > 0.05$ ).

**Table 6.1.** Lactation yields of milk and milk product potentials from Holstein-Friesian (F), Jersey (J) and crossbred (FxJ) first lactation heifers and standard errors.

Trait <sup>1</sup>	F <sup>2</sup>			FxJ <sup>2</sup>			J <sup>2</sup>			Breed effect			Heterosis		
	Mean	SE		Mean	SE		Mean	SE		F-J	SE	P-value	FxJ	SE	P-value
Days in Milk	212 <sup>b</sup>	1.81		214 <sup>a</sup>	1.71		213 <sup>ab</sup>	1.94		-1.78	1.58	0.264	1.97	1.3	0.13
Milk (L)	3121.8 <sup>a</sup>	48.3		2947.0 <sup>b</sup>	45.7		2751.6 <sup>c</sup>	51.7		633.3	41.5	<.001	93.6	34.2	0.006
Fat (kg)	142.9 <sup>c</sup>	2.25		149.9 <sup>a</sup>	2.13		147.0 <sup>b</sup>	2.41		-1	1.96	0.61	11.8	1.62	<.001
Protein (kg)	113.6 <sup>a</sup>	1.69		112.3 <sup>a</sup>	1.59		107.7 <sup>b</sup>	1.8		12.5	1.46	<.001	5.86	1.2	<.001
Lactose (kg)	160.0 <sup>a</sup>	2.47		151.6 <sup>b</sup>	2.34		142.0 <sup>c</sup>	2.64		30.9	2.12	<.001	5.06	1.75	0.004
Fat percentage	4.63 <sup>c</sup>	0.05		5.11 <sup>b</sup>	0.05		5.38 <sup>a</sup>	0.06		-1.09	0.04	<.001	0.16	0.04	<.001
Protein percentage	3.70 <sup>c</sup>	0.02		3.86 <sup>b</sup>	0.02		3.97 <sup>a</sup>	0.02		-0.39	0.02	<.001	0.05	0.02	0.002
Lactose percentage	4.86 <sup>c</sup>	0.01		4.88 <sup>b</sup>	0.01		4.89 <sup>a</sup>	0.01		-0.05	0.01	<.001	0.01	0.01	0.942
P:P+L	0.42 <sup>a</sup>	0.002		0.43 <sup>b</sup>	0.002		0.44 <sup>c</sup>	0.002		-0.02	0.001	<.001	0.003	0.001	0.002
SCS	5.89	0.09		5.92	0.09		5.87	0.11		0.01	0.08	0.936	0.07	0.07	0.325
WMP (kg)	347.6 <sup>a</sup>	6.08		316.6 <sup>b</sup>	5.75		290.2 <sup>c</sup>	6.51		92.6	5.2	<.001	4.74	4.29	0.26
SMP (kg)	232.0 <sup>a</sup>	4.09		210.9 <sup>b</sup>	3.87		193.1 <sup>c</sup>	4.38		62.7	3.49	<.001	2.94	2.88	0.308
Butter (kg)	168.8 <sup>b</sup>	2.84		179.1 <sup>a</sup>	2.68		176.3 <sup>a</sup>	3.04		26.1	4.86	<.001	25.4	4.01	<.001
Cheese (kg)	358.9 <sup>b</sup>	5.6		364.9 <sup>a</sup>	5.3		351.6 <sup>b</sup>	5.99		-4.86	2.47	0.049	15.3	2.04	<.001

<sup>a,b,c</sup> Means with different letters denote significant differences ( $P < 0.05$ ).

<sup>1</sup>P:P+L = protein-to-protein-plus-lactose; SCS = somatic cell score, calculated as  $\text{Log}_2$ (somatic cell count); WMP = whole milk powder; SMP = skim milk powder.

<sup>2</sup>F = Holstein-Friesian; J = Jersey; FxJ = Holstein-FriesianxJersey crossbred.

Estimates of genetic variance and heritability are presented in Table 6.2. Heritabilities were lower for TFY and TPY than TMY and TLY (0.15 and 0.14 vs 0.23 and 0.22). Estimates of heritability for WMP and SMP were moderate (0.31), compared with the lower heritabilities for butter and cheese (0.16 and 0.13). Fat percentage had the greatest estimate of heritability (0.45) followed by P:P+L, PP and LP.

**Table 6.2.** Estimates of Variance components and heritabilities ( $h^2$ ) with their associated standard errors of the mean for total lactation milk production traits and milk product potential.

Trait <sup>1</sup>	$\sigma_a^2$	$\sigma_e^2$	$\sigma_{total}^2$	$h^2$
Total milk yield	51898	172367	224270	0.23 ± 0.04
Total fat yield	74.1	420.2	494.4	0.15 ± 0.04
Total protein yield	39.2	232.4	271.6	0.14 ± 0.03
Total lactose yield	129.3	459.0	588.4	0.22 ± 0.04
Fat percentage	0.13	0.15	0.28	0.45 ± 0.06
Protein percentage	0.02	0.03	0.05	0.40 ± 0.05
Lactose percentage	0.005	0.008	0.013	0.35 ± 0.05
P:P+L	0.0001	0.0002	0.0003	0.42 ± 0.06
WMP	1096	2497	3293	0.31 ± 0.05
SMP	503	1125	1627	0.31 ± 0.04
Butter	124.5	656.4	780.9	0.16 ± 0.04
Cheese	390.8	2618	3009	0.13 ± 0.03

<sup>1</sup>P:P+L = protein-to-protein-plus-lactose ratio; WMP = whole milk powder potential; SMP = skim milk powder potential.  $\sigma_a^2$  = animal additive genetic variance;  $\sigma_e^2$  = residual error variance;  $\sigma_{total}^2$  = sum of all variances.

Estimates of genetic and phenotypic correlations are presented in Table 6.3. Total milk yield and TLY had both a very high genetic and phenotypic correlation. There was a very high genetic correlation between WMP and SMP with TMY and TLY, as well as a very high genetic correlation between butter and TFY and cheese and TPY which was expected given product specifications.

**Table 6.3.** Estimates of genetic and phenotypic correlations and standard errors for total lactation yields of milk production traits and estimated milk product potential.

Trait <sup>1</sup>	TMY	TFY	TPY	TLY	FP	PP	LP	P:P+L	WMP	SMP	Butter	Cheese
TMY		0.75±0.01	0.92±0.01	0.99±0.01	-0.38±0.01	-0.34±0.01	-0.08±0.02	-0.26±0.02	0.94±0.01	0.93±0.01	0.70±0.01	0.85±0.01
TFY	0.42±0.12		0.84±0.01	0.73±0.01	0.30±0.01	0.08±0.02	-0.09±0.02	0.13±0.02	0.57±0.01	0.56±0.01	0.99±0.01	0.90±0.01
TPY	0.86±0.04	0.53±0.11		0.91±0.01	-0.15±0.02	0.03±0.02 <sup>ns</sup>	-0.08±0.02	0.07±0.02	0.77±0.01	0.77±0.01	0.81±0.01	0.95±0.01
TLY	0.98±0.01	0.39±0.12	0.82±0.11		-0.38±0.01	-0.34±0.01	0.07±0.02	-0.32±0.01	0.96±0.01	0.96±0.01	0.69±0.01	0.84±0.01
FP	-0.67±0.08	0.37±0.12	-0.45±0.01	-0.68±0.08		0.64±0.01	-0.04±0.02	0.60±0.01	-0.54±0.01	-0.54±0.01	0.36±0.01	0.01±0.02 <sup>ns</sup>
PP	-0.69±0.08	-0.10±0.14 <sup>ns</sup>	-0.24±0.14	-0.72±0.08	0.63±0.06	-0.08±0.11	-0.02±0.02 <sup>ns</sup>	0.92±0.01	-0.54±0.01	-0.55±0.01	0.13±0.02	0.09±0.02
LP	-0.16±0.12	-0.19±0.14	-0.29±0.13	0.03±0.13 <sup>ns</sup>	0.01±0.11 <sup>ns</sup>	0.94±0.01	-0.41±0.09	-0.39±0.01	0.16±0.02	0.17±0.02	-0.10±0.02	-0.08±0.02
P:P+L	-0.58±0.09	-0.03±0.14 <sup>ns</sup>	-0.13±0.14	-0.68±0.08	0.58±0.07	-0.84±0.05	0.14±0.11	-0.82±0.05	-0.54±0.01	-0.55±0.01	0.17±0.02	0.13±0.02
WMP	0.93±0.02	0.24±0.13	0.66±0.08	0.97±0.01	-0.74±0.06	-0.84±0.05	0.15±0.11	-0.83±0.05	0.99±0.01	0.99±0.01	0.52±0.01	0.69±0.01
SMP	0.93±0.02	0.24±0.13	0.65±0.08	0.97±0.01	-0.74±0.06	-0.84±0.05	0.15±0.11	-0.83±0.05	0.99±0.01	0.99±0.01	0.51±0.01	0.88±0.01
Butter	0.33±0.13	0.99±0.01	0.46±0.12	0.30±0.13	0.46±0.11	-0.03±0.14	-0.16±0.13	0.02±0.13 <sup>ns</sup>	0.16±0.14	0.15±0.14	0.50±0.01	0.88±0.01
Cheese	0.72±0.01	0.76±0.07	0.92±0.03	0.68±0.08	-0.15±0.14	-0.11±0.14 <sup>ns</sup>	-0.22±0.14	-0.02±0.14 <sup>ns</sup>	0.50±0.11	0.72±0.07	0.50±0.01	0.88±0.01

<sup>1</sup>TMY = total milk yield; TFY = total fat yield; TPY = total protein yield; TLY = total lactose yield; FP = fat percentage; PP = protein percentage; LP = lactose percentage; P:P+L = protein-to-protein-plus-lactose ratio; WMP = whole milk powder potential; SMP = skim milk powder potential.

Genetic correlations shown below the diagonal and phenotypic above.

ns= non-significant correlations (P > 0.05) all other correlations are significantly different to zero (P < 0.05).

## Discussion

Heritability estimates for milk yield traits in this study were similar to previous studies using lactation yields (Welper & Freeman 1992; Spelman & Garrick 1997; Roman et al. 2000; Johnson et al. 2000; Pryce & Harris 2006), although TFY and TPY heritabilities were at the lower end of the range of reported values (Welper & Freeman 1992; Spelman & Garrick 1997; Pryce & Harris 2006). The heritability estimates for FP, PP and LP were similar to those in American J cattle reported by Roman et al. (2000) who found lower heritability for LP compared to FP and PP, but higher than the estimates of Ptak et al. (2012) in Polish Holstein-Friesians.

This paper presents the first estimates of heritability for potential yields of dairy products for WMP, SMP, butter and cheese. Whole and skim milk powder potentials had the highest heritabilities of the four investigated product scenarios. These were simulated product yields when using all milk for that product, F cows were found to have greatest yields of WMP and SMP. This simulated difference can be linked to the favourable P:P+L ratio, which the model uses to balance fat, protein and lactose therefore producing a greater amount of product. The heritability of 0.31 for WMP indicates that it is possible to select directly for milk product yields, this could allow for the contracted herd production of milk with specific herds of cows which can be contracted for the purpose of a specific product production, or to reduce the lactose demand in the entire industry by breeding cows which are better suited to the milk product profile. The heritability of cheese (0.13) is similar to those reported by Bittante et al. (2013) for across herd cheese yield (0.185) and liquid whey production (0.130). While TMY, TFY, TFP and PP heritability estimates in this study were higher than for

mozzarella in buffalo cattle reported by Rosati & Van Vleck (2002) with the estimate for cheese heritability being similar, however, the estimate was lower than the reported value of Aspilcueta-Borquis et al. (2010).

Whole milk powder is currently the largest export product of the New Zealand dairy industry (Fonterra 2014) making up nearly 70% of dairy exports in the 2013-2014 dairy season. This represents a large change in the product portfolio of the industry over the past 11 years, from 44% of exports in 2003 to almost 75% in 2013 (Fonterra 2003; 2014). As a consequence, changes in sale value or processing cost of WMP impact the dairy industry quickly, as occurred between the 2013-2014 and 2014-2015 dairy seasons, when there was a 50% reduction in WMP prices in eight months, reducing payouts received by farmers from \$8.40/kg milksolids in 2013-2014 to a forecast \$4.40/kg milksolids for 2014-15 (Global Dairy Trade 2014; Fonterra 2015). One of the factors affecting the value of milk supplied by the farmer is the composition of that milk and the composition is affected by the animals used by the farmer (Lopez-Villalobos et al. 2000; Geary et al. 2010). In a previous study it was found that FxJ cows could be the most profitable animals for the New Zealand dairy industry, as more FxJ can be run per ha than F cows, and they produce more milk than J cows (Lopez-Villalobos et al. 2000). In a similar study investigating the milk income from different breeds (Sneddon et al. 2015b), the income per lactation also indicated that total milk revenue could be increased through using crossbred cows. The study of Lopez-Villalobos et al. (2002) showed that an increased milk value per L was associated with an increased profit per ha or per cow. That study was different, however, as it evaluated the changes in responses to selection on casein or fat concentrations. Lopez-Villalobos et al. (1998) investigated the effect on butter value from changes in butter production, which

indicated that increases in butter production decreased butter value. However, if the decrease in value could be overcome by increased yields of WMP or casein the total value of the milk could increase, as greater yields overcome lowered value.

The ratio of P:P+L can be used as a proxy predictor of a milk's suitability to produce WMP (Sneddon et al. 2014). The ideal P:P+L for WMP is around 0.38 (Geary et al. 2010). Holstein-Friesian cows have P:P+L closer to ideal than J cows which is indicated by the high breed effect for WMP. Crossbred animals allow for increased yields of products relative to J, except for butter.

While none of these scenarios (with 100% of milk used for each product) show a current industry picture, they do allow for the estimation of genetic parameters and breeding values for total product potentials. These scenarios also indicate differences between the historic dairy industry and potential future markets if current trends in product portfolios are continued (Fonterra 2003; 2014). All scenarios used the same product values, however, it is possible that in situations where some products (such as casein) are supplied in great quantities their values would change.

Systematic crossbreeding could create New Zealand cows which can produce milk more suited to the dairy product portfolio along with beneficial heterosis for production, fertility and survivability that provides an overall benefit to the New Zealand dairy industry. It could be argued that systematic crossbreeding is already occurring, with FxJ cows increasing from 19% of the national herd in 1998-1999 to 42.6% in the 2013-2014 dairy season (LIC 1999; LIC & DairyNZ 2014). Previous research has shown that the maximum proportion of FxJ cows that can be supported, without detrimental effects on

genetic gains, is around 90%, with J and F effective cow populations around 3% of the national herd (Lopez et al. 2000).

## **Conclusion**

It is possible to directly select for product yields in a breeding scheme given estimates of genetic parameters for milk products. However, this may be to the detriment of other traits, such as fertility, somatic cell count and live weight which are also important for the efficient conversion of feed into farmer profit. Under WMP- or SMP-dominated product portfolios, the milk value per lactation was maximised using FxJ cows. In a butter-dominated scenario, F cows provided the greatest total income, but there was no difference between breeds under a cheese-production scenario for lactation milk value. Breed choice for greatest return is dependent on product portfolio and the market for those products. Currently the New Zealand dairy industry can benefit from using FxJ cows with current exports dominated by WMP and SMP. The use of genetic parameters and correlations for dairy product yields could increase the rate of gain in specific dairy product yields, but have to be evaluated in conjunction with the other traits of interest in breeding worth.

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## Chapter 7

### **Responses in lactose yield, lactose percentage and protein-to-protein-plus-lactose ratio from index selection in New Zealand dairy cattle**

NW Sneddon<sup>a\*</sup>, N Lopez-Villalobos<sup>a</sup>, RE Hickson<sup>a</sup>, SR Davis<sup>b</sup>, L Shalloo<sup>c</sup>, DJ Garrick<sup>a</sup>  
and U Geary<sup>c</sup>

<sup>a</sup>Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Private  
Bag 11-222, Palmerston North, New Zealand;

<sup>b</sup>Livestock Improvement Corporation, Private Bag 3016, Hamilton 3240, New Zealand;

<sup>c</sup>Dairy Production Department, Teagasc, Moorepark Production Research Centre,  
Fermoy, Co. Cork, Cork, Ireland

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**Abstract**

The breeding goal of the New Zealand dairy industry is to improve the genetic capability of cows to convert pasture-based feed into farmer profit. The New Zealand dairy industry exports over 95% of milk produced and the most significant product by export volume is whole milk powder (WMP). The current selection objective Breeding Worth (BW) will increase yields of protein and fat, potentially shifting milk composition further from the ideal composition for making WMP as protein increases faster than lactose. This study aimed to investigate the correlated responses in lactose yield (LY), lactose percentage (LP) and protein-to-protein-plus-lactose ratio (P:P+L) following selection for BW, BW plus LY, BW plus LP and BW plus P:P+L. Selection for BW is predicted to have per-cow responses of 54.92 kg milk/year, 2.22 kg fat/year, 1.78 kg protein/year and 2.84 kg lactose/year. When lactose was included in the selection objective in the form of LY, LP or P:P+L, genetic responses ranged from -59.98 kg milk/year when selecting for P:P+L to 61.08 kg milk/year when selecting for LY and from -2.67 kg lactose/year when selecting for P:P+L to 3.70 kg lactose/year when selecting for LY. The industry could reduce imported lactose requirements per tonne of WMP by 6-11% by including lactose into the selection objective, compared with selection on BW alone.

**Keywords:**

Lactose; selection objective; milk processing; correlated responses; New Zealand

## Introduction

The breeding goal for genetic improvement of the New Zealand dairy industry is to improve the genetic capability of the cows to convert feed into farm profit. This breeding goal is expressed as a selection objective called Breeding Worth (BW) which ranks the genetic superiority or inferiority of an animal expressed in dollars of net profit per 5 tonnes of dry matter consumed (NZAEL 2014).

The selection objective is calculated as the sum of the true breeding values and economic values. Selection indices are used as a predictor of a selection objective. However, there are many potential selection indices which can represent a selection objective, however, selection index theory predicts the selection index which maximises the correlation between the best selection index and selection objective (Hazel 1943).

The Breeding Worth selection objective is calculated as:

$$BW = \sum_{i=1}^7 BV_i \times EV_i$$

where  $BV_i$  is the true breeding value of an animal for trait  $i$  and  $EV_i$  its corresponding economic value. Traits considered in BW are lactation yields of milk, fat and protein, mature cow live weight, somatic cell score (SCS) calculated as  $\text{Log}_2(\text{somatic cell count})$ , cow fertility and residual survival (NZAEL 2015). The selection index is of the same form as the selection objective using estimated breeding values, predictor traits were also the same as objective traits.

The estimated breeding values in BW are expressed relative to a genetic base animal defined as the average cow born in 2000 (DairyNZ 2013). Correlated responses in lactose from selection on BW are not routinely reported as lactose is currently excluded from payment systems for milk, herd testing records and genetic evaluations. The BW index was introduced in 1996 including fat, protein, milk yield, live weight and survival (Spelman & Garrick 1997). Over time BW has been modified and improved, with the addition of new traits of economic importance, to reach its current form to include 7 traits (DairyNZ 2013).

New Zealand exports dairy products representing over 95% of milk produced in New Zealand and the most significant products by export volume are whole milk powder (WMP), followed by skim milk powder (SMP). These two products represented more than 70% of dairy exports in 2013 (Fonterra 2014). The shift in focus from cheese and butter production in the 1970's and 1980's to increasing amounts of milk powders in the 1990's to present has generated market signals that have resulted in significant changes to the way in which the New Zealand dairy herd is bred, with a shifting emphasis from fat yield to protein yield as the major trait of economic importance. The inclusion of lactose yield into BW has not been undertaken because the high genetic correlation (0.98) with milk yield implies BV for lactose yield would be almost identical to BV for milk yield (Sneddon et al. 2015), and there has been no value put upon lactose by Fonterra. However, current selection limits milk volume which has a negative economic value while increasing protein and fat yields. The consequence has been shown to reduce the WMP production potential of the New Zealand dairy industry (Sneddon et al. 2014). However, that previous study assumed lactose percentage was fixed and lactose yield responses could not be separated from responses in milk yield. A trait called

protein-to-protein-plus-lactose (P:P+L), which is the ratio of protein yield to protein yield plus lactose yield, was calculated as a proxy of the capacity to produce WMP. The present study allows for a less than perfect genetic correlation between lactose yield and milk yield and quantifies correlated responses in lactose yield, lactose percentage and P:P+L ratio from selection for BW and modified BW indices including BW plus lactose, BW plus lactose percentage and BW plus P:P+L.

## **Materials and methods**

### *Selection indices and selection objectives*

Selection indices were constructed using selection theory (Hazel 1943) to investigate eight different selection objectives (Table 7.1). The traits included were the same as those in the BW selection index plus various measures of lactose. The base scenario was selection on BW with the economic values as published in the February 2014 economic value update (NZAEL 2014).  $BW_{HLY}$  is BW with LY included at the value of PY,  $BW_{LLY}$  is BW with LY included at the value of FY,  $BW_{LLP}$  is BW with LP included at the same value as PY,  $BW_{HLP}$  is BW with LP included at 100 times the value of PY,  $BW_{LPL}$  is BW with P:P+L included at a negative value equal to the value of PY and PY excluded from the objective,  $BW_{MPL}$  is BW with P:P+L included at a negative value equal to 100 times the value of PY and PY excluded from the index and  $BW_{HPL}$  BW with P:P+L included at a negative value equal to 1000 times the value of PY and PY excluded from the index. All economic values and relative emphases are shown in Table 7.1.

**Table 7.1.** Economic values and relative emphasis (in brackets) for traits in Breeding Worth (BW) and different selection objectives investigated including selection for lactose yield (LY), lactose percentage (LP) and protein-to-protein-plus-lactose (P:P+L).

Trait <sup>2</sup>	Selection objective <sup>1</sup>									
	BW	BW <sub>LLY</sub>	BW <sub>HLV</sub>	BW <sub>LLP</sub>	BW <sub>HLP</sub>	BW <sub>LPL</sub>	BW <sub>MPL</sub>	BW <sub>HPL</sub>		
Milk (kg)	-0.099 (14.6)	-0.099 (12.5)	-0.099 (8.2)	-0.099 (14.5)	-0.099 (9.9)	-0.099 (24.3)	-0.099 (22.0)	-0.099 (11.9)		
Fat (kg)	2.04 (13.6)	2.04 (11.6)	2.04 (7.7)	2.04 (13.5)	2.04 (9.2)	2.04 (22.5)	2.04 (20.4)	2.04 (11.1)		
Protein (kg)	9.17 (39.9)	9.17 (34.0)	9.17 (22.5)	9.17 (39.7)	9.17 (27.2)					
Liveweight (kg)	-1.66 (13.1)	-1.66 (11.2)	-1.66 (7.4)	-1.66 (13.1)	-1.66 (9.0)	-1.66 (21.8)	-1.66 (19.8)	-1.66 (10.7)		
Fertility (%)	7.18 (5.1)	7.18 (4.3)	7.18 (2.9)	7.18 (5.0)	7.18 (3.5)	7.18 (8.5)	7.18 (7.7)	7.18 (4.2)		
SCS (units)	-38.37 (8.7)	-38.37 (7.4)	-38.37 (4.9)	-38.37 (8.7)	-38.37 (5.9)	-38.37 (14.5)	-38.37 (13.1)	-38.37 (7.1)		
Residual survival (days)	0.135 (5.0)	0.135 (4.3)	0.135 (2.8)	0.135 (5.0)	0.135 (3.4)	0.135 (8.3)	0.135 (7.6)	0.135 (4.1)		
Lactose (kg)		2.04 (14.7)	9.17 (43.6)							
Lactose (%)				9.17 (0.5)	917.0 (31.9)					
P:P+L						-9.17 (0.1)	-917.0 (9.4)	-9170.0 (50.9)		

<sup>1</sup>BW = breeding worth; BW<sub>LLY</sub> = BW with additional low relative economic weighting for lactose yield (LY); BW<sub>HLV</sub> = BW with additional high relative economic weighting for LY; BW<sub>LLP</sub> = BW with additional low relative economic weighting for lactose percentage (LP); BW<sub>HLP</sub> = BW with additional high relative economic weighting for LP; BW<sub>LPL</sub> = BW with additional low relative economic weighting on protein-to-protein-plus-lactose (P:P+L) with protein yield (PY) excluded from the index; BW<sub>MPL</sub> = BW with additional medium relative economic weighting on P:P+L with PY excluded from the index; BW<sub>HPL</sub> = BW with additional high relative economic weighting for P:P+L with PY excluded from the index.

<sup>2</sup>SCS = Somatic cell score calculated as Log<sub>2</sub>(somatic cell count); P:P+L = protein-to-protein-plus-lactose ratio.

The indices were of the form

$$I = b_1x_1 + b_2x_2 + \dots + b_mx_m = \mathbf{b}'\mathbf{x}$$

Where  $x_i$  is an observation on the  $i$ th trait and  $b_i$  is the selection index coefficient (or weighting) for that trait. In vector notation  $\mathbf{b}' = [b_1, b_2, \dots, b_m]$  and  $\mathbf{x}' = [x_1, x_2, \dots, x_m]$ .

The selection objectives were of the form

$$H = a_1g_1 + a_2g_2 + \dots + a_ng_n = \mathbf{a}'\mathbf{g}$$

Where  $g_i$  is the true breeding value of the  $i$ th trait and  $a_i$  is the economic value of the corresponding trait. In vector notation  $\mathbf{a}' = [a_1, a_2, \dots, a_n]$  and  $\mathbf{g}' = [g_1, g_2, \dots, g_n]$ .

The vector  $\mathbf{b}$  was calculated from solving the equation

$$\mathbf{b} = \mathbf{P}^{-1}\mathbf{G}\mathbf{a}$$

Where  $\mathbf{P}$  is the  $n \times n$  phenotypic variance-covariance matrix of the traits ( $n$ ) used in the selection index and  $\mathbf{G}$  is the  $n \times m$  genetic covariance matrix between traits in the selection index ( $n$ ) and traits in the aggregate genotype ( $m$ ). For all scenarios traits included in the selection index were the same as those included in the selection objective, predictor traits were also the same as objective traits.

*Calculation of genetic gain*

Correlated responses ( $R$ ) to selection were calculated using selection index theory (Cameron 1997). This was done individually for each of the 8 investigated scenarios using the equation:

$$R_j = \frac{\mathbf{b}'\mathbf{C}_j}{\sqrt{\mathbf{b}'\mathbf{P}\mathbf{b}}}$$

Where  $R_j$  is the  $R$  for the  $j$ th trait and  $\mathbf{C}_j$  is the  $j$ th column in matrix  $\mathbf{C}$ ,  $\mathbf{C}$  is a matrix that includes the genetic covariances between all traits included in the selection index, selection objective and other traits of interest (LY, LP, P:P+L and PY) if they were not in either index. Matrices  $\mathbf{P}$  and  $\mathbf{C}$  were derived from parameters shown in Table 7.2, assumed values were calculated as the average proportion of the known correlations between known traits. Genetic and phenotypic correlations are in Table 7.2. Genetic parameters were taken from several sources (Spelman & Garrick 1997; Pryce & Harris 2006; Sneddon et al. 2016), these matrices were checked to ensure they were positive definitive and those that were not underwent bending using the procedure of Jorjani et al. (2003), these bent matrices were checked against the originals to check for differences and the new bent matrix was then used in the selection index calculations.

**Table 7.2.** Genetic (below diagonal) and phenotypic (above diagonal) correlations among traits used in investigated selection indices for breeding worth and breeding worth including either lactose yield, lactose percentage and protein-to-protein-plus-lactose ratio.

Traits <sup>a</sup>	$\sigma_g$	$h^2$	$r$	MY	FY	PY	LWT	Fertility	SCS	Residual survival	LY	LP	P:P+L
Milk yield (MY)	227.81 <sup>c</sup>	0.23 <sup>c</sup>	0.60 <sup>b</sup>		0.73 <sup>c</sup>	0.91 <sup>c</sup>	0.25 <sup>e</sup>	-0.002 <sup>e</sup>	-0.13 <sup>e</sup>	0	0.99 <sup>c</sup>	-0.08 <sup>c</sup>	-0.26 <sup>c</sup>
Fat yield (FY)	10.27 <sup>c</sup>	0.29 <sup>e</sup>	0.60 <sup>b</sup>	0.54 <sup>c</sup>		0.82 <sup>c</sup>	0.24 <sup>e</sup>	0.02 <sup>e</sup>	-0.09 <sup>e</sup>	0	0.73 <sup>c</sup>	-0.09 <sup>c</sup>	0.13 <sup>c</sup>
Protein yield (PY)	6.72 <sup>c</sup>	0.29 <sup>e</sup>	0.60 <sup>b</sup>	0.86 <sup>c</sup>	0.69 <sup>c</sup>		0.30 <sup>e</sup>	0.02 <sup>e</sup>	-0.10 <sup>e</sup>	0	0.91 <sup>c</sup>	-0.08 <sup>c</sup>	0.07 <sup>c</sup>
Live weight (LWT)	12.24 <sup>e</sup>	0.39 <sup>e</sup>	0.65 <sup>b</sup>	0.28 <sup>e</sup>	0.33 <sup>e</sup>	0.36 <sup>e</sup>		0.05 <sup>e</sup>	0.04 <sup>e</sup>	0	0.25 <sup>d</sup>	0.00004 <sup>d</sup>	-0.00004 <sup>d</sup>
Fertility	1.10 <sup>e</sup>	0.03 <sup>e</sup>	0.05 <sup>e</sup>	-0.15 <sup>e</sup>	-0.06 <sup>e</sup>	-0.05 <sup>e</sup>	0.03 <sup>e</sup>		-0.02 <sup>e</sup>	0	0.00005 <sup>d</sup>	-0.000005 <sup>d</sup>	0.000005 <sup>d</sup>
SCS	0.35 <sup>e</sup>	0.18 <sup>e</sup>	0.30 <sup>e</sup>	0.04 <sup>e</sup>	0.12 <sup>e</sup>	0.06 <sup>e</sup>	-0.01 <sup>e</sup>	-0.10 <sup>e</sup>		0	-0.09 <sup>d</sup>	-0.16 <sup>d</sup>	0.13 <sup>d</sup>
Residual survival	57.40 <sup>e</sup>	0.07 <sup>e</sup>	0.11 <sup>e</sup>	0	0	0	0	0	0		0 <sup>d</sup>	0 <sup>d</sup>	0 <sup>d</sup>
Lactose yield (LY)	13.02 <sup>c</sup>	0.50 <sup>c</sup>	0.67 <sup>c</sup>	0.98 <sup>c</sup>	0.39 <sup>c</sup>	0.82 <sup>c</sup>	0.23 <sup>d</sup>	-0.14 <sup>d</sup>	-0.20 <sup>d</sup>	0 <sup>d</sup>		0.07 <sup>c</sup>	-0.32 <sup>c</sup>
Lactose percentage (LP)	0.08 <sup>c</sup>	0.64 <sup>c</sup>	0.64 <sup>c</sup>	-0.16 <sup>c</sup>	-0.19 <sup>c</sup>	-0.29 <sup>c</sup>	0.00004 <sup>d</sup>	-0.0001 <sup>d</sup>	-0.10 <sup>d</sup>	0 <sup>d</sup>	0.03 <sup>c</sup>		-0.39 <sup>c</sup>
P:P+L	0.01 <sup>c</sup>	0.43 <sup>c</sup>	0.60 <sup>c</sup>	-0.57 <sup>c</sup>	0.01 <sup>c</sup>	-0.13 <sup>c</sup>	-0.00004 <sup>d</sup>	0.0001 <sup>d</sup>	0.12 <sup>d</sup>	0 <sup>d</sup>	-0.66 <sup>c</sup>	-0.45 <sup>c</sup>	

$\sigma_g$  = genetic standard deviation;  $h^2$  = heritability;  $r$  = repeatability.

<sup>a</sup> SCS = Somatic cell score calculated as  $\text{Log}_2(\text{somatic cell count})$ ; P:P+L = protein-to-protein-plus-lactose ratio.

<sup>b</sup> Spelman & Garrick (1997).

<sup>c</sup> Sneddon et al. (2016).

<sup>d</sup> Assumed values

<sup>e</sup> Pryce & Harris (2006).

Variances and co-variances for each of the individual pathways were formulated using the methodology of Pretto et al. (2012). Due to the differences in sources of information the formulas were as follows

### Cow pathways

Elements in matrix **P**

$$P_{ii} = \left[ r + \frac{1-r}{n} \right] \times \sigma_{pii}^2$$

$$P_{ij} = \frac{\sigma_{pij} + (n-1) \times \sigma_{gij}}{n}$$

Elements in matrix **C**

$$C_{ii} = \sigma_{gii}^2$$

$$C_{ij} = \sigma_{gij}$$

### Bull pathways

Elements in matrix **P**

$$P_{ii} = \frac{[r + (1-r/n)] + (p-1)k \times h^2}{p} \times \sigma_{pii}^2$$

$$P_{ij} = \frac{(\sigma_{pij} + (n-1) \times \sigma_{gij}/n) + k \times \sigma_{gij}}{p}$$

Elements in matrix **C**

$$C_{ii} = a \times \sigma_{gii}^2$$

$$C_{ij} = a \times \sigma_{gij}$$

Where

$\sigma_{pii}^2$  = phenotypic variance of trait *i*.

$\sigma_{gii}^2$  = genetic variance of trait *i*.

$\sigma_{pij}$  = phenotypic covariance between traits *i* and *j*.

$\sigma_{gij}$  = genetic covariance between traits *i* and *j*.

*n* = number of phenotypic records per animal (own performance in cow pathways, performance of daughters in bull pathways).

$h^2$  = the heritability of the trait

*r* = repeatability of the trait.

*p* = number of animals in progeny group.

*k* = relationship among animals in progeny groups (half-sibs 0.25).

*a* = relationship among animals in progeny groups and animals to evaluate (bull to daughter = 0.5).

### ***Breeding scheme***

The four pathways of selection (Rendel & Robertson 1950) were used to calculate an overall industry rate of genetic gain. The assumptions used in the four pathways are presented in Table 7.3, specifically for cows to breed cows (CC), cows to breed bulls (CB), bulls to breed cows (BC) and bulls to breed bulls (BB). Selection intensities

carried by pathways were as follows; all cows were available for the CC pathway; CB was calculated using all cows in lactations 3 and 4: 440 bulls available for progeny test for BC, BB with the top 10% selected for BC and top 2% for BB. For the calculation of selection intensity 99.85% of animals in CC, 0.25% (2640 cows, 6 cows to produce 1 bull for progeny test) of animals in CB, 10% (44 bulls) of animals in BC, 2.05% (9 bulls) of animals in BB were available for selection respectively, based on Lopez-Villalobos & Garrick (2005). Generation intervals were 5.6, 4.2, 7 and 6.5 years for CC, CB, BC and BB respectively. These were based on the age structure of the national herd (LIC & DairyNZ 2014) for the CC pathway. For CB it was based on calves being born when 80% of cows were 4 years old and 20% were 5 years old. The BC and BB generation intervals were based on time required to gain progeny records on 85 daughters. Number of records per animal was based on Spelman & Garrick (1997) with 2 records on cows and 85 records on daughters.

**Table 7.3.** Assumptions pertaining to the four pathways of selection, including starting population size, proportion selected, intensity of selection ( $i$ ), generation interval, number of records and number of progeny (in sire proving scheme).

Pathway <sup>1</sup>	Population	Proportion selected	$i$	Generation interval (years)	Number of records	Number of progeny
CC <sup>2</sup>	4,800,000	0.998	0.02	5.6	2	0
CB <sup>2</sup>	1,056,000	0.003	3.033	4.2	2	0
BC <sup>3</sup>	440	0.10	1.755	7.0	4	85
BB <sup>3</sup>	440	0.02	2.420	6.5	4	85

<sup>1</sup>CC = cows to breed cows; CB = cows to breed bulls; BC = bulls to breed cows; BB = bulls to breed bulls.

<sup>2</sup>Records on the animal itself.

<sup>3</sup>Records on progeny.

### ***Industry production of milk components and dairy products***

The genetic responses were used in the industry model described in Sneddon et al. (2014) to generate industry and per cow milk production responses after 10 years of selection, which did account for overlapping generations and assumed 100% use of artificial insemination. The base cow was assumed to have a genetic potential consistent with phenotypic production of 4,480 kg of milk, 222 kg of fat, 169 kg of protein, 210 kg of lactose and 460 kg of live weight (LIC & DairyNZ 2013). The calculations used in this paper estimate changes to the industry production of milk, fat, protein and lactose yields and live weight over ten years based on steady state genetic gains for milk, fat, protein and lactose yields and live weight. The industry is constrained by total area of 1.677 million ha (LIC & DairyNZ 2013) and feed availability (12,090 kg DM intake/ha), leading to decreases in stocking rate as feed demand per cow increases, energy requirements were calculated from milk, fat, and protein yields and live weight. The estimated industry milk production from 10 years of selection for each selection objective was then used in the Moorepark processing sector model (Geary et al. 2010) to estimate the potential milk product yields. The model of Geary et al. (2010) is a mass balance milk processing model, which can simulate varying product portfolios. In this study 60% of milk was used to produce WMP, 23.5% of milk was used for SMP, 14% of milk for cheese, 0.5% for butter and 2.0% for casein. The product mix was used as an approximation of the Fonterra 2012-2013 product yields (Fonterra 2012a; 2012b; 2012c; 2013).

Values of WMP, SMP, cheese, butter, lactose, BMP and casein were obtained from Global Dairy Trade (2015) historic results (averaged from 15 May 2013 to 19 May

2015). The value of WP was obtained from the European Commission (2015) historic milk product values (average 19 May 2013 to 17 May 2015) and converted to US dollars using NZForex (2015) historic exchange rate values for each day there was a WP value. Total industry income was calculated by multiplying the yield of each dairy product by its value.

## Results

Genetic responses are in Table 7.4 for each of the scenarios. Under selection for BW the predicted genetic response was MY 54.92 kg/year, FY 2.22 kg/year, PY 1.78 kg/year and LY 2.84 kg/year. Live weight was predicted to increase at 1.04 kg/year, residual survival was predicted to increase at 0.077 days/year, with a small decrease in fertility, SCS, LP and P:P+L. With LY included in the selection objective with the same economic weighting as PY ( $BW_{HLY}$ ), the rate of gain in MY and LY increased to 61.08 kg/year and 3.70 kg/year respectively. Fat yield and PY decreased to 1.71 kg/year and 1.77 kg/year respectively. Live weight gains increased to 1.17 kg/year. Fertility, SCS, LP and P:P+L all had small negative responses. Residual survival had a decrease in the response rate to 0.02 days/year.

**Table 7.4.** Correlated responses per year in traits for the current New Zealand dairy industry selection objective (Breeding Worth) and alternative selection objectives including either lactose yield, lactose percentage or the ratio of protein-to-protein-plus-lactose.

Trait <sup>2</sup>	Selection objective <sup>1</sup>									
	BW	BW <sub>LLY</sub>	BW <sub>HLY</sub>	BW <sub>LLP</sub>	BW <sub>HLP</sub>	BW <sub>LPL</sub>	BW <sub>MPL</sub>	BW <sub>HPL</sub>		
Milk (kg)	54.92	59.90	61.08	54.96	21.84	-59.98	-49.46	32.33		
Fat (kg)	2.22	2.03	1.71	2.22	0.80	-0.95	-0.93	0.15		
Protein (kg)	1.78	1.84	1.77	1.78	0.59	-1.36	-1.31	0.29		
Live weight (kg)	1.04	1.14	1.17	1.04	0.65	-1.35	-1.48	-0.16		
Fertility (%)	-0.0256	-0.0328	-0.0381	-0.0257	-0.0190	0.0343	0.0370	0.0021		
SCS (units)	-0.0027	-0.0060	-0.0090	-0.0028	-0.0145	-0.0154	-0.0206	-0.0117		
Residual survival (days)	0.077	0.052	0.023	0.077	0.064	0.150	0.175	0.044		
Lactose (kg)	2.84	3.37	3.70	2.85	2.07	-2.55	-2.67	0.03		
Lactose (%)	-0.0099	-0.0072	-0.0038	-0.0096	0.0142	0.0030	0.0020	-0.0025		
P:P+L (units)	-0.0004	-0.0004	-0.0004	-0.0004	0.0002	0.0016	0.0004	-0.0030		

<sup>1</sup>BW = breeding worth; BW<sub>LLY</sub> = BW with additional low relative economic weighting for lactose yield (LY); BW<sub>HLY</sub> = BW with additional high relative economic weighting for LY; BW<sub>LLP</sub> = BW with additional low relative economic weighting for lactose percentage (LP); BW<sub>HLP</sub> = BW with additional high relative economic weighting for LP; BW<sub>LPL</sub> = BW with additional low relative economic weighting on protein-to-protein-plus-lactose (P:P+L) with protein yield (PY) excluded from the index; BW<sub>MPL</sub> = BW with additional medium relative economic weighting on P:P+L with PY excluded from the index; BW<sub>HPL</sub> = BW with additional high relative economic weighting for P:P+L with PY excluded from the index.

<sup>2</sup>SCS = Somatic cell score calculated as  $\text{Log}_2(\text{somatic cell count})$ ; P:P+L = protein-to-protein-plus-lactose ratio.

The response in MY was less than the  $BW_{HLY}$  scenario when the economic value of LY was reduced to equal that of FY ( $BW_{LLY}$ ), but still greater than BW alone. Fat yield and LY responses were both intermediate between BW and  $BW_{HLY}$ , with PY having a greater response than under the  $BW_{HLY}$  scenario. Fertility, SCS, LP and P:P+L all had small negative responses and residual survival had small positive responses.

Under selection for LP at the same economic value as PY ( $BW_{LLP}$ ), responses in all traits were similar to those under BW alone, however, there were very slightly higher responses in MY and LY than under BW. When this value was increased 100 fold ( $BW_{HLP}$ ), however, response rates changed dramatically, with responses in MY, FY and PY more than halved. Lactose percentage was predicted to have a small increase. This was the largest predicted genetic response per year for LP of all scenarios.

When investigating the P:P+L scenarios PY was removed as an economic trait in the index to avoid double counting. In the scenarios when P:P+L was equal to the negative equivalent of PY ( $BW_{LPL}$ ) or 100 times PY's ( $BW_{MPL}$ ) original value, the genetic responses became negative for all yield traits (MY, FY, PY and LY). When a very high emphasis was placed upon P:P+L (1000 times the original value of protein) ( $BW_{HPL}$ ) the genetic responses were positive rates of gain, however these were just over half those in the BW scenario for MY and were around 10% of the gains for FY, PY and LY. All scenarios selecting on P:P+L led to a decrease in live weight and a positive response in fertility. The  $BW_{HPL}$  scenario led to the most negative genetic response in P:P+L, however this was still small at -0.003 units per year.

The relative emphasis of each trait are in Table 7.1 for each selection objective. Under selection on BW, PY has the greatest economic emphasis, followed by MY and FY. Under selection for BW<sub>HLY</sub> the emphasis on all traits decreased relative to LY, which was the most emphasised trait. For BW<sub>LLY</sub> the relative emphasis was similar to BW with LY slightly higher than MY or FY. Similarly when selecting for BW<sub>LLP</sub>, relative emphasis on traits was similar compared with the BW scenario and LP accounted for a very small amount of the total emphasis. Under selection for BW<sub>HLP</sub> the LP emphasis was similar to levels for PY in BW, decreasing the relative emphasis on all other traits. The selection objectives that included P:P+L and excluded PY, (BW<sub>LPL</sub>), resulted in a relative emphasis that was lower than that of LP in BW<sub>LLP</sub>, while all other traits had increased relative emphasis. Under BW<sub>MPL</sub> the relative emphasis on P:P+L was around a similar level to that of SCS in BW, while all other traits had greater emphasis than in BW. In the final scenario with BW<sub>HPL</sub>, the relative emphasis was half of the total and decreased all other traits to levels around 3% below their emphasis in BW.

Changes in cow numbers, milk production per cow and industry milk production after 10 years of selection are in Table 7.5. The base year had 4.8 million cows, producing on average 3,943 kg of milk, 197 kg of fat, 150 kg of protein and 185 kg of lactose, for a total production of 18.9 billion kg of milk, 943 million kg of fat, 720 million kg of protein and 889 million kg of lactose. Under selection for BW, MY per cow increased by 12.2%, FY increased by 9.6%, PY increased by 10.7% and lactose increased by 13.2%, total cow numbers decreased by 4.7%. Industry production increased by 7.0%, 4.7% 5.3% and 7.9% for MY, FY, PY and LY respectively, without accounting for increases in the survivability in these cows.

The greatest reductions in cow numbers occurred under selection for BW,  $BW_{LLP}$  and  $BW_{LLY}$ , the greatest increase in cow numbers occurred under selection for  $BW_{LPL}$ . Milk yield per cow increased the most under selection for  $BW_{HLY}$ , while the greatest reduction occurred under selection for  $BW_{LPL}$ . The greatest increase in FY per cow was estimated to occur under selection for either BW or  $BW_{LLY}$ , while selection for  $BW_{LPL}$  or  $BW_{MPL}$  reduced FY. Protein yield per cow increased the most under selection for  $BW_{HLY}$  and experienced the reductions when selecting for either  $BW_{LPL}$  or  $BW_{MPL}$ . The greatest increase in LY per cow was estimated to occur under selection for  $BW_{HLY}$  followed by  $BW_{LLY}$  with selection for either  $BW_{LPL}$  or  $BW_{MPL}$  reducing LY production. When considered as the overall industry, milk, protein and lactose production, was greatest under selection for  $BW_{HLY}$  with fat production greatest under selection for BW and  $BW_{LLP}$ . Industry production of all components was least under selection for  $BW_{LPL}$  and  $BW_{MPL}$ .

**Table 7.5.** Estimated milk, fat, protein and lactose production per cow, across the industry (thousands of tonnes) and the size of the required cow population based on the genetic gains derived after 10 years of selection for the current selection objective or alternative selection objectives including lactose yield, percentage and the ratio of protein-to-protein-plus-lactose.

Trait	Base year	Selection objective <sup>1</sup>							
		BW	BW <sub>LLY</sub>	BW <sub>HLY</sub>	BW <sub>LPL</sub>	BW <sub>HLP</sub>	BW <sub>LPL</sub>	BW <sub>MPL</sub>	BW <sub>HPL</sub>
Number of cows	4,800,000	4,575,294	4,575,974	4,587,058	4,575,208	4,678,336	4,871,803	4,859,567	4,700,449
Yield per cow									
Milk (kg)	3,943	4,425	4,458	4,466	4,425	4,202	3,650	3,721	4,273
Fat (kg)	197	216	215	213	216	207	195	195	202
Protein (kg)	150	166	166	166	166	158	144	145	156
Lactose (kg)	185	210	213	216	210	205	173	173	191
Fat percentage	4.99	4.88	4.82	4.76	4.88	4.92	5.33	5.24	4.73
Protein percentage	3.81	3.74	3.72	3.71	3.74	3.75	3.96	3.89	3.64
Lactose percentage	4.70	4.74	4.78	4.82	4.74	4.87	4.75	4.64	4.46
Industry yield									
Milk (billion kg)	18.925	20.245	20.402	20.488	20.246	19.657	17.781	18.081	20.083
Fat (million kg)	944	988	983	975	988	966	949	947	950
Protein (million kg)	720	758	760	760	758	737	704	704	731
Lactose (million kg)	889	959	976	989	960	957	845	838	897

<sup>1</sup>BW = breeding worth; BW<sub>LLY</sub> = BW with additional low relative economic weighting for lactose yield (LY); BW<sub>HLY</sub> = BW with additional high relative economic weighting for LY; BW<sub>LPL</sub> = BW with additional low relative economic weighting for lactose percentage (LP); BW<sub>HLP</sub> = BW with additional high relative economic weighting for LP; BW<sub>LPL</sub> = BW with additional low relative economic weighting on protein-to-protein-plus-lactose (P:P+L) with protein yield (PY) excluded from the index; BW<sub>MPL</sub> = BW with additional medium relative economic weighting on P:P+L with PY excluded from the index; BW<sub>HPL</sub> = BW with additional high relative economic weighting for P:P+L with PY excluded from the index.

The highest PP (3.96%) was achieved under selection for  $BW_{LPL}$ , this also produced the highest FP (5.33%), whereas the highest LP (4.87%) was achieved under selection for  $BW_{HLP}$ . The highest P:P+L (0.456) was achieved under selection for  $BW_{MPL}$  and the lowest (closer to the ideal) was achieved under selection for  $BW_{HLY}$ .

Milk product yields and the levels of lactose deficit are in Table 7.6. When using 60% of milk for WMP, a total of 214,200 tonnes of lactose was required to fill the deficit. Whole milk powder production was greatest under selection for  $BW_{HLY}$ , while WMP production was lower than the base year for  $BW_{LPL}$  and  $BW_{MPL}$ . The greatest reduction in lactose deficit was modelled under selection for  $BW_{HLP}$  followed by  $BW_{HLY}$  with all selection indices including P:P+L increasing the lactose deficit. Skim milk powder production was greatest under selection for  $BW_{HLY}$ , with least SMP produced when selecting for  $BW_{LPL}$  or  $BW_{MPL}$ , the same was seen for cheese, casein and WP. Butter production was greatest under selection for  $BW_{LPL}$  or  $BW_{MPL}$  with least butter produced when selecting for  $BW_{HPL}$ , the same trend was seen for BMP.

The most efficient scenario for use of imported lactose (measured as kg of imported lactose/tonne of WMP) was  $BW_{HLY}$  at 103.7 kg of lactose per tonne of WMP produced, a reduction of 21.8% relative to the base year (126.3 kg). Followed by  $BW_{HLP}$  at 103.8 kg of lactose per tonne of WMP, a 21.6% reduction relative to base year. The least efficient scenario was  $BW_{MPL}$  at 140.3 kg of lactose per tonne of WMP, a 10.0% increase in the deficit relative to the base year.

**Table 7.6.** Industry production of milk products (thousands of tonnes) and industry income (millions of \$US) based on genetic gains derived after 10 years of selection for current selection objective or alternative selection objectives including lactose yield, percentage and the ratio of protein-to-protein-plus-lactose.

Product <sup>2</sup>	Base year	Selection objective <sup>1</sup>									
		BW	BW <sub>LLY</sub>	BW <sub>HLY</sub>	BW <sub>LLP</sub>	BW <sub>HLP</sub>	BW <sub>LPL</sub>	BW <sub>MPL</sub>	BW <sub>HPL</sub>		
WMP	1695.7	1781.9	1787.3	1791.5	1781.9	1733.9	1650.6	1649.4	1721.7		
SMP	469.7	495.5	497.9	499.7	495.6	483.2	454.8	454.8	478.1		
Cheese	331.5	348.3	349.3	350.1	348.3	338.9	322.9	322.6	336.4		
Butter	413.9	429.8	422.2	411.0	429.8	424.8	436.2	436.4	410.0		
BMP	49.8	51.7	50.9	49.7	51.7	51.9	54.3	53.1	46.9		
Casein	11.8	12.4	12.5	12.5	12.4	12.1	11.5	11.5	12.0		
WP	150.9	171.9	174.4	176.4	171.9	170.6	151.7	151.2	162.1		
Total industry income (millions \$US)	11,039	11,632	11,652	11,648	11,632	11,382	10,856	10,841	11,165		
Lactose deficit	214.2	204.4	194.2	185.8	204.4	180.1	227.7	231.4	222.6		
Change in lactose deficit (%)	-	-2.18%	-8.71%	-11.85%	-3.91%	-13.46%	5.88%	0.25%	3.55%		

<sup>1</sup>BW = breeding worth; BW<sub>LLY</sub> = BW with additional low relative economic weighting for lactose yield (LY); BW<sub>HLY</sub> = BW with additional high relative economic weighting for LY; BW<sub>LLP</sub> = BW with additional low relative economic weighting for lactose percentage (LP); BW<sub>HLP</sub> = BW with additional high relative economic weighting for LP; BW<sub>LPL</sub> = BW with additional low relative economic weighting on protein-to-protein-plus-lactose (P:P+L) with protein yield (PY) excluded from the index; BW<sub>MPL</sub> = BW with additional medium relative economic weighting on P:P+L with PY excluded from the index; BW<sub>HPL</sub> = BW with additional high relative economic weighting for P:P+L with PY excluded from the index.

<sup>2</sup>WMP = whole milk powder; SMP = skim milk powder; WP = whey powder; BMP = butter milk powder.

The greatest total industry income was achieved under selection for  $BW_{LLY}$  (5.26% increase over base), followed by selection for  $BW_{HLY}$  (5.23% increase). Selection for  $BW_{LPL}$  or  $BW_{MPL}$  reduced the total industry income (-1.68 and -1.83% respectively).

## **Discussion**

The genetic responses to selection on BW simulated in this study were higher than the industry reported values (54.9 kg MY compared to 44 kg MY) for 2012 (most recent publication of genetic gains) but closer to published gains prior to 2012 (Bryant 2012). The study by Spelman & Garrick (1997) on the then inclusion of live weight into the early BW showed that genetic gains in PY would be greater than FY and that MY would increase at 29 kg per year. The inclusion of LY in the selection objective increased the genetic gains in MY, as could be expected given the high genetic correlations between MY and LY ((0.95-0.99)Johnson et al. 2000; Miglior et al. 2007; Sneddon et al. 2012). Gains in MY and LY were not equal, however. Lactose percentage increased from 4.70% to 4.82% over 10 years under the  $BW_{HLY}$  scenario, indicating that it may be possible to increase LP through selection on LY while restricting MY. Intense selection on LP was also found to increase LP, showing the possibility to alter LP through genetic selection. Genetic gain estimations for FY and PY were similar in this study to those reported for industry for the dairy season 2011-2012 (Bryant 2012) (2.22 vs 2.22 kg/year and 1.82 vs 1.78 kg/year for FY and PY in the New Zealand industry and the present study, respectively). Genetic gains in fertility, SCS, live weight and residual survival were lower than industry reports; this may be explained by the bending procedures used in the selection index, as well as different

genetic and phenotypic variances used in this study due to differences in selected populations.

Selection responses in all production traits to the two selection objectives that included P:P+L with lower emphasis ( $BW_{LPL}$  and  $BW_{MPL}$ ) were negative, this suggests that the weighting was not sufficient (relative emphasis of 0.1% and 9.4% for P:P+L in each scenario respectively) to overcome the negative weighting on MY (relative emphasis of 24.3% and 22.0% in each scenario respectively) in these objectives. As a result MY, FY, PY and LY all experienced negative genetic gains. These scenarios did, however, result in positive gains in fertility and were the only selection objectives to achieve this, this is most likely due to the greater economic emphasis placed upon fertility.

The base cow in this simulation had similar milk production to the industry average animal in the 2012-2013 dairy season (LIC & DairyNZ 2014). Selection on  $BW_{LPL}$  or  $BW_{MPL}$  produced a cow with production similar to the 2003-2004 dairy season (LIC & DairyNZ 2014), indicating that these selection objectives would reverse 10 years of genetic gain. Limiting land area and feed available may reduce the potential increases in industry production, but under selection for BW the total milk production increased 7.0% while stock numbers reduced 4.7%, indicating that BW would produce a more feed efficient cow in terms of milk product production. This was not the same for the objectives  $BW_{LPL}$  and  $BW_{MPL}$  which increased stock numbers and decreased milk production, indicating that a less feed efficient cow (for milk production) was created.

Changes in LP were found in most scenarios to be smaller than changes in FP or PP, which was consistent with the study of Vos & Groen (1998). That may be a result of the

smaller genetic variance in LP than FP and PP. High direct selection pressure (either  $BW_{HLP}$ ,  $BW_{MPL}$  or  $BW_{HPL}$ ) was required to alter LP faster than FP or PP, which were not directly selected upon.

A previous study (Sneddon et al. 2014) into the potential outcomes of breeding for BW was based on the assumption that LP would remain constant under selection for BW, but this study indicates that LP could increase over time. The report by Sneddon et al. (2014) showed a 14% increase in the lactose deficit after 10 years of selection for BW, based on steady state LP, however, this study indicated that there may actually be a 2.19% reduction in lactose deficit. These differences can be associated with differences between an assumed correlated response and a correlated response from selection index theory. As the earlier study of Sneddon et al. (2014) assumed that lactose would remain static at 4.7%, however, this study indicates that selection will affect LP. The lactose deficit can be further reduced under selection for  $BW_{HLY}$  or  $BW_{HLP}$  in a situation where 60% of milk is being used for WMP production.

Selection on the ratio of P:P+L did not have the anticipated outcome with the genetic gains decreasing the ratio over time. Including P:P+L in the selection objective increased the amount of additional lactose required to produce a tonne of WMP relative to the base year, even though total milk and WMP production was reduced. This is possibly due to differences in the heritabilities between the numerator (0.29) and denominators (0.29 and 0.50) in the ratio (Gunsett 1984). Due to the very small genetic variance in the trait (0.00011), high emphasis is required to cause a shift in the ratio and removes relative selection emphasis from the other traits in the index. Studies have

shown that differential selection on the components on ratio results in a greater response than selection on the ratio itself (Zetouni et al. 2015).

Selection on BW increased the efficiency of WMP production by reducing the requirement for imported lactose per tonne of WMP (114 kg/tonne vs 126 kg/tonne in the base year). The value of this cannot be completely evaluated, but would amount to a saving of between \$10 and \$18 per tonne of WMP or between \$9 and \$33 million over the industry. This would be dependent on the value of lactose, which has ranged from a high price in 2012-2013 of (\$1,967/tonne) to lower prices in 2014-2015 of (\$1,076/tonne) (Global Dairy Trade 2015). Using selection for  $BW_{HLY}$  and  $BW_{HLP}$  the savings could be more than doubled to \$30 or \$70 million per year over the entire industry. Including LY at the economic value of FY would save between \$30 and \$57 million, this scenario also kept the other traits very similar to the gains that would be achieved using just BW.

When evaluated on a total industry income basis, the scenario which gave the greatest gross return was  $BW_{LLY}$  (5.26% higher relative to base), because butter production was increased relative to the base. Whereas in  $BW_{HLY}$ , butter production decreased relative to BW, causing a decrease in total income. Savings in lactose costs have to be greater than losses in income from reductions in other product yields. In the  $BW_{HLP}$  scenario, the largest decrease in lactose deficit, the reductions in total WMP yield is greater than the savings in lactose leading to a total increase in income of 3.0% relative to base year, lower than BW alone which is a 5.1% increase compared to the base year. Selection for  $BW_{LPL}$  and  $BW_{MPL}$  decreased total product yields relative to the base year and accordingly decreased total income by 1.7% and 1.8% respectively. High selection on

P:P+L led to a small increase in total income (1.1%). These results indicate that inclusion of LY at a lower emphasis (such as  $BW_{LLY}$ ) could be advantageous in increasing farmer incomes compared with selection on BW alone.

## Conclusion

This study is the first to show that the selection objective in New Zealand is both increasing the efficiency of milk production and also reducing the requirement for imported lactose in WMP production. This is also the first study to evaluate the effect of including lactose into the selection objective on the milk product portfolio and lactose requirements in the New Zealand dairy industry. The industry could reduce imported lactose requirements per tonne of WMP by 6-11% within 10 years of including lactose into the selection objective. If imported lactose becomes a significant issue for the industry (market pressures) the most efficient means to reduce external lactose requirements from this study would be to include LY with an economic value similar to FY into the selection objective, compared with selection on Breeding Worth alone.

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## **Chapter 8**

### **General discussion**



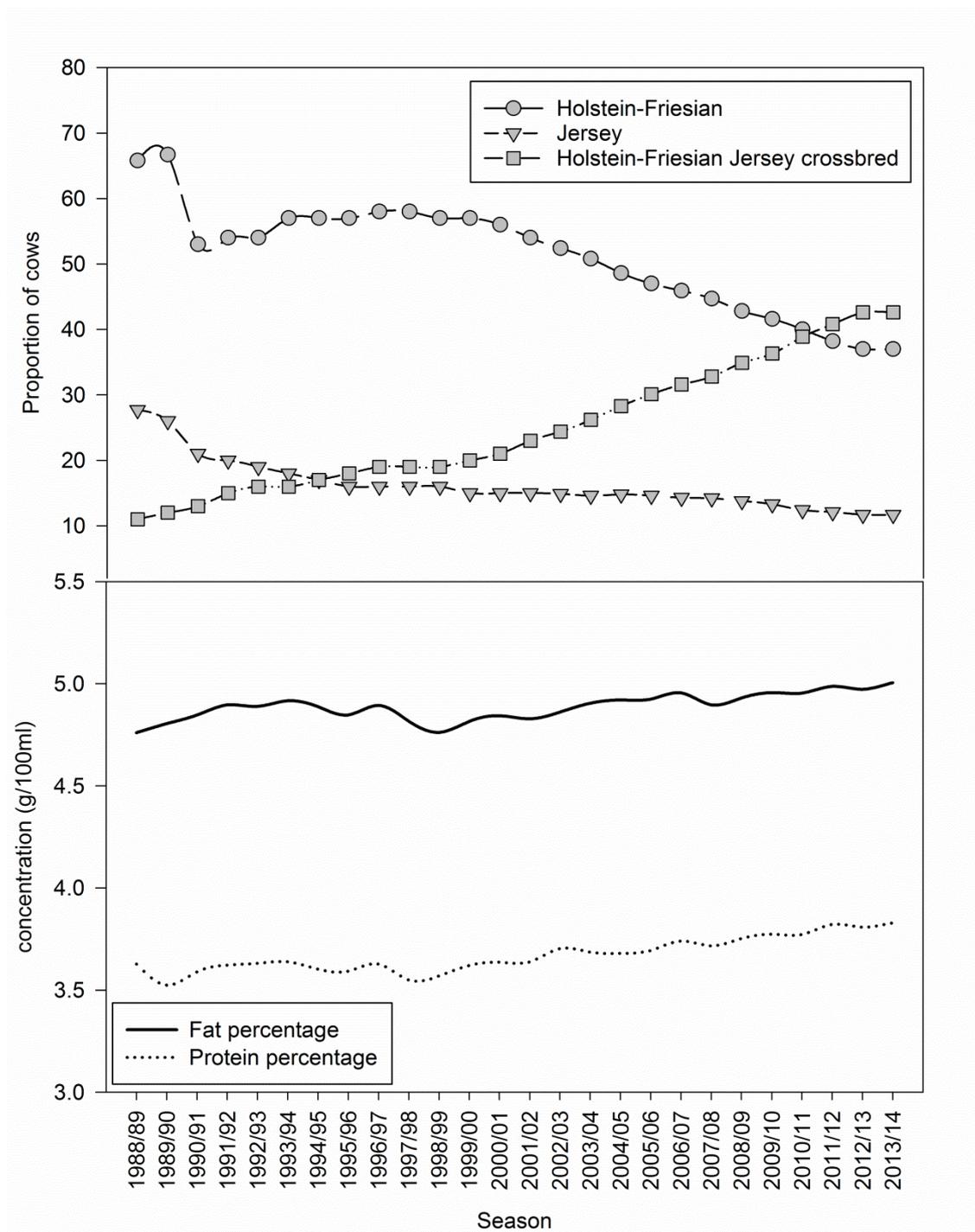
The composition of milk in New Zealand is the result of the breed composition of the national herd and is modified over time by selection for Breeding Worth (BW). Selection for BW puts a greater emphasis on protein yield than fat yield and a penalty on milk volume (NZAEL 2015). The expectation is to increase the milk solids (fat + protein) content of the milk.

This change has resulted in a decrease in the proportion of F cows in the herd, lifting the fat and protein concentrations. Crossbreeding between Holstein-Friesian (F) and Jersey (J) has been widely used by farmers over the last 15-20 years with the number of crossbred cows growing from 625,000 (19% of the national herd) in 1998-1999 (LIC 1999) to 2.1 million (42.6% of national herd) in 2013-2014 (LIC & DairyNZ 2014). The changes in breed composition of the national herd and the protein and fat contents of New Zealand milk over the past 26 years are shown in Figure 8.1. Fat percentage has increased from 4.85% in 1979-1980 to 5.01% in 2013-2014 and protein percentage has increased from 3.58% in 1979-1980 to 3.83% in 2013-2014.

When the economic values for the traits included in BW are generated, the national product portfolio is taken into account but lactose has not been considered as a trait for inclusion in the selection objective despite its importance in the production of whole (WMP) and skim milk powders (SMP). Over this time the export based product portfolio has rapidly altered due to international market demands from a product mix in 1998-2000 where WMP and SMP were 30% and 25%, respectively, (Garrick & Lopez-Villalobos 2000) to a product mix in 2012-2013 where WMP and SMP make up 60% and 24%, respectively (Sneddon et al. 2014). Both WMP and SMP have to meet an international codex requirement for exportation, with the WMP's standard set at 26.5%

fat, 25.1% protein and 39.8% lactose (codex standard 207-1999, WHO & FAO 2011). However, the composition of New Zealand milk is currently in lactose deficit relative to the available protein that could be used in the export-based, product portfolio (Fonterra 2014; LIC & DairyNZ 2014). This deficit means that if New Zealand milk was dried directly into WMP it would have a composition of 36.9% fat, 28.3% protein and 34.8% lactose (Sneddon et al. 2014).

The industry was traditionally capable of moving lactose as a by-product of cheese and casein into WMP and SMP to fully utilise the available fat and protein. Alternatively the composition of WMP and SMP can be met by removing excess fat and protein through separation and ultrafiltration. However, to return the maximum value of fat and protein in WMP, Fonterra opted to import lactose to fill the deficit when producing WMP; this created a lactose deficit within New Zealand for the current product portfolio. Fonterra has investigated several alternatives for filling this deficit, these included; purchasing lactose on the international market, purchasing cheese processing plants overseas to send lactose to New Zealand and the modification of the selection objective and index to incorporate lactose (Fonterra 2015a). This thesis evaluated the possibility of changing the composition of New Zealand milk through the modification of the selection objective, to decrease the lactose deficit.



**Figure 8.1.** Changes in breed composition of the national herd and fat and protein concentration in milk from the New Zealand dairy industry over 26 dairy seasons (1988-2014) (LIC & DairyNZ 2014).

## **Genetic parameters and genetic correlations of production traits including lactose yield and percentage**

Genetic parameters for total milk production lactation records were estimated in chapter 6 for use in a selection objective. Estimation of genetic parameters for milk product potentials was also presented in Chapter 6. Heritabilities of total milk, fat, protein and lactose yields were estimated to be 0.23, 0.15, 0.14 and 0.22, respectively, which were similar to values seen in previous studies (Welper & Freeman 1992; Spelman et al. 1997; Johnson et al. 2000; Pryce & Harris 2006). Lactose percentage and P:P+L heritabilities were estimated to be 0.35 and 0.42, respectively, indicating that it would be possible to improve these traits with genetic selection, while the heritability of lactose percentage was lower than reported values (Welper & Freeman 1992; Vos & Groen 1998; Miglior et al. 2007; Hossein-Zadeh & Ardalan 2011). Heritability estimates for the milk product potentials ranged from 0.13 for cheese to 0.31 for WMP and SMP. While there are genetic parameters reported for cheese production (Bittante et al. 2013), this was the first attempt to estimate the heritability of WMP and SMP.

With new parameter estimates for milk products, there is the potential to include these traits directly in a selection scheme. This will allow the milk product traits with the greatest genetic variation to be identified and, as such, identify the traits which have the potential to be modified under genetic selection. In this thesis, genetic variation in WMP and SMP traits was found to be greater than that of lactose yield, lactose percentage or P:P+L. The greater genetic variation indicates that the rate of gain for these traits may be greater than when selecting on even lactose yield, the moderate heritabilities are also advantageous to the selection on these traits.

### **Processing considerations and methods to deal with lactose deficit or excess**

Milk composition has a major influence on the product portfolio which can be made from that milk. In chapter 4 the effects of changes to product portfolios in Ireland and New Zealand (as well as chapter 5 for New Zealand) were investigated. As expected, it was found that as the proportion of milk processed into WMP increased, the potential for lactose to become a limiting factor increased. Milk composition and product portfolio can explain the differences in lactose deficits between Ireland and New Zealand in 2012. The Milk from Ireland had lower fat, protein and lactose percentages and P:P+L than milk from New Zealand (LIC & DairyNZ 2012; Central Statistics Office (CSO) 2013). Most milk in Ireland is currently processed into cheese, butter and SMP, with only around 30% used for production of powders (WMP and SMP), while New Zealand is predominantly a powder producer with over 70% of milk processed into powder. The combination of a lower P:P+L ratio and a lower powder production means that the Irish industry does not have as great a lactose deficit compared with New Zealand. The Irish industry is still in a slight lactose deficit for the milk being used for WMP, but lactose can be diverted from cheese into powders to allow the domestic and international demand of all dairy products without importing lactose or extracting extra fat into butter and extra protein into casein.

In New Zealand the lactose deficit of 331,000 tonnes (Fonterra 2014) is too great to be filled with the lactose available from cheese production (14% of milk into cheese, with 80% lactose recovery from whey powder would make ~100,000 tonnes of lactose available). New Zealand currently leads the world in the development of technology to

recover lactose from whey, but there is a limit to the amount of lactose which can be recovered.

The deficit is currently met with imported lactose; however, this may restrict the markets available for final product in the future, particularly where the markets require a 100% country-of-origin product. This does not seem to have become a restriction on Fonterra yet, with the amount of WMP produced increasing each year with greater imports of lactose. While there is the possibility to reduce the WMP production and in doing so reduce the lactose deficit this will be an unfavourable solution while it is profitable to incorporate imported lactose into the system. Further improvements in the recovery of lactose from whey and exploration of lactose recovery from butter milk, there is currently around 20,000 tonnes of lactose sold in butter milk powder.

### **Selection objectives**

#### *Selection for ratios*

In Chapter 7 several different selection objectives were investigated, one of the traits selected upon was  $P:P+L$ . The inclusion of ratios into the selection index causes mathematical difficulties where the heritabilities of the numerator and denominator are imbalanced (Gunsett 1984), as is the case with  $P:P+L$  (0.40 for protein percentage vs 0.35 for lactose percentage, chapter 6)

This difference in heritabilities between the numerator and denominator shifts the selection intensity to the trait with the greater heritability. In Chapter 7, this shifted the

emphasis to protein, firstly through differences in numerator and denominator and secondly due to a degree of double counting within the ratio. This would be expected to occur for any ratio made up of more than 2 components or where the heritabilities (and the genetic variations) are different between the numerator and denominator.

Selection on a ratio may still be possible if the numerator and denominator can be balanced. This was to an extent achieved in the long term breeding trial of Vos & Groen (1998) from 1987 to 1993 (three generations) two lines of cattle were developed with one selected for a lesser protein-to-fat in milk ratio and the other for a greater ratio. The trial reported by Vos & Groen (1998) also showed the possibility to alter lactose percentage through breeding.

Under selection with low to moderate relative emphasis on P:P+L, the lactose deficit increased by 5.88% and 0.25%, for low and moderate relative emphasis respectively and per cow milk production decreased by 293 kg and 222 kg, for low and moderate emphasis respectively. This decreased the overall efficiency of the dairy industry (same feed intake, less milk). Only under high relative emphasis for P:P+L did WMP production increase relative to the base year (1.5% increase after 10 years). From this it was concluded that selection on P:P+L does not provide a suitable solution to the lactose deficit and has the potential to increase the overall costs to the industry while reducing total industry income.

It can be concluded from the results of the selection index chapter that selection on the components of the ratio provides a faster and more directed change in the ratio than selection using the ratio alone. This was a surprising outcome, as it was assumed that

selection for the ratio would improve it. However, the greater relative emphasis required to decrease the ratio meant that the total milk production was negatively affected. To show this, the selection index from chapter 7 was set to two different scenarios, one where only protein yield and lactose yield were included in the index at the values of \$9.17/kg and \$4.60/kg, respectively and one where only P:P+L was included in the index with an economic value of \$9170/unit P:P+L. After ten years of selection, the protein-lactose index had decreased P:P+L from 0.447 to 0.436, whereas over the same period the P:P+L index had decreased only from 0.447 to 0.446.

### *Selection for milk lactose percentage*

In chapter 7, lactose percentage was included into the selection objective. This required a relatively large emphasis on the trait to achieve a favourable change in lactose percentage. To an extent, selection on a percentage will have the same mathematical difficulties as selecting for a ratio, as the numerator (fat, protein or lactose yield in this case) may have a different heritability than that of the denominator (milk yield) (Gunsett 1984). The difference in heritabilities was small when considering lactose percentage (0.22 vs 0.23 for lactose and milk yield respectively), which should result in a relatively balanced ratio for selection.

Selection on a percentage, however, has the potential to be an unappealing prospect for the farmer, unless it is included in a payment system, when considering the selection objective as a whole. As the lower genetic variation in percentage traits relative to yield traits would require percentage traits to have higher economic values. In chapter 7 lactose percentage (a trait for which no payment is received) required an economic

value 100 times greater than protein yield (which farmers are paid for) to achieve an increase in lactose compared with the current selection objective. The high relative emphasis on lactose percentage resulted in an increase of lactose percentage from 4.70 to 4.87 over 10 years of simulated genetic gains and decreased the lactose deficit by 13%. However, this high economic weighting may appear to be unjustified by farmers, who are not paid for lactose percentage, as well as decreasing the genetic gains in fat and protein substantially (a 64% and 67% decline, respectively).

There have been no long term selection experiments for increasing lactose percentage in cattle or any other species, however, there are a range of lactose percentages in mammals, from 0.7% in grey seals to 7.0% in humans (Gibson 1987; Fox and McSweeney 1998). While the biological limit for lactose percentage in dairy cattle is not known, it can be estimated by the physiological requirement for milk to be isosmotic with blood at around 7%. Data from the New Zealand national dairy herd has lactose percentages ranging from 2.8 to 6.8% (unpublished data). However, this range may include animals which are under physiological stresses (Auldist et al. 1995; Malek dos Reis et al. 2013) and measurement errors.

### *Selection for lactose yield*

The effect of including lactose yield in the selection objective was evaluated in Chapter 7. This selection method (selection on lactose yield) had one of the best responses in reducing the lactose deficit for the current product portfolio. These results were similar to those of Gibson et al. (1989) where differential selection on yield traits (milk yield and lactose yield) would result in changes to the lactose percentage over time. The

selection methods were different between Gibson et al. (1989) and this thesis, however, both indicate that differential selection pressures on yields could change lactose percentage faster than selection on percentage. Selection for lactose yield may also provide a more appealing form for inclusion in the national selection objective as yield is an easily visualised trait for the farmer and a low economic value was found to achieve reasonable decreases in the lactose deficit.

For lactose yield to be included into the selection objective would require Fonterra to redevelop its payment system to include lactose so that both an accurate value of lactose is returned to the farmer and for an estimated rate of genetic gain to be estimated for the national herd.

The larger genetic variation in lactose yield also increases the potential rate at which improvements can be achieved. There is still a processing difficulty associated with selection on lactose yield, as milk yield and lactose yield have a high genetic correlation (0.92-0.98; Welper & Freeman 1992; Johnson et al. 2000; Miglior et al. 2007). Therefore, increases in milk volumes with no change the composition of that milk would simply increase the costs associated with transporting, storing and drying the liquid volume to produce powdered products.

Improvements in drier technology may reduce the impacts of increased milk volume. Currently, an increase of 1 litre in milk volume without increases in milk component yields is associated with an increase in costs of around 3.7 cents per litre. While small, to get enough lactose to fill the current deficit (300,000 tonnes/ \$531 million (Fonterra 2014)) would require an extra 6.4 billion litres of milk, assuming no increase in protein

or fat (as decrease in concentrations within milk) with an associated transport and storage cost of approximately \$240 million per year.

### **Inclusion of the lactose in the payment system**

Previous research has supported a proposal for Fonterra to incorporate a lactose value into the farm gate milk price to farmers (Garrick & Lopez-Villalobos 2000). This payment system should account for the increased liquid volume costs (3.7 cents per litre) as a reflection of the cost of increasing liquid volume, but also account for the reduction in imported lactose costs (Fonterra 2014) while maintaining a fair value for all farmers as part of the cooperative structure. This could be done in a similar fashion to that of Synlait (Chapter 2) or through a system which rewards a greater lactose concentration or a lower P:P+L, although this payment system may have the same issues as the selection indices including the ratio.

Any payment system incorporating lactose has to return an equal value of lactose to all farmers. Further, 1 kg of lactose from a F cow must be the same value as 1 kg of lactose from a J cow even if the total amount of product produced from these two cows is different. Currently no value is returned to Fonterra farmers for lactose. However, the lactose value supplements the values of fat and protein, with lactose value spread across protein and fat (Holmes et al. 2007). Inclusion of lactose into a payment system decreases the value of protein more than fat (Holmes et al. 2007).

If lactose is included in the payment system as lactose yield, it has the potential to overcome the penalty applied for greater milk volumes. However, this does not appear to have happened at Synlait where fat, protein, lactose and milk volume are all included in the payment system. Another scenario could be to apply a premium for greater lactose percentage so for example 0.01% higher lactose attracts a premium price. A premium system may incentivise increased lactose yields while maintaining the penalty on increased volume.

This thesis has highlighted that the lactose deficit will continue to grow if nothing is done to change the composition of milk produced by the New Zealand cow relative to lactose or if the current trend in making increasing proportions of milk into WMP is continued. Both of these outcomes (increasing WMP production and decreasing suitability of milk for WMP) can have a negative impact on the New Zealand dairy farmer. To an extent this has been seen in the 2014-2015 dairy season with an almost 50% reduction in payment to farmers (from \$8.80/kgMS in 2013-2014 to \$4.40/kgMS in 2014-2015) which resulted from a huge decline in the value of WMP (Fonterra 2015b).

Using the genetic gain results from chapter 7 and the processing model of Geary et al. (2010), four scenarios were considered for the lactose deficit if WMP was to decrease as a proportion of the product portfolio. The first was the channel mix (the typical product mix is 2000) from Garrick & Lopez-Villalobos (2000): the second was a modified version of this which maintains a higher WMP production (as new factories have been built to process WMP); the third was the amount of WMP which could be produced if lactose was not imported for the production of WMP after ten years of selection for BW

with 75% lactose recovery from whey powder; the fourth was the amount of WMP which could be produced if lactose was not imported after ten years of selection for BW with an economic value for lactose of \$2.04 ( $BW_{LLY}$ ) with 75% lactose recovery from whey powder. The yields of products (and lactose deficit) from this analysis are presented in Table 8.1. Lactose was recovered from whey powder with an efficiency of 75% was considered as a conservative value based on current maximums of around 80% (Archer 1998, Mollea et al. 2013).

**Table 8.1.** Yields of milk, dairy products and associated lactose deficit (,000s tonnes) under two different product portfolios after 10 years of selection for breeding worth in New Zealand.

Milk trait	Modified channel mix <sup>1</sup>	Channel mix <sup>2</sup>	No lactose <sup>3</sup>	$BW_{LLY}$ no lactose <sup>4</sup>
Milk yield	20,245	20,245	20,245	20,402
Fat yield	988	988	988	983
Protein yield	758	758	758	760
Lactose yield	959	959	959	976
Fat percentage	4.88	4.88	4.88	4.82
Protein percentage	3.74	3.74	3.74	3.73
Lactose percentage	4.74	4.74	4.74	4.78
Product <sup>5</sup>				
WMP	1,336.39	890.93	1,667.22	1,701.90
SMP	578.12	723.23	394.49	401.33
Cheese	621.90	547.27	348.27	350.31
Butter	446.91	594.22	460.13	443.01
BMP	54.33	71.47	47.17	50.68
Casein	12.45	24.89	41.22	34.23
WP	130.10	114.49	72.85	73.71
Lactose	-6.38	-32.85	-	-

<sup>1</sup>Modified channel mix (45% WMP, 26% SMP, 25% cheese, 2% butter, 2% casein) modified from Garrick & Lopez-Villalobos 2000 accounting for changes in product mix (Fonterra 2003; 2014).

<sup>2</sup>Channel mix (30% WMP, 25% SMP, 22% cheese, 19% butter, 4% casein) from Garrick & Lopez-Villalobos 2000.

<sup>3</sup>No lactose purchased for WMP production (starting mix 60%WMP; 23.5% SMP; 14% cheese; 0.5% butter; 2.0% casein).

<sup>4</sup>No lactose purchased for WMP production after 10 years of selection for  $BW_{LLY}$  ( $BW + \$2.04/ \text{kg}$  lactose yield) (starting mix 60%WMP; 23.5% SMP; 14% cheese; 0.5% butter; 2.0% casein).

<sup>5</sup>WMP = whole milk powder, SMP = skim milk powder, BMP = butter milk powder, WP = whey powder (75% lactose recovery).

The results of the forecasting in Table 8.1 indicate that if the proportion of milk processed into WMP were to decrease to levels similar to the situation of the modified channel mix, the deficit could be reduced from around 200,000 tonnes (chapter 7) to around 6,000 tonnes. Therefore, a large potential exists to reduce the deficit in lactose through modification of the product portfolio and the current downturn in WMP values (Global Dairy Trade 2015) could prompt the diversification of the product portfolio of the New Zealand dairy industry. When considering the possibility to remove imported lactose from the system, it can be seen that with 60% of milk processed into WMP, but balanced for lactose content (no imported lactose), the yield of WMP is 34,000 tonnes greater when lactose is included into the selection objective compared to the current BW. This represents an increase in the efficiency of New Zealand milk to produce WMP from including lactose yield into the selection objective. In chapter 4 the production of WMP with no external lactose was investigated and found to be less profitable than continuing with the current strategy, for the economic analysis used. However, the effects on industry incomes would be driven by future market outlooks and current and future processing capacity.

### **Future work**

#### ***Inclusion of the lactose in the selection objective***

Lactose could be included into the selection objective as lactose yield with a low economic weighting, similar to that of fat (\$2.04 in 2014, a relative emphasis of 14% NZAEL (2014)) this would have little impact on the other traits (milk and protein increased slightly and fat decreased slightly).

Before lactose can be included into a selection objective its economic value must be determined, this requires an evaluation of the net value that lactose can return to the farmer after accounting for the costs associated with producing that lactose.

***A new, holistic approach to economic value estimations***

With the improvements in computing power and ability to link programs, future work could include the development of linked animal, farm and industry processing models and to the selection objective. So as to have the selection objective altered by the costs in the animal and farm models and the outputs of the processing model. This model would incorporate aspects of chapters 3, 4, 5, 6 and 7 from this thesis. A model linking all these aspects would have the ability to alter the selection scheme using future product markets but also react to on farm cost changes. This model would also open the possibility to produce breeding values for specific milk products.

The Irish dairy industry is already using a similar approach with a processing model, modelling potential future processing portfolios, providing the new economic values to be used in the Irish selection objective (Shalloo 2013).

***A novel method to produce EBVs for milk products***

The production of breeding values for milk products could provide a quick and easy way to show farmers what cows and bulls best suited to each of the products. This may even provide a useful culling guide for farmers if the processing sector can provide

signals efficiently to the industry on the relative values of each product and which products will have increasing demand into the future. These signals would also be of benefit to farmers supplying niche products such as boutique cheese makers. For example, this situation could see the production of breeding values tailored to the production of niche soft cheeses such as brie and camembert.

These new breeding values could then be used in new selection objective selecting solely for that trait. This could potentially maximise the rate of genetic gain for different milk products, with the ability for milk processors to provide semen to its suppliers to increase its processing efficiency through providing a more optimal milk for processing into the desired end products. However, breeding is a long term investment where the benefits compound over time and as such frequent or large alternations to the product portfolio would not be beneficial for these breeding values.

### **Limitations**

The use of daily milk yields from first lactation heifers may have limited the precision of genetic parameter estimations presented in this thesis. However, the results were similar to both nationally and internationally published data (Welper & Freeman 1992; Roman et al. 2000; Johnson et al. 2000). In addition, Hossein-Zadeh & Ardalan (2011) reported similar genetic parameters for milk yield and fat, protein and lactose percentages for first lactation cows compared with mixed age cows. Therefore, the genetic parameters for lactose reported in this thesis are unlikely to be significantly biased

The approaches in chapters 4, 5 and 7 were restricted to a few key scenarios involving changes in proportions of WMP and cheese. This was done as there is an almost unlimited number of possibilities available. Attempts were made in this thesis to maintain a consistent range of scenarios which considered linear changes in proportions of milk used in WMP, SMP, butter and cheese. However, a more complex range of scenarios was investigated in chapter 4, to understand the effect of more extreme changes in product mix. Given the significant changes to the international dairy markets in the last 12 months it may now be relevant to include scenarios where both cheese and butter increased as proportions of the product portfolio.

This thesis did not investigate the development of a payment system including lactose, however this would have to be developed to balance against the value of lactose in the milk and the cost of importing lactose. It is possible that the price returned to farmers for lactose is less than the cost saving by increasing lactose supply. However, this balance has not been investigated in this thesis.

Likewise, the distribution of milk product breeding values was not investigated in this thesis, neither was a selection scenario similar to the one in chapter 3 run to investigate the effect of selecting on the top 10% of cows for each milk product. If these breeding values could be produced for all cows in the New Zealand dairy industry (or in the sire proving scheme) it is possible that the breeding value for WMP (or product of interest) could replace BW as the selection objective in New Zealand. This could maximise the rate at which the lactose deficit can be reduced. The development of a selection objective containing the milk product breeding values is a future project that has developed from this thesis.

## **General conclusions**

The inclusion of lactose yield into the selection objective in this thesis provided a long term accumulative solution to reducing the requirement for imported lactose. Recovery of lactose from whey and decreases in WMP production also provided within industry solutions to decreasing the lactose deficit. When combined, these two solutions may have the potential to completely eliminate the need for New Zealand to rely on imported lactose to produce WMP but may have a negative economic effect on the industry.

From the results presented, it can be concluded that lactose should be included into the selection objective to increase the supply of lactose available from milk in New Zealand. The economic value would be developed from a payment system incorporating lactose yield. Lactose yield and milk yield breeding values are highly correlated but estimating these two traits individually would allow for the identification of outlier animals which increase lactose more than milk volume.

The ratio  $P:P+L$ , while a useful tool for determining the suitability of milk for WMP production, is not a trait which can be included into a selection objective without causing mathematical problems. However, it may be possible to include milk products directly into the selection objective, but this needs further investigation to determine the feasibility of so doing.

If the New Zealand dairy industry wants to continue to increase the proportion of milk processing into WMP, the lactose deficit will also continue to increase under the current

selection objective. But, this can be reduced going into the future by incorporating lactose yield into the selection objective now, with little detrimental effect on the other traits in BW.

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## **Appendix One**

Statements of contribution to doctoral thesis containing publications for chapters: 2, 3, 5, 6 and 7.





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**STATEMENT OF CONTRIBUTION  
TO DOCTORAL THESIS CONTAINING PUBLICATIONS**

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

**Name of Candidate:** Nicholas William Sneddon

**Name/Title of Principal Supervisor:** Professor Nicolas Lopez-Villalobos

**Name of Published Research Output and full reference:**

Sneddon NW, Lopez-Villalobos N, Hickson RE, Shalloo L 2013. Review of milk payment systems to identify the component value of lactose. Proceedings of the New Zealand Society of Animal Production 73: 33-36.

**In which Chapter is the Published Work:** 2

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:  
and / or
- Describe the contribution that the candidate has made to the Published Work:

The candidate collated the literature and wrote the first draft of the review, with supervisors providing review, questions, and comments around the flow and the content for the expansion of ideas or additions of further sections.

Candidate's Signature

Date

Principal Supervisor's signature

Date





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**Name/Title of Principal Supervisor:** Professor Nicolas Lopez-Villalobos

**Name of Published Research Output and full reference:**

Sneddon NW, Lopez-Villalobos N, Davis SR, Hickson RE, Shalloo L 2014. Genetic parameters for milk components including lactose from test day records in the New Zealand dairy herd. *New Zealand Journal of Agricultural Research* 58: 97-107.

**In which Chapter is the Published Work:** 3

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:  
and / or
- Describe the contribution that the candidate has made to the Published Work:

The candidate sorted the data provided by LIC, performed the analysis with input from Prof. Nicolas Lopez-Villalobos on the models used, and wrote the first draft of paper then under took changes with guidance from supervisors (co-authors).



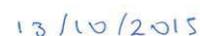
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**Name/Title of Principal Supervisor:** Professor Nicolas Lopez-Villalobos

**Name of Published Research Output and full reference:**

Sneddon NW, Lopez-Villalobos N, Davis SR, Hickson RE, Shalloo L, Garrick DJ, Geary U 2015. Predicted Dairy Product Yields and Deficits of Lactose for Manufacturing under Differing Selection and Manufacturing Scenarios in New Zealand. *New Zealand Journal of Agricultural Research* 58 432-440. doi: 10.1080/00288233.2015.1073160

**In which Chapter is the Published Work:** 5

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:  
and / or
- Describe the contribution that the candidate has made to the Published Work:

The candidate performed the analysis using the processing model developed by Una Geary, Laurence Shalloo, Dorian Garrick and Nicolas Lopez-Villalobos, with post processing modifications under taken by the candidate and wrote the first draft of the paper and undertook corrections and suggested changes under guidance from supervisors (and co-authors).

Candidate's Signature

Date

Principal Supervisor's signature

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**Name of Candidate:** Nicholas William Sneddon

**Name/Title of Principal Supervisor:** Professor Nicolas Lopez-Villalobos

**Name of Published Research Output and full reference:**

Sneddon NW, Lopez-Villalobos N, Davis SR, Hickson RE, Shalloo L, Garrick DJ, Geary U 2016. Estimates of genetic and crossbreeding parameters for milk components and potential yield of dairy products from New Zealand dairy cattle. *New Zealand Journal of Agricultural Research*. 59. doi. 10.1080/00288233.2015.1131723

**In which Chapter is the Published Work:** 6

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:  
and / or
- Describe the contribution that the candidate has made to the Published Work:

The candidate performed sorted the data provided by LIC, the processing model used in this chapter was developed by Nicolas Lopez-Villalobos and Dorian Garrick, undertook the analysis with statistical models decided on with Nicolas Lopez-Villalobos and wrote the first draft of the paper with changes and corrections done under guidance from supervisors (and co-authors).

Candidate's Signature

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**Name of Candidate:** Nicholas William Sneddon

**Name/Title of Principal Supervisor:** Professor Nicolas Lopez-Villalobos

**Name of Published Research Output and full reference:**

Sneddon NW, Lopez-Villalobos N, Davis SR, Hickson RE, Shalloo L, Garrick DJ, Geary U 2016. Responses in lactose yield, lactose percentage and protein-to-protein-plus-lactose ratio from index selection in New Zealand dairy cattle. *New Zealand Journal of Agricultural Research*. 59. doi: 10.1080/00288233.2015.1131724.

**In which Chapter is the Published Work:** 7

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:  
and / or
- Describe the contribution that the candidate has made to the Published Work:

The candidate developed the selection index model using published methodologies, with checking of the matrices done under guidance of Nicolas Lopez-Villalobos and Dorian Garrick, performed the analysis using the processing model developed by Una Geary, Laurence Shalloo, Dorian Garrick and Nicolas Lopez-Villalobos, with post processing modifications undertaken by the candidate who wrote the first draft of the paper and undertook changes and corrections under guidance of supervisors (and co-authors).

Candidate's Signature

Date

Principal Supervisor's Signature

Date