Comparative study of first lactation performance of Norwegian Red crossbred cows with traditional breeds in New Zealand dairy systems

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Abstract

The Norwegian Red (NR) dairy breed has garnered global interest due to its breeding objectives, which prioritize health and fertility traits alongside production performance. The increasing demand for enhanced robustness in dairy cattle worldwide has led to the integration of this breed into various production systems. In New Zealand, some dairy farmers are utilising semen from Norwegian Red bulls, exploring the potential benefits of this breed under New Zealand's unique pastoral farming conditions. The aim of this research was to compare the first lactation performance of F_1 NR cattle with traditional New Zealand breeds. Data for this study was collected from six dairy farms in Southland, New Zealand, during the 2022–2023 milk production season. Data was collected from 1178 first lactation cows including 4639 herd-tests of daily yields of milk, fat, protein, somatic cell counts, and persistency. Animals included 386 NR cross (NRX), 231 Holstein Friesian (F), 84 Holstein Friesian cross (FX), 134 Holstein Friesian ×Jersey (FJ) and 58 Jersey cross (JX) cows. Findings indicate Holstein Friesian cows produced the greatest cumulative milk yield (3,744 kg), 138.6 kg more than NRX cows. The JX demonstrated the highest yields for protein, fat, and milksolids, while the NRX exhibited significantly lower yields for most of these lactation parameters. There were no significant differences between the breed groups for milk yield and milksolids yield, persistency and somatic cell score (somatic cell score = Log2 somatic cell count). Lactation curves for milk and milksolids yield were modelled for each breed, with the F cows initially outperforming the other breed groups, then for the remainder of both lactation curves, differences among breeds were not significant. Overall, the lactation performance of the NRX tends to be reduced in comparison to the traditional New Zealand breeds. These results pertain specifically to first lactation cows; therefore it is necessary to undertake further analysis to evaluate the long-term productivity and longevity of the NR breed under New Zealand conditions. This research provides an initial insight into the performance of the NR breed in New Zealand's pastoral farming systems.

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List of Abbreviation

F	Holstein Friesian
FX	Holstein Friesian ×
FJ	Holstein Friesian × Jersey
JX	Jersey cross
NR	Norwegian Red
NRX	Norwegian Red cross
MY	Milk yield
PY	Protein yield
FY	Fat yield
MSY	Milksolid yield
SCC	Somatic cell count
SCS	Somatic cell score

Chapter 1

General introduction

The New Zealand dairy farming system is unique compared to those in other countries, with the defining feature being the efficiency of pasture utilisation to produce milk. Most dairy farms are spring calving, which aims to utilise the increased growth of pasture during the spring and late autumn. This requires a strict calving interval to maintain the 365-day cycle, therefore key events in the dairy calendar are match to the pasture availability (Verkerk, 2003). The national dairy herd comprises three main breed groups: Holstein Friesian, Jersey, and Holstein Friesian × Jersey, with the largest proportion being the crossbred, (DairyNZ and LIC, 2023a). The New Zealand dairy industry has prospered with the utilisation of the crossbred dairy cow, as it is been well performing in milksolid production, which is reflected in the remuneration from the New Zealand dairy payment system – rewarding fat and protein content and penalising milk volume (Sneddon et al., 2016).

It is well established that the crossbred cow performs best under New Zealand's seasonal pasture-based system. Lopez-Villalobos et al. (2000) hypothesised that a three-way rotational crossing system could increase profitability for pasture-based systems in New Zealand. The theoretical benefits of a three-way cross come from enhanced hybrid vigour, which can result in improved fertility, health, and increased longevity. Some New Zealand dairy farmers have been introducing a Scandinavian breed into their herd, through three-way crossing, to further improve health traits in their herd. This breed is the result of a breeding program combining local Scandinavian breeds, and other international breeds, with the aim of creating a highly productive, robust dairy cow. The Norwegian Red's breeding objective has had a heavy focus on health and fertility traits since the 1970s, unlike in New Zealand where the focus was purely on production until 1995, since then liveweight, somatic cell score, fertility and survival have been included in the selection index. The current breeding objective for the Norwegian Red places a 24% emphasis on milk production, 22% on mastitis resistance, and 15% on fertility, reflecting the breed's goal of developing a robust and resilient dairy cow (Steine et al., 2008). The Norwegian Red has sparked global interest, with dairy farmers in various countries adopting the breed to enhance the health, fertility, and longevity of their herds. Studies undertaken around the world have concluded that by three-way cross with the Norwegian Red can reduced incidence of mastitis (Rinell & Heringstad., 2018) and have improved fertility (Walsh et al., 2008) in comparison to Holstein Friesian, and Holstein Friesian × Jersey. Therefore, the Norwegian Red could be introduced to enhance certain health traits that the existing breeds lack.

For Norwegian Reds to be economically viable in New Zealand, they must maintain current production levels within the country's low-intensity, pasture-based farming system. Studies conducted overseas have concluded that Norwegian Red crossbreeds tend to have reduced milk yields (Ferris et al., 2013; Heins et al., 2006; McClearn et al., 2020) but comparable milksolid yields (Begley et al., 2009) when compared to Holstein Friesians.

The objectives of this thesis are to analyse the lactation yields of primiparous F1 Norwegian Red crossbred cows under New Zealand's low-intensity, pasture-based dairy farming conditions, and to compare their performance with traditional breeds such as Holstein Friesian, Jersey, and their crosses. It aims to provide valuable insights for farmers and industry professionals seeking information on this breed's potential and performance within the New Zealand dairy farming conditions.

Chapter 2

Literature Review: Comparative study of first lactation performance of Norwegian Red crossbred cows with traditional breeds in New Zealand dairy systems.

2.1 New Zealand dairy industry

Dairy production in New Zealand is typically a spring calving, pasture-based system, operating on a 365-day interval. New Zealand dairy farming depends on yearly climatic cycles and subsequent pasture growth which determine the timing of key events. An early spring calving strategy is used mostly which aims to synchronise the herd feed demand with peak pasture growth. Milk production of dairy cows is matched to this pattern of pasture growth; therefore, the highest milksolid production occurs in synchrony with increased availability of high-quality pasture. In autumn, the weather changes, and pasture growth slows, quality decreases, cows are dried off. This is to avoid going into a negative energy balance, and to prepare for the next season's calving (Harris, 2005). This subsequently results in the entire herd being non lactating for approximately three months during the late autumn to winter period (Holmes et al., 2002). There are limitations in feed availability in a pasture-based system, but increasingly there are varying levels of supplementary feed on farms to match deficits. These include maize silage, pasture siliage and cereal grains, along with by-products such as palm kernel extract and distiller's grain. The feeding of supplementary feeds allows farmers to overcome pasture deficits, maintain cow body condition and improve milksolid production.

The New Zealand dairy sector's total export revenue for the 2023 financial year was approximately 22 billion NZD, and in the 2024 financial year was 26 billion NZD (Ministry of Primary Industries, 2024). The dairy industry accounted for 3.2% of gross domestic product in 2023, which can be further subdivided into dairy farming (2.2%) and dairy processing (0.9%) (Partners, 2023). Among all goods-producing sectors in New Zealand, dairy farming is the largest at $8 billion, and the third largest is dairy processing at $3.4 billion. Consequently, any significant financial losses or market changes in these sectors would have a major impact on the New Zealand economy. Most local dairy products are exported, and these can be subdivided into whole milk powder (31.9%), butter and dairy products (17.7%), protein products (13.2%), cheese (11.1%), infant formula (7.7%), skim milk powder (9.6%), fluid milk and cream (5.6%), other 2.2%, and yogurt, buttermilk and kephir (0.9%) (Partners, 2023). In the 2022/23 dairy season, New Zealand dairy companies processed 20.7 billion litres of milk which contained 1.87 billion kilograms of milksolids. The average milk production per cow was 393 kg of milksolids, made up of 221kg of milkfat and 173kg of milk protein (LIC and DairyNZ, 2023). The New Zealand dairy payment scheme is focused on milksolids due to the high proportion of dairy products exported (<95%) (Partners, 2023). The milk payment system operates according to a simplified equation A+B-C, where A represents the value per kilogram of fat, B denotes the value per kilogram of protein, and C corresponds to the milk volume, cost to process and transport (Sneddon et al., 2013). In this system, milksolids (fat and protein) are assigned positive economic value, whilst the milk volume is penalised. This milk payment informs dairy farmers that most dairy products are not exported in their fluid form, instead, the liquid is evaporated during processing of these products.

The total New Zealand dairy cattle population in the 2022/2023 was 4.642 million milking cows, with the 57% of the population located in the North Island, and the remaining 43% in the South Island (LIC and DairyNZ, 2023). In 2022/2023, the average herd size in the North Island was 432 cows and in the South Island was 587 cows. The national dairy herd is composed mostly of crossbred Holstein Friesian and Jersey (FJ) (59.9%), then Holstein Friesian (F) (24.4%), Jerey (J) (7.7%), and followed by a small proportion of other breeds (8%). The portion of other breeds include Guernsey, Brown Swiss, Norwegian red, and their crossbreeds.

The New Zealand dairy cow population has seen three notable breed changes since 1940. The milking Shorthorn and English Friesian was the predominant breed in 1940, and by the 1960s, 80% of the population was the Jersey breed. The upgrading of the Jersey with Holstein Friesian began in 1960, with the introduction of North American derived Holstien genetics, thus the New Zealand Holstien-Friesian was developed. The proportion of Holstien Friesian in the national herd peaked in the late 1980s (Harris and Kolver, 2001). Research undertaken in the 1990s investigating the pure-bred Jersey and New Zealand Holstien Friesians revealed both breeds had similar efficiency (ability to convert pasture into profit) and benefited from heterosis through crossbreeding (greater performance of traits in crossbred relatives to parental performance), (Bryant et al., 1985; Alhborn and Byrant, 1992). This resulted in more widespread use of crossbreeding in New Zealand. The New Zealand national breeding objective is called breeding worth. This evaluates the genetic merit of dairy cows by their ability to produce efficiently by converting feed into profit. Breeding worth is quantified by dollars of net farm profit from five tonnes of dry matter ($/5t DM) and is a measure of an economic efficiency calculated as genetic superiority or inferiority to convert feed into profit (Lopez-Villalobos and Garrick, 2005). The genetic evaluation of the New Zealand dairy industry is undertaken by Dairy NZ, through the New Zealand Animal Evaluation Limited which oversees the national evaluation. The notable dairy cow traits are classified into two categories: production efficiency traits and robustness traits. The individual effective emphases of each trait is shown in Table 2.1, show a 63% weight on production efficiency traits and 37%

weight on robustness traits (DairyNZ, 2024a). The higher emphasis on the production efficiency traits is due to the greater impact on profitability than the robustness traits. The traits included in the breeding objective are those that reflect profit from milk, beef, cost of reproduction, animal health and feed in the New Zealand dairy industry (Lopez-Villalobos and Garrick, 2005). Each trait included have economic values and their subsequent emphases, as shown in Table 2.1 (DairyNZ, 2024b). The positive economic value for certain traits encourages the breeding values for those traits in dairy cattle to increase. Conversely, negative economic values discourage certain traits such as milk volume and liveweight, preventing them from increasing as traits with positive economic values improve (Sneddon et al., 2013). Individual traits are multiplied by the corresponding economic value to give an individual animal's breeding worth. Since the introduction of the breeding objective there has been a consistent upwards trend in breeding worth, as illustrated in Figure 2.1. Currently, DairyNZ is aiming to include genomic data into the breeding worth values. This will allow for a faster rate of genetic gain compared to the current method that utilises phenotype, pedigree and progeny proving schemes. In the progeny proving process, a prospective bull undergoes progeny testing, where his genetic worth is determined based on the performance of its daughters. If the bull is found to have sufficient genetic value after this evaluation, its semen is then sold through artificial insemination companies, (Harris, 2005; DairyNZ, 2024c). This entire process, from the bull's birth to the use of its semen in artificial breeding programs, typically takes five years. In contrast, genomically selected bulls can be available for use in artificial breeding programs much sooner, aproximately three years of age, as these bulls can have their DNA tested immediately after birth (DairyNZ, 2024c). Individual companies which supply farmers with artificial insemination, these companies also undertake own genetic evaluations. New Zealand Animal Evaluation Limited allows for genetic evaluation for comparison of genetic merit of all dairy cattle regardless of breed, sex, age, and company. The dairy industry is heavily reliant on artificial breeding, therefore much of the selection decisions are within purview of the company the farmer has chosen. However, farmers can select breeds of dairy cow to include and individual sires that they purchase from the artificial breeding companies.

Table 2.1. The ten traits included in the New Zealand Breeding Worth index and their economic values (EV) and relative weight (RE) in December 2023 (DairyNZ, 2024b).

Trait category	Trait (units)	EV ($/unit)	RW
Production efficiency	Milk protein ($/kg)	6.83	19.1
	Milk fat ($/kg)	4.85	19.1
	Milk volume ($/L)	-0.01	9.4
	Liveweight ($/kg)	-1.59	15.1
Robustness	Somatic cell score ($/SCS)	-46.21	5.7
	Fertility ($/PR42[1])	5.77	12.4
	Gestation length ($/day)	-1.89	1.6
	Functional survival ($/%)	1.88	1.4
	Body condition score ($/unit)	164.09	7.9
	Udder overall (score)	0	8.4

[1]PR42= percentage of cows conceived in the first 42 days from the start of the mating.

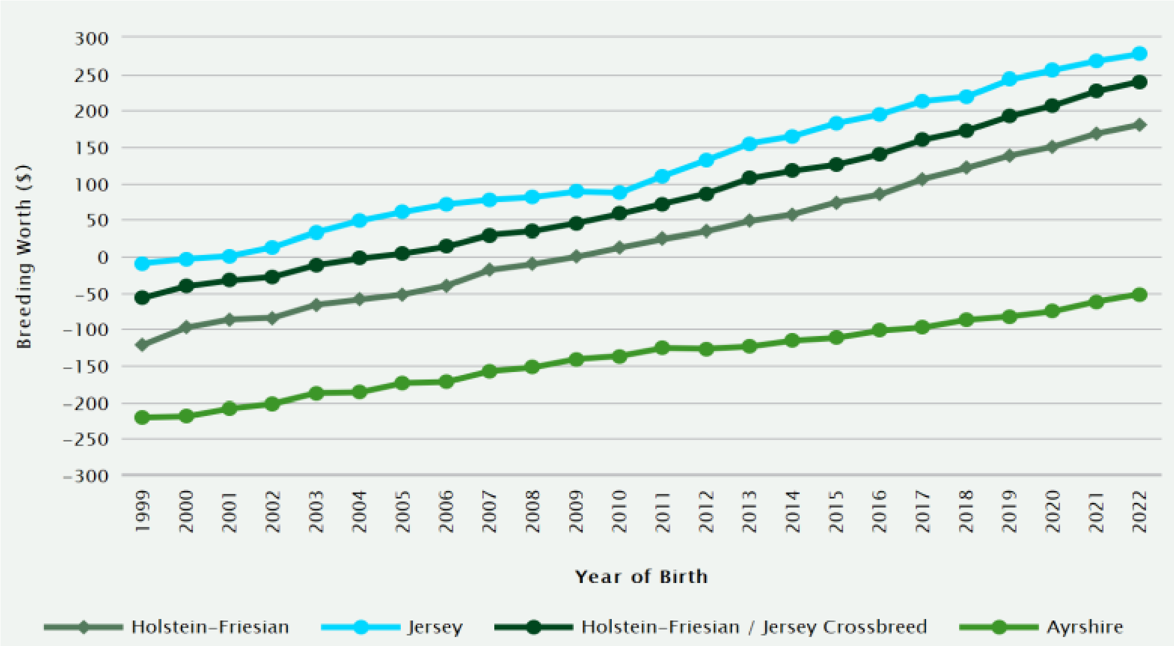

Figure 2.1. Trend in Breeding Worth by breed category from 1998-2021, (DairyNZ, 2024a).

2.2 Three-way crossbreeding

In New Zealand crossbreeding has mostly been limited to two breeds of F and J, which evidently increased a wide range of production traits. Lopez-Villalobos et al. (2000) hypothesized that a three-way rotational crossing system could increase profitability for pasture-based systems in New Zealand. Three-way crossbreeding initially involves two parents from distinct breeds being bred together, producing a hybrid (F_1). The F_1 is then crossed with a third breed. This breeding program maximises hybrid vigour in the three-way cross, as the genetic diversity introduced enhances desirable traits such as growth rate, fertility, disease resistance, and overall productivity. A portion of New Zealand dairy farmers have been exploring three-way crossbreeding to further improve some traits in their dairy cattle. Some have been using the Norwegian Red in their breeding programmes; this breed has been gaining popularity internationally due to its claimed improved health and fertility performance. Therefore by utilising this breed in a three-way crossbreeding program with the FJ it has been aimed to maintain the production and efficiency, while enhancing health and fertility traits.

2.3 The Norwegian Red breed – overview

2.3.1 The Norwegian Red breed

In the early 1900s, Norwegian dairy farmers were facing challenges with low milk production and poor animal health. At that time Norway had several distinct local cattle breeds. To overcome these challenges, a breeding program began with a mixture of native and imported breeds including the Norwegian Red-and-White, Red Polled, Eastland, Ayrshire, Swedish Red-and-White and Holstein Friesian, which resulted in the Norwegian Red (NR) (Buchanan et al., 2002). Unlike many breeds, the NR it is not a result of a closed breeding in a population. In 1963 the NR breeders introduced a total merit index, where different traits were weighed against one another. Objectives were grouped by; milk, growth rate, utility traits and health and fertility. This is an interesting contrast to New Zealand, where selection objectives were solely based on production until 1995 (Harris, 2005). The NR breed organisation, Geno, administers and develops the breeding objective, which encompasses production, fertility and health traits. Geno aims are to improve animal welfare, reduce antibiotic use, and ensure sustainable dairy production (Geno, 2024a). The NR breeding goal uses 14 traits and indexes which are grouped into a total merit index. The current weighting of the breeding target in 2023 has a 23% emphasis on milk production and 53% emphasis on health, fertility and disease resistance traits, (Geno, 2024b). Table 2.2 presents the current total merit index with the relative weight for each trait. The NR has an average mature weight of around 610 kg. Most of the NR cows are polled, and some are homozygous polled. Coat colouring is typically red and white.

Due to this extensive breeding objective, the NR breed is claimed to be healthier overall compared to other dairy breeds. This reputation has sparked global interest, with dairy farmers in various countries adopting the breed to enhance the health, fertility, and longevity of their herds. There have been no studies conducted within New Zealand's dairy production system to analyse the performance of this breed. However, several studies have been carried out overseas. Reviewing these studies can provide insight into the potential milk production, health and fertility traits performance of this breed compared with other common dairy breeds in New Zealand, including the F and J. For any breed to be included in a three-way cross in New Zealand, it must be economically viable and maintain current production levels under New Zealand’s low intensity pasture-based system.

Table 2.2. Total merit index with relative emphasis on traits of Norwegian Red cattle in 2023 (Geno, 2024b).

Trait	Relative weight (%)
Milk	23
Udder	27
Animal health	8
Fertility	9
Meat	8
Hoof health	4
Leg	3
Body exterior	2
Other properties	8
Single genes (AH1, BTA12)	8

2.3.2 Norwegian Red - milk production

Milk production is a crucial performance indicator for New Zealand dairy cows, as it directly impacts the economic efficiency and profitability of dairy farms. Evaluating the milk production of NR dairy cows will provide insight into the breed's potential performance and determine whether their production is comparable to that of New Zealand dairy cows. There are several studies undertaken overseas that report on the milk production of the NR and its crossbreeds, in comparison to the F and J. Important traits to assess the milk production of a dairy cow include milk yield (MY) (kg/cow), fat yield (FY) (kg/cow), protein yield (PY) (kg/cow), and milksolid yield (MSY) (kg/cow).

MY is a crutical factor in assessing the suitability of the NR breed in New Zealand, as the total volume of milk produced by a cow directly impacts the payment a farmer receives. Table 2. 3 presents the cumulative MY from several studies undertaken on the NR and their crosses, compared to other breeds. Significant differences were found across all breed groups in majority of the studies. Heins et al. (2006) performed a study under United States of America pastoral farming condition, assessing milk production of F and NR×F in their first lactation. Results indicated that the F had a significantly greater MY compared to the NR×F. Begley et al. (2009) investigated first lactation F×NR, NR and F under Irish farming conditions. Results showed that greatest MY was observed in the F. The F×NR group produced significantly less

MY than the F group, but significantly more than the NR. McClearn et al. (2020), investigated F, F×J, and NR×FJ under Irish conditions across lactations 1to 5, and found F had a significantly greater MY compared to NR×FJ and F×J. Walsh et al. 2008 also undertook a comparative study under Irish farming conditions on F and NR; results showed that there was no significant differences in MY between the two breed groups. Ferris et al. (2014) preformed a study investigating the performance of F and NR in first lactation under Northern Ireland conditions, finding F had a significantly greater MY compared to the NR. Overall, studies on the performance of the NR and its crossbreeds tend to show that F consistently outperform NR and NR crosses in terms MY.

Milk fat constitutes a major portion of the overall milksolids, and a higher milksolid content results in greater payments for farmers. As a key component in the dairy industry, milk fat is essential to produce products like cheese and butter. Table 2.3 shows the cumulative FY for several studies comparing NR, its crosses to different breeds. Heins et al. (2006) found no significant differences in FY in F and NR×F breed groups. McClearn et al. (2020) observed F×J had significantly greater FY compared to both F and NR×FJ. Walsh et al. (2008) indicated that F produced significantly greater FY compared to the NR. Overall, these studies show that NR and its crosses tend to have a similar or reduced FY compared to F and F×J.

Milk protein is also an important part of overall milk solids, and higher protein content in milk contributes to increased payments for farmers. Milk protein is key to many dairy products such as infant formula, cheese, yogurt etc. Therefore, is an important comparison point when analysing the production of the Norwegian Red breed. Table 2. 3. shows the PY from several studies. Heins et al. (2006) found that F produced significantly greater PY compared to NR. In both McClearn et al. (2020) and Walsh et al. (2008) found no significant differences in PY across the breed groups they each examined. The overall trend seen in these studies found that for PY the NR and its crosses produce similar or reduced PY.

Milksolids yield (MSY; fat yield + protein yield) content in milk is important in New Zealand dairy production as the payment to dairy farmers is primarily based on the amount of milksolids produced, rather than volume of milk. Table 2.3. Presents cumulative MSY from several studies undertaken on the NR and their crosses. Heins et al. (2006) revealed that F had a significantly greater MSY compared to NR×F. Begley et al. (2009) found no significant difference in MSY for both F and NR×F, but the NR had significantly reduced MSY. McClearn et al. (2020) found no significant differences between F×J and F when compared to NR×F. However, NR×FJ had a reduced MSY compared to F×J but was not significantly different from F. Ferris et al. (2014) revealed that the F had significantly greater MSY compared to the NR×F. The trend seen among the mentioned studies is that the NR and its crosses tend to have a similar or lower MSY production compared the F and F×J.

The results of the several comparative studies undertaken on the NR and its crosses have shown that NR, NR×F, and NR×FJ produce either similar or reduced MY, PY, FY and MSY when compared to F and F×J. As these studies were conducted in various dairy systems worldwide, with differing environments and feed concentrate levels, the actual milk production observed are unlikely to be replicated in a New Zealand production system. This is due to the low input nature of New Zealand dairy farming. But the overall trends seen between the breed groups indicate that the NR crossbreds are unlikely to outperform the milk production of common New Zealand dairy breeds, F, and F×J. The noted studies have not chosen the NR breed to enhance milk production, but instead to utilise the health traits and reproductive performance the NR has been selected upon for many decades. To determine the suitability of NR crossbreds in New Zealand, an analysis of their milk production, health, and fertility should be performed.

Table 2.3. Values for production traits of Norwegian Red (NR), and its crosses compared to other breeds in other countries.

				Production yields			
Reference	Country	Lactation	Breed	MY (kg/cow)	FY (kg/cow)	PY (kg/cow)	MSY (kg/cow)
Heins et al. (2006)	USA	1	F	9,757[a]	346	305[a]	651[a]
			NR×F	9,281[b]	340	297[b]	637[b]
Begley et al. (2009)	Ireland	1	F	5,358[a]			398[a]
			NR×F	5,331[a]			394[a]
			NR	5,151[b]			377[b]
McClearn et al. (2020)	Ireland	All	F	5,720[a]	252[b]	208	460[ab]
			F×J	5,476[b]	261[b]	208	469[a]
			NR×FJ	5,366[b]	250[b]	204	453[b]
Walsh et al. (2008)	Ireland	1-5	F	5,925	266[a]	202	
			NR	5,788	216[b]	198	
Ferris et al. (2013)	ŪK	1	F	6,264[a]			443[a]
			NR	5,956[b]			427[b]

[a,b,c] Least-squares means with different superscripts in each column are significantly different ($P<0.05$)

(MY) Milk yield, (FY) fat yield, (PY) protein yield, and (MSY) milk solid yield (fat + protein).

Breeds: F= Holstein Friesian, J = Jersey, NR = Norwegian Red

2.3.3 Norwegian Red – reproductive and fertility performance

Reproductive performance is one of the most important determinants of production efficiency in New Zealand’s pasture based dairy system, with mating and calving being restricted to a limited period of the year. Pregnancy in the cow last approximately 280 days, and every cow on farm is expected to produce one calf each year. Therefore, the calving period duration is approximately 10-14 weeks which is timed to coincide with the onset of increased pasture growth (Verkerk, 2003). Thus, the cow has on average 80 days in which to recover from pregnancy, and resume normal reproductive activity, be mated to maintain the desired 365-day calving interval. To achieve this requires good reproductive management practices and cows to be highly fertile. A farm’s profitability is highly dependent on achieving a high pregnancy rate within a short interval for the herd (Holmes, 2001).

There have been no studies conducted within New Zealand's dairy production system analysing the reproductive performance of the NR, however, there are limited studies undertaken overseas. The objective of this review is to understand the reproductive performance of NR crossbred cows. This is evaluated using; calving to first service interval (CSI), calving to conception interval (CCI), pregnancy rate to first service (PRFS), percentage of cows conceived in the first 42 days from the start of the mating (PR42), pregnancy rate at the end of mating period (PR) and number of services for conception (SC). These comparison points are critical indicators of reproductive performance dairy cows in New Zealand.

Calving to first service interval (CSI) is the reproductive measure referring to the number of days between a cow calving and the first attempt of artificial breeding, shown in Table 2. 4. During this period, cows resume their normal reproductive behaviour indicating readiness for mating. A shorter CSI is ideal to maintain a 365-day calving interval. Begley et al. (2009) conducted a study comparing F×NR and NR under Irish farming conditions and found no significant difference for CSI between the breed groups in first lactation animals. McClearn et al. (2020) conducted a study of the F, F×J, FJ×NR under UK farming conditions from lactation 1-5. Results indicated that the F and FJ×NR had the shortest CSI, and the F×J had a significantly longer CSI. Walsh et al. (2008) conducted a study under Irish farming conditions and found F had a significantly longer CSI compared to the NR.

Calving to conception interval (CCI) refers to the period from calving to when a cow successfully conceives, shown in Table 2. 4. A shorter CCI is preferred, showing cows are maintaining an optimal reproductive cycle therefore achieving early conception rates. Begley et al. (2009) study indicated that the NR×F had a significantly shorter CCI compared to F; NR did not differ significantly from both F and NR×F. McClearn et al. (2020) found that there was no significant difference between F, F×J and FJ×NR. Walsh et al. (2008) conducted a study investigating NR and F under Irish farming conditions of cows in lactation 1-5; results indicate that the F had a significantly longer CCI compared to the NR.

Pregnancy rate to first service (PRFS) refers to the percentage of cows conceived to the first insemination, shown in Table 2.4. A higher PRFS indicates that a high proportion of the cows are cycling and successfully conceive in their first mating. This reflects a cow's higher fertility performance early in the mating season. Begley et al. (2009) found no significant differences in PRFS amongst F, NR×F and NR. Ferris et al. (2014) studied F and NR in their first lactation under U.K dairy farming conditions and reported that F had a higher PRFS, compared to NR.

Percentage of cows conceived in the first 42 days from the start of the mating (PR42) shows the proportion of cows that conceive in the first 6 weeks of the mating season, shown in Table 2. 4. This results from a high proportion of cows successfully mated early in the season; a high PR42 helps to maintains the 365-day calving interval and demonstrates strong fertility performance. Begley et al. (2009) indicated that the NR×F, and the NR had a significantly higher PR42, compared to the F. In a different study, McClearn et al. (2020) found no significant differences among the F, F×J and NR×FJ for PR42.

Pregnancy rate (PR) refers to the overall in-calf rate at the end of the mating seasons, shown in Table 2.4., indicating the portion of the cows that successfully conceived throughout the mating period. Begley et al. (2009) and McClearn et al. (2020) found no significant differences among F F×J and NR×FJ for PR. Walsh et al. (2008) reported that the NR had significantly greater PR compared to F.

Number of services for conception (SC) refers to number of services for conception, shown in Table 2. 4. SC is aimed to be 1, i.e. one instance a cow has been presented for insemination. Begley et al. (2009) indicated that the NR×F and NR had significantly reduced SC compared to F×J. Walsh et al. (2008) found no significant differences across breed groups for SC.

Several studies comparing the NR breed and its crosses with other common breeds have shown that the NR crossbreeds tend to have a shorter or similar CSI and CCI. The NR and its crossbreeds also demonstrated a high or comparable proportion of PRFS, PR42, and PR, as well as a reduced or similar SC. Overall, the NR has shown to have an improved fertility in comparison to other breeds. Reproductive management, cow body condition, and nutrition are major factors affecting a herd's fertility. Consequently, management practices greatly influence the overall performance of the animals, and their true reproductive performance may not always be accurately reflected. Regarding the suitability of the NR breed in New Zealand's dairy production system, the most relevant study compared NR×FJ, FJ, and F breeds under Irish dairy farming conditions. It found that the CSI was shorter for the NR×FJ, but the other reproductive measures showed no significant differences. However, these findings may not directly translate to New Zealand conditions due to differences in climate, pasture management, and farming practices. Further research is needed to evaluate the performance of the NR crossbreeds under local conditions to determine their true reproductive potential and performance within the New Zealand dairy production system.

Table 2.4. Values of fertility traits of the Norwegian Red (NR), and its crosses compared to other breeds in other countries.

				Fertility traits[1]					
Reference	Country	Lactation	Breed	CSI (d)	CCI (d)	PRFS (%)	PR42 (%)	PR (%)	SC
Begley et al. (2009)	Ireland	1	F	80	86[a]	57	67[b]	91	1.72[a]
			NR×F	79	82[b]	60	75[a]	93	1.57[b]
			NR	79	84[ab]	58	73[a]	95	1.57[b]
McClearn et al. (2020)	Ireland	All	F	85[a]	94		88	96	
			F×J	91[b]	95		87	93	
			NR×FJ	84[a]	93		84	93	
Ferris et al. (2014)	ŪK	1	F			41[b]			
			NR			48[a]			
Walsh et al. (2008)	Ireland	1-5	F	73[a]	90[a]			80[b]	1.98
			NR	70[b]	85[b]			91[a]	1.82

[a,b,c] Least-squares means with different superscripts in each column are significantly different (P<0.05).

[1] CSI= calving to service interval (days), CCI= calving to conception interval (days), PRFS= pregnancy rate to first service (%), PR42= percentage of cows conceived in the first 42 days from the start of the mating (%), PR= pregnancy rate at end of mating period (%), SC= number of services for conception (count).

Breeds: F= Holstein Friesian, J = Jersey, NR = Norwegian Red

2.3.4 Norwegian Red - health trait performance

Dairy cattle can be affected by a wide variety of diseases which can reduce productivity and animal welfare, increase costs and wastage. Mastitis and lameness are the two most prevalent diseases on dairy farms both in New Zealand and worldwide. Bovine mastitis can be defined as inflammation of the mammary gland, often caused by bacterial infection or trauma to the udder. It is one of the most economically important production diseases (Seegers et al., 2003). Mastitis has been estimated to cost the New Zealand dairy industry approximately $180 million a year (Malcolm, 2006). Most cases are treated with intramammary antibiotics, directly administered into the affected quarter of the udder. The direct cost of mastitis includes cost of treatment, discarded milk (due to use of antibiotics) and increased labour cost for treatment (Seegers et al. 2003). Lameness is also a persistent disease found in dairy herds; it can be characterised by abnormal gait or difficulty in movement often caused by pain in the foot or joint of the cow. Lameness can substantially affect production, reproduction, welfare and economic performance (Huxley, 2013). There have been no studies conducted within New Zealand's dairy production system analysing the performance of the NR health traits, however, there a number of studies undertaken overseas. The objective of this review is to understand the health traits of NR crossbred cows using; somatic cell score (SCS), mastitis (%) and lameness (%). These common diseases affecting dairy cattle in New Zealand and are critical indicators of health traits of dairy cows.

To detect mastitis, somatic cell count (SCC) is commonly used, which identifies the levels of white blood cells found in a milk sample. If the SCC levels are elevated, it shows an active immune response. Somatic cell score (SCS) is $\log_{10}$ SCC, which is presented in Table. 2. 5. The average SCS from various studies undertaken on the NR is shown in Table 2. 5. Begley et al. (2009) conducted a study comparing F×NR and NR under Irish farming conditions and found F and NR to have significantly higher SCS compared to the NR×F. McClearn et al. (2020) conducted a study of F, F×J, FJ×NR in lactations 1 to 5 under UK farming conditions and found no significant difference in SCS between breed groups. Ferris et al. (2014) studied F and NR in their first lactation under U.K. dairy farming conditions and reported that F had a higher SCS compared to NR. Heins & Hansen (2012) investigated the F and F ×NR in lactations 1-5 under USA pastoral dairy farming conditions and found that the Holstien had a greater SCS compared to the F ×NR. These studies have all shown the crossbred NR cows have a reduced or similar SCS in comparison to theF, NR and F×J.

Mastitis cases are commonly identified by on farm staff, using a diagnostic tool and milk samples. Mastitis frequency by breed from various studies is shown in Table 2. 5. McClearn et al. (2020) reported mastitis cases by the percentage of cows with at least one mastitis case per year and found that there was no significant difference between F, F×J, FJ×NR. Begley et al. (2009) measured mastitis by the percentage of the herd with two or more cases in a year as a single occurrence. Results suggested that NR×F had a significantly lower incidence of mastitis compared to F and NR. These finding indicate the NR crosses tends to have a reduced or similar incidence of mastitis compared to the F, F×J, and NR.

Lameness is often recorded using locomotion score and inspection of the hoof, being diagnosed by the farmer. Generally, lameness is remedied by hoof trimming or antibiotics administered by either the farmer or veterinarian. Lameness frequency by breed from various studies is shown in Table 2. 5. McClearn et al. (2020) reported lameness incidence as the percentage of cows with at least one lameness during the year and found no significant differences among the F, F×J, FJ×NR. Rinell and Heringstad, (2018) investigated the F and NR×F under Israeli commercial farming conditions, measuring lameness by the proportion of cows with at least one case of lameness per year; results indicated that the NR×F had a reduced frequency of lameness in comparison to the F. These reports found that the crossbred NR had a reduced or similar incidence of lameness when compared to the F and NR.

Several studies comparing the NR breed and its crosses with other common breeds have demonstrated that NR crossbreeds generally have similar or lower SCS, and reduced incidence of mastitis and lameness. Overall, NR crossbreeds have shown potential to improve certain health traits in dairy cattle through crossbreeding. Management factors play a crucial role in reducing negative health outcomes in dairy cattle. As a result, management practices significantly impact the overall health and performance of the animals, meaning that an animal's health status may not always be accurately reflected. For the NR suitability in New Zealand, the studies mentioned in this review may not directly translate to New Zealand dairy conditions due to differing production systems, climate and nutrition differences. Therefore, further research should be undertaken to understand the NR health status under New Zealand dairy farming conditions.

Table 2.5. Values for health traits of the Norwegian Red (NR), and its crosses compared to other breeds in other countries.

				Health traits[1]		
Reference	Country	Lactation	Breed	SCS	Mastitis (%)	Lameness (%)
Begley et al. (2009)	Ireland	1	F	2.04[a]	11.9[a]	
			NR×F	1.97[b]	6.0[b]	
			NR	1.93[a]	10.4[a]	
McClearn et al. (2020)	Ireland	1-5	F	5.02	5.1	18.4
			F×J	4.65	6.9	13.8
			NR×FJ	4.35	7.9	15.3
Ferris et al. (2014)	ŪK	1	F	5.16[a]		
			NR	4.99[b]		
Heins & Hansen. (2012)	USA	1-5	F	3.27[a]		
			F×NR	3.12[b]		
Rinell & Heringstad. (2018)	Israel	1	F			8.22[a]
			NR×F			4.19[b]

[a,b,c] Least-squares means with different superscripts in each column are significantly different ($P<0.05$).

[1] SCS= somatic cell count = $Log_{10}SC$

Breeds: F= Holstein Friesian, J = Jersey, NR = Norwegian Red

2.4 Conclusion

The purpose of this review was to evaluate the performance of NR and its crosses in comparison to other dairy breeds, focusing on milk production, reproductive traits, and health performance. The NR demonstrated equivalent or reduced milk production compared to other common dairy breeds, but showed significantly improved fertility traits. Additionally, the NR exhibited lower SCS and reduced incidences of mastitis and lameness, highlighting its potential for improved health traits. Incorporating NR into New Zealand dairy herds may offer an opportunity to enhance reproductive and health traits and therefore, improve overall improved herd performance. There is limited knowledge on the lactation performance of the NR under New Zealand's unique dairy farming system. Therefore, the objectives of this thesis are to evaluate the lactation yields of primiparous F1 NR crossbred cows under New Zealand's low-intensity, pasture-based dairy farming conditions and to compare their performance with traditional breeds, F, J and F×J.

Chapter 3
Material and Methods

3.1 Animals

Herd test records were obtained from 1,178 primiparous dairy cows from six spring calving dairy farms located in Southland, New Zealand during the 2022-2023 season. The six farms have a combined effective area of 2,970 hectares. Five of the six farms have A2 bred herds, and all farms in this study are European Union certified organic dairy farms.

3.2 Pedigree and herd testing data

Cows were classified into breed groups derived from the animal's breed composition and expressed as a fraction of 16, which was extracted from MINDA® (https://www.lic.co.nz/products-and-services/minda/), the database of the Livestock Improvement Corporation (LIC), New Zealand. The summary of the breed groups and breed proportion is shown in Table 3.1. Only records from these breeds were included, records pertaining to other breeds or animal with missing breed identification were excluded. The data set included 3,559 herd test records, from the 1,176 first lactation animals.

Table 3.1 Number of animals by breed and breed proportion included in data set.

Breed	Breed proportion in 1/16's	Number of animals
Holstein Friesian (F)	if proportion of Holstein Friesian >= 14	231
Holstein Friesian cross (FX)	if proportion of Holstein Friesian >=11 and <=13	84
Jersey cross (JX)	if proportion of Jersey >=11 and <=13	58
Holstein Friesian cross Jersey (FJ)	if proportion of Holstein Friesian = 10, 9, 8, 7, 6 and Jersey = 6, 7, 8, 9, 10.	134
Norwegian Red cross (NRX)	if proportion of Norwegian Red = 8	386
Total		1,176

Individual's milk yields were recorded via herd tests, which were conducted four times throughout the season (July 2022 to May 2023). Animals needed to have a minimum of three recorded herd tests to be included in the analysis. The herd test records obtained from MINDA® included age, breed composition, pedigree information, calving date, cumulative and daily milk yield (MY), fat yield (FY), protein yield (PY), milk solids (fat plus protein) yield (MSY) and somatic cell count (SCC). An average somatic cell score (SCS) during the lactation for each cow was derived from the SCC herd-tests, where SCS was calculated as SCS = Log_2 SCC.

3.3 Lactation curve and persistency

Records of daily yields of milk, fat and protein of all animals were plotted against days in milk. Legendre polynomials were chosen to standardise values to the interval [-1, …., 1], and the coefficients were then calculated using the Rodrigues formula (Askey 2005):

$P_{0(t)} = 1,$

$P_{1(t)} = x,$

$P_{2(t)} = \frac{1}{2}(3x^2 - 1),$

$P_{3(t)} = \frac{1}{2}(5x^3 - 3x),$

$P_{4(t)} = \frac{1}{8}(35x^4 - 30x^2+3),$

$P_{5(t)} = \frac{1}{8}(63x^5 - 70x^3+15x)$

Where $x = -1 + 2\,\frac{(t - tmin)}{(tmax - tmin)}$, with t_{min} = 1 and t_{max} = 280.

The random regression model was represented as follows:

$$y_{ti} = (\beta_0 P_0 + \beta_1 P_1 + \beta_2 P_2 + \cdots + \beta_n P_n) + (\alpha_{0i} P_0 + \alpha_{1i} P_1 + \alpha_{2i} P_2 + \cdots + \alpha_{ni} P_n) + e_{ti},$$

where β values are the regression coefficients of the lactation curve of the population, α values are random regression coefficients describing the lactation curve for animal i, n is the maximum polynomial order, and eti is the random residual for animal i at time t. The estimates of β and α were obtained using the MIXED procedure of SAS version 9.4 (SAS 2004) with the COVTEST option for covariance parameter estimates. Polynomials of orders 2, 3, 4, and 5 were tested. Based on the Akaike (AIC) and Bayesian (BIC) information criteria (smallest is the best), an orthogonal polynomial of order 3 was considered the best fit for modelling daily milk, fat, protein and milksolids (fat plus protein) yields. The best covariance structure of random residuals was a compound symmetry for the modelling of repeated records on the same animal, also based on AIC and BIC values.

Total yields were obtained using the predicted daily yields. Persistency (P) was defined as the ability of a cow to maintain production after peak yield is reached. Using predicted daily yields for milk and milksolids, cumulative estimated yield from day 1 to 90 (A) and from day 181 to 270 (C), a measure of persistency was calculated as,

$$P = \frac{C}{A} \times 100$$

Where larger values of P indicate greater lactation persistency.

3.4 Statistical analysis

The resulting data was analysed using SAS version 9.4 software (SAS Institute Inc, Cary NC, USA). Analysis of variance for lactation length, 280-d total yields of milk (MY), fat (FY), protein (PY), milksolids (MSY), random regression coefficients for MY and MSY, and average SCS were tested using a mixed model analysis using the PROC MIXED procedure in SAS version 9.4 software (SAS Institute Inc, Cary NC, USA).

For this model F-values were used to assess the significance of the influence of the fixed effect on the dependent variables. The least-squared means (LSM) and the standard errors (SE) for breed groups were obtained and used in multiple mean comparisons using Fisher's least significant difference test. Significant differences were declared at $P<0.05$.

Chapter 4
Results

4.1 Total yields

Table 4.1. presents descriptive statistics of traits analysed in this study and Table 4.2 presents the lease-quared means for milk production traits and persistency for each of the different breed groups. The average lactation length across all breeds was 240 days, with a standard deviation of 16 days and the coefficient of variation of 7%. Lactation length varied between breeds (P<0.0001), with FJ and JX cows having the longest lactation of 248±2 days, compared to the F (244±1 days), FX (242±2 days) and NRX (242±1 day). The average total MY was 3,608 kg, with a standard deviation of 718 kg and a coefficient of variation of 20%; the F (3,743 ± 51kg/cow) had a significantly (P<0.05) greater MY, followed by FJ, FX, NRX and the lowest was JX (3,537 ± 95 kg/cow). Total FY average across breeds was 167 kg, with a standard deviation of 34 kg and coefficient of variation of 20%; JX (184 ± 4 kg/cow) and FJ (177 ± 3) cows had significantly (P<0.05) greater FY than F, FX and NRX cows. The average total PY was 143 kg with a standard deviation of 27 kg and a coefficient of variation of 19%. The PY in NRX (140 ± 1 kg/day) was significantly (P<0.0001) lower compared to that of the other four genetic groups. The average MSY across breed groups was 309 kg with a standard deviation of 59% and a coefficient of variance 19%; JX (334 ± 8 kg) had the highest MSY, followed by FJ (327 ± 5 kg), F (316 ± 4 kg), FX (314 ± 6 kg), and the NRX which had the lowest MSY (303 ± 3 kg).

4.2 Persistency

Persistency is shown in Table 4.1 and persistency by breed is given in Table 4.2. The overall average for persistency of MY was 60% with a standard deviation of 10%, and coefficient variance of 17%. There were no significant differences among breed groups for persistency for MY (P=0.0833). The average MSY for persistency was 71%, with a standard deviation of 11% and a coefficient of variation of 11%. For MSY persistency there were no significant differences across the breed groups (P=0.2558).

4.3 Somatic cell count

Overall SCS (cells/ml) is shown in Table 4.1 and SCS by breed is given in Table 4.2. The average SCS was 5.683 cells/ml with a standard deviation of 1.470 and a coefficient of variation of 26%. There was no overall significant difference among the breeds for SCS (P=0.3098).

Table 4.1 Descriptive statistics for lactation length, total yields for milk, fat, protein, and milksolids (fat plus protein), persistency of milk and milksolids, and average somatic cell score in primiparous cows.

	Mean	SD	CV (%)	Minimum	Maximum
Lactation length (d)	240	16	7	155	268
Total yields (kg/cow)					
Milk	3,608	718	20	1228	6124
Fat	167	34	20	42	292
Protein	143	27	19	44	237
Milksolids	309	59	19	86	529
Persistency[1] (%)					
Milk	60	10	17	31	117
Milksolids	71	11	15	43	167
Somatic cell score	5.683	1.470	26	1.584	12.931

[1]Persistency was calculated as P = (C/A)×100, where A is the accumulative yield from day 1 to 90 and C is the cumulative yield from day 181 to 270.

Table 4.2. Least-squared means and standard errors for lactation length, total yields for milk, fat, protein, milksolids, persistency of milk and milksolids, and somatic cell score in primiparous cows from five breed groups.

	Friesian	Friesian cross	Friesian × Jersey	Jersey cross	Norwegian Red cross	P Value
No. of cows	231	134	84	58	386	
Lactation length (d)	244^{b} ± 1	242^{b} ±2	248^{a} ±2	248^{a} ±2	242^{b} ±1	<0.0001
Total yield (kg/cow)						
Milk	$3,743^{a}$ ± 51	$3,673^{b}$ ± 61	$3,689^{ab}$ ± 77	$3,537^{c}$ ± 95	$3,605^{bc}$ ± 38	<0.0001
Fat	168^{b} ± 2	168^{b} ± 2	177^{a} ± 3	184^{a} ± 4	163^{b} ± 1	<0.0001
Protein	148^{a} ± 2	146^{a} ± 2	149^{a} ± 2	149^{a} ± 3	140^{b} ± 1	<0.0001
Milksolids	316^{b} ± 4	314^{b} ± 6	327^{ab} ± 5	334^{a} ± 8	303^{c} ± 3	<0.0001
Persistency (%)						
Milk	60 ± 1	58 ± 1	59 ± 1	56 ± 1	61 ± 1	0.0833
Milk solid	71 ± 1	70 ± 1	73 ± 1	73 ± 2	73 ± 2	0.2558
Somatic cell score (cells/ml)	5.619 ± 0.10	5.791 ± 0.13	5.698 ± 0.16	6.075 ± 0.19	5.620 ± 0.08	0.3098

^{a,b,c} Least-squared means with different superscripts in each column are significantly different (P<0.05).

4.4 Lactation curves

Table 4.3 details the estimate of the regression coefficients describing the lactation curve of MY and MSY for each breed group in the study. Figures 4.1 and 4.2 show the lactation curves fitted for each breed groups, for MY and MSY respectively. At the start of the MY lactation curve (intercept), breed group F had a significantly higher intercept compared to the others, followed by FX, NRX and FJ, while JX had the lowest intercept (P=0.071). At the next regression coefficient (α_0), again F had the highest value (-6.52), which was followed by breed groups FX, NRX, FX and JX (P= 0.0280). The remaining regression coefficients did not differ significantly, (a2 P= 0.4833, and a3 P=0.5406) across the breed groups. The MSY lactation curve showed significant differences across all regression coefficients except α_3. Breed group F had a significantly greater intercept value (α_0), while the remaining breed groups showed no significant differences from each other (P = 0.0182). At regression coefficient α_1, F had the highest value, followed by FX, FJ, FX and JX, and the lowest value was NRX, (P=0.0024). At (α_2) the F showed a significantly higher value, then next highest was NRX, FX, FJ and JX, (P=0.0149). The remaining regression coefficient, α_3, did not differ significantly (P=0.4279) across the breed groups.

Table 4.3. Least-squared means and standard error of regression coefficients of the milk yield and milksolids yield lactation curve modelled with a third-order Legendre polynomial fitted to in primiparous cows of Holstein Friesian (F), Holstein Friesian cross (FX), Holstein Friesian × Jersey (FJ), Jersey cross (JX) and Norwegian Red cross breeds (NRX).

Breed	Regression coefficient			
	α_0	α_1	α_2	α_3
Milk yield				
F	$16.09^{a} \pm 0.18$	$-6.52^{a} \pm 0.15$	0.88 ± 0.12	-0.39 ± 0.11
FJ	$14.45^{bc} \pm 0.28$	$-5.87^{bc} \pm 0.26$	0.26 ± 0.19	0.30 ± 0.17
FX	$14.90^{b} \pm 0.22$	$-6.28^{ab} \pm 0.19$	0.59 ± 0.15	0.32 ± 0.14
JX	$13.48^{d} \pm 0.35$	$-5.55^{c} \pm 0.29$	0.16 ± 0.23	1.33 ± 0.21
NRX	$15.33^{b} \pm 0.18$	$-5.95^{bc} \pm 0.15$	0.74 ± 0.12	-0.32 ± 0.11
P-value	0.0071	0.0280	0.4833	0.5406
Milksolids yield				
F	$1.413^{a} \pm 0.01$	$-0.397^{a} \pm 0.09$	$0.133^{a} \pm 0.01$	-0.055 ± 0.01
FJ	$1.337^{b} \pm 0.02$	$-0.366^{abc} \pm 0.02$	$0.058^{c} \pm 0.01$	-0.034 ± 0.01
FX	$1.338^{b} \pm 0.03$	$-0.391^{ab} \pm 0.01$	$0.096^{b} \pm 0.01$	-0.021 ± 0.01
JX	$1.323^{b} \pm 0.03$	$-0.354^{bc} \pm 0.02$	$0.028^{c} \pm 0.02$	-0.013 ± 0.01
NRX	$1.347^{b} \pm 0.01$	$-0.350^{bc} \pm 0.02$	$0.110^{ab} \pm 0.01$	-0.064 ± 0.01
P-value	0.0182	0.0024	0.0159	0.4279

[a,b,c] Least-squared means with different superscripts in each column and milk component are significantly different (P<0.05).

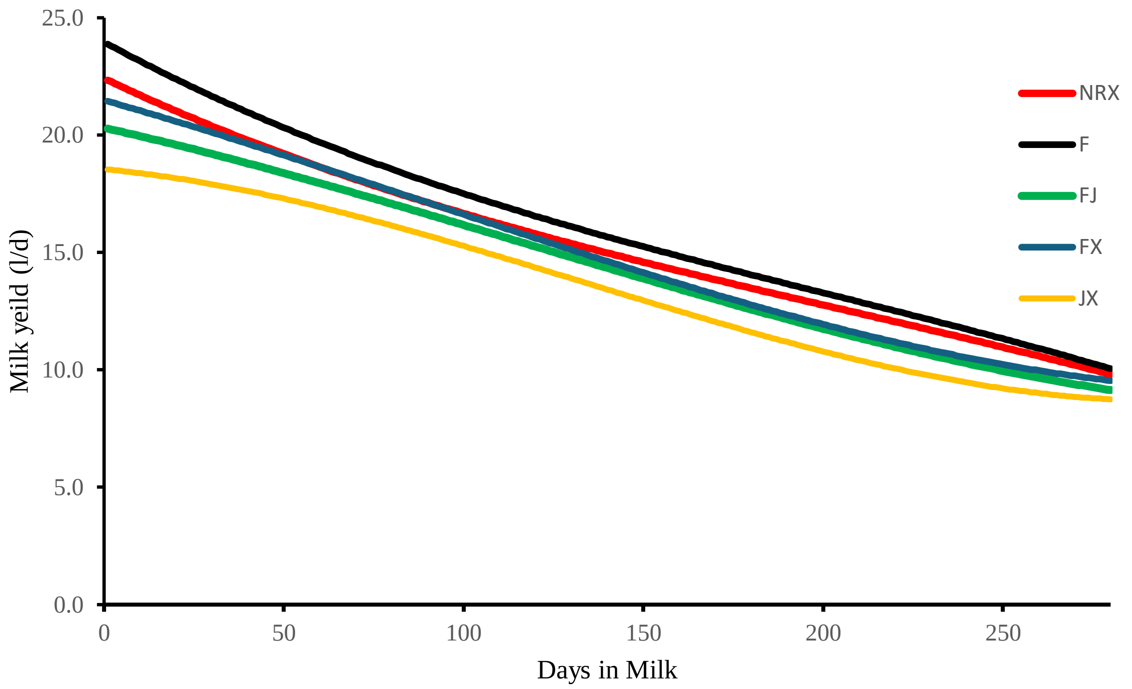

Figure 4.1. Lactation curve for milk yield of primiparous cows of Holstein Friesian (F), Holstien Friesian cross (FX), Holstien Friesian × Jersey (FJ), Jersey cross (JX) and Norwegian Red cross (NRX) breeds.

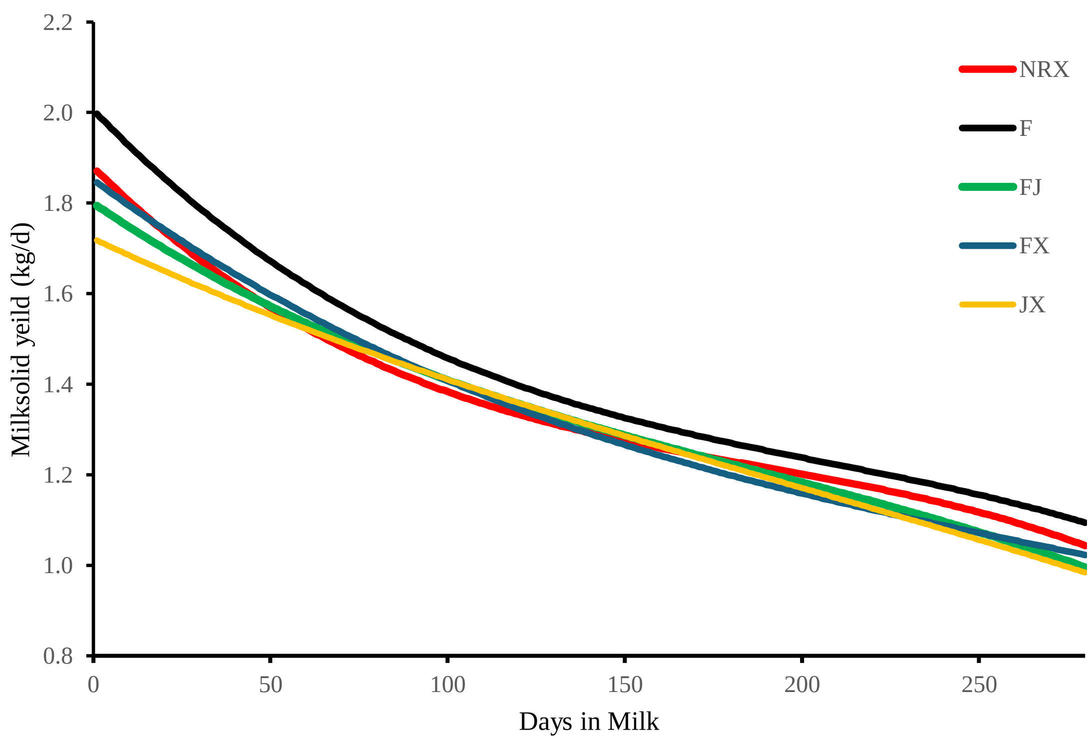

Figure 4.2. Lactation curve for milksolid yield of primiparous cows of Holstein Friesian (F), Holstien Friesian cross (FX), Holstien Friesian × Jersey (FJ), Jersey cross (JX) and Norwegian Red cross (NRX) breeds.

Chapter 5

Discussion

This study aimed to investigate lactation yields of primiparous F_1 Norwegian Red cross (NRX) under New Zealand dairy conditions in comparison to traditional breeds. The NR breed has not yet been investigated under local dairy conditions. The study examined important production traits; milk yield (MY), fat yield (FY), protein yield (PY), milk solid yeild (MSY), somatic cell count (SCS), and persistency for MY and MSY, and lactation curves of several breed groups including NRX. The findings of this study provide insight into how the NRX performs under New Zealand farming conditions, with the results highlighting significant advantages or limitations of the NRX compared to New Zealand's traditional breeds. Therefore, this study can to provide insight to the industry about the initial production of the NR in New Zealand.

5.1 Total yields

Significant differences were observed in milk production across the different genetic groups. The F cows exhibited the greatest total MY, and JX cows showed the greatest FY and MSY. This can be attributed to the greater genetic merit for MY of F cows and for MSY of JX cows compared to cows from the other breed groups (Harris, 2005). Previous studies by Hickson et al. (2006) indicated that F cows produced the greatest total MY, and Lembeye et al. (2016) reported that FJ cows had a greater total FY and PY compared to J cows.

Limited studies have compared the NRX with F or J for milk production under grazing conditions, as presented in this study. In the current study NRX cows had the lowest total PY, FY and MSY and the second lowest MY. Ferris et al. (2018) compared F cows to Swedish Red×J×F cows in pasture-based systems in Northern Ireland. The study reported that F cows had greater MY, but MSY was similar between the two groups. McClearn (2020) studied F, J×F, and NR×(J×F) cows over three lactations in Ireland and reported HF cows had the greatest MY during the first lactation, while J×F cows had the greatest PY and FY. The trends in MY, FY, and PY remained consistent across the subsequent lactations. Similarly, Walsh et al. (2008) conducted a five-year study comparing NR and F cows, reporting no significant differences in MY between the two breeds. The findings of the current study are consistent with McClearn (2020), indicating that NRX cows do not outperform F cows in MY or J cows in MSY.

Lopez-Villalobos et al. (2022) reported that in New Zealand dairy cattle, the MY of F, J, and FJ cows increased with each successive lactation, peaking in the fourth. It is well established that as cows mature, MY and MSY continue to rise, typically reaching their greatest levels by the fourth or fifth lactation (Lopez-Villalobos et al., 2022). To gain a more comprehensive understanding of long term NRX lactation performance under local conditions, further research is needed on subsequent lactations as the cows reach maturity. While this study provides valuable insights into first lactation data, it does not analyse the long-term production potential of NRX cows. Future studies should assess how production traits change across multiple lactations. This will provide an evaluation of NRX cow's performance as they mature reaching full production potential, allowing for more accurate comparisons with traditional New Zealand breeds.

5.2 Persistency

Lembeye et al. (2016) reported that J cows exhibited greatest persistency for MSY compared with F and FJ cows, and FJ cows had the greatest persistency for MY compared to F and J. Houdek et al. (2024) investigated the persistency of production of Holstein, and Viking Red×Holstein. In first-lactation cows, Viking Red×Holstein crossbreds did not show significant differences from the Holstein in milk and fat production persistency, but they had significantly greater persistency in protein production. In the current study, there was no significant difference in MY or MSY persistency across all breed groups, similar to the findings of Houdek et al. (2024). High persistency cows are more likely to experience adverse outcomes associated with asynchronous lactation and pasture availability. Cows with greater persistency have increased energy requirements due to greater yields being maintained throughout the season. Energy available from pasture declines as the season progresses; this may result in a mismatch of energy requirements and feed availability, which can lead to decreased milk production and negatively impact the overall health of animals (López-Villalobos, 2005). Conversely, cows with lower persistency are not fully utilising the available pasture for production. As inputs fluctuate throughout the season, maintaining a consistent level of persistency across the herd is essential. Persistency can be observed in the lactation curves, Figure 4.1 and 4.2, where the intercept (α_0), is notably higher than all other breed groups in both lactation curves. However, by the end of the lactation period, the variation between the breed groups becomes comparatively insignificant. Therefore, no breed group demonstrates a significantly greater ability to maintain production after peak yield is reached.

5.3 Somatic cell score

Increased levels of SCC in milk indicate an immune response to mastitis which is the inflammation of the udder, often caused by bacterial infection or trauma to the udder. In the current study, F, FX, and NRX cows did not have significantly lower SCS compared to FJ cows. Begley et al. (2010) reported that NRX cows had a reduced frequency of clinical mastitis compared to F cows. McClearn et al. (2020) found no significant difference in the SCC of NRX, J, and F between breed groups. Although Buckley et al. (2014) reported that crossbreeding with NR produced more robust cows, the small variance in SCC across breed groups observed in this study contrasts with these reports, as the NRX was not significantly different to the other breed groups. In future studies, recording of individual cows' clinical mastitis cases may give a better insight into mastitis frequency in the NRX, compared to the method used in this study of SCS. Other studies have shown there is potential to improve health traits of traditional dairy breeds with the use of NR bulls.

5.4 Lactation curves

Lactation curves provide a visual and statistical representation of MY and MSY production throughout a lactation period, offering insight into the onset of milk production and a cow's ability to sustain production over time. In this study lactation curves were modelled using a 3rd order Legendre polynomial. F cows showed they had the highest intercept (α_0) and steepest decline (α_1), while JX cows had reduced MY decline (α_1). For MSY, F cows had higher values for a0, α_1, and α_2, evidence in a sharper peak in MSY. In contrast, JX and FJ cows had lower α_1 and α_2 values, suggesting a more gradual decline and maintained MSY production. Lembeye et al. (2016) investigated lactation curves of F, J, and F × J cows on once-a-day milking and found similar trends to the present study. F cows had the highest intercept (α_0) and the steepest decline (α_1). No significant differences were observed across breed groups for the α_2 and α_3 coefficients, consistent with the findings of this study.

Houdek et al. (2024) investigated first-lactation curves of Holstein, Viking Red × Holstein, and VR × (Holstein × Montbéliard) cows. Finding that for MY curve, Holstein cows had the highest intercept and maintained more consistent MY production than the other breeds throughout the curve. For the MSY lactation curve Holstein cows also had the highest intercept (α_0), but no significant differences were observed among the breed groups for the remainder of the lactation. Lactation curves in this study do not display a significant peak lactation point, and the gradual decrease in the remainder of the lactation. This is likely due to the initial data collection taking place in late September to early October; this period of lactation is associated with peak lactation yield (Edwards et al., 2014). Therefore, if data was collected closer to the commencement of lactation and again around peak calving, the curve would likely display the typical characteristics expected of a lactation curve.

5.5 Study limitations

The sample size in this study was relatively small and limited to a single location in New Zealand. Increasing the sample population and including samples from multiple locations across New Zealand will allow for a greater understanding of the breeds production. Additionally, since data collection occurred at only four time-points during the season, increasing the frequency of data collection would provide greater insights. The peak lactation point in the lactation curve was missed because the timing of data collection did not capture this phase; also as well increased data collection frequency would result in greater accuracy of results. This study was only limited to analysing the SCS for health traits. Another limitation of this study is that the data was only collected from only first-lactation animals.

5.6 Future research

Based on the findings of this research, there are recommended some aspects areas for further study on the NR in New Zealand dairy farming. Since NR is reported to exhibit superior health traits, further studies should be conducted to explore these in greater detail. For example, additional evaluations could include udder scoring, records of clinical mastitis in a season, fertility performance, and lameness records. It would also be valuable to investigate other key traits relevant to New Zealand dairy cattle, such as beef production longevity and economic analysis.

It is well established that dairy cows typically do not reach their peak production until their third or fourth lactation. Therefore, analysing data from subsequent lactations in the future would provide a more comprehensive understanding of NR lifetime production. This would assess the lifetime production potential as cows reach maturity.

At the dairy farms where data collection occurred, the farmer chose to backcross the NRX individuals with F, resulting in offspring that are ¾ F and ¼ NR in future years. Studying this genotype would be valuable for understanding milk production and whether it aligns more closely with the results observed in the F breed in this study. Additionally, the farmer plans to conduct a similar backcross with NR, resulting in offspring that are ¾ NR and ¼ F. Evaluating backcrosses with higher proportions of NR genetics could reveal whether increased genetic contribution enhances health traits.

5.7 Conclusions

This study aimed to evaluate the lactation yields of primiparous F_1 NRX cows under New Zealand's low-intensity pasture-based dairy farming conditions. It compared NRX with traditional breeds F, J and their crosses. The findings revealed significant differences in milk production across the breed groups. F cows exhibited the greatest total MY, while JX had the highest FY and MSY. The NRX cows, however, showed the lowest PY, FY and MSY, the second lowest MY, indicating that they did not outperform the traditional breeds in these key production traits. Persistency analysis showed no significant differences in MY or MSY persistency among the breed groups. This suggests that NRX cows have a similar ability to maintain production after peak yield compared with traditional breeds. Somatic cell score, an indicator of mastitis incidence, did not differ significantly between NRX cows and other breeds, which contrasts with some overseas studies that suggested improved mastitis resistance in the NR breed. Lactation curve modelling revealed that F cows had the highest initial MY but experienced the steepest decline over time. In contrast, JX and FJ cows demonstrated a more gradual decline in MSY, indicating better persistency in milk solids production.

While this study provides valuable initial insights into the performance of NRX cows under New Zealand dairy farming conditions, the NRX did not outperform traditional breeds in key production traits during their first lactation. However, given the Norwegian Red's reputed advantages in health traits, incorporating NR genetics could still offer benefits. Comprehensive long-term studies are necessary to determine whether NRX cows can contribute to improving the sustainability and efficiency of New Zealand's dairy industry without adversely affecting milk production levels.

References

Ahlborn G, Bryant AM. 1992. Production, economic performance and optimum stocking rates of Holstein-Friesian and Jersey cows. Proceedings of the New Zealand Society of Animal Production 52: 7-9.

Askey R. 2005. The 1839 paper on permutations: Its relation to the Rodrigues formula and further developments. In Mathematics and Social Utopias in France: Olinde Rodrigues and His Times, History of Mathematics; Altmann, S., L., Ortiz, E.L., Eds.; American Mathematical Society: Providence, RI, USA, 2005; Volume 28, pp. 105–118, ISBN 978-0-8218-3860-0.

Begley N, Buckley F, Pierce KM, Fahey AG, Mallard BA. 2009. Differences in udder health and immune response traits of Holstein-Friesians, Norwegian Reds, and their crosses in second lactation. Journal of Dairy Science 92: 749-757.

Bryant AM, Cook MAS, Macdonald KA. 1985. Comparative dairy production of Jerseys and Friesians. Proceedings of the New Zealand Society of Animal Production 45: 7–11.

Buchanan DS. 2002. Animals that produce dairy foods: Major Bos taurus breeds. In in Encyclopedia of Dairy Sciences, Elsevier Inc. Editor J. W. Fuquay. Second Edition (San Diego: Academic Press): 284–292.

DairyNZ, & LIC. 2022. New Zealand dairy statistics: 2021-22.

DairyNZ. 2023a. Breeding worth. Available at: https://www.dairynz.co.nz/animal/breedingdecisions/breeding-worth/. [Accessed 03 August 2024]

DairyNZ. 2024b. Economic values. Available at: https://www.dairynz.co.nz/animal/breedingdecisions/economic-values/. [Accessed 02 Augus 2024]

DairyNZ. 2024c. Better breeding worth. Available at: https://www.dairynz.co.nz/news/betterbreeding-worth/. [Accessed 03 August 2024]

Edwards JP, Jago JG, Lopez-Villalobos N. 2014. Analysis of milking characteristics in New Zealand dairy cows. Journal of Dairy Science 97: 259–269.

Ferris CP, Patterson DC, Gordon FJ, Watson S, Kilpatrick DJ. 2014. Calving traits, milk production, body condition, fertility, and survival of Holstein-Friesian and Norwegian

Red dairy cattle on commercial dairy farms over 5 lactations. Journal of Dairy Science 97: 5206-5218.

Geno. 2024a. Norwegian Red characteristics. Available at: https://www.norwegianred.com/about-norwegian-red/norwegian-red-characteristics/ [Accessed 20 August 2024]

Geno. 2024b. The Norwegian estimated breeding values. Available at: https://www.norwegianred.com/about-norwegian-red/norwegian-ebvs/. [Accessed 20 August 2024]

Harris BL. 2005. Breeding dairy cows for the future in New Zealand. New Zealand Veterinary Journal 53: 384-389.

Harris BL, Kolver ES. 2001. Review of Holsteinization on intensive pastoral dairy farming in New Zealand. Journal of Dairy Science 84: E56–E61.

Heins BJ, Hansen LB. 2012. Short communication: Fertility, somatic cell score, and production of Normande x Holstein, Montbéliarde x Holstein, and Scandinavian Red x Holstein crossbreds versus pure Holsteins during their first 5 lactations. Journal of Dairy Science 95: 918–924.

Holmes CW. 2001. Managing fertility in the New Zealand dairy herd. Proceedings of the New Zealand Society of Animal Production 61: 135-140.

Holmes CW, Brookes IM, Garrick DJ, Mackenzie DDS, Parkinson TJ, Wilson GF. 2002. Milk Production from Pasture: Principles and Practices. Massey University.

Houdek ES, Hazel AR, Lopez-Villalobos N, Hansen LB, Heins BJ. 2024. Lactation curves of Montbéliarde-sired and Viking Red-sired crossbred cows and their Holstein herdmates in commercial dairies. Journal of Dairy Science 107: 3753-3767.

Huxley JN. 2003. Impact of lameness and claw lesions in cows on health and production. Livestock Science 156: 64-70.

Kirkland RM, Patterson DC, Keady TWJ, Moss BW, Steen RWJ. 2007. Beef production potential of Norwegian Red and Holstein-Friesian bulls slaughtered at two ages. Animal 1: 1506-1514.

Lembeye F, López-Villalobos N, Burke JL, Davis SR, Richardson J, Sneddon NW, Donaghy DJ. 2016. Comparative performance in Holstein-Friesian, Jersey and crossbred cows milked once daily under a pasture-based system in New Zealand. New Zealand Journal of Agricultural Research 59: 351-362.

Lopez-Villalobos N, Garrick DJ. 2005. Methodology for the design and enhancement of genetic improvement programs illustrated in the context of the New Zealand dairy industry. Agrociencia IX: 553-568.

Lopez-Villalobos N, Garrick DJ, Holmes CW, Blair HT, Spelman RJ. 2000. Profitabilities of some mating systems for dairy herds in New Zealand. Journal of Dairy Science 8: 144-153.

Lopez-Villalobos N, Ariyarathne HBPC, Hickson RE. 2022. Genome-wide association studies for maturity rate in grazing dairy cows. Proceedings of the 12th World Congress on Genetics Applied to Livestock Production, Rotterdam, The Netherlands. 2822-2825. Wageningen Academic publishers.

Malcolm D. 2006. The cost of mastitis. Proceedings of the Seasonal Approach to Managing Mastitis (SAMM) Conference: 183-195.

McClearn B, Delaby L, Gilliland TJ, Guy C, Dineen M, Coughlan F, Buckley F, McCarthy B. 2020. An assessment of the production, reproduction, and functional traits of Holstein-Friesian, Jersey×Holstein-Friesian, and Norwegian Red×(Jersey×Holstein-Friesian) cows in pasture-based systems. Journal of Dairy Science 103: 5200-5214.

New Zealand Ministry of Primary Industries. 2024. Situation and outlook for primary industries. Available at: https://www.mpi.govt.nz/dmsdocument/62637-Situation-and-Outlook-for-Primary-Industries-SOPI-June-2024

Partners S. 2023. Dairy's economic contribution to New Zealand. Retrieved from DairyNZ: https://www.dairynz.co.nz/resources/?page=1&types=Research

Rinell E, Heringstad B. 2018. The effects of crossbreeding with Norwegian Red dairy cattle on common postpartum diseases, fertility and body condition score. Animal 12: 2619-2626.

Seegers H, Fourichon C, Beaudeau F. 2003. Production effects related to mastitis and mastitis economics in dairy cattle herds. Veterinary Research 34: 475-491.

Sneddon NW, Lopez-Villalobos N, Davis SR, Hickson RE, Shalloo L, Garrick DJ. 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: 79-89.

Verkerk G. 2003. Pasture-based dairying: Challenges and rewards for New Zealand producers. Theriogenology 59: 553-561.

Walsh S, Buckley F, Pierce K, Byrne N, Patton J, Dillon P. 2008. Effects of breed and feeding system on milk production, body weight, body condition score, reproductive performance, and postpartum ovarian function. Journal of Dairy Science 91: 4401-4413.