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The use of high genetic merit Angus and Hereford bulls in a New Zealand dairy herd

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Abstract

Calves born to dairy cows that are not required as replacements for the dairy herd can be sold for beef production. The value of these calves depends on their potential for meat production, consequently, beef-cross-dairy calves are generally more valuable than dairy breed calves. Angus and Hereford are the predominant beef-breed breeds in New Zealand, with Hereford bulls more commonly used in the dairy industry than Angus. The key concern of dairy farmers when choosing a service bull to generate calves for sale for beef production is the health and production of the dairy cow or heifer, requiring a focus on calving difficulty where birth weight of the calf is a contributing factor. The gestation length of the calf impacts the calving interval and calving spread and therefore days in milk of the cow. Of most importance to a beef producer, is how the calf will perform in a beef rearing system. Limited research exists regarding which beef-breed bulls are most appropriate for mating to dairy cows and heifers, and whether there are negative impacts of the bull on milk production and rebreeding of the cow or heifer, which should be considered alongside a change in calf value. The general objective of this thesis was to identify what type, in terms of estimated breeding value (EBV) or genetic merit, of Angus and Hereford bulls are appropriate for mating to dairy cows and heifers.

Data from 980 singleton beef-cross-dairy calves and 952 artificially bred mixed-aged dairy cows were used to compare 65 Angus and Hereford service sires of differing genetic merit using a progeny test. Mean progeny birth weight, gestation length, age at weaning and pre-weaning ADG differed among sires, while assistance at birth was less than 1%. The relationship between breeding values calculated from the data and published birth weight and gestation length EBV indicate that the published EBV are good predictors of progeny performance in a beef-cross-dairy system. There was no effect of service sire on post-calving live weight, days in milk, milk production or inter-calving interval of mixed-aged cows. Relationships between calf gestation length and the dam's date of calving and pregnancy rate, and between calf birth weight and survival indicate the potential for an effect of service sire. However, as lighter calves and shorter gestation lengths are preferable for beef-cross-dairy calves, selection of beef-breed service sires with these traits should minimise any negative effects. Results from this experiment indicate that the bulls used in this experiment, and other bulls with similar EBV for birth weight and gestation length would be suitable for mating mixed-aged dairy cows.

Data collected from 304 first-calving heifers and their calves allowed the comparison of Angus, Hereford and Jersey breed bulls specifically selected for use over dairy heifers.

Calves sired by Angus and Hereford bulls were heavier at birth than Jersey-sired calves, and 3.6%–10% of beef-sired calves were assisted. There was no difference in the body condition score, pre-calving live weight, milk production, pregnancy rate, inter-calving interval, re-calving date and 21-day re-calving rate of heifers mated to the different breeds of bulls. For dairy heifers, the suitability of beef-breed bulls is reliant on minimising calving difficulty, and selection for bulls with lighter birth weight EBV tended to decrease calving assistance. Provided easy calving bulls are used, the similarities in milk production, rebreeding performance and survival provides evidence for the use of beef-breed bulls over dairy heifers.

Overall, the results presented in this thesis provide evidence towards the successful use of high genetic merit beef-breed bulls in New Zealand dairy herds, providing a greater value calf, with little or no negative effect on the dairy cow or heifer. For mating to mixed-aged dairy cows, beef-breed bulls which produce comparable calves to the alternative dairy bulls are most appropriate, industry EBV can be used to predict progeny birth weight and gestation length. For mating to dairy heifers, bulls which have very high calving ease and very low birth weight EBV are suitable to minimise the risk of calving difficulty.

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Although you are no longer here, and will not see the end of this journey, I know that you
would be immensely proud.

*"You're off to Great Places! Today is your day! Your mountain is waiting.
So... get on your way!"*

Oh! The Places You'll Go
Dr Seuss, 1990

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List of Abbreviations

AB	Artificial breeding
ADG	Average daily gain
BCS	Body condition score
BV	Breeding value
CIDR	Controlled Internal Drug Release insert
DOC deviation	Deviation from median date of calving / birth
DOM deviation	Deviation from median date of mating / conception
EBV	Estimated breeding value
FY	Fat yield
Live weight LWT	Dam / cow mean live weight over the 30 days post calving
MA	Mixed-aged cow herd
MS	Milksolids yield
MY	Milk yield
PC BCS	Grouped pre-calving body condition score
PD	Pregnancy detection
PY	Protein yield
RB BCS	Grouped pre-mating body condition score
SD	Standard deviation of the mean
SE	Standard error of the mean

General Introduction

Surplus dairy-sired calves from the dairy industry are typically sent for slaughter at less than 2 weeks old (Thomas and Jordaan, 2013, Cook, 2014, Hickson et al., 2015, Handcock et al., 2019a). There is an opportunity to increase the volume of beef produced and reduce wastage from the dairy industry by repurposing the surplus calves by using beef-breed bulls over dairy cows for non-replacement matings and rearing the progeny for beef production. Beef-breed bulls can be used to produce a calf of greater value than that of a dairy-bull sired calf (Hickson et al., 2015). Angus and Hereford are the most common beef breeds in New Zealand (Beef+LambNZ, 2019a), with Hereford reported as the most common beef breed used in the dairy industry (DairyNZ, 2019).

In New Zealand, artificial breeding (AB) is used to breed approximately 72% of mixed-aged cows (DairyNZ, 2019). Most herds have a period of AB to genetically superior dairy-breed bulls, then use a period of natural mating; artificial breeding with semen from beef-breed bulls is also popular alongside AB to dairy-breed bulls (LIC, 2019a, LIC, 2019b, LIC, 2020c). Artificial breeding is used to a lesser extent in dairy heifers, with the majority naturally mated (DairyNZ, 2017b, DairyNZ, 2020b). The most prevalent bull breed used for mating with dairy heifers, and mixed-aged cows after the AB period is finished, in New Zealand, is Jersey as the breed is associated with a lighter birth weight calf, and has a lower risk of calving difficulty (DairyNZ, 2007, Hickson et al., 2015).

The key interest of dairy farmers when choosing a service bull for dairy cows is the health and production of the dairy cow or heifer (Cook, 2014). The primary focus for selecting service bulls for non-replacement matings, is on calving difficulty, of which calf birth weight is a contributing factor (Burfening et al., 1978, Arthur et al., 2000, Hickson et al., 2008b, Mee, 2008). The link between calf birth weight and calving difficulty has led to dairy farmers having concerns about using beef-breed bulls over dairy cows (Mee, 2008) because beef-breed bulls may produce heavier calves than a dairy breed bull. Also of importance, is the gestation length of the calf, because this has impacts on the calving interval and calving spread and therefore days in milk (Winkelman and Spelman, 2001, Donkersloot, 2014). Of less importance to the dairy farmer, but of high importance to a beef producer is how the resulting calf will perform in a beef rearing system.

The main objectives of this thesis are:

- To evaluate the birth weight, gestation length and progeny growth of individual Angus and Hereford bulls for beef-cross-dairy calf production

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- To evaluate the relationship between BreedPlan estimated breeding value and beef-cross-dairy progeny performance for birth weight, gestation length and pre weaning growth for individual Angus and Hereford bulls
- To identify whether there is an effect of service sire on the body condition score, milksolids yield and rebreeding success of mixed-aged dairy cows serviced by Angus and Hereford bulls
- To compare the birth weight, calving assistance and survival of calves born to first calving heifers mated to Angus, Hereford or Jersey bulls, and the pre-weaning growth of Angus- and Hereford-sired calves
- To identify whether there are differences in the body condition score, milk production and rebreeding success of first calving heifers mated to Angus, Hereford or Jersey bulls
- To identify characteristics that can be used to distinguish between new-born calves born to dairy cows and Angus or dairy breed bulls
- To determine the income from sale of surplus calves generated using Angus, Hereford and Jersey bulls
- To identify possible options for incorporation of beef-breed semen or bulls into dairy herds and consider factors contributing to their suitability to the system

The outcome of this research will provide evidence as to whether beef-breed bulls are suitable for breeding to mixed-aged dairy cows and maiden dairy heifers. Providing beef-breed bulls can be suitable, this research will provide a foundation to identify what type of bulls, with respect to estimated breeding values, are appropriate for mating to dairy cows.

Chapter 1 – Review of Literature

The New Zealand dairy industry

The New Zealand dairy industry is predominantly a pasture-based system, and one of the major constraints is that cows need to maintain a 365-day calving interval to match feed demand to feed supply (Grosshans et al., 1997, Holmes et al., 2007, Amer et al., 2016). The 365-day calving interval is a key driver of profitability of dairy farms.

In the last 40 years the New Zealand industry has increased from 2.1 million cows (1975-76), to 4.95 million (2018-19) (DairyNZ, 2019). The breed composition of the New Zealand dairy herd has changed, from a predominantly straight-bred Holstein-Friesian and Jersey herd, to a herd with Holstein-Friesian-Jersey crossbred cows as the most dominant breed (Garrick and Lopez-Villalobos, 1998, Back, 2017). The New Zealand dairy herd was dominated by Jersey cattle in the early 1960's, Holstein-Friesian from the late 1960's and since 2012, the Holstein-Friesian-Jersey crossbred breed has been the dominant breed (DairyNZ, 2012b, Back, 2017, DairyNZ, 2019). The breed make-up of the 2018-2019 national dairy herd was 48.5% Holstein-Friesian-Jersey crossbred (18.4% increase since 2005-06 season), 33.1% Holstein-Friesian (13.9% decrease) and 8.6% Jersey (6% decrease) (LIC, 2006, DairyNZ, 2019).

The primary income source of a NZ dairy farm is milksolids (combined fat and protein) production, representing approximately 93% of dairy farm income (Cook, 2014, DairyNZ, 2018). Whereas the proportion of income from calf sales contributes far less, with net livestock sales representing around 6% of which calf sales are a small proportion (~1%) (Cook, 2014, DairyNZ, 2018)).

Bulls used

Of mixed-aged cows, 71.5% of New Zealand dairy cows are artificially bred (AB), with many bred to superior dairy-breed bulls (e.g. Holstein-Friesian, Jersey, Holstein-Friesian-Jersey crossbred) to produce replacement heifers (DairyNZ, 2019). Both dairy- and beef-breed bulls are used over the 28.5% of remaining cows. These are typically the later mated cows, as farmers prefer to generate the replacements from first cycle cows. Both AB and natural mating are used with beef- or dairy-breed bulls used after dairy AB, and the calves generally have no future in the dairy industry.

Artificial insemination is used to a lesser extent in dairy heifers. Approximately 20% (based on data reported in the New Zealand dairy statistics) of heifers are artificially inseminated (DairyNZ, 2019). Heifers are not observed daily as milking cows are, therefore, artificial insemination in maiden heifers is associated with greater labour costs and usually

accompanied by a synchronisation process as an alternative to daily observations and inseminations.

The method primarily used to select genetically superior dairy breed bulls used for artificial breeding in New Zealand is by progeny testing. Progeny testing allows the performance of sires to be compared through recording the performance of their offspring (Robertson and Rendel, 1950, Powell et al., 2003, Hayes et al., 2009). Progeny testing dairy bulls involves recording the performance of the daughters in a milking herd (Robertson and Rendel, 1950, Hayes et al., 2009); progeny testing beef-breed bulls involves the performance of the progeny from birth until slaughter and recording of the carcass characteristics and meat quality attributes (Flanagan, 1982, Baker et al., 1984). Progeny testing of beef-breed bulls for use in dairy herds is currently limited in New Zealand.

Natural mating is used both for heifers, and for cows after a period of AB (Holmes et al., 2007) in most herds. The most prominent breed for natural mating over cows and especially with heifers is, anecdotally, the Jersey breed because it generates a lighter birth weight calf, born with lower calving difficulty (DairyNZ, 2007, Holmes et al., 2007, Hickson et al., 2015).

When milk is worth less to the farmer, the use of beef-breed bulls mated to dairy cows increases, as the farmer seeks alternative income sources, i.e. rearing calves to sell for meat (Fouz et al., 2013). Beef-breed bulls are used to produce a calf of greater value than that of a dairy bull sired calf, and to produce heifer calves whose breed can be identified with certainty in order to separate them from those kept as replacements and those to be sold (Hickson et al., 2015). However, to be profitable for the dairy herd, the beef-breed bulls need to perform in comparison to the dairy bulls in terms of the impact on the cow at calving, subsequent milking and rebreeding, and by producing calves with comparable birth weights (Hickson et al., 2015).

Calves

The dairy industry currently produces about 4 million calves per year, of which approximately 26% are kept as replacement heifers (Cook, 2014, Hickson et al., 2015). Therefore, the remaining calves have the potential for rearing for beef production. Approximately 1.8 million calves were processed as bobby calves at less than 2 weeks of age, and 836,000 (2014 total) were reared and finished for beef (Cook, 2014, Hickson et al., 2015, Beef+LambNZ, 2019a). The high number of bobby calves slaughtered each year illustrates the opportunity to increase the income from calf production by using beef-breed bulls and rearing progeny rather than slaughtering them at less than 2 weeks old (Cook,

2014). However, this must not come at the expense of level of milk production, health or survival of the cow.

The calf is not a major profit driver in a dairy system, representing c.1% of farm income (Cook, 2014). However, there is increasing interest in sustainable farming and dairy cow and calf welfare (DairyNZ Strategy for Sustainable Farming 2013-2020, 2013; Agricultural Research Group on Sustainability NZ). The bobby calf is considered a weak link in the marketing of New Zealand dairy products, with the New Zealand dairy industry receiving negative media exposure, both nationally and internationally, relating primarily to treatment of bobby calves (Farmwatch.org.nz, 2016; Stuff.co.nz, 2016). In the future, the dairy industry may use sexed semen to produce replacement dairy heifers (DairyNZ, 2007, Wilson, 2014). With sexed semen, less cows will need to be bred to produce replacement heifers, providing the opportunity increase the number of beef-breed bulls currently used in artificial breeding, with the progeny reared for meat production.

New Zealand beef industry

The number of cattle in the national beef herd is 3.82 million as at 30 June 2019 (Beef+LambNZ, 2019b). Of the beef cattle herd, 1.02 million are breeding cows and heifers (Beef+LambNZ, 2019a, Beef+LambNZ, 2019b), with the remaining population breeding bulls and finishing cattle. Straight-bred Angus make up the largest proportion (34%) of the national beef herd in the 2018-19 season, Holstein-Friesian is the second most prominent breed (13%, majority as bulls for bull-beef), then Hereford (11%) (Beef+LambNZ, 2019a).

Traditionally the beef industry consisted of a beef-breeding cow producing calves, but now beef sourced from the dairy industry contributing a larger proportion of beef (Morris and Kenyon, 2014, Beef+LambNZ, 2017). This dairy-sector production is from bobby calf slaughter, cull dairy cow slaughter and from calves purchased (either at four days old or after weaning) from dairy herds being raised for beef production (Morris, 2013, Morris and Kenyon, 2014, Beef+LambNZ, 2016a). Typically, the purchased calves are Holstein-Friesian, or beef-cross-Holstein-Friesian (Morris and Kenyon, 2014). The total number of cattle processed for the year ended 30/9/19 was 2.6 million cattle and 1.8 million calves, of these numbers the dairy-beef contribution included 1.8 million calves (including bobby calves) and a portion of the 1.03 million cull cows (Beef+LambNZ, 2019a). The latest reported figures regarding the proportion of beef originating from the dairy industry show that of the 2.45 million cattle estimated to have been slaughtered in the 2016-2017 season, 69% originated from the dairy industry, being cull dairy cows, dairy heifers and breeding bulls (41%) and dairy-beef steers, heifers and bulls (28%) (Beef+LambNZ, 2016b).

By retaining and finishing surplus dairy calves, rather than slaughtering them at a few days of age, New Zealand's beef production could be further increased within a relatively short period. Low beef prices increase the bobby calf kill while high prices tend to increase the proportion of dairy bred calves raised for beef production (Morris, 2013). However, the increase in beef production needs further consideration as to the increased number of cattle to feed, particularly with the current carcass evaluation suiting cattle finished at ~22 months of age.

Using beef-breed bulls in the dairy industry

The priority of a dairy farmer is the health and survival of the dairy cow and their milk production (Cook, 2014). With a higher milk price, the value of the calf to the farmer is less important than milk production; and a higher proportion of Jersey sires are used, as the breed is associated with less calving difficulty and consequently an increased cow survival rate (Holmes et al., 2007, Hickson et al., 2015, DairyNZ, 2017b, DairyNZ, 2019). When the milk price is low, nearer the breakeven price, and the value of milk is less than the cost to rear extra calves for sale, the dairy farmer has an increased interest in beef production, with calf sales as an alternative source of income (Fouz et al., 2013). However, the milk production and the health of the cow is still prioritised above the potential value of calf sales (Cook, 2014, Hickson et al., 2015). Surplus dairy-sired calves from the dairy industry are typically sent for bobby calf slaughter at less than 2 weeks old (Thomas and Jordaan, 2013).

Dairy cows are selected for milk composition and volume, live weight, fertility and survivability in the herd, consequently dairy bulls used for artificial breeding are chosen on these characteristics for producing dairy heifer replacements. There is little selection for bulls used for natural mating and/or artificial breeding when not generating replacement heifers, as the main purpose of these matings is to achieve a pregnancy, rather than the characteristics of the resulting calf.

Angus and Hereford bulls are the most common beef breeds in New Zealand (Beef+LambNZ, 2019a), with Hereford anecdotally currently the most common beef-breed bull used in the dairy industry (Holmes et al., 2007, DairyNZ, 2019). However, there are smaller populations of a number of beef-breed bulls available for use in the New Zealand dairy industry, not all of which offer the same level of recording as Angus and Hereford (Table 1.1).

Table 1.1. Beef breeds in New Zealand offered by artificial breeding companies, whether the breed is recorded in BreedPlan, with the population of 2018-born females indicating the relative size of each populations.

Breed ¹	New Zealand Breedplan	Population ²
Angus	Yes	7082
Hereford	Yes	5031
Charolais	Yes	533
Simmental	Yes	966
Murray Grey	Yes	226
Gelbvieh	Yes	60
Devon (Red & South)	Yes	453
Beef Shorthorn	Yes	340
Galloway (including Belted, White)	Yes	150
Blonde D'Aquitaine	Yes	187
Speckle Park	International only	1235 ³
Belgian Blue	No New Zealand Breedplan	
Dexter	No New Zealand Breedplan	
Inra	No New Zealand Breedplan	
Limousin	No New Zealand Breedplan	
Lowline Angus	No New Zealand Breedplan	
Meuse-Rhine-Issel	No New Zealand Breedplan	
Piedmontese	No New Zealand Breedplan	
Stabilizer / Profit Maker	No New Zealand Breedplan	
Red Angus	No New Zealand Breedplan	
Red Poll	No New Zealand Breedplan	
Santa Gertrudis	No New Zealand Breedplan	
Scottish Highland	No New Zealand Breedplan	
Wagyu	No New Zealand Breedplan	

¹ Beef-breeds (Semen from at least 1 bull) offered by Livestock Improvement Corporation, CRV Ambreed and Samen in 2020. ² Population of 2018-born active females recorded in New Zealand Breedplan as at September 2020. ³ Number of Speckle Park females recorded worldwide on Breedplan as at September 2020.

Finishing dairy origin beef cattle

Holstein-Friesian bull calves make up a significant (1998: 69%; Charteris et al. (1998)) proportion of calves born to dairy cows and reared for beef production (Charteris et al., 1998). Beef-sired calves also represent a great and increasing proportion of beef production arising from the dairy industry (Charteris et al., 1998, Morris and Kenyon, 2014, Beef+LambNZ, 2016b, Beef+LambNZ, 2017). In the New Zealand carcass evaluation system, bulls are graded for processing beef, while steers and heifers are graded differently (table beef) (Charteris et al., 1998, NewZealandMeat, 2004). Historically steers and heifers fetched a greater price per kilo carcass compared to processing beef, at present, however, the difference is small (~\$5.00/kg for processing beef, ~\$5.50/kg for table beef, 2018-19 season average) (Beef&LambNZ, 2020).

When purchasing beef-cross-dairy calves, there is a preference for Holstein-Friesian or beef-sired calves, rather than Jersey or Holstein-Friesian-Jersey crossbred calves for beef production (Muir et al., 2001, Morris and Kenyon, 2014, Coleman, 2016). The exclusion of

Jersey and Jersey-cross animals from beef production reflects the slower growth, lighter carcasses and yellower fat compared to Holstein Friesian, and consequently, leading to inferior grading at slaughter and a lower price per kg carcass (Butler-Hogg and Wood, 1982, Barton et al., 1994, Burke et al., 1998, Muir et al., 2001).

There is a view in the beef industry that meat from dairy breeds is of inferior eating quality compared with beef breeds, which is generally not supported by experimental evidence, the only difference being fat colour which does not affect the eating quality (Muir et al., 2000b, Muir et al., 2001, Schreurs et al., 2014, Coleman, 2016, Coleman et al., 2016). Increasing the proportion of Jersey genetics in dairy-beef cattle reduces the proportion of muscle in the live weight and therefore, the meat yield (Schreurs et al., 2014, Coleman, 2016, Coleman et al., 2016). Although not genetically selected for beef production, there are few differences in the meat quality characteristics from different breeds of cattle and preference tests show that any differences are unlikely to be identified by the consumer (Koch et al., 1976, Purchas and Barton, 1976, Purchas et al., 1992).

With the opportunity to increase the production from the dairy industry, there needs to be consideration of the whole production chain. The production chain spans from generation of beef-cross-dairy calves, growth from birth until 'finish' and slaughter, carcass characteristics and meat quality. Consideration also needs to be given to the availability of land required for growing and finishing cattle and may also require thought regarding the classification of cattle at slaughter. This thesis focuses on the generation of calves for beef production and potential effects on the dairy cow, although the other previously mentioned factors need to be considered for beef-cross-dairy production.

Important traits to consider in a beef-cross-dairy system

When making management decisions whether to use a beef-breed bull across the dairy herd, the dairy cow factors to take into consideration are future milk production, the ability of the cow to get pregnant again for the following season (rebreeding), gestation length and the ease of calving. These factors contribute to driving profitability of the dairy farm (Dhakal et al., 2013). If the sire-breed of the calf has a negative impact on these factors, the dairy farmer runs the risk of losing income.

Birth weight of the calf will be discussed first, as it has been identified as an influencing factor for calving difficulty, gestation length, milk production and rebreeding success. The birth weight of the calf is also related to pre-weaning growth of the calf.

Ease of calving is important as difficult calvings increase labour cost, increase the risk of cow and calf mortality and can negatively impact rebreeding and milk production. Gestation length, although a trait of the calf, is important to consider as date of calving determines the number of days in milk and consequently milk production (Holmes et al., 2007). In addition, a shorter gestation length, whether that be compared with the breed average or different breeds used, could be used to condense the calving season and/or maintain the 365-day calving interval, and also to increase the number of days between calving and rebreeding (Holmes et al., 2007, Donkersloot, 2014).

Milk production is important as it is the primary source of income for the dairy farm (Holmes et al., 2007), in New Zealand farmers get paid for milksolids production. Rebreeding is important to consider as, in order to lactate in the following season, and survive in the herd, the cow needs to get pregnant again (Holmes et al., 2007). The timeframe for getting pregnant following calving varies, depending on the calving date, however in order to maintain a 365-day calving interval, the cow must conceive within 80-85 days of calving (Holmes et al., 2007) coinciding with peak lactation. Additionally, poor reproductive performance delays the mean calving date and decreases the days in milk and milk production in the following season (Roche et al., 1992, Xu and Burton, 1996, Grosshans et al., 1997).

In addition to factors influencing the cow, the growth and future performance of the resulting calf is an important consideration. Those in the industry rearing and or buying the calves born to a beef-cross-dairy mating need some assurance of the growth of calves born to dairy calves, especially if shifting the focus from a previously straight-bred beef-breed or Holstein-Friesian bull beef system.

Finally, a consideration into calf identification is growing in importance as crossbreeding in New Zealand is increasing, especially when crossbreeding with beef-breed cattle. Identifying the newborn calf at birth, for the dairy farmer to identify and keep replacement dairy calves. For farmers selling beef-cross-dairy calves, knowing the breed of the calf, ideally shortly after birth is important when treating calves of different breeds differently, and for beef farmers purchasing beef-cross-dairy calves.

Birth weight of calves

Birth weight of the calf is a recurring factor which the literature reports having an effect on milk production, rebreeding success, calving difficulty and gestation length. Factors which influence the birth weight of the calf include the breed and sex of the calf, and the parity of the dam.

Birth weight of calves reported in literature are summarised in Table 1.2. Hereford calves are typically heavier at birth than Angus calves (Burris and Blunn, 1952, Baker et al., 1974, Long and Gregory, 1974, Smith et al., 1976, Gregory et al., 1978). There is a lack of more recent literature especially in New Zealand on birth weight of beef-breed cattle. The weights may not be representative of today's Angus and Hereford cattle as there has been selection pressure placed on growth rate in the 1990's and 2000's which has led to greater birth weights (Morris, 2019).

New Zealand Holstein-Friesian calves are heavier at birth than Jersey calves, with Holstein-Friesian-Jersey crossbred intermediate to the straight breeds (Holmes et al., 2007, Cardoso et al., 2015, Hickson et al., 2015, Back et al., 2016). Dhakal et al. (2013) reported that with increasing proportion of Holstein-Friesian genetics (relative to Jersey) the birth weight of the calf increases. Comparing beef- and dairy-breeds indicates that Hereford breed calves are generally heavier than Holstein-Friesian calves (Hickson et al., 2015), and Hereford-cross-Holstein-Friesian calves are heavier than Holstein-Friesian calves (Hickson et al., 2014) (Table 1.2).

Bull calves tend to be heavier than heifer calves (Table 1.2) (Everitt and Jury, 1972, Smith et al., 1976, Maltecca et al., 2006, Dhakal et al., 2013, Hickson et al., 2015). As the age of dam increases, birth weight tends to increase (Table 1.2) (Long and Gregory, 1974, Burfening et al., 1978, Dhakal et al., 2013). Gestation length is also has an influence on birth weight as an increase in gestation length results in an increase in birth weight at a decreasing rate (Burfening et al., 1978).

Birth weight is a moderately heritable trait, with heritability estimates of 0.21 – 0.53, with New Zealand Angus using a heritability estimate of 0.32 for calculations of BreedPlan estimated breeding values (Burfening et al., 1978, Burfening et al., 1981, Bennett and Gregory, 1996, Coffey et al., 2006, Maltecca et al., 2008, Angus-NZ, 2018).

Table 1.2. Average birth weight (kg) of straight-bred and crossbred Angus, Hereford, Holstein-Friesian, Jersey and Holstein-Friesian-Jersey crossbred calves from published literature

Source	Sex of calf	Angus	Hereford	Holstein-Friesian	Jersey	HF-J crossbred	Dam Age ¹	Straight-bred or crossbred	Location
Everitt and Jury (1972)	Bull	27.7		38.7	24.3	31.2	All	Straight bred	NZ
	Heifer	27.1		37.1	22.4	28.5			
Baker et al. (1974)	Both	24.6	28.1					Straight bred	NZ
Long and Gregory (1974)	Both	29.0	30.4				All	Sire-breed	USA
Bourdon and Brinks (1982)	Bull	34.1	35.5				All	Straight bred	USA
	Heifer	31.6	33.6						
Maltecca et al. (2006)	Bull			40.1		38.7	MA	Holstein dams	USA
	Heifer			39.2		38.1			
Olson et al. (2009)	Both			37.7	22.5		All	Straight bred	USA
Dhakal et al. (2013)	Both			33.8	22.1		All	Straight bred	USA
Hickson et al. (2015)				36.1	27.6	31.7	Heifer	Straight bred	
	Heifer			32.5	28.9	30.9	Heifer	Dam breed	NZ
					34.1	30.5	32.6	MA	Dam breed
Hickson et al. (2015)	Heifer		39.8	38.4				Holstein-Friesian dam	NZ
	Bull		43.2	41.8					
Cardoso et al. (2015)	Heifer			37.5	24.5	30.2	MA	Straight bred	NZ
Back et al. (2016)	Heifer			36.3	26.8	31.1	MA	Straight bred	NZ
Jeyaruban et al. (2016)	Both	36.5	38.8				All	Straight bred	Australia/NZ

HF-J: Holstein-Friesian-Jersey crossbred. ¹ Heifer: 2-year-old, first calving; MA: 3+ year old cow with 1 or more previous calving; All: Both Heifer and MA cows, not separated,

Calving difficulty

Dystocia is the term used to describe calving difficulty and is defined as: a difficult birth that results from a prolonged calving or a prolonged or severe assisted extraction (Meijering, 1984, Mee, 2004, Mee, 2008, Stafford, 2011). A normal calving takes between 30 minutes and 4 hours after the appearance of the amnion (Mee, 2008, Noakes et al., 2009).

Internationally, dystocia rates in Holstein-Friesian dairy herds vary between 2 and 7% (Mee, 2008). In New Zealand Holstein-Friesian dairy cows, instances of calving difficulty are 3.8% for mixed-aged cows and 6.5% for heifers (Xu and Burton, 2003, Mee, 2008), with reports of up to 15% for heifers and 10% for mixed-aged New Zealand Holstein-Friesian cows (Holmes et al., 2007, Stafford, 2011).

Scoring of the severity of dystocia has been reported, using scales with 2 to 5 classes (Berger et al., 1992, Gaines et al., 1993, Meadows et al., 1994, Paputungan et al., 1994, Whittier et al., 1994, Nix et al., 1998, Johanson and Berger, 2003, Pryce et al., 2006, Lombard et al., 2007, Fiedlerova et al., 2008, Mee, 2008, Hickson, 2009, Fouz et al., 2013). However, as dystocia scoring is a subjective classification, comparing studies is difficult due to different interpretations of dystocia (Hickson, 2009).

Dystocia in cattle occurs when there is a failure in at least one of the three main components of calving: expulsive forces, birth canal adequacy and the fetus (size and/or position) (Mee, 2008, Noakes et al., 2009, Stafford, 2011). The cause of the dystocia will determine treatment and outcome for the cow and calf, but ultimately whether assistance is given is dependent on the management system (Stafford, 2011). The causes of dystocia may be classified as proximal, intermediate and ultimate, and are described in Table 1.3.

Table 1.3. Causes of dystocia in cows. From Mee (2008), Stafford (2011)

Type	Cause
Proximal	Feto-pelvic disproportion, abnormal fetal position, and maternal related causes (uterine inertia, vulval or cervical stenosis, and uterine torsion)
Intermediate	Gestation length, fetal oversize, birth canal undersize, hypocalcemia, hypomagnesaemia and parturient stress
Ultimate	Fetal gender, multiple fetuses, fetal abnormalities, sire, dam, breed, parity, dystocia history, age, season, nutrition, exercise, disease, herd size, region and their interactions

In first-calving heifers, the most common causes of dystocia (descending order of importance) are feto-maternal disproportion, abnormal fetal position and vulval stenosis (Lombard et al., 2007, Mee, 2008). In cows in their second or subsequent calving (mixed-aged cows), the most common causes are abnormal fetal position, FMD, multiple fetuses,

uterine inertia, uterine torsion and cervical stenosis (Lombard et al., 2007, Mee, 2008). The focus of this literature review will be primarily on the causes, feto-maternal disproportion and presentation, and risk factors related to the calf, rather than maternal related causes.

Feto-maternal disproportion is the most common type of dystocia (Meijering, 1984, Hickson et al., 2006, Hickson et al., 2008a, Hickson et al., 2008b, Mee, 2008), and is the result of the calf being too large relative to the dam (Hickson et al., 2006). The primary determinants of feto-maternal disproportion are calf birth weight and maternal size or live weight, (Meijering, 1984, Smeaton et al., 2004, Hickson et al., 2008b, Mee, 2008). The feto-maternal relationship is influenced by calf sire, parity, mating live weight, age, weight and body condition score (BCS) of the dam at calving (Mee, 2008). In dairy cows, to decrease the risk of dystocia, selection for low calf birthweight rather than for increased dam pelvic area or culling small heifers, is preferred (Mee, 2008).

Correct and abnormal presentation is shown in Figure 1.1. Abnormal calf presentation is, in order of prevalence, seen as posterior presentation, foreleg malposture (not pictured, legs not presented correctly alongside head), breech malpresentation or cranial malposture (head folded back or under) (Figure 1.1) (Mee, 2008, Noakes et al., 2009). Abnormal presentation of the fetus (malpresentation) at calving has a relatively low prevalence (<5%) (Meijering, 1984, Mee, 2008); but is the most common cause (20-40% of cases) of dystocia in multiparous cows (Meijering, 1984, Mee, 2008). Fetal malpresentation is primarily influenced by multiple births, having a 4x higher risk than singleton births (Mee, 2008).

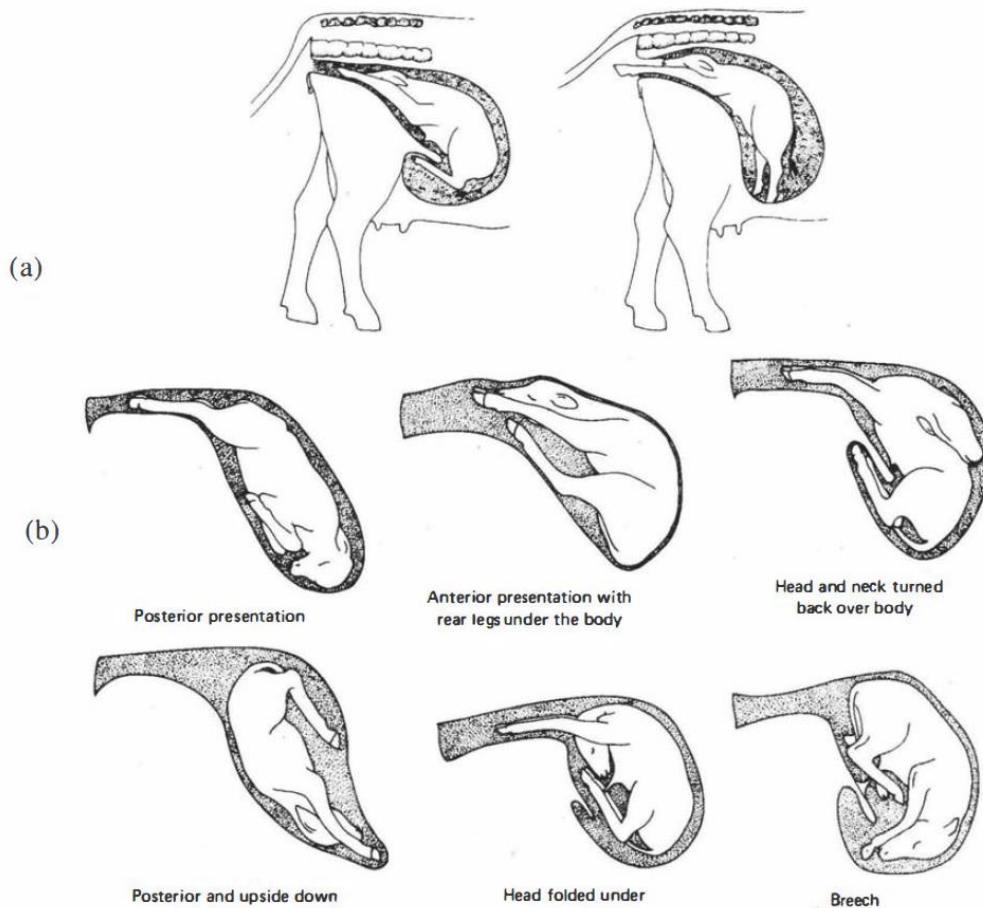


Figure 1.1: Correct (a) and abnormal (b) fetal presentation in calving cattle (Hickson (2009), adapted from Sorensen (1979)).

Risk factors for the causes of dystocia detailed above include birth weight of the calf, gestation length of the calf, sex of the calf, parity of the dam and breed. The shape of the calf is commonly perceived as a risk factor for dystocia, however, literature on the relationship between shape of the calf and the incidence of dystocia, when adjusted for birth weight, shows no relationship between shape and dystocia (Nugent and Notter, 1991, Nugent et al., 1991). Therefore, the relationship between shape and calving difficulty will not be further investigated.

Birth weight of the calf is the most important predictor of risk for dystocia (Burfening et al., 1978, Arthur et al., 2000, Hickson et al., 2008b, Mee, 2008). Generally, an increase in calf birth weight is associated with an increased risk of dystocia (Johanson and Berger, 2003, Hickson et al., 2008b, Mee, 2008). A study of Irish Holstein cattle demonstrated a threshold for the relationship between 42 and 45 kg birth weight, after this the dystocia rate increases significantly (Ménissier and Foulley, 1979, Mee, 2008). Although, this threshold is dependent on breed of cow and calf, and parity of the cow (Meijering, 1984).

Shorter (<265d) and longer (>285d) gestation lengths are associated with an increased risk of dystocia, particularly in primiparous dairy cows (Philipsson, 1976, Meijering, 1984, Mee, 2008). The increased risk of dystocia from shorter gestation lengths can be attributed to increased proportions of twins and premature calves in cows with shorter gestations (Meijering, 1984). Increased risk of dystocia from longer gestations can be attributed to oversized calves at birth, as fetal growth in the last month can be 0.3-0.4 kg/day (Meijering, 1984).

The risk and severity of dystocia is greater in male calves compared with heifer calves (Meijering, 1984, Morris et al., 1986, Lombard et al., 2007, Hickson et al., 2008b, Fouz et al., 2013). A 1-13% higher incidence of assistance for male calves compared to female calves has been reported, however the proportion of assistance in different studies varies considerably (4 – 40%) (Morris et al., 1986, Lombard et al., 2007).

There is an increased risk of dystocia when crossbreeding dairy cows with beef-breed bulls, particularly continental European breeds (Mee, 2008). The dystocia risk is greater when crossbreeding with larger breeds, such as where the calf is relatively larger compared with the dam than what would occur with cows bred to the same breed (Mee, 2008). The increased risk of dystocia is likely due to the differences in birth weight (previous section) and gestation length (following section)

Costs to the farmer, regarding calving difficulty may include an increased requirement for labour and economic implications, and health and survival implications to the cow and calf (Berg, 1979, Meijering, 1984, Naazie et al., 1989, Arthur et al., 2000, Pryce et al., 2006, Mee, 2008, Hickson et al., 2010). The economic value of these costs is likely to vary considerable between farms.

Veterinary assistance and procedures such as caesarean section may be uneconomic if the cost of assistance is greater than \$200 (Hickson et al., 2010) and a straight forward caesarean section in New Zealand can be \$300-350 not including the cost of drugs and the call out fee (Personal Communication: Jessica Byrnes-Clark, Massey University Farm Services, June 2018). However, the alternative may be at the cost of the life of the cow and/or calf. Excluding the costs relating to increasing culling, management and veterinary costs, the impacts on production, fertility and cow/calf morbidity and mortality are linked to approximately 41, 34 and 25% respectively of the total cost of dystocia (Dematawena and Berger, 1997, Mee, 2008, Stafford, 2011).

A cow which requires assistance at calving has been associated with a decrease in production in the subsequent lactation, reduced fertility, and either directly or indirectly,

survival of the cow (Brinks et al., 1973, Laster et al., 1973, Meijering, 1984, Buckley et al., 2003, Mee, 2008, Hickson et al., 2010, Fouz et al., 2013). A difficult calving may negatively impact the volume of fat and protein produced in the resulting lactation (Fouz et al., 2013), in addition, there may be a decrease in the volume of milk produced over the lactation after a very difficult calving (Dematawena and Berger, 1997, Fouz et al., 2013). The postpartum anoestrous interval (PPAI) may be lengthened (9-22 days longer) in cows having experienced calving difficulty, with PPAI length increasing with level of assistance (Fouz et al., 2013).

Calving problems may also result in an increased calf mortality both prior to and after parturition (Anderson and Bellows, 1967, Laster and Gregory, 1973, Meijering, 1984, Lombard et al., 2007, Hickson et al., 2010), the likelihood of mortality increases as difficulty increases (Fouz et al., 2013). Survival to both 24 hours and weaning is decreased in calves which have experienced a difficult calving (Hickson et al., 2006).

Gestation length

The New Zealand dairy industry is a pasture-based system with a peak of grass growth in spring/early summer, one of the major constraints is that cows need to maintain a 365-day calving interval (Grosshans et al., 1997, Holmes et al., 2007, Stachowicz et al., 2015, Amer et al., 2016). The 365-day calving interval is a key driver of profitability in dairy cattle in a pasture based system when pasture growth is not evenly distributed, and gestation length is an important contributor to calving interval (Winkelman and Spelman, 2001, Norman et al., 2011, Donkersloot, 2014, Stachowicz et al., 2015). Gestation length is a trait of the calf and is the period between conception and calving (Meyer et al., 2000, Norman et al., 2011). Gestation length is important to consider as it determines the number of days in milk and milk production. A longer gestation period results in fewer days in milk and the cow will on average, calve later in the following season (Holmes et al., 2007, Donkersloot, 2014).

The breeding companies, Livestock Improvement Corporation (LIC) and CRV Ambreed, which supply semen for artificial insemination in New Zealand offer semen from short gestation length bulls. With the intention of using semen from these bulls after the required matings needed to produce replacement heifers, Short gestation length bulls can be used to bring the expected calving date earlier in the calving season for cows which were mated late in the breeding season (Winkelman and Spelman, 2001, Donkersloot, 2014). New Zealand LIC and CRV Ambreed short gestation length dairy bulls are Holstein-Friesian, Jersey or Holstein-Friesian-Jersey crossbred bulls and produce calves born up to 10 days earlier than those sired by average gestation length dairy bulls (LIC, 2012, CRVAmbreed, 2020). However, the calves sired by these bulls are of low value as the LIC do not allow the keeping

of these calves as replacement dairy cattle or breeding stock (LIC, 2012) and so the calves are generally sold for slaughter at 4 days of age. Beef-breed bulls have an advantage in that calves can be sold for greater value than those from a dairy bull. However, calves born to beef-breed bulls need to have comparable gestation lengths to those from the alternative dairy bulls, so that using these beef-breed bulls does not negatively affect the 365-day calving interval. The breeding companies do offer short gestation length beef-breed semen, although the breeding objective for the providers of these bulls may focus solely on gestation length, whereas to be desirable for beef-cross-dairy production, bulls with suitable EBV for birth weight, gestation length, growth, carcass characteristics and meat quality would be more desirable. Additionally, the short gestation length beef-breed bulls provided by LIC and CRV Ambreed are sold as a no choice pack, where information regarding individual bulls is not available.

Published gestation lengths for dairy- and beef-breed cattle are summarised in Table 1.4. The average gestation length of New Zealand dairy cattle (Jersey, Holstein-Friesian and Holstein-Friesian-Jersey crossbreed) is 280-282 days (Baker et al., 1990, Grosshans et al., 1997, Winkelman and Spelman, 2001, Donkersloot, 2014, Stachowicz et al., 2015, Amer et al., 2016). In beef-breed cattle, genetic evaluation of gestation length is limited by the need to use artificial breeding so that the start of gestation (conception) is known for calculation for gestation length (Meyer et al., 1990), therefore, less data is available for New Zealand Angus and Hereford breeds, particularly when the beef-breed bulls are used over dairy cows. Data suggests that the approximate gestation length for Angus and Hereford calves is 280-281 days and 284-285 days respectively (Burriss and Blunn, 1952, Wheat and Riggs, 1958, Bourdon and Brinks, 1982, Baker et al., 1990, Jeyaruban et al., 2016).

The normal range of gestation length is considered to be within three standard deviations of the mean (Grosshans et al., 1997). The standard deviation presented in literature ranges 4-8 days (Burriss and Blunn, 1952, Everitt and Jury, 1972, Smith et al., 1976, Macmillan, 1979, Baker et al., 1990, Mujibi and Crews, 2009, Norman et al., 2009, Amer et al., 2016, Jeyaruban et al., 2016).

Calves born to mixed-aged (multiparous) cows tend to have a longer gestation length than calves born to first-calving heifers (primiparous). Published data suggests that the gestation length of calves born to mixed-aged cows was longer than calves born to first-calving heifers by 1-2 days (Norman et al., 2009, Olson et al., 2009, Dhakal et al., 2013). However, there are also studies which report no difference in the gestation length of calves born to dams of different ages or parities (Baker et al., 1990).

Male calves tend to have longer gestation lengths than female calves by 1-2 days regardless of breed (Burriss and Blunn, 1952, Bourdon and Brinks, 1982, Baker et al., 1990, Winkelman and Spelman, 2001, Olson et al., 2009). The greatest influence on gestation length is multiple fetuses (Norman et al., 2009). Multiple fetuses are associated with a decrease in gestation length compared with singleton calves (Echternkamp and Gregory, 1999, Norman et al., 2009).

Published data report an increase in the frequency of stillbirths for calves with a short or long gestation length (Meyer et al., 2001, Norman et al., 2009, Norman et al., 2011). The likelihood of stillbirth is the least when gestation length was closest to the average (Meyer et al., 2000, Norman et al., 2011). The likelihood of stillbirths increase as shorter gestation length calves are often small and weak, whereas long gestation length calves can grow too big, causing calving difficulty (Norman et al., 2011).

There is literature which suggests a reduced milk production in the lactation following the birth of a short gestation calf (Reynolds et al., 1990, Norman et al., 2009, Norman et al., 2011, Donkersloot, 2014). Norman et al. (2009) found that gestation length increased as milk yield increases, with the difference being 0.6 days longer for cows producing 14,000 kg compared with 8,000 kg. Reynolds et al. (1990) found that cows bred to sires classed as high in milk production had 2.8 day longer gestation lengths than cows mated to sires classed as medium in milk production. However, in a New Zealand seasonal system where the majority of cows are dried off as a herd rather than individuals, the increase in milk production from a longer gestation may be comparable to increased days in milk resulting from a shorter gestation. There is no data pertaining to the genetic correlation between gestation length and milk production in seasonal dairy herds. Overseas studies, evaluating data collected from multiple herds, reported a weak negative correlation (range -0.13 to -0.24) between gestation length and 305-day (non-seasonal) milk, fat or protein yield (Toghiani, 2012, Eaglen et al., 2013)

Heritability estimates for gestation length in cattle range between 0.27 to 0.69 (Meijering, 1984, Azzam and Nielsen, 1987, Baker et al., 1990, Winkelman and Spelman, 2001, Norman et al., 2009, Maltecca et al., 2011, Stachowicz et al., 2015, Amer et al., 2016, Angus-NZ, 2018). There is limited data on the heritability estimated of beef-breed cattle, as artificial breeding is not as widely used in the beef industry as the dairy industry.

Table 1.4. Published mean gestation length for calves of different breeds.

Reference	Location	Breed	Angus	Hereford	Jersey	Holstein-Friesian ¹	HF-J crossbred ²	Combined breeds
Burris and Blunn (1952)	USA	Straight breed	281.7	286.1				
Wheat and Riggs (1958)	USA	Sire-breeds	279.5	284.9				
Everitt and Jury (1972)		Straight breed			282.3 M 280.5 F	282.0 M 280.1 F	281.3 M 280.2 F	
Smith et al. (1976)	USA	Straight breed	281.6	285.6				
Bourdon and Brinks (1982)	USA	beef half siblings	281.9 M 280.6 F	285.9 M 284.3 F				
Baker et al. (1990)	NZ	Sire-breeds	281	282	283	280		
Grosshans et al. (1997)	NZ	Straight breed					281	
Winkelman and Spelman (2001)	NZ	Straight breed						282.7 M 281.1 F
Norman et al. (2009)	USA	Straight breed			278.4 R2 280.0 MA	277.8 R2 279.4 MA		
Olson et al. (2009)	USA	Straight breed			280.0	279.0		
Dhakal et al. (2013)	USA	Straight breed			275.0	274.2		
Eaglen et al. (2013)	UK	Straight breed				281		
Donkersloot (2014)	NZ	Straight breed			280.9	280.8	280.7	
Amer et al. (2016)	NZ	Straight breed					281.3	
Jeyaruban et al. (2016)	NZ	Straight breed	280.8	284.8				

USA: United States of America; NZ: New Zealand; UK: United Kingdom; M: male calf; F: female calf; R2: calf born to first calving heifer; MA: calf born to mixed-aged cow. ¹ Holstein-Friesian and Holstein cattle. ² HF-J: Holstein-Friesian-Jersey crossbred

Gestation length is positively correlated (genetic and phenotypic correlation) to birth weight, with literature reporting genetic correlations of 0.18 – 0.64 (Burfening et al., 1978, Philipsson, 1979, Burfening et al., 1981, Maltecca et al., 2008) and phenotypic correlations of 0.2 – 0.32 (Burfening et al., 1978, Burfening et al., 1981). Literature also reports positive genetic (0.09 – 0.3) and phenotypic (0.05 – 0.47) correlations between gestation length and calving assistance (Burfening et al., 1978, Philipsson, 1979, Burfening et al., 1981).

Pre-weaning growth of beef-cross-dairy calves

With increasing interest in sustainable farming and bobby calf welfare, combined with the trend towards use of sexed semen, the opportunity for beef production from the dairy industry is increasing. Calves sold from the dairy industry to beef producers are normally sold at 4-days-old, or as weaned calves at approximately 100kg (Morris and Kenyon, 2014). Unlike in the beef industry, the growth of calves is not a profit driver in the dairy industry (Law et al., 2013). Other than the growth of replacement dairy heifers, calf production is a by-product of milk production. Profitability of calf rearing is dictated by the price of the calf at sale (4 days old or weaned) and the input costs of rearing (Muir et al., 2000a), therefore, the profitability of rearing calves will be affected by calf growth and survival. There is limited published literature on pre-weaning growth of beef-cross-dairy or straight-beef-breed beef calves reared artificially as most of the literature focuses on growth of calves in the beef-breeding herd (reared on dam) rather than calves artificially reared from the dairy herd.

Calf growth to weaning can be influenced by the size, sex and breed of the calf. Calf growth although is also highly influenced by nutrition (Moallem et al., 2010, McCoard et al., 2014) which is not in the scope of this review.

Birth weight has an effect on the growth of the calf as there is a positive genetic correlation between birth weight and mature weight that means that the progeny from bulls with low birth weight estimated breeding values (EBV) tend to be lighter when finished, which decreases their desirability to the beef industry (Hickson et al., 2006). Male calves grow faster pre-weaning than female calves (Burriss and Blunn, 1952, Marlowe and Gaines, 1958, Long and Gregory, 1974, Smith et al., 1976, Burfening et al., 1978, Law et al., 2013).

There is little literature focussing on the pre-weaning growth period in artificially reared beef-breed calves. The pre-weaning period in a beef production system is based on the calf suckling off its dam and the pre-weaning period is generally longer than the artificial rearing period, therefore, the studies are not comparable.

In a beef breeding system, where the calf is not separated from its dam, one USA study reported that Angus sired calves tended to grow faster pre-weaning than Hereford sired calves (Long and Gregory, 1974), however another study suggested that sire-breeds with lower birth weights tended to have lower ADG, and lower weaning (200d) weights (Gregory et al., 1978).

Artificially reared New Zealand dairy calf experiments have shown that Holstein-Friesian calves grow faster than Jersey breed calves pre-weaning, therefore are weaned at a younger age (Cardoso et al., 2015, Back et al., 2016). The growth rate of Holstein-Friesian-Jersey crossbred is not significantly different to the Holstein-Friesian breed calves (Cardoso et al., 2015, Back et al., 2016).

Heritability of pre-weaning growth in the literature is expressed as a weight as a certain age (usually standardised at 200 days) or growth to weaning, and is primarily a trait measured in beef-breed cattle, where the calf was reared on the cow for around 200 days (Beef+LambNZ, 2017). Heritability estimates of beef-breed pre-weaning growth heritability range 0.12 – 0.32 (~200-day weaning weight) (Burfening et al., 1978, Mrode and Thompson, 1990, Bennett and Gregory, 1996, Angus-NZ, 2018, Martín et al., 2018), with the evaluation system used for New Zealand Angus cattle (BreedPlan) estimating 200-day weight heritability as 0.12 (Angus-NZ, 2018).

The typical pre-weaning period in dairy born calves involves artificial rearing for a shorter time and consequently calves are weaned lighter than in a beef cow-calf system. There is little literature estimating the heritability of pre-weaning growth in an artificial rearing system, with a weaning weight estimated heritability of 0.45 – 0.59 from international studies (Coffey et al., 2006, Brotherstone et al., 2007). For the beef-breed bulls available to use over New Zealand dairy cows, where estimated breeding values (EBV, BreedPlan) are available, the EBV relating to pre-weaning growth is 200-day weight (BreedPlan, 2015). There is no literature pertaining to how well a Beef 200-day weight EBV, created using data collected in a beef cow-calf system, relates to the pre-weaning growth of calves reared in an artificial rearing system.

Literature suggests a positive but variable genetic correlation (0.17 – 0.60) (Pabst et al., 1977, Burfening et al., 1978, Gregory et al., 1978, Bennett and Gregory, 1996, Coffey et al., 2006, Brotherstone et al., 2007) and weak phenotypic correlation (0.19) (Burfening et al., 1978) between birth weight and weight at between 50 and 200 days.

Milking performance

In New Zealand, the primary income of dairy farms is the sale of milk, and farmers are paid per kilogram of milksolids (Sneddon et al., 2013). Dairy processors use a multi component pricing system, which in New Zealand, prices milk on the basis of different values for fat and protein yields (kg), along with the cost of processing the milk volume (litres) (Emmons et al., 1990, Sneddon et al., 2013). Therefore, milk production in New Zealand is generally expressed as milksolids (fat + protein, kg) production.

Factors which may influence milk production include the length of lactation, breed and age of the cow, the birth weight of the calf, calving difficulty and nutrition (Macmillan, 1979, Chew et al., 1981, Butler-Hogg and Wood, 1982, Correa et al., 1993, Dematawena and Berger, 1997, Burke et al., 1998, Lopez-Villalobos et al., 2000, Buckley et al., 2003, Johanson and Berger, 2003, Swali and Wathes, 2006, Heins et al., 2008, Valour et al., 2013, Græsbøll et al., 2015, Hess et al., 2016, Spaans et al., 2018, DairyNZ, 2019). Of these factors, the service sire may influence lactation length (via gestation length), birth weight of the calf, and calving difficulty.

The New Zealand dairy industry is based on a seasonal milk production system determined by the seasonal growth of pasture (Macmillan et al., 1990, Grosshans et al., 1997). The seasonal system also means that cows in each herd are often dried off at a similar time, therefore the calving spread is a key determinant of lactation length (Macmillan, 1979, Hess et al., 2016). A cow that calves later in the season will have a shorter lactation, and therefore produce less milk than one which calves early. Calving interval is strongly influenced by the reproductive success of the cow (detailed in the following section) and the gestation length of the calf (detailed previously) (Macmillan, 1979, Roche et al., 1992, Xu and Burton, 1996, Roche et al., 2000, Winkelman and Spelman, 2001, Norman et al., 2011, Donkersloot, 2014, Stachowicz et al., 2015).

There is literature that indicates an effect of the service sire on milk production, which theorised that birth weight of the calf may be the physiological driver (Adkinson et al., 1977, Thatcher et al., 1980). Literature investigating whether milk production of the dam is influenced by between birth weight of the calf is limited, and the effect is not consistent among studies, with literature reporting increased (Græsbøll et al., 2015) and decreased (Chew et al., 1981, Swali and Wathes, 2006) milk production from dams producing heavier calves. Similarly, reports of an association between calving difficulty and milk production, also conflict, in that different studies have reported that calving assistance resulted in increased (Græsbøll et al., 2015) or decreased (Correa et al., 1993, Dematawena and Berger, 1997, Johanson and Berger, 2003) milk production.

During the first half of the lactation period, a dairy cow in good condition at calving generally lost about 50% of her body fat reserves due to being in a negative energy balance over peak lactation (Butler-Hogg et al., 1985, Gregory et al., 1998). For cows in lesser body condition (less body reserves to mobilise) or on a lower plane of nutrition (being in a negative energy balance), milk production will likely be less than that of cows fed to appetite (Buckley et al., 2003, Valour et al., 2013). New Zealand dairy cows are recommended to be at a minimum body condition score of 5.0 for mixed-aged cows, 5.5 for heifers at calving, and at mating a minimum score of 4.0; with the change in body condition score over early lactation not recommended to be more than 1 condition score (DairyNZ, 2012a).

Holstein-Friesian cows tend to produce greater milk volumes than Jersey and Holstein-Friesian-Jersey crossbred cows, whereas Jersey cows tend to have a greater percentage of milksolids (Butler-Hogg and Wood, 1982, Burke et al., 1998, Lopez-Villalobos et al., 2000, Heins et al., 2008, Spaans et al., 2018, DairyNZ, 2019). The New Zealand dairy statistics also report a difference in the milk production from cows of different ages. Milk volumes tend to increase as the cow ages, and presumably in subsequent lactations peaking at around ~6 years of age (5th lactation) then decreasing; whereas milksolids yields tend to peak at 4-5 years of age (3rd – 4th lactation) (DairyNZ, 2019).

Rebreeding

As New Zealand has a pasture-based dairy system, dairy cows need to maintain good reproductive performance by getting in calf every year, calving successfully and maintaining a 365-day calving interval (Macmillan, 1979, Roche et al., 1992, Xu and Burton, 1996, Grosshans et al., 1997, Roche et al., 2000, Buckley et al., 2003, Holmes et al., 2007, Stachowicz et al., 2015, Amer et al., 2016).

Good reproductive efficiency requires dairy cows to have high submission rate for mating and high pregnancy rate per service and contributes to maximising milk production and days in milk (Roche et al., 1992, Xu and Burton, 1996, Roche et al., 2000). Poor reproductive performance of a dairy herd may delay the mean calving date, increase the calving spread and reduce the herd milk yield by decreasing the average days in milk (Macmillan, 1979, Xu and Burton, 1996).

The main measures of reproductive performance in the New Zealand dairy industry are the 6-week in-calf rate, and the not-in-calf rate. The 6-week in-calf rate is driven by the 3-week submission rate and the conception rate (DairyNZ, 2017b). However, the 6-week in-calf-rate can only be reliably determined when an early aged-pregnancy diagnosis is performed (Hemming et al., 2018). In studies where early aged-pregnancy diagnosis was not

performed or recorded, the percentage of cows calving within 21 or 42 days of the planned start of calving can be used to evaluate reproductive performance (Brownlie, 2012).

Reproductive success is strongly influenced by the interval between calving and first oestrous (post-partum anoestrous interval), oestrous detection, body condition score and live weight (for heifers) and calving difficulty (Xu and Burton, 1996, Fox et al., 1999, Fouz et al., 2013, Shorten et al., 2015).

Achieving a 365 day calving interval and assuming a 282 day gestation, the breeding season should begin 83 days after the planned start of calving (Xu and Burton, 1996). Given there is an approximately 6 week period before the cow experiences her first postpartum ovulation, the cow needs to have calved within 5 weeks after the planned start of calving, to increase the chance the cow is cycling by the start of the following breeding season (Xu and Burton, 1996). First-calving heifers tend to take longer than older cows to resume normal cyclic activity (Grosshans et al., 1997, Holmes et al., 2007), which is one reason why heifers tend to be mated earlier than mixed-aged cows. Delays in cows showing oestrous behaviour or failure of the farmer to detect oestrus can influence overall herd performance

In artificially bred herds, a factor affecting reproductive performance is correct oestrus detection in order to present the cow for AB at the appropriate time to maximise the chance of conception (Xu and Burton, 1996, Holmes et al., 2007). Good reproductive performance, as measured by in-calf rate, is attained by submitting as many cows as possible during the first 3-4 weeks (approximately 1 oestrous cycle) of the breeding season, along with a high conception rate (Xu and Burton, 1996). Errors in heat detection may affect the reproductive performance of cows during the AB season (Xu and Burton, 1996). Failure to accurately detect heat may delay the mating of the cow for one cycle (~21 days), incurring direct and indirect costs to the farm (Xu and Burton, 1996).

Body condition score is commonly used as a proxy for energy reserves (Fox et al., 1999, Pryce and Harris, 2004, Pryce et al., 2007). New Zealand research has identified BCS as a useful selection criterion for fertility and it is a good phenotypic indicator of fertility (Fox et al., 1999). DairyNZ reports that calving at 1 condition score lower than recommended (4 instead of 5, on a 1-10 scale) will result in cows taking 8-10 days longer to begin cycling post-partum, resulting in a later calving date, a reduced lactation length and reduced milk production in the following season (Roche et al., 2007, DairyNZ, 2017a).

The reproductive performance of maiden heifers is directly related to liveweight at mating and calving (Handcock et al., 2016, DairyNZ, 2017b, Handcock, 2019, Handcock et al., 2020) In addition, if the live weight of the heifer at calving is below target, the fertility during the

second breeding is reduced (DairyNZ, 2017b, Handcock et al., 2020). Live weight targets are 60% of mature live weight at 15 months old (first breeding), and 90% at 22 months (prior to first calving) with benefits on reproductive performance in the first (maiden) and second (rebreeding) breeding periods (McNaughton and Lopdell, 2012, Handcock et al., 2016, Handcock et al., 2020).

Calf identification

In the New Zealand dairy industry there are three main fates of calves, reared to be replacements, sold for slaughter/rearing or reared for beef. If a dairy farmer uses a beef-breed bull to increase value of surplus calves, it is important that the farmer can identify the breed of calves born, as to retain only dairy-breed calves as replacements or identify calves for sale.

In a situation where a beef-breed bull is used to naturally mate the remainder of the cows after a period of artificial breeding to a dairy-breed bull, the variation in gestation length between breeds and individuals within breed mean that the calves born to different types of bulls may overlap. Alternatively, if artificial breeding to both dairy and beef-breed bulls at the same time, the calves will be born in the same period of calving.

Beef-breed bulls in the past have been used so that the resulting calves are readily identifiable from the dairy breed calves, and sometimes as a marker to separate the end of artificial breeding and the start of natural mating. This system is ideal in a straight bred dairy herd, where the dairy calves (primarily HF and J) are easily identifiable from the beef-cross-dairy calves. However with decreasing proportions of straight bred cows in the national herd, and close to half of the herd now being Holstein-Friesian-Jersey crossbred breed (Muir et al., 2001, Back, 2017, DairyNZ, 2019), identification of calf breed is not as simple.

Of beef-breed bulls used in the New Zealand dairy herd, anecdotally, the main breed is Hereford (DairyNZ, 2019), in part because the resulting calf will have a white face, making the beef-cross calf easy to identify. When an Angus bull is used, the resulting calves are usually completely black, and they may look similar to Holstein-Friesian-Jersey crossbred and some Holstein-Friesian calves. As DNA sampling for parentage analysis is costly and not widely used in commercial situations, other phenotypic factors may be useful to identify these calves. Previous authors have reported using colour of coat markings, ears and noses to identify different genotypes in adult cattle and sheep (Pitt, 1920, Dry, 1924, Ibsen, 1933, Dry, 1936, Bogart and Ibsen, 1937).

Identifying the breed of calf at birth is important, so that the dairy farmer is able to retain appropriate dairy-breed heifers as replacements, and dairy-beef calf rearers are able to purchase beef-cross calves for rearing. Typically, the dairy farmer wants to retain only dairy-breed heifers, and to identify all the available dairy-breed heifers to maximise the opportunity for selection among potential replacements. In contrast, the dairy-beef calf rearer is generally less concerned with the need to identify all available beef-cross calves but does not want to mistakenly rear Holstein-Friesian-Jersey crossbred calves in place of Angus-cross calves. Calves for which the buyer is confident are beef-cross-dairy are worth more to the dairy-beef calf rearer, Calves are usually sold from the dairy farm at 4 days of age, so the breed of the calf needs to be identified within this timeframe.

There are six distinct areas of colouring on cattle. One is the colour of the pigmented skin; the other areas relate to the location of white skin/hair patches. The regions of the body where white patches may be present are the head (forehead and the white head typical of the Hereford breed), legs below the knee (hock), inguinal area, body (not including head, and lower leg), and the tongue. Only the phenotypes of Angus, Hereford, Holstein-Friesian, Jersey and their first-crosses are considered in this section.

The genes responsible for coat colour of straight-bred cattle have been previously investigated (Gowen, 1918, Ibsen, 1933), and so the expected phenotypes of straight-bred calves are as follows:

- Angus: a completely black coat with a black nose and tongue and no white spotting, although some calves may have a white inguinal spot.
- Holstein-Friesian: a black coat with black skin and white patches around the body and head, including white legs below the knee and a pink tongue.
- Jersey: coat colour a diluted shade of red (fawn) with blackened hairs and a black, pink or black and pink spotted nose and tongue.
- Hereford: a red coat with a white head, tail, feet, underside and stripe along the backbone with a pink tongue.

The genes influencing these areas of colouring are outlined below.

A red (R) colour gene is present in all breeds of cattle, but it not always shown due to other genes being epistatic to it (Ibsen, 1933). The red colour gene causes red hair, and brown skin pigmentation (Ibsen, 1933). A black colouring gene ('B', recessive form 'b') is present in Angus and HF breeds of cattle and causes all hair and skin, tongue, nose and hooves to be pigmented black (Gowen, 1918, Ibsen, 1933). A black spotting gene ('Bs', recessive form 'bs') is present in and responsible for the type of black pigmentation found in Jersey cattle (Ibsen,

1933). The black spotting gene does not cause pigmentation of all hairs, but rather is concentrated to spots, and pigmentation of the skin, nose, tongue and hooves (Ibsen, 1933). The black spotting gene is not fully expressed at birth, rather the black pigmentation increases as the animal ages (Ibsen, 1933).

There are also genes responsible for the white patches present on the head, legs below the knee (hock), inguinal area, body (not including head, and lower leg), and the tongue. A recessive form of a white spotting gene (*s*) is present in HF cattle and is responsible for the lack of pigmentation in patches of skin, hair (particularly on the head), tongue and nose (Ibsen, 1933). The tongue is reportedly entirely unpigmented, while the extent of pigmentation in the other areas is correlated with the proportion of white in the coat (Ibsen, 1933). The dominant form of the white spotting gene (*S*) is responsible for entire body pigmentation, therefore no white spotting occurs (Ibsen, 1933). The white spotting gene has two modifying genes, which determine the amount of white spotting (*'Lw'* = small amount of white spotting, *'lw'* = large amount of white spotting) and white spotting below the knees (*'Pl'* = pigmented legs, *'pl'* = white legs) (Ibsen, 1933). The recessive form of the *'pl'* modifier is present in HF cattle and is responsible for the white legs below the knees to the hoof (Ibsen, 1933), which is typical of this breed. A form of the dominant white spotting gene (*S_H*) is unique to the Hereford breed and responsible for the Hereford pattern of a white head, white feet, tail, underbelly and a white stripe (length and width varying) over the backbone (Gowen, 1918, Ibsen, 1933). Another form of the dominant white spotting gene is the inguinal white form (*in*). The inguinal white form is not allelomorphic to the self-form and the recessive form (Gowen, 1918, Ibsen, 1933). The inguinal region includes the teats or udders in females, and rudimentary teats, sheath and scrotum in males (Ibsen, 1933). There are animals, particularly Angus and some HF crossbred cattle, which are entirely pigmented apart from an inguinal spot (Ibsen, 1933). However, if the animal has a white underside, it is not possible to determine the presence of an inguinal spot.

In reference to the descriptions of the above genes (Gowen, 1918, Ibsen, 1933), the expected phenotype and genotypes of straight bred cattle are outlined in Table 1.5. The genotypes are taken from (Ibsen, 1933), only include the genes described above. The breed descriptions above agree with the descriptions given by Gowen (1918) for Angus, Friesian and Jersey straight-bred cattle.

Table 1.5. Coat colour of and white spotting in Angus, Holstein-Friesian, Jersey and Hereford cattle in reference to the six regions of colouring outlined above. The genotype of each breed responsible for each phenotype is presented in italics.

Angus	Holstein-Friesian	Jersey	Hereford
Coat / skin colour			
Black	Black	Diluted red, blackened hairs	Red
<i>BB</i>	<i>BB</i>	<i>bb BsBs</i>	<i>bb</i>
Tongue / nose			
Black	Pink	Pink / Black / Pink & Black	Pink
<i>BB</i>	<i>BB ss</i>	<i>bb BsBs</i>	<i>bb</i>
Head			
Not white	Not white	Not white	White
<i>Ss</i>	<i>ss</i>	<i>ss</i>	<i>SHSH</i>
Inguinal spot			
Present in some animals	Masked by white spotting	None	None, White underbelly
<i>InIn / inin</i>			<i>SHSH</i>
Legs			
No white legs	White legs below the knee	No white legs	White legs below the knee
	<i>Plpl</i>		<i>SHSH</i>
Body spots			
No white spots	White spots varying size	No white spots	White tail, underside, backbone
<i>SS</i>	<i>Ss</i>	<i>SS</i>	<i>SHSH</i>
Amount of white spotting			
No white spots	Small amount	No white spots	Small amount
	<i>LwLw/Lwlw</i>		<i>LwLw/Lwlw</i>
	Large amount		Large amount
	<i>lwlw</i>		<i>lwlw</i>

Gowen (1918) reported that white face, flank and tail markings in Angus, Holstein-Friesian, and Jersey first-crosses are suppressed when one of the parents has no white markings (solid colour); and that white throat, rump, shoulder and leg markings are recessive, supporting the recessive nature of the 's' gene described by Ibsen (1933). The white inguinal region spot is dominant where other white markings are recessive (Gowen, 1918). Tongue pigmentation in Angus, Holstein-Friesian, and Jersey first-cross cattle, was reported by Gowen (1918) that pigmentation (black) is dominant to unpigmented (pink) tongue colour. The findings from Gowen (1918) indicate that all Angus-cross calves will have no white markings aside from a white spot in the inguinal region in some animals, and have a black tongue.

Based on Ibsen's descriptions of the genes, and descriptions of Angus, Holstein-Friesian and Jersey first-cross mature-age cattle from Gowen (1918), the first-cross of the breeds outlined above could be expected to have the following phenotypes:

- Holstein-Friesian-cross-Jersey: coat colour ranging from the Holstein-Friesian type black with white patches, to a black coated animal with little to no white patches. Tongue colour black, pink or black and pink spotted.
- Angus-cross-Holstein-Friesian: completely black coat with a black tongue, small inguinal spot.
- Angus-cross-Jersey: completely black coat with a black tongue, small inguinal spot.
- Hereford-cross-Holstein-Friesian: black coat with white face markings. White legs below the knee.
- Hereford-cross-Jersey: coat colour ranging from red to black, with white face markings.

First-cross Hereford-cross-dairy cattle are easily identified by the presence of a white head despite the coat colour and presence of white spotting, however, the phenotypes of Angus-cross-dairy and Holstein-Friesian-Jersey calves can be similar, so identifying the Angus-cross calves from the Holstein-Friesian-Jersey crossbred calves is unlikely to be accurate using coat colour alone.

In cattle, horns grow from the cornual process, an extension of the frontal bone, located lateral to the external occipital protuberance (poll of the head), caudally on the skull. Horns in cattle begin as buds within the skin, becoming attached to the frontal bone at around 2 months of age. The term polled refers to the genetic absence of horns in a species which would normally have horns; this term does not include animals with scurs (small rudimentary horns) (Brenneman et al., 1996). The polled condition is dominant over the horned condition in cattle (Bateson and Saunders, 1902, Brenneman et al., 1996). Horns cannot be diagnosed with absolute certainty until 3 months of age (Cole and Johansson, 1948).

The inheritance of the polled/horned conditions is influenced by a gene mutation (p to P) (Prayaga, 2007). The poll gene (P) is dominant over the horned condition (p), and in cattle is present in both sexes (Bateson and Saunders, 1902, Spillman, 1905, Barrington and Pearson, 1906, Lloyd-Jones and Evvard, 1916, Cole and Johansson, 1948).

In New Zealand, Holstein-Friesian and Jersey (dairy) cattle are predominantly horned (pp), while Angus cattle are polled (PP), Hereford cattle can be either horned (pp) or polled (PP or Pp) (Gowen, 1918, Cole and Johansson, 1948, Williams and Williams, 1952, Windig et al., 2015). The expected expression of horns in first-cross progeny are all Angus-cross-dairy calves will be heterozygous polled (Pp) whereas, the expression in Hereford-cross-dairy calves is dependent on the horn status of the Hereford bull. Homozygous polled (PP) bulls

will produce calves which are heterozygous polled (Pp), heterozygous polled (Pp) bulls will produce approximately half heterozygous polled progeny (Pp) and half homozygous horned progeny (pp), finally, horned (pp) bulls will produce horned progeny (pp).

In addition, included in the description of the horn/poll conditions is the scur gene (Sc/sc) (White and Ibsen, 1936, Long and Gregory, 1978, Frisch et al., 1980, Brenneman et al., 1996, Prayaga, 2007). The gene for scurs is masked by the presence of horns. Scurs grow in the same position on the frontal bone as horns, therefore, the presence of horns masks the expression of scurs (Prayaga, 2007). Occasionally an animal expressing scurs at a young age (6-9 months) may develop horns later in life (Brenneman et al., 1996), additionally animals which were identified as polled when young (6 months) can grow small scurs later in life (Prayaga, 2007).

The dominance of the polled condition over the horned condition suggests that the identification of Angus-cross calves in a dairy herd using presence of horns would be more accurate than looking at coat colour alone. However, with the possible delayed development of horns, and without knowing the genotype of the sires or dams as to whether the animal is heterozygous for the polled gene, or which form of the scur gene the animal carries, the presence of horns may not be as accurate as DNA testing to determine breed by parentage analysis.

Summary of literature review

There is a great opportunity for increasing the volume of beef produced in New Zealand by rearing more calves produced from the dairy industry. This review of the literature has shown that the research into beef-cross-dairy production has been limited to using dairy or dairy-cross-beef cows in a beef production system; rather than the use of beef-breed bulls to produce calves artificially reared in a dairy production system. In addition, the research into beef-cross-dairy has largely focussed on post-weaning growth, as that is the major profit driver in a beef production system, rather than the effect on the cow. Hence there is limited research into the effect of the use of beef-breed bulls on dairy cows, and limited information about the type of bulls are suitable for use in a dairy herd, with respect to minimising negative impacts on the cow, and generating beef-cross-dairy calves for beef production.

Therefore, the aims of this thesis are:

- To evaluate the birth weight, gestation length and progeny growth of individual Angus and Hereford bulls for beef-cross-dairy calf production (Chapter 2).

- To evaluate the relationship between EBV and beef-cross-dairy progeny performance for birth weight, gestation length and pre weaning growth for individual Angus and Hereford bulls (Chapter 2).
- To identify whether there is an effect of service sire on the body condition score, milksolids yield and rebreeding success of mixed-aged dairy cows serviced by Angus and Hereford bulls (Chapter 3).
- To compare the birth weight, calving assistance and survival of calves born to first calving heifers mated to Angus, Hereford or Jersey bulls, and the pre-weaning growth of Angus- and Hereford-sired calves (Chapter 4).
- To identify whether there are differences in the body condition score, milk production and rebreeding success of first calving heifers mated to Angus, Hereford or Jersey bulls (Chapter 4).
- To identify characteristics that can be used to distinguish between new-born calves born to dairy cows and Angus or dairy breed bulls (Chapter 5).
- To evaluate the economic differences between sale income of calves in relation to costs of breeding for a mating strategy using a Jersey bull or 3 alternative strategies using beef-breed bulls (Chapter 6).

With an overlying objective of identifying what type of bulls are appropriate for mating to dairy cows, and to identify suitable individual bulls for mating to mixed-aged cows by means of progeny testing.

Chapter 2 – Birth weight, gestation length and pre-weaning growth and survival of Angus- and Hereford-sired calves born to mixed-aged dairy cows

This Chapter has been published in part elsewhere. It has been reformatted and presented here with permission:

Coleman LW, Back PB, Lopez-Villalobos N, Blair HT and Hickson RE. 2018. Heritability of gestation length in beef-cross-dairy calves born to Angus and Hereford bulls. World Congress on Genetics Applied to Livestock Production, Auckland, New Zealand. p326.

Abstract

The primary interest of dairy farmers when choosing a service bull dairy cows, for production of non-replacement calves, is the health and production of the dairy cow. This requires focus on calving difficulty, of which calf birth weight is a contributing factor. The gestation length of the calf is also important, as this has impacts on the calving interval and calving spread and therefore days in milk. Of high importance to a beef producer, but not necessarily the dairy farmer, is how the resulting calf will perform in a beef rearing system. Some beef-breed bulls available to the dairy industry have performance-based estimated breeding values (EBV) published by BreedPlan, so bulls could be selected for use over dairy cows which would minimise the risk of calving difficulty (lighter birth weight EBV) and for shorter gestation length. The aim of this experiment was to compare the birth weight, gestation length and pre-weaning growth of progeny born to mixed-aged dairy cows artificially bred to a selection of Angus and Hereford bulls, and to compare the progeny performance to the bull's BreedPlan EBV. The birth weight, gestation length and pre-weaning growth of 980 Angus- and Hereford-sired calves born to mixed-aged dairy cows were used to compare the progeny performance of individual Angus and Hereford bulls, to calculate EBV for birth weight, gestation length and age at weaning and to calculate correlations between traits. Mean progeny birth weight (range 33.3 – 41.4 kg), gestation length (range 276.1 – 288.6 days), age at weaning (range 70.3 – 88.3 days) and pre-weaning ADG (range 0.63 – 0.76 kg/d) differed among sires ($P < 0.001$). Less than 1% of calves experienced an assisted birth. Estimated breeding values for birth weight, gestation length and age at weaning were calculated for each sire and regressed against the BreedPlan EBV. The relationship between the birth weight and gestation length EBV indicate that the BreedPlan EBV are good predictors of progeny performance in a beef-cross-dairy system. There was a negative genetic correlation (-0.31) and positive phenotypic correlation (0.36) between gestation length and birth weight. Age at weaning was negatively correlated with birth weight (genetic: -0.56, phenotypic: -0.57) in that low birth weight calves were older at weaning. There were many bulls with lighter birth weight and shorter gestation progeny which make them suitable for use over dairy cows. Results from this experiment indicate that the bulls used in this experiment, and other bulls with similar EBV for birth weight and gestation length would be suitable for mating mixed-aged dairy cows.

Introduction

The primary interest of the dairy farmer when choosing a service bull for dairy cows, after matings to generate replacement heifers, is the health and production of the dairy cow (Cook, 2014). This requires focus on calving difficulty, of which calf birth weight is a contributing factor. The link between calf birth weight and calving difficulty has led to dairy farmers having concerns about using beef-breed bulls over dairy cows (Mee, 2008) because beef-breed bulls generally produce heavier calves than Jersey bulls. Also of importance is the gestation length of the calf, as this impacts on the calving interval and calving spread and therefore days in milk. Of high importance to a beef producer, but not necessarily the dairy farmer, is how the resulting calf will perform in a beef rearing system.

Surplus dairy-sired calves from the dairy industry are typically sent for slaughter at less than 2 weeks old (Thomas and Jordaan, 2013, Cook, 2014, Hickson et al., 2015, Handcock et al., 2019a). There is an opportunity to increase the volume of beef produced and reduce wastage from the dairy industry by repurposing the surplus calves born every year by using beef-breed bulls and rearing the progeny for beef production. Beef-breed bulls can be used to produce a calf of greater value than that of a dairy-bull sired calf (Hickson et al., 2015). Angus and Hereford are the most common beef breeds in New Zealand (Beef+LambNZ, 2019a), with Hereford anecdotally currently the most common beef breed used in the dairy industry (DairyNZ, 2019).

Some beef-breed bulls available to the dairy industry have performance-based estimated breeding values (EBV) published by BreedPlan. Therefore, bulls could be selected for using over dairy cows which would minimise the risk of calving difficulty (lighter birth weight EBV), and also improve gestation length (shorter gestation length EBV). In addition, the bulls could be chosen on progeny growth potential (greater 200 – 600-day weight EBV). There is no published literature regarding how accurate EBV, calculated using data collected in a beef production system, are when the bull is used over dairy cows. A New Zealand study (Burggraaf, 2017) did indicate that when selecting beef-breed bulls for using over dairy cows, EBV for calving ease and birth weight, and later life liveweight EBV should be considered in order to optimise benefits for dairy and beef industries. However, the study did not directly compare progeny performance to bull EBV, and the study was limited to a small number of Hereford bulls from the same bull breeder bred to dairy cows.

The aim of this experiment was to compare the birth weight, gestation length and pre-weaning growth of progeny born to mixed-aged dairy cows artificially bred to a selection of

Angus and Hereford bulls, and to compare the progeny performance to the published bull EBV.

Materials and methods

The experiment was conducted at C. Alma Baker Trust NZ Ltd. Limestone Downs dairy farm, 16 km south of Port Waikato, New Zealand (latitude: 37.49 S, longitude: 174.77 E). The study and all handling procedures were approved by the Massey University Animal Ethics Committee (MUAEC 15/65).

Animals

The experiment included 980 singleton calves, born over a three-month period (July to September) in each of two consecutive years (2016, n=512; 2017, n=468). Calves were born to mixed-aged dairy cows artificially bred using semen from Angus and Hereford bulls. Calves born alive or dead were included in the experimental analysis.

Dams

There were 701 and 749 mixed-aged cows mated to generate calves for the experiment in 2015 and 2016, respectively; these cows comprised the entire dairy herd at Limestone Downs that were observed in oestrus during a 63- and 54-day mating period, respectively. The cows were predominantly Holstein-Friesian or Holstein-Friesian-Jersey crossbred cows with a small proportion of Jersey and Ayrshire (pure and crossed) breeds, however, breed recording of the herd was incomplete, with 31% cows having unknown breed proportions.

Sires

The Angus and Hereford bulls used in this experiment were selected from bulls nominated for progeny testing by breeders, where selection was based on EBV and aimed to achieve a spread of birth weight, gestation length and 600-day weight. Birth weight was restricted to the lighter half of each breed to minimise calving difficulty. Where multiple similar sires were available, selection favoured those with superior intramuscular fat and eye muscle area EBV. Semen used in the experiment was donated by the bull breeders. All semen was collected by commercial breeding centres and passed quality checks at freezing.

Sixty-five bulls (Angus n=31, Hereford n=34) were selected to represent a range of EBV for birth weight (within the top 50% of the breed), gestation length and 600-day weight (not presented in this thesis). There were 25 bulls used in both years, and 23 bulls used solely in 2016 and 17 bulls used solely in 2017. The most recent Breedplan published EBV for each bull (as at January 2020) are presented in Appendix A.1. The data collected in this experiment did not feed into the calculation of the BreedPlan EBV for these bulls.

Methodology

Generation of experimental calves – Artificial breeding

Lactating mixed-aged cows were artificially bred (AB) to Hereford or Angus bulls over a 9- and 7-week breeding period in 2015 (09/10/2015 – 11/12/2015) and 2016 (10/10/2016 – 03/12/2016), respectively.

Bulls in each year were allocated to one of 8 (2015) or 7 (2016) mating teams, which were rotated each day of mating. Cows submitted for insemination were allocated at random to the bulls in the team assigned for that day.

Bulls intended for use in 2015 only were used for 39 inseminations, whereas bulls intended for use in both years were used for 20 inseminations in 2015. New bulls were used for 39 inseminations in 2016, and the number of inseminations per bull used previously from 10-30 depending on the conception rate in the previous year. The aim was to generate ~15 calves per sire total over the two matings.

All inseminations were carried out by a LIC technician, and each mating was recorded in herd management software (MINDA™, LIC, Hamilton, New Zealand).

Calving

All calves born in the previous 24 hours (alive or dead) were brought into the calf shed daily at approximately 10 am. Live calves were tagged with visual and electronic tags upon arrival at the shed.

Calving assistance was scored on a scale of 1-5, representing: no assistance (1), easy pull (2), hard pull or mechanical assist (3), vet assistance (4) and malpresentation (5). Guidelines for checking calving cows was maximum 8 hours between checks. Cows due to calve were checked first in the morning and last in the afternoon, with assistance given at the discretion of the farm staff.

Parentage and, therefore, sire-breed was determined by DNA parentage assignment (Zoetis, Dunedin, New Zealand), using tissue samples obtained by taking a small sample from the ear with a punch gun (Allflex).

Calf rearing

All calves were fed 2 litres of first-milking colostrum within 24 hours of arrival in the calf shed. In 2016 only, 119 of the calves born in the first 3 weeks of calving were sent to a professional calf rearer in Tirau (Top Notch Calves) at a minimum of 7 days old until weaning. The remainder of the calves born in 2016, and all calves born in 2017 were reared

on the dairy farm. For the period from birth until weaning any deaths were recorded, along with the date, and, if known, the cause of death.

Calves remaining at the dairy farm were reared under commercial management until weaning. Calves were group-fed 4 litres of whole milk per day and were offered *ad libitum* meal from birth until weaning. Calves had access to pasture from approx. 4 weeks-of-age. In year 1 (2016), calves were offered Calf Candy starter (20% Crude Protein (CP), MilkWel dairy feeds, Tuakau, New Zealand) while indoors, then Calf Candy Grower (18% CP, MilkWel dairy feeds, Tuakau, New Zealand) once outdoors on pasture. In year 2 (2017), for the first 3 weeks, calves were offered *ad libitum* TopCalf Formula 1 (16.2% CP, Ingham Feeds and Nutrition, New Zealand), mixed approximately 50:50 with Nourish calf meal (18.5% CP, Gavins, Gordonton, New Zealand); for the remaining time until weaning, the Nourish meal was fed.

Calves sent to the calf rearer were offered 3L milk per feed twice a day for the first 3 weeks, then 4L once a day until weaning. Calves were fed colostrum or whole milk for approximately 6 weeks, and a 50:50 mixture of stored colostrum and milk powder (Ancalf, NZAgBiz, Hamilton, New Zealand) for the remainder of the time until weaning. All calves were offered *ad libitum* meal (Top-Notch Blend, Seales Winslow, Morrinsville, New Zealand) until weaning, and had no access to pasture during the pre-weaning period.

Weaning

Calves reared at the Limestone Downs dairy farm were weaned off milk at a minimum of 85 kg. Weaning began on October 5th in both years, with calves being weighed every 1-3 weeks until all calves were weaned. All calves at the Tirau calf rearer were weighed weekly and weaned to a minimum of 75 kg. Calves were weaned by progressively dropping milk fed by 0.5L/calf/day over a period of one week.

In 2016, all bull calves were castrated at (8-13 weeks-of-age; Tirau reared) or shortly after weaning (10-20 weeks-of-age; Limestone Downs reared). In 2017, shortly before weaning, all bull calves were castrated and all calves with horn buds or scurs were disbudded at around 9 weeks-of-age.

Measurements

Date of birth was recorded as the date which the calf was brought into the rearing shed. Breed and sex of all calves (alive and dead) were also recorded upon entry.

Birth weight was recorded on arrival to the shed, prior to being fed. Birth weight was recorded using a Pratley calf weigh crate (Prattley Industries LTD., Temuka, New Zealand)

and a Tru-Test weigh-head (EziWeigh7i, Tru-Test, Auckland, New Zealand) and load bars (MP600, Tru-Test, Auckland, New Zealand). Dead calves were also weighed when collected.

Calf conception date was determined using the artificial breeding records (recorded in MINDA™ software) to identify the date when the DNA-assigned dam was inseminated using semen from the DNA-assigned sire. Gestation length was calculated as date of birth less conception date.

As calves were weaned at a minimum weight, age at weaning in days was calculated as a measure of pre-weaning growth. Pre-weaning average daily gain (ADG) was calculated as weaning weight less birth weight divided by the age at weaning.

Post-calving live weight of the dam, as a mean of the weights recorded within 30d post calving was calculated from the ProTrack Scale (LIC, Hamilton, New Zealand) walk over weights after each milking. Dam body condition score (BCS) was recorded prior to calving (14/06/2016 and 29/06/2017) on a 1-10 scale (DairyNZ, 2012a) by the same person each time.

Data cleaning

Over the two years of the experiment 1019 calves were born. Data from 39 calves were removed prior to analysis. The 39 excluded calves consisted of: seven with no sire assigned by DNA parentage analysis; 30 twin-born calves; and 2 calves born prematurely (<260 days gestation).

Calves which were assigned a sire by parentage assignment were included in the data analysis (n=980). Dam was unknown for 8 of the calves, and age of the dam was unknown for a further 19 calves for which dam was known. These calves were included in the dataset, but not included in analysis of birth weight and gestation length which the models included dam age. Mating records for the cows were not complete and a further 84 calves had no gestation length record and were not included in the analysis of gestation length.

Calving assistance and calf survival were analysed as binary traits. Calving assistance was simplified from the 1-5 scale to classified as unassisted (0) or assisted (1; for correctly presented calves). Malpresented calves requiring assistance were given a missing value for assistance (Chapter 1, Figure 1.1). Malpresented calves (n=6; 0.6%) were only included in analysis of survival. Calf deaths were recorded for the calving (prior to calf collection) and rearing (calf collection to weaning) periods. One calf was excluded from the analysis of survival during rearing and overall survival as it was mistakenly identified as a non-

experimental calf and was physically removed from the experiment after birth weight was measured.

Deviation from median date of birth was calculated for calves born within year. Deviation from median date of conception was calculated for all calves with a gestation length record. Calves born or conceived before the median date were assigned a negative value.

A 30-day mean post-calving live weight for individual dams, within year, was calculated using all weights recorded in the 30 days post calving. Live weights were cleaned to remove outliers by calculating the mean and standard deviation for each cow within year. Live weight records for individuals which fell more than four standard deviations from the mean within year were removed, and the mean recalculated (Pietersma et al., 2006, Handcock et al., 2019b). This method was iterated until no more records were deleted (Pietersma et al., 2006, Handcock et al., 2019b). This left a dataset comprised of 36,751 live weight records (261 records removed) from 927 cows within year.

Dam pre-calving body condition score (BCS) was grouped into ≤ 4 , 4.5 and ≥ 5 . Dam age was grouped into 3, 4, 5, 6, 7+ years of age.

To compare the pre-weaning growth of calves based on the recommended purchase weight ranges, calves were split into light (< 35 kg), medium (35 – 39.9 kg) and heavy birth weight (≥ 40 kg) categories kg (Muir et al., 2002, Beef+LambNZ, 2018).

Statistical analysis

Data were analysed using SAS (Version 9.4, SAS Institute Inc., Carey, North Carolina, USA).

Descriptive statistics (mean, median, standard deviation, and range of observations) were calculated at a herd level for the parameters: birth weight, gestation length, age at weaning, weaning weight, pre-weaning ADG, and calving difficulty, calf survival during the calving and rearing periods and overall survival; and traits used in the analysis – deviation from median date of calving, and dam post-calving live weight.

Least squares mean pre-weaning ADG of calves based on recommended purchase weight ranges (Muir et al., 2002, Beef+LambNZ, 2018) were obtained using a linear mixed model. Birth weight range (light: < 35 kg, medium: 35 – 39.9kg, heavy: ≥ 40 kg), breed of sire, sex of calf and rearing location within year were fitted as fixed effects and deviation from median date of birth was fitted as a covariate, sire nested within breed was fitted as a random effect.

There were too few calves requiring assistance at birth to warrant statistical analysis.

Birth weight, gestation length and weaning traits

Least squares means for progeny birth weight, gestation length, age at weaning and pre-weaning average daily gain for each sire were obtained using a generalised linear model in SAS. Effects fitted in models are outlined in Table 2.1.

The model for birth weight included the fixed effects of sire nested within breed, breed of sire, year born, sex of calf and dam age. Deviation from median date of birth and dam post-calving live weight were fitted as covariates. The fixed effect of dam pre-calving BCS was considered and removed from the final model as not significant ($P>0.05$).

Table 2.1. Fixed effects, covariates and random effects fitted in sire breed models for birth weight, gestation length, pre-weaning growth and calf survival models. Effects fitted regardless of significance are indicated by “B”, effects considered and kept where significant at $P<0.05$ are indicated by “✓”, and if removed where not significant, indicated by an “X”.

Model	Sire models				Sire-breed models	
	Birth weight GLM	Gestation length GLM	Age at weaning GLM	Pre-weaning ADG GLM	Survival Calving period Glimmix	Survival Rearing Period Glimmix
Fixed effects						
Sire (breed)	B	B	B	B		
Sire-breed	B	B	B	B	B	B
Sex of calf	B	B	B	B	B	B
Year born	B	B			B	B
Rearing location			B	B		
Age of Dam	✓	✓	X	X	X	X
PC BCS	X	X			X	
Calving assistance					X	
Covariates						
DOB deviation	✓	X	X	✓	✓	X
Dam live weight	✓	X	X	X	X	
DOM deviation		X				
Weaning weight			✓			
Birth weight					✓	
Birth weight squared					✓	
Random effect						
Sire (Breed)					B	B

PC BCS: Pre-calving body condition score of the dam; DOB deviation: deviation from the median date of birth, within year; DOM deviation: deviation from the median date of mating of the dam, within year.

The model for gestation length included the fixed effects of sire nested within breed, breed of sire, year born, sex of calf and dam age. The fixed effect of dam pre-calving body condition score (PC BCS), and covariates of deviation from median date of conception and birth, and dam post-calving live weight were considered and removed from the final model as not significant ($P>0.05$).

The models for age at weaning and pre-weaning ADG included the fixed effects of sire nested within breed, breed of sire, sex of calf and rearing location within year, and the random effect of sire nested within breed of sire. The model for age at weaning included the covariate of weaning weight. The fixed effect of dam age, and covariates of deviation from median date of birth and dam post-calving live weight were considered and removed from the final model as not significant ($P>0.05$). Deviation from median date of birth was included in the model for pre-weaning ADG ($P<0.05$).

To evaluate how individual bulls performed across different traits, the sire least squares means for birth weight, gestation length and age at weaning were used to calculate the relationship between traits using a linear regression model in SAS. The predicted value and the 95% confidence intervals were plotted for each comparison.

Calf survival

The probabilities of calves, by breed of sire, surviving the calving and rearing periods were calculated with a generalised linear mixed model specifying binomial distribution in SAS. Effects fitted in models are outlined in Table 2.1.

The model for survival of the calving period included the fixed effects of calf sire-breed, year born and sex of calf, and the random effect of calf sire nested within breed. Deviation from median date of birth, birth weight and birth weight squared were fitted as covariates. The fixed class effects of calving assistance (including malpresented calves), age of dam and dam pre-calving grouped body condition score; and the covariate effect of dam post-calving live weight were considered and removed from the final model as not significant ($P>0.05$).

The model for survival of the rearing period included the fixed effects of calf sire-breed, year born and sex of calf, and the random effect of calf sire nested within breed. This model did not include calves which did not survive the calving period. The fixed effects of age of dam and dam pre-calving BCS, and the covariates of deviation from median date of birth, dam post-calving live weight, birth weight and birth weight squared were considered and removed from the final model as not significant ($P>0.05$). The rearing location contemporary group was not fitted as there were too few deaths of calves reared in one of the locations.

Mean, and the 95% confidence interval, for survival of the calving period and overall, for the range of calf birth weights were generated using the estimate function in SAS, specifying the proportion of calves in each level for the fixed effects fitted in the model.

An odds ratio with 95% confidence interval for probability of not surviving the calving or rearing periods or the overall experiment for assisted (including malpresented) calves, compared with non-assisted calves, was calculated.

Variance components

Variance components required for the calculation of estimated breeding values and genetic and phenotypic correlations were obtained using a linear mixed model in SAS. Birth weight, gestation length and age at weaning models were the same as described as above, with sire nested within breed fitted as a random effect rather than a fixed effect.

The estimated residual variance from the linear model was used to calculate an estimate of genetic variance for the Angus and Hereford bulls using the equation $\sigma_g^2 = \frac{h^2\sigma_e^2}{1-h^2}$, where σ_g^2 is the genetic variance, h^2 is the Angus NZ heritability estimate from BreedPlan (Angus-NZ, 2018), and σ_e^2 is the residual variance calculated in the linear model. The heritability estimates used in this calculation were 0.32 for birth weight, 0.65 for gestation length and 0.12 for age at weaning (heritability of 200-day weight).

Estimation of breeding values

Estimates of residual and genetic variation and heritability estimates (Angus-NZ, 2018) were used to calculate EBV for birth weight, gestation length and age at weaning for each bull. Performance data used for calculation of EBV included only data collected from the present experiment.

Estimated breeding values were calculated using ASReml (Gilmour et al., 2009) with a single-trait animal model, specifying the genetic and residual variance. Models for birth weight and gestation length included the contemporary group of year, the fixed class effects of sex and age of dam and random effect of animal, while proportion of Angus (0 for Hereford-sired calves and 0.5 for Angus-sired calves) was fitted as a covariate to account for the breed-cross and sire-breed of each calf. The birth weight model included the covariate of deviation from median date of birth and dam post-calving live weight. The model for age at weaning included the contemporary group of location-year, the fixed class effect of sex, random effect of animal and covariates of proportion of Angus and weaning weight. The pedigree fitted in the model included 3 generations on the sire side (sire, grandparents and great-grandparents), and dam of the calf.

The accuracy of each EBV was derived from the standard error of prediction of the EBV calculated in ASReml, using the following equation (Mrode, 2005). Genetic standard deviation is the square root of the genetic variance used to calculate the EBV.

$$Accuracy = \sqrt{1 - \left(\frac{\text{Standard Error of prediction}}{\text{Genetic Standard Deviation}} \right)^2}$$

Regression of estimated breeding values on BreedPlan EBV

The relationship between calculated EBV for each trait and the relevant BreedPlan EBV for the sires was calculated using a linear regression model in SAS. Angus and Hereford sires were analysed separately. Calculated EBV for birth weight, gestation length and age at weaning were regressed against the Breedplan EBV for respective traits (200d weight was used as the comparable BreedPlan trait for age at weaning). The predicted EBV and the 95% confidence intervals were plotted for each trait and sire-breed.

Genetic and phenotypic correlations

Genetic and phenotypic correlations between birth weight, gestation length and age at weaning were obtained using the statistical package ASReml (Version 4, Gilmour et al. (2009)) with a multitrait animal model. Models for birth weight and gestation length included the contemporary group of year, the fixed class effects of breed, sex and age of dam and random effect of animal. The birth weight model also included the covariate of deviation from median date of birth and dam post-calving live weight. The model for age at weaning included the contemporary group of location-year, the fixed class effects of breed and sex, random effect of animal and covariate of weaning weight. Residual and genetic variance as outlined above, were fixed in the models.

Results

This experiment included 980 calves born to Angus (n=468) or Hereford (n=512) sires, in 2016 (n=512) or 2017 (n=468). Both bull (n=524) and heifer (n=456) calves were included and reared at one of 2 locations in 2016 (Limestone Downs n=393; Tirau n=119) and at Limestone Downs in 2017.

Descriptive statistics for traits of calves analysed in this experiment are shown in Table 2.2. The mean calf birth weight was 36.8 kg with a range of 30 kg, whilst the mean gestation length was 281.3 days, with a range of 33 days. Calves were weaned at an average of 81.5 days of age (range 74 days) and grew at 0.69 kg/day (range 0.56 kg/day). Less than 1% of calves required assistance at birth.

Table 2.2. Number of calves, mean, standard deviation (SD), and range for traits analysis in this Chapter.

Trait	n	Mean	SD	Range
Birth weight (kg)	980	36.8	4.7	23.5 – 53.5
Gestation length (days)	869	281.3	4.7	266 – 299
Age at weaning (days)	876	81.5	11.5	47 – 121
Pre weaning ADG (kg/day) ¹	873	0.69	0.08	0.41 – 0.97
Assisted birth (%) ²	974	0.72		
Survival of the calving period (%) ³	980	95.41		
Survival of the rearing period (%) ⁴	934	96.15		
Overall survival (%)	979	91.73		

¹ ADG = average daily gain. ² Not including malpresented calves. ³ Calving period: prior to calf collection. ⁴ Rearing period: from calf collection to weaning.

Calves born to the Angus bulls were born 1.3 kg lighter and had a 3.2-day shorter gestation length than those born to the Hereford bulls ($P < 0.05$; Table 2.3). There was no difference between calves born to the Angus or Hereford bulls for age at weaning and pre-weaning ADG ($P > 0.05$).

Table 2.3. Least squares mean (\pm standard error of the mean) birth weight, gestation length, age at weaning and pre-weaning average daily gain (ADG) for calves sired by Angus and Hereford bulls.

	n	Angus	Hereford	P (Breed)
Birth weight (kg)	927	36.2 \pm 0.3 ^a	37.5 \pm 0.3 ^b	0.005
Gestation length (days)	869	279.7 \pm 0.4 ^a	282.9 \pm 0.4 ^b	<0.001
Age at weaning (days)	873	82.2 \pm 0.7	80.8 \pm 0.7	0.135
Pre-weaning ADG (kg/day)	873	0.69 \pm 0.005	0.68 \pm 0.005	0.693

^{a,b} Different superscripts denote means within a row are significantly different at $P < 0.05$

Considering the purchase weight recommendations in the industry (Muir et al., 2002, Beef+LambNZ, 2018), there was no difference in the pre-weaning ADG of calves born small

(<35 kg; 0.68 ± 0.006 kg/day), medium (35-40 kg; 0.68 ± 0.005 kg/day) and heavy (>40 kg; 0.69 ± 0.005 kg/day) ($P=0.257$).

Progeny performance

Progeny means for birth weight and gestation length, age at weaning and pre-weaning average daily gain (ADG) for each individual sire are presented in Appendix A.2.

Birth weight of calves was significantly affected by sire ($P<0.001$). The mean progeny birth weight ranged from 33.3 kg to 41.4 kg (Figure 2.1; Appendix A.2). Fifty-two percent of Angus bulls produced calves with birth weight between 32 and 33.9 kg, whereas only 24% of Hereford bulls produced calves within this range. Overall, 94% of sires produced calves that weighed less than 40 kg (expected progeny birth weight from a Holstein-Friesian bull, Hickson et al. (2015)).

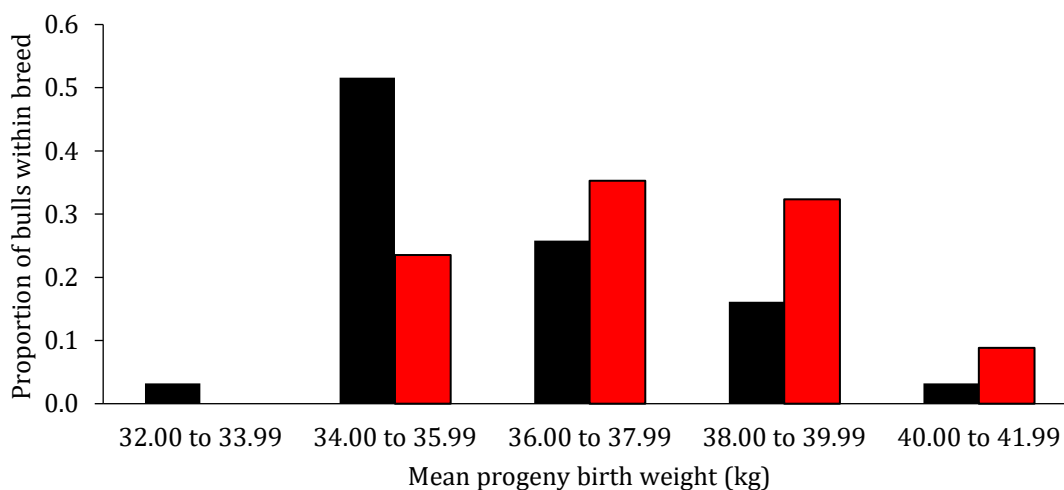


Figure 2.1. Proportion of Angus (black bar) and Hereford (red bar) bulls with mean progeny mean birth weight falling within each range of birth weights.

Calf gestation length was significantly different for sires ($P<0.001$), with the best sire producing calves born on average 12.5 days earlier than the worst sire (276.1 vs 288.6 days; Figure 2.2; Appendix A.2). All Angus sires had a mean progeny gestation length of less than 284 days, whereas only 65% of the Hereford sires produced calves in this range. The average gestation length for New Zealand dairy cattle is 281 days (Baker et al., 1990, Grosshans et al., 1997, Winkelman and Spelman, 2001, Donkersloot, 2014, Stachowicz et al., 2015, Amer et al., 2016), 51% of the bulls used in this experiment had a mean progeny gestation length less than 281 days.

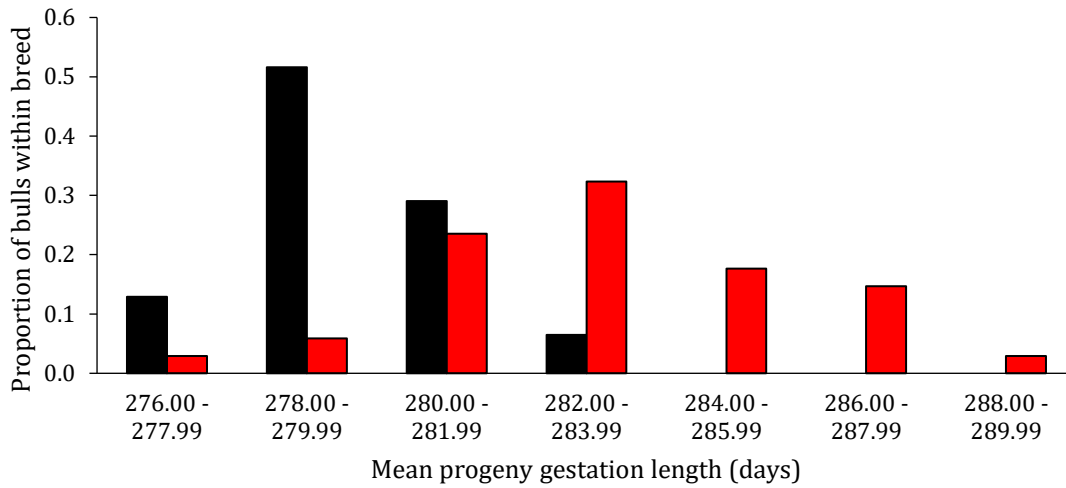


Figure 2.2. Proportion of Angus (black bar) and Hereford (red bar) bulls with mean progeny mean gestation length falling within each range of gestation lengths.

There was a difference in mean progeny age at weaning among sires ($P < 0.001$), with the mean progeny age at weaning ranging from 70.3 days to 88.3 days (Figure 2.3; Appendix A.2). Sixty-five percent of the bulls produced calves which were weaned between 78.0 and 85.9 days.

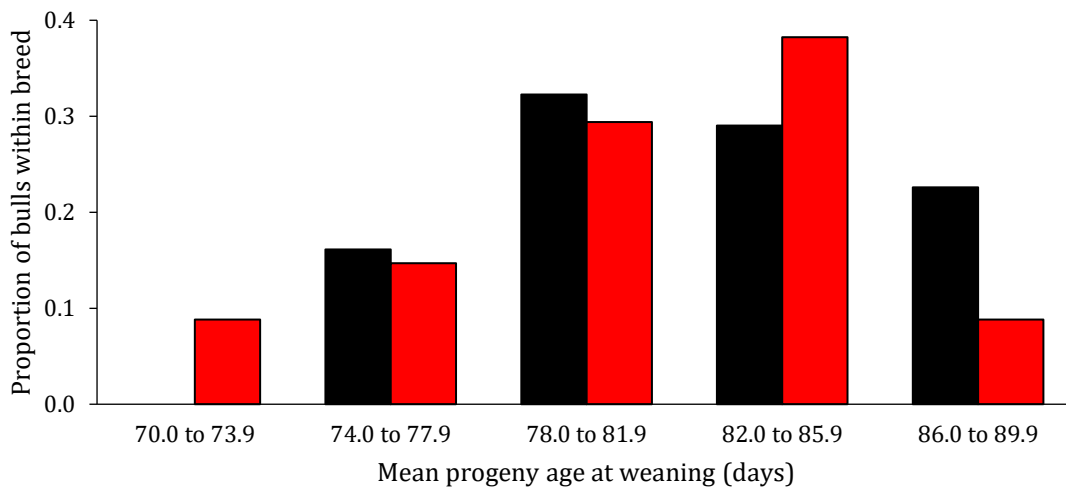


Figure 2.3. Proportion of Angus (black bar) and Hereford (red bar) bulls with mean progeny mean age at weaning falling within each range of ages.

There was a difference in mean progeny ADG between different sires ($P < 0.001$, Figure 2.4). Mean progeny ADG ranged from 0.63 kg/day to 0.75 kg/day (Figure 2.4; Appendix A.2), with fifty-five percent of Angus bulls, and 59% of Hereford sired producing calves with growth rates between 0.65 and 0.7 kg/d.

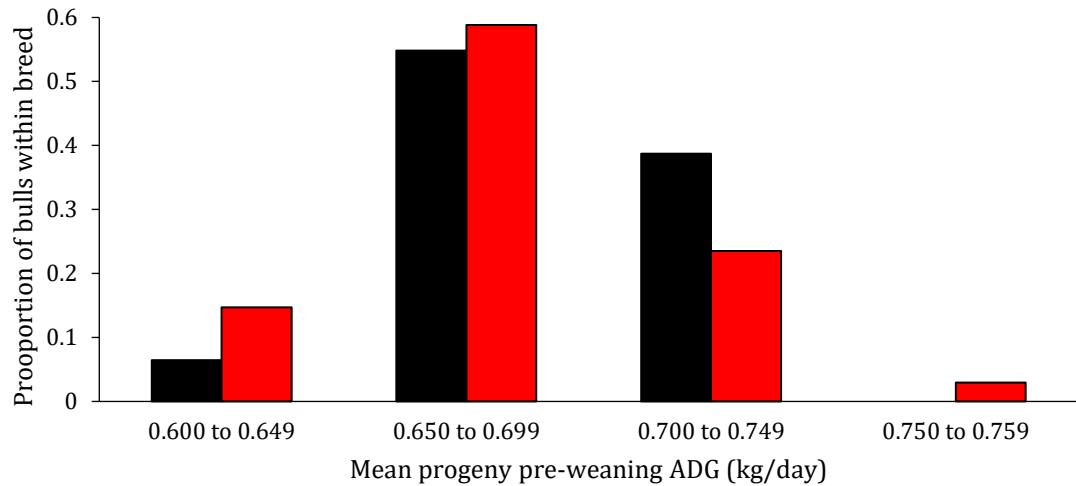


Figure 2.4. Proportion of Angus (black bar) and Hereford (red bar) bulls with mean progeny mean pre-weaning ADG falling within each range of ADG.

Relationship between progeny traits

Gestation length was positively related to birth weight ($P=0.003$), although the relationship was weak ($R^2=0.13$; Figure 2.5). Figure 2.5 illustrates that sires producing progeny with a longer gestation length also tended to produce heavier progeny. There is variation between bulls, where there are bulls that produce heavier calves despite having a short gestation.

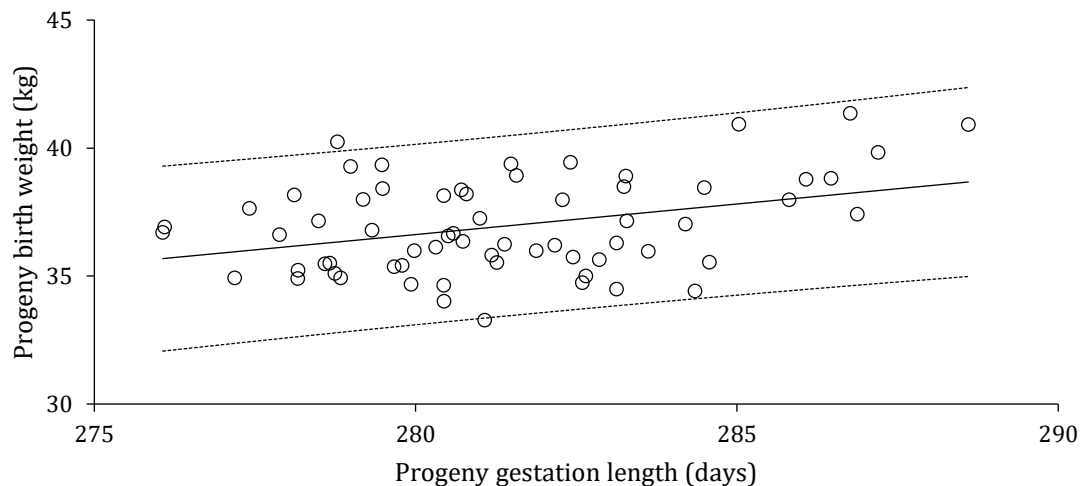


Figure 2.5. Relationship between progeny gestation length and progeny birth weight. Individual bulls indicated by circles, with 95% confidence intervals indicated by dashed lines. Regression equation: birth weight = 0.24 ± 0.08 * gestation length - 30.24 ± 21.80 ; $R^2 = 0.13$; $P=0.003$.

There was a moderate negative relationship between progeny birth weight and age at weaning ($R^2=0.33$; $P<0.001$; Figure 2.6). This relationship indicated that the sires producing lighter birth weight calves also produced calves that older when weaned. Although there were two bulls which fall outside of the 95% confidence interval, indicating that the calves were born lighter and weaned earlier than the relationship suggests (more desirable; bull indicated by circle below the lower confidence interval line); or produced calves which were born heavier and grew slower, and were weaned older than the relationship suggests (less desirable; bull indicated by circle above the upper confidence interval line).

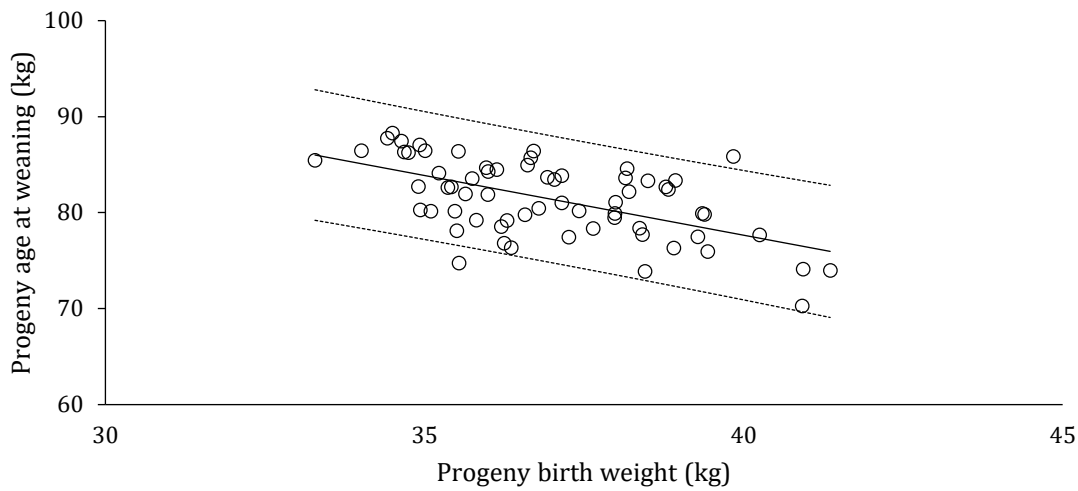


Figure 2.6. Relationship between progeny age at weaning and progeny birth weight. Individual bulls indicated by circles, with 95% confidence intervals indicated by dashed lines. Regression equation: age at weaning = -1.24 ± 0.22 * birth weight + 127.40 ± 8.16 ; $R^2 = 0.33$; $P < 0.001$.

Figure 2.7 illustrates that there was no relationship between progeny gestation length and age at weaning in the sires evaluated in this experiment ($P=0.066$).

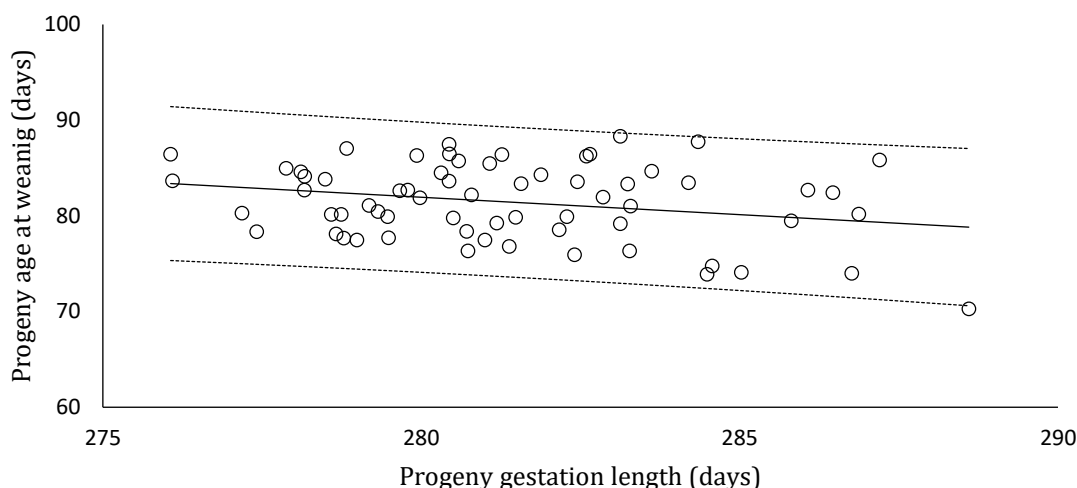


Figure 2.7. Relationship between progeny age at weaning and progeny gestation length. Individual bulls indicated by circles, with 95% confidence intervals indicated by dashed lines. Regression equation: age at weaning = -0.36 ± 0.17 * gestation length + 183.69 ± 48.53 ; $R^2=0.05$; $P=0.066$.

Assistance at birth and survival

There were seven calves (of the 974 normally presented calves) across the two years of the experiment which required assistance; these accounted for 0.72% of births over the two years.

Over the course of the experiment 81 calves (of the 980 born) died, accounting for 8.3% of calves born. There were 45 calves in the experiment that were born dead or died prior to being removed from the dam (calving period, 4.6%), and 36 calves died during the period from arrival at the rearing shed to weaning (rearing period, 3.6%). There was no influence of sire-breed of calf on the survival of calves ($P>0.05$, Table 2.4).

Table 2.4. Survival (%) of Angus- and Hereford-sired calves during the calving and rearing periods, and overall. Values are least squares means \pm SE.

	n	Angus	Hereford	P-value
Calving ¹	980	96.5 \pm 0.9	95.5 \pm 0.9	0.440
Overall ²	979	91.6 \pm 1.3	92.2 \pm 1.2	0.759

¹ Calving period represents birth to removal from dam; ² Overall survival from birth until weaning, one calf was not included in the analysis of overall survival due to being mistakenly sold after the calving period.

Birth weight of the calf had both linear (calving: $P=0.021$, overall: $P=0.011$) and quadratic (calving: $P=0.016$, overall $P=0.013$) effects on the survival of the calving period, and overall, indicating that there is an optimal range of birth weight, such that calves of lighter and heavier birth weights were less likely to survive than medium sized calves (Figure 2.8).

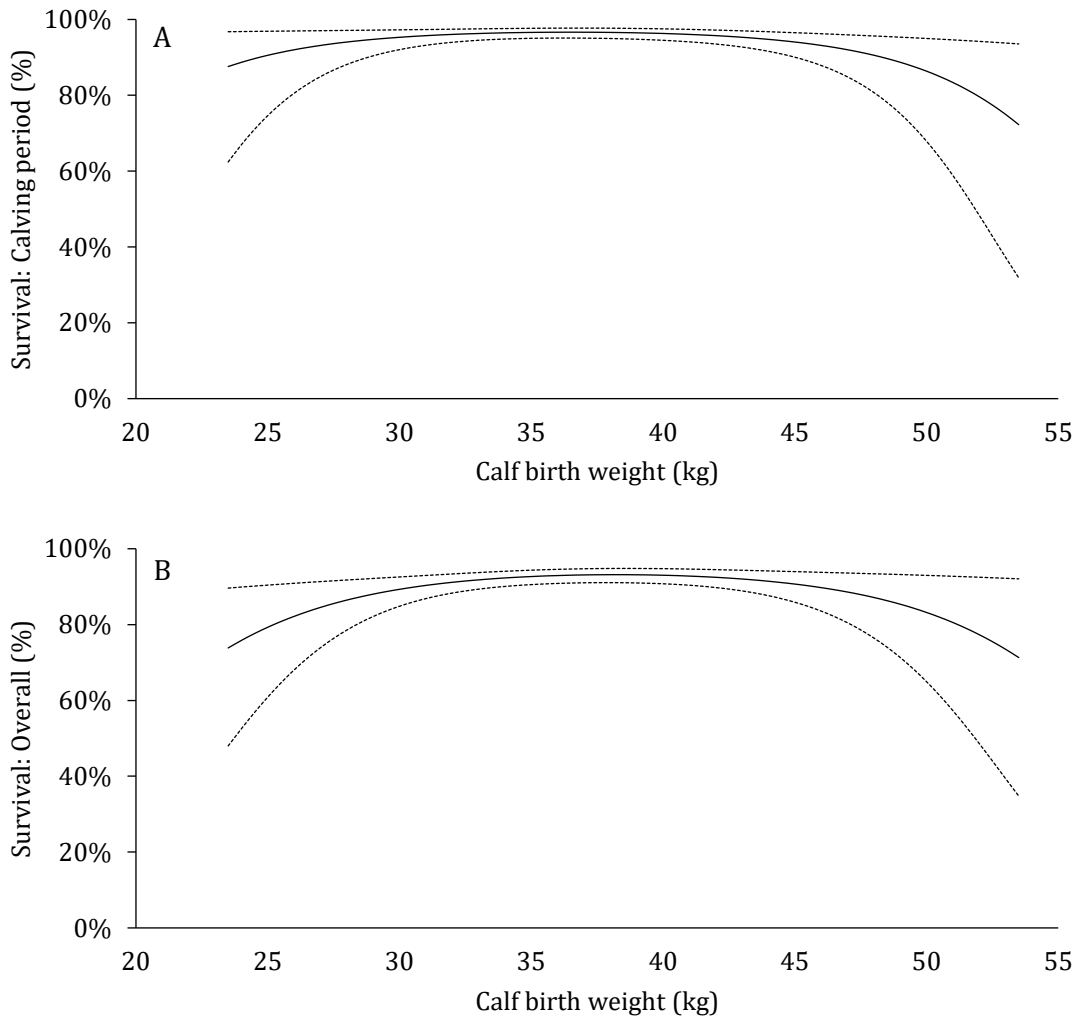


Figure 2.8: Survival of calves at different birth weights during the calving period (A, prior top calf collection) and overall (B, calf collection to weaning), with 95% confidence intervals indicated by a dashed line.

Mean survival of the calving period was 95.4%, and overall survival was 91.7%. The birth weight thresholds for greater-than-mean survival were 30.5 – 42.5 kg for the calving period and 33 – 43.5 kg overall (Figure 2.8).

Of the 13 calves (of the 980 born) requiring calving assistance, five did not survive the calving period and a further five died prior to weaning. A calf requiring assistance was 0.069 (95% confidence interval: 0.022 – 0.221) times as likely to survive the calving period and 0.024 (95% confidence interval: 0.006 – 0.088) times as likely to survive overall compared with a calf born unassisted ($P < 0.001$).

Estimated breeding values

The residual and genetic variances used in the analysis of estimated breeding values and genetic and phenotypic variance are illustrated in Table 2.5.

Table 2.5. Published heritability values and calculated residual and genetic variance used in the calculation of estimated breeding values⁴ (EBV) for Angus and Hereford bulls.

	Birth weight	Gestation length	200d weight
Breedplan EBV			
Heritability ¹	0.32	0.65	0.12
Beef-cross-dairy EBV			
Residual variance ²	16.32 kg	18.73 days	96.12 days
Genetic variance ³	7.68 kg	34.68 days	13.10 days

¹ Heritability estimates from Breedplan EBV for Angus cattle (Angus-NZ, 2018). ² Estimates of residual variance calculated data collected in the present experiment ³ Genetic variance calculated using the calculation: heritability = genetic variance / (residual variance + genetic variance).

The calculated birth weight estimated breeding values for bulls used in this experiment ranged 12.6 kg (Figure 2.9; Appendix A.3). The Angus bulls tended to have smaller birth weight EBV (mean EBV -2.44 kg) than the Hereford bulls (mean EBV -0.14 kg), indicating that in a beef-cross-dairy system, calves sired by the Angus bulls will be lighter than calves sired by the Hereford bulls.

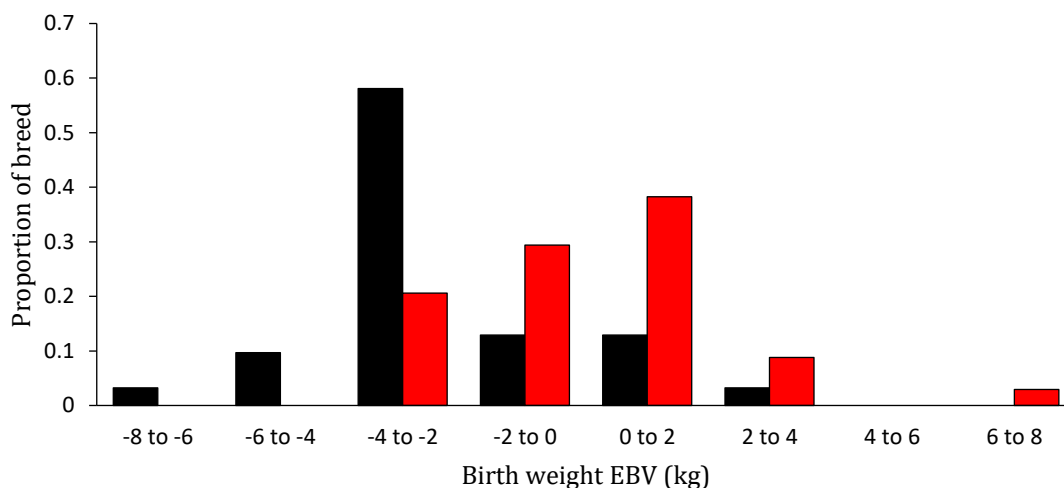


Figure 2.9. Proportion of Angus (black bar) and Hereford (red bar) bulls with birth weight estimated breeding values (EBV) falling within each range of EBV.

The calculated gestation length EBV ranged 18.3 days across all bulls (Figure 2.10; Appendix A.3). The Angus bulls had shorter gestation length EBV (mean EBV -6.81 days) compared with the Hereford bulls (mean EBV -0.41 days) indicating that in a beef-cross-dairy system, the progeny from Angus bulls will have a shorter gestation length than those from Hereford bulls.

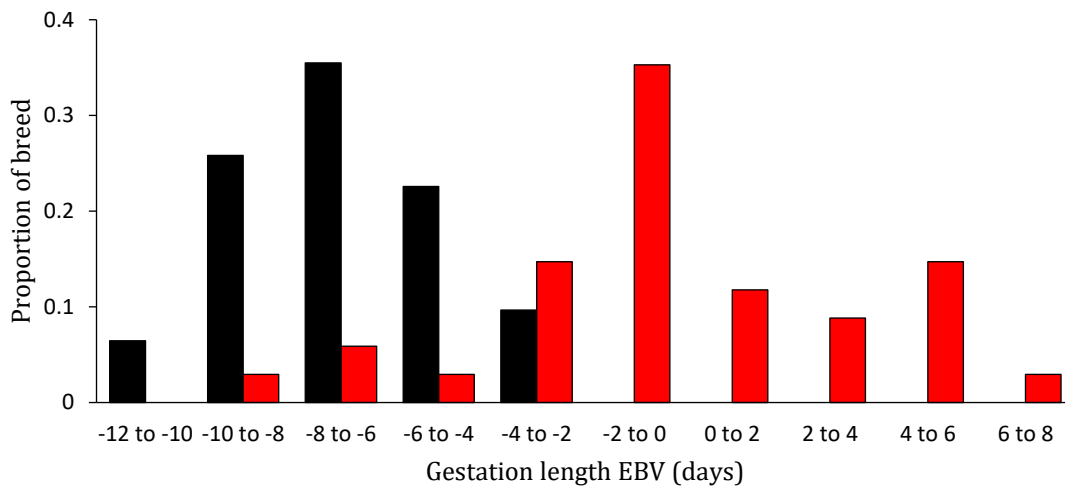


Figure 2.10. Proportion of Angus (black bar) and Hereford (red bar) bulls with gestation length estimated breeding values (EBV) falling within each range of EBV.

The calculated age at weaning EBV ranged 11.8 days across all bulls (Figure 2.11; Appendix A.3); and the Hereford bulls tended to have smaller EBV (mean EBV -0.01 days) than the Angus bulls (mean EBV 3.63 days).

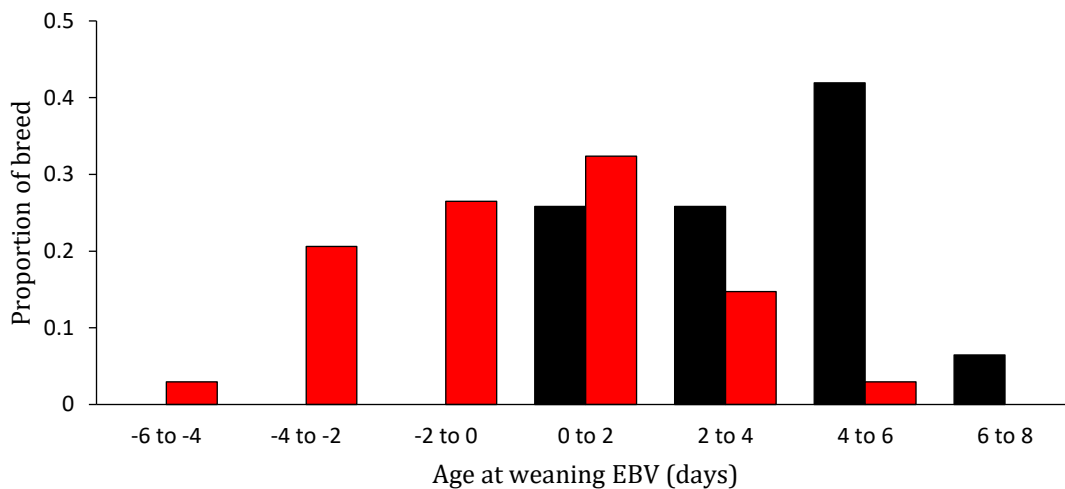


Figure 2.11. Proportion of Angus (black bar) and Hereford (red bar) bulls with age at weaning estimated breeding values (EBV) falling within each range of EBV.

Relationship between calculated and BreedPlan estimated breeding values

There was a positive linear relationship between the calculated birth weight EBV and Breedplan EBV for both Angus and Hereford bulls (Figure 2.12), where a 1 kg increase in the Breedplan EBV would result in a 0.96 ± 0.16 or 0.70 ± 0.16 kg increase in the EBV of the

bull when used in a beef-cross-dairy system for Angus and Hereford bulls respectively. The relationship between the calculated and Breedplan EBV was moderate with 56% (R^2) of the variation in the calculated EBV being explained by the variation in the Breedplan EBV for Angus bulls, and 37% (R^2) for Hereford bulls ($P < 0.001$, Figure 2.12).

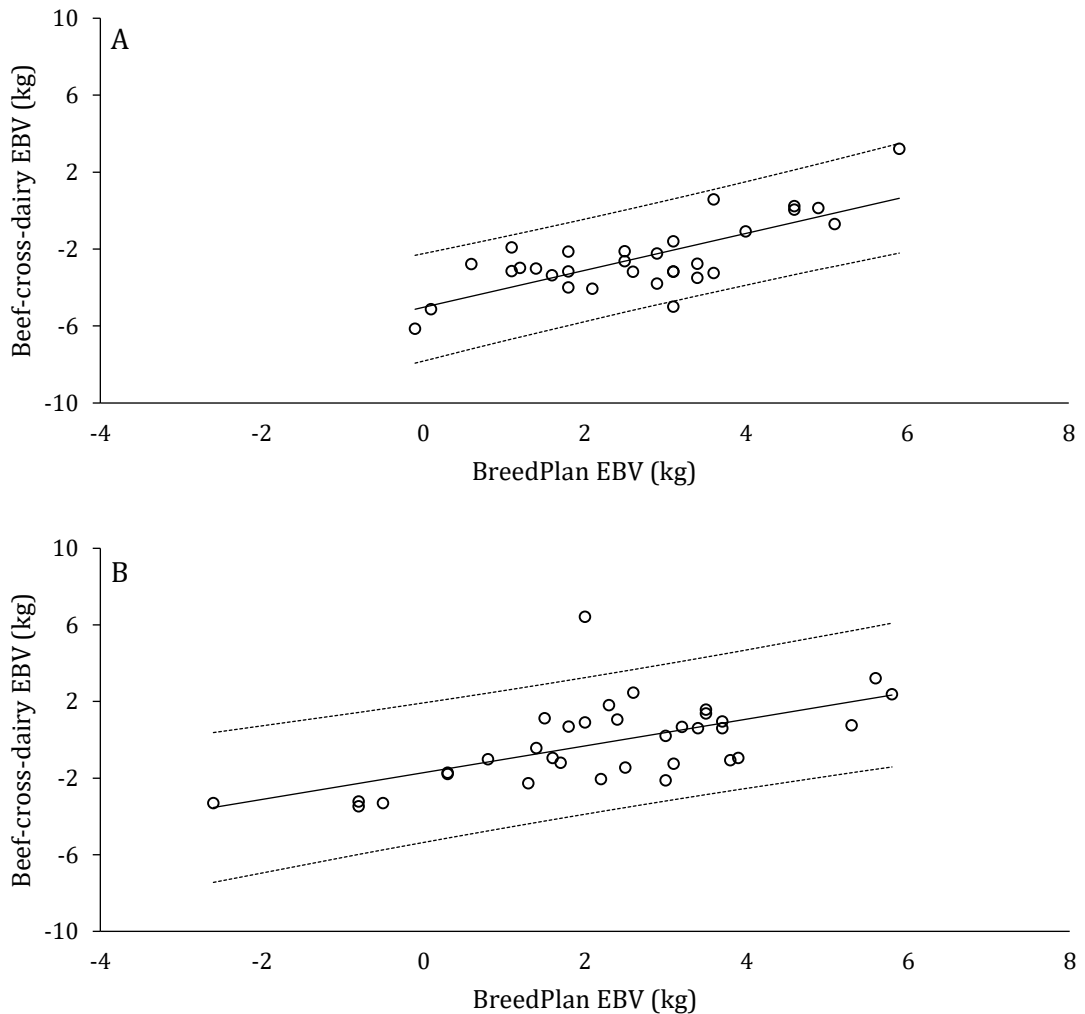


Figure 2.12: Relationship between Breedplan birth weight EBV and calculated beef-cross-dairy birth weight EBV for (A) Angus ($R^2=0.56$) or (B) Hereford ($R^2=0.37$) bulls with 95% confidence intervals (dashed line).

There was one Hereford bull for which the relationship between the calculated and Breedplan EBV was especially weak. When this bull was considered to be an outlier and removed, the relationship was stronger ($R^2 = 54\%$), although there was only a small change in the regression coefficient (from 0.70 to 0.71 kg).

There was a positive linear relationship between the calculated gestation length EBV and Breedplan EBV for both Angus and Hereford bulls (Figure 2.13), in that a 1 day increase in the Breedplan EBV resulted in a 0.56 ± 0.12 or 0.86 ± 0.13 day increase in the EBV when used

in a beef-cross-dairy system for Angus and Hereford bulls, respectively. The relationship between the calculated and Breedplan EBV was moderate with 44% (R^2) of the variation in the calculated EBV being explained by the variation in the Breedplan EBV for Angus bulls, and 57% (R^2) for Hereford bulls ($P < 0.001$, Figure 2.13).

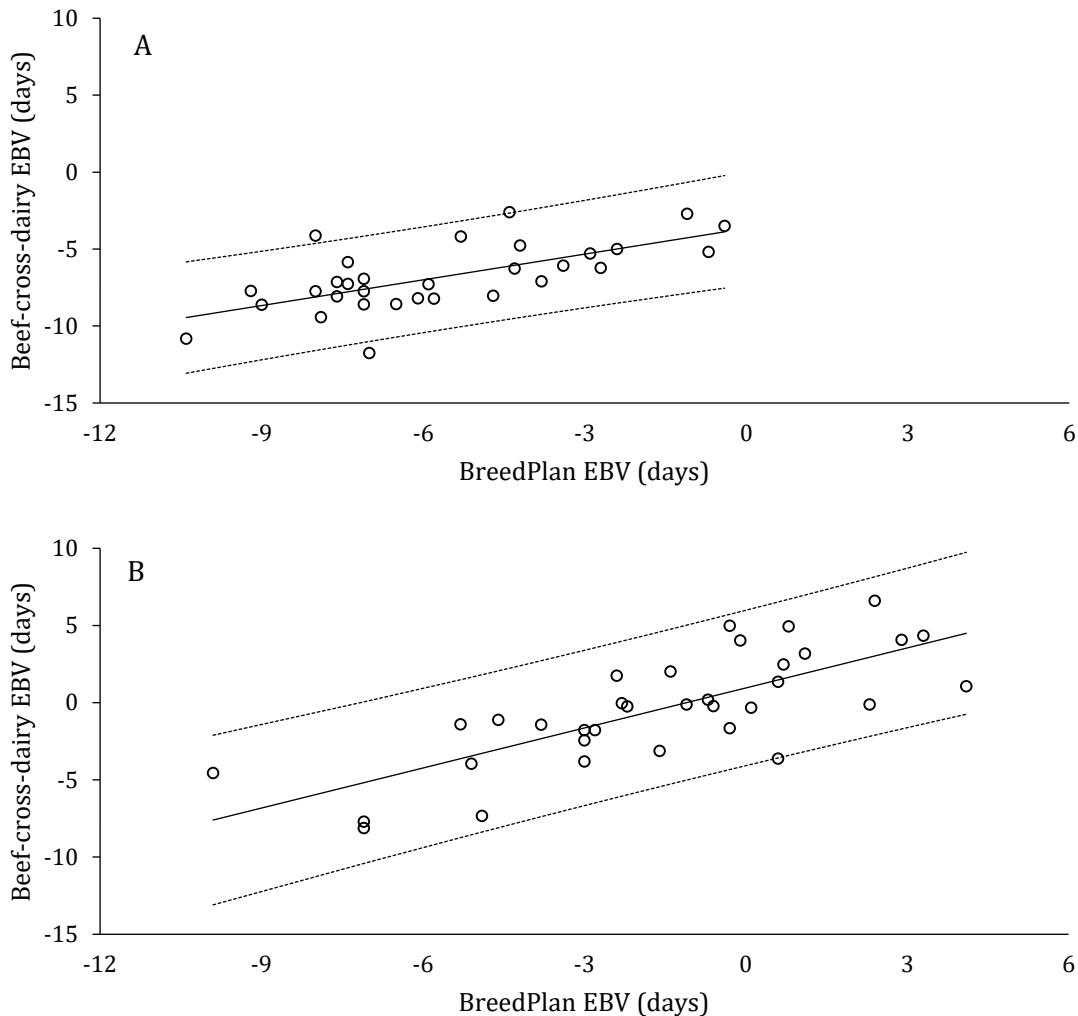


Figure 2.13: Relationship between Breedplan gestation length EBV and calculated beef-cross-dairy gestation length EBV for (A) Angus ($R^2=0.44$) or (B) Hereford ($R^2=0.57$) bulls with 95% confidence intervals (dashed line).

There was a negative linear relationship between the calculated age at weaning EBV and Breedplan 200-day weight EBV for both Angus and Hereford bulls (Figure 2.14). A 1 kg increase in the Breedplan EBV resulted in a 0.12 ± 0.04 or 0.10 ± 0.05 day decrease in the age at weaning EBV when used in a beef-cross-dairy system for Angus and Hereford bulls, respectively. The relationship between the calculated age at weaning EBV and the Breedplan 200-day weight EBV was weak in that 27% (R^2) of the variation in the calculated EBV was explained by the variation in the Breedplan EBV for Angus bulls ($P=0.003$). For

Hereford bulls, 11% (R^2) of the variation in the calculated EBV was explained by the variation in the Breedplan EBV, however this relationship was not significant ($P=0.061$, Figure 2.14).

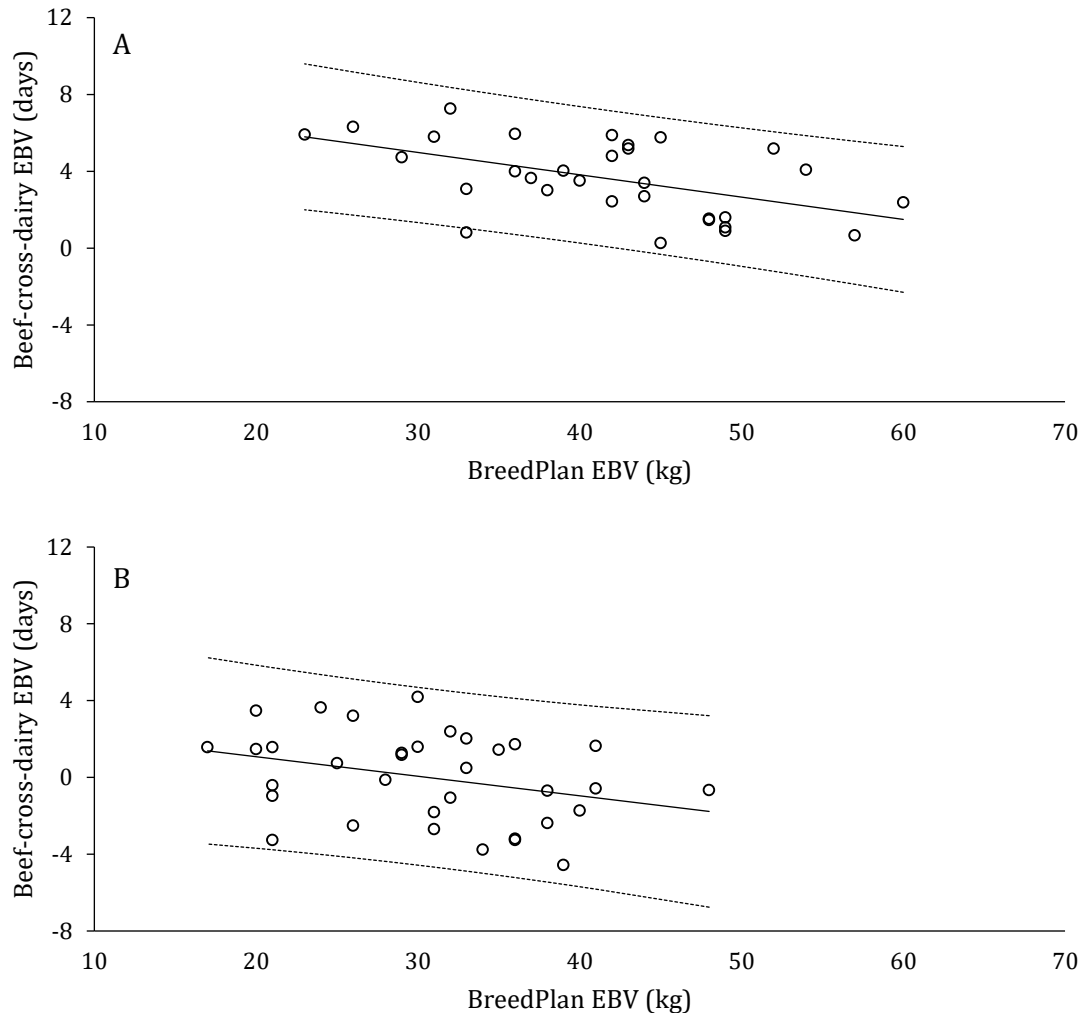


Figure 2.14: Relationship between Breedplan 200 day weight EBV and calculated beef-cross-dairy age at weaning EBV for (A) Angus ($R^2=0.28$) or (B) Hereford ($R^2=0.12$) bulls with 95% confidence intervals (dashed line).

Genetic and phenotypic correlations between traits

The genetic correlation between birth weight and age at weaning was strong, however unfavourable as the correlation was negative (Table 2.6), such that calves with lower birth weight genetics also were genetically slower to reach weaning weight. There was a moderate but unfavourable genetic correlation between gestation length and birth weight, and moderate, favourable correlation between gestation length and age at weaning (Table 2.6). The genetic correlations had large standard errors, indicating potential for the magnitude of the correlation to be under- or over-estimated, however, the direction of the

correlation is likely to be correct, maintaining the unfavourable genetic correlation of birth weight with both gestation length and age at weaning.

Table 2.6: Genetic (below diagonal, \pm SE) and phenotypic (above diagonal, \pm SE) correlations between birth weight, gestation length and age at weaning.

	Birth weight	Gestation length	Age at weaning
Birth weight		0.36 \pm 0.04	-0.57 \pm 0.02
Gestation length	-0.31 \pm 0.19		-0.20 \pm 0.04
Age at weaning	-0.56 \pm 0.18	0.25 \pm 0.27	

Birth weight and gestation length had a moderate positive phenotypic correlation (Table 2.6), where calves with a longer gestation length were born heavier. The phenotypic correlation between age at weaning and birth weight was strong and negative, indicating that calves born light were slow growing to weaning. The phenotypic correlation between age at weaning and gestation length was moderate and negative (Table 2.6).

Discussion

Progeny performance

Calf birth weight, gestation length, age at weaning and pre-weaning ADG differed among the sires used in this experiment. There was a tendency for the Angus-sired calves to be born lighter and have shorter gestation than the Hereford-sired calves, however, this did not translate to a difference in the age at weaning or pre-weaning ADG between the Angus- and Hereford-sired calves.

There was variation among the sires for progeny birth weight. Progeny mean birth weight showed a normal distribution, with the calves sired by Angus bulls in this experiment tending to be lighter at birth than the Hereford-sired calves, however, within sire breed, there were both light and heavy birth-weight bulls. This is consistent with previous literature that reported a 1.4 – 3.5 kg greater difference for Hereford than Angus calves (Baker et al., 1974, Long and Gregory, 1974, Gregory et al., 1978, Bourdon and Brinks, 1982, Jeyaruban et al., 2016). It should be highlighted that the current experiment is not a breed comparison because individual bulls were selected to achieve a spread of EBV, although birth weight EBV was restricted to the lighter half of the breed and therefore do not represent the breed as a whole.

In dairy herds, birth weights are often only known for heifer calves. The birth weight of heifer calves born in this experiment (Angus-cross = 34.9 ± 0.4 kg, Hereford-cross = 36.2 ± 0.4 kg, Appendix A.4.) were similar to straight-bred Holstein-Friesian (36.1 kg), and greater than average birth weights of straight-bred Jersey (27.6 kg) and Holstein-Friesian-Jersey crossbred (31.7 kg) heifer calves born to New Zealand dairy cows (Hickson et al., 2015). The primary competition for beef-cross-dairy calves are calves sired by a Holstein-Friesian bull (Morris and Kenyon, 2014, Beef+LambNZ, 2019a). Holstein-Friesian bulls are easily accessible to dairy farmers, and Holstein-Friesian-sired bull calves represent the surplus calves from the generation of replacement heifers. The birth weight of heifer calves born in this experiment indicate that calves born to Hereford bulls, similar to those used in the experiment, would be in line with known birth weights for Holstein-Friesian-sired calves, with calves sired by Angus bulls being lighter. There is a lack of published birth weights from dairy-breed bull calves born in New Zealand dairy herds to compare with the bull calves born in this experiment; Hickson et al. (2015) evaluated a small population of straight-bred Holstein-Friesian calves reporting 38.4 kg heifer and 41.8 kg bull calves.

There are industry recommendations for purchasing 4-day-old dairy origin calves for rearing for beef production, based on Holstein-Friesian bull calves; the ideal weight is 40 kg

or greater, with a minimum purchase weight of 35 kg (Muir et al., 2002, Beef+LambNZ, 2018). However, the pre-weaning growth rate (ADG) of calves in the present experiment did not indicate a difference in the growth rates between small (<35 kg), medium (35 – 40 kg) and heavy (>40kg) calves. The mean birth weight of calves in this experiment was only 1.8 kg greater than the recommended minimum, and only 26% of calves were at or above the ideal 40kg weight. Under the current recommendations 34% of the calves in this experiment would not be recommended to purchase for rearing for beef production (<35kg); therefore, the recommendations for rearing beef-cross-dairy calves may need to be reassessed.

More Angus bulls than Hereford bulls used in this experiment produced calves with shorter gestation lengths compared with the dairy average gestation length (<281 days; 25 Angus bulls versus 8 Hereford bulls). The difference in gestation length of calves between sire-breeds in this analysis is in agreement with literature, which reports that straight-bred or cross-bred Angus calves have a shorter gestation than Hereford breed calves (range 1 – 5.4 days) (Burriss and Blunn, 1952, Wheat and Riggs, 1958, Long and Gregory, 1974, Smith et al., 1976, Gregory et al., 1978, Bourdon and Brinks, 1982, Baker et al., 1990, Jeyaruban et al., 2016). The bulls producing shorter gestation length calves were also likely to produce lighter birth weight calves. However, the relationship between gestation length and birth weight in the present experiment was weak ($R^2=0.13$) and indicated that the reduction in birth weight that accompanied shorter gestation length was variable among bulls.

New Zealand dairy cattle have an average gestation length of 280-282 days (Baker et al., 1990, Grosshans et al., 1997, Winkelman and Spelman, 2001, Donkersloot, 2014, Stachowicz et al., 2015, Amer et al., 2016). Of the bulls used in this experiment, 33 bulls (61.5%) offered advantages in gestation length by producing calves with shorter gestations than average dairy calves (281 days). A shorter gestation length benefits the dairy industry by decreasing the calving interval, which would reduce the calving spread, and due to calving earlier in the season, there is the potential for cows to have more days in milk (Macmillan and Moller, 1977, Macmillan et al., 1990, Donkersloot, 2014, Coffey et al., 2016, Hess et al., 2016).

The gestation length of beef-cross-dairy calves in this experiment was longer than what would be expected when using a LIC short gestation length bull (which are approximately 10 days shorter than average 281 days) (LIC, 2012). The progeny resulting from the LIC short gestation breeding programme are not recommended for retention as replacement heifers (Donkersloot, 2014), and the resulting calves provide little source of direct income to the dairy farm as they are not considered worth rearing by beef producers. In contrast, the progeny resulting from the use of beef-breed bulls are of greater value, however, the

cows mated to these bulls would likely have a longer pregnancy and, therefore, potentially fewer days in milk. The relative values of milk and beef fluctuate during and between seasons with changing supply and demand. Therefore, the income from surplus calves for beef production becomes more desirable when the milk price decreases towards break-even price (season average operating expenses \$5.13/kg MS DairyNZ (2018), offering another source of income, but is less of a focus for the farmer when the milk price is high.

The pre-weaning growth of the calves born in this experiment did not differ between the Angus and Hereford bulls. There is a lack of literature focussing on the pre-weaning growth period of artificially reared beef-cross-dairy calves. The pre-weaning period in a beef production system is based on the calf suckling off its dam and the pre-weaning period is generally longer (~200 days) (Morris, 2017), than an artificial rearing period (~90 days, recommended minimum 6 weeks) (Muir et al., 2000a, Cardoso et al., 2015, Back et al., 2016, Back, 2017, DairyNZ, 2017a), therefore the traits are not comparable.

Research from USA in a beef production system suggests that breeds with heavier birth weights grow faster (Long and Gregory, 1974, Gregory et al., 1978, Reynolds et al., 1990). This also aligns with the previously mentioned recommendations for calf rearing from Beef + Lamb New Zealand, based predominantly on Holstein-Friesian bull calves reared at the Poukawa research centre, where heavier calves tended to grow faster and were weaned earlier than lighter (<35 kg) calves (Muir et al., 2001, Muir et al., 2002, Beef+LambNZ, 2018). The progeny data from bulls in this experiment illustrated that the low birth weight bulls tended to also be weaned later. However, this was not a perfect relationship and there is scope to select bulls that produced lighter birth weight calves that grew faster and were weaned earlier than other bulls with similar birth weight calves.

Assistance at birth and survival

The rate of assisted births in this experiment (0.71%) was lower than the reported assistance rates (range 2.0 – 20.9%) for New Zealand mixed-aged dairy- and beef-breed cattle in literature (Everitt and Jury, 1972, Morris et al., 1986, Xu and Burton, 2003, Stafford, 2011). Published studies suggest that there is a greater incidence of calving difficulty in Hereford (cross and straight bred) calves compared with Angus (cross and straight bred) calves; and in calves with greater birth weights (Long and Gregory, 1974, Smith et al., 1976, Gregory et al., 1978, Baker et al., 1990). The low incidence of assisted births in this experiment illustrate that the bulls used in the experiment were suitable to be used over mixed-aged dairy cows, and it can be assumed that bulls with a similar or lighter birth weight EBV to those used in the experiment should be suitable also. The birth weight EBV for most bulls were within a range of 0.2 to 5.7 kg for Angus bulls, and -2.2 to 3.5 kg for

Hereford bulls, therefore bulls with birth weight EBV within this range would be suitable. However, further work would be needed to determine an upper limit of birth weight EBV.

Survival of calves in the experiment from birth until weaning was 91.7%, with no effect of sire-breed on survival during the calving and rearing periods. Mortality during the calving period in the present experiment was 4.6% which is comparable to perinatal mortality of New Zealand dairy calves reported by Cuttance et al. (2017). The rate of calf mortality during the rearing period (3.85%) seen in this experiment was comparable to that reported in a survey of New Zealand dairy farms (4.1%) (Cuttance et al., 2017) and New Zealand dairy farm calf rearing operations (3%) (Thomson et al., 2018). The same calf rearing operations survey reported mortality for specialist calf rearing operations, which was lower (1.7%), than seen in the present experiment, although this operation system does not include calves less than 4 days of age (Thomson et al., 2018). The incidences in mortality during the rearing period (≥ 1 day of age, where day 0 = arrival in the calf shed), in the present experiment ranged from 1 to 99 days of age, with 33% of calves that died, doing so before 4 days of age. In the present experiment, calves which experienced assisted births had a greater likelihood of mortality, which is supported by results from studies which found increased incidences of stillbirths and illness and mortality in assisted calves (Smith et al., 1976, Burfening et al., 1978, Reynolds et al., 1990, Pryce et al., 2006, Lombard et al., 2007).

Estimated breeding values

Estimated breeding values (BreedPlan) are calculated for bulls across many breeds available to New Zealand dairy farmers. Using EBV would offer the dairy farmer increased confidence of the beef-breed bull producing desirable calves in their system i.e. low birth weight or shorter gestation length. However, these EBV are calculated within breed, and in a straight-bred beef-breed production system, whereas, the use of bulls in the dairy industry would result in beef-cross-dairy progeny that are artificially reared. The results from this experiment suggests that the birth weight and gestation length progeny performance are able to be predicted from the BreedPlan EBV.

Aside from the system the bulls are used in, there are two primary differences between the calculation of the industry BreedPlan EBV and those calculated in the present experiment (beef-cross-dairy EBV). The beef-cross-dairy EBV was calculated using a single trait model, whereas the BreedPlan EBV are calculated using a multi trait model, where more than just the trait of interest are included in the model for each EBV. The Breedplan EBV are also calculated within breed, whereas the aim of this experiment was to compare the performance of individual bulls, so the EBV were calculated across both breeds used in the experiment.

Although BreedPlan EBV are available to dairy farmers, a beef-cross-dairy specific genetic evaluation would encompass both Angus and Hereford bulls, and ideally more breeds, representative of the many beef breeds available in New Zealand. An across breed genetic evaluation would give more options for dairy farmers to choose a bull which would suit their system and preferences. The EBV calculated in this experiment were calculated from the population of both Angus-sired and Hereford-sired calves born to dairy cows. The Angus bulls in this experiment tended to have lower birth weight, gestation length EBV and greater age at weaning EBV compared with the Hereford bulls, although there was a large range in EBV from bulls across both breeds.

The data collected in the present experiment and data used for the calculation of BreedPlan EBV used different populations of cattle, therefore, different progeny genotypes would be present in each population as a result of mendelian sampling. The relationship between the industry BreedPlan EBV and those calculated in this experiment for birth weight (r^2 : Angus = 0.56, Hereford = 0.37) and gestation length (r^2 : Angus = 0.44, Hereford = 0.57) were moderate; suggesting that the Breedplan EBV can be used to select desirable beef-breed bulls for use in the dairy industry. As the relationship between the industry BreedPlan EBV and the calculated EBV was moderate, using the BreedPlan EBV would be sufficient for selecting within breeds. However, a beef-cross-dairy specific genetic evaluation would offer a comparison between bulls of different breeds.

The relationship between the Breedplan EBV for 200-day weight and the calculated EBV for age at weaning was weak (r^2 : Angus = 0.27, Hereford = 0.11), however, there was a relationship in that bulls with greater 200d weight EBV had smaller age at weaning EBV indicating that the progeny of bulls with heavier 200d EBV would grow faster in an artificial rearing system. The BreedPlan 200d weight EBV is an indicator of pre-weaning growth in a beef rearing system where the calf remains with the cow, and therefore, is calculated using information collected in a different rearing system to the age at weaning EBV, using information from artificially reared calves. Therefore, a beef-cross-dairy EBV specific for artificially reared progeny may be more appropriate. If age at weaning EBV for calves were available at point of sale, farmers would be able to select progeny from bulls with smaller age at weaning EBV which would indicate those calves would reach weaning weight sooner, and therefore cost less to rear. On the other hand, the rearing practices across dairy farms and specialist calf rearers in New Zealand are highly variable (Thomson et al., 2018) and management is likely to impact the performance of progeny, and therefore the occurrence of the genetic and environmental interaction would need further investigation using bulls in a range of rearing systems.

The ideal beef-breed bull for using to mate mixed-aged dairy cows, would produce calves with an equal or better birth weight and gestation length than average alternative Holstein-Friesian bull (40 kg, Hickson et al. (2015); 281 days, Donkersloot (2014)). The 40kg birth weight also coincides with the dairy-beef calf purchase recommendations (Muir et al., 2002, Beef+LambNZ, 2018). Under the BreedPlan genetic evaluation, the ideal bulls would be at or below +7.64 kg / +6.93 kg for birth weight EBV, and for gestation length EBV -2.37 days / -4.60 days for Angus and Hereford bulls, respectively. These thresholds were estimated using the relationship between mean progeny birth weight and gestation length from this experiment and the Breedplan EBV for the bull, weighted by the number of progeny per bull (Appendix A.5). Comparing the threshold EBV to the BreedPlan percentile bands for Angus (ABRI-Breedplan, 2020a) and Hereford (ABRI-Breedplan, 2020b) bulls, the threshold EBV for birth weight and gestation length indicate that there are a greater proportion of Angus bulls than Hereford bulls which would be suitable for mating to dairy cows. This is due to the tendency of the Angus breed to be lighter at birth than Hereford cattle, and that the mean gestation length of Angus cattle is shorter than the dairy average gestation length. In order to produce a calf with an equal or shorter gestation length than a Holstein-Friesian bull, the threshold EBV indicates that only the Hereford bulls within the top ~3% of the breed for gestation length are suitable (ABRI-Breedplan, 2020b).

Because there are a large proportion of appropriate bulls, in terms of low birth weight and short gestation length, within the Angus breed and to a lesser extent the Hereford breed, there is scope for additional selection of other trait EBV, which would increase the value of the calf in the beef industry. These other traits could include growth (400 or 600 day), carcass quality (carcass weight, eye muscle area) and meat quality (intramuscular fat). Using artificial breeding rather than naturally mating increases the choice of bulls, as very superior bulls will be too expensive to purchase for natural mating. There is a great opportunity for breeding companies to offer increased selection among the beef-breed semen currently provided.

Genetic and phenotypic correlations

Birth weight and gestation length had a moderate negative genetic correlation which is in contrast to published literature (range 0.15 - 0.63) (Burfening et al., 1978, Cundiff et al., 1986, Baker et al., 1990, Reynolds et al., 1990, Crews Jr, 2006, Mujibi and Crews, 2009, Jeyaruban et al., 2016). The population of calves in this experiment represents one that has had negative selection pressure applied to both birth weight and gestation length traits by the bull breeders, and when selecting bulls for the present experiment. Birth weight and gestation length are traits which are not commonly selected for by beef-breed bull breeders,

therefore the population of bulls used in the present experiment may be unusual compared to other studies. There was however, a moderate positive phenotypic correlation between birth weight and gestation length, which agrees with other studies which report a positive correlation (Burfening et al., 1981, Cundiff et al., 1986, Baker et al., 1990, Crews Jr, 2006). The negative genetic correlation indicates that selection for shorter gestation length may result in heavier calves at birth, perhaps a result a changing development of short gestation calves so that the calf is fully grown at parturition rather than born prematurely.

Birth weight was negatively correlated (genetic and phenotypic) with age at weaning, which indicates that calves born heavier have greater pre-weaning growth rates, which is supported by experiments in a traditional beef system with positive genetic correlations between birth weight and 200d weight. Therefore, selection of bulls with lighter birth weights would likely be at the detriment of pre-weaning growth, and potentially growth post-weaning. The negative correlations between birth weight and age at weaning also suggests that there may be a threshold for a limit of selection for decreasing birth weights, in order to be desirable for the dairy industry, as this may come at a cost of increased rearing costs for the calf. The bulls in this experiment were suitable for using over mixed-aged dairy cows as there were very few incidences of assisted births. Therefore, selecting to further decrease the birth weight EBV of bulls would be unnecessary. Using bulls similar to those used in the present experiment would generate calves that are weaned at a similar age to dairy breed calves.

Limitations

The individual cow breeds were unknown in this experiment, and so the likely differences in dam breed contributing to variation in calf growth, were unable to be accounted for. Post-calving live weight of the dam was considered in the analysis of pre-weaning growth to account for differences in size of dams, as literature illustrates a size difference between Holstein-Friesian and Jersey cows (Butler-Hogg and Wood, 1982, Burke et al., 1998, Lopez-Villalobos et al., 2000, Heins et al., 2008, Spaans et al., 2018).

The use of a beef-cross-dairy genetic evaluation allowing for the comparison of bulls of different breeds, unlike the current genetic evaluation (BreedPlan) would add value to the beef-cross-dairy calf production. However, the EBV calculated in this experiment were limited by the lack of straight bred calves in the population and that all calves were born on the same farm and reared in the same environment. The breed proportions of the dam and ancestry of the dam was unknown, therefore relationship links between the dams could not be accounted for unlike the sire, for which a 3-generation pedigree was fitted into the calculation of EBV, estimates of heritability and correlations between traits. The unknown

dam breed and lack of dam pedigree meant that heritabilities were unable to be calculated from this dataset, and some genetic variation in the population was unable to be determined. The standard errors of the genetic correlations were large (0.18 – 0.25, Table 2.6) reflecting a large genetic variation in the dataset. The standard errors of the phenotypic correlations were much lower (0.02-0.04, Table 2.6) indicating that the phenotypic variation among the data was smaller. Being able to account for the breed proportions of the dam, and a pedigree of the dam in the calculation of the correlations between traits would result in lower standard errors for the genetic correlations.

In order to provide a more reliable evaluation, a larger population of calves would be needed, increasing the number of progeny per sire with known dam parentage allowing further relationships to be identified.

The calculation of EBV and correlations in the experiment used published heritability estimates for Angus bulls to estimate the genetic variance. Heritability estimates were unable to be obtained for the population because of the limitations in this dataset, therefore, industry estimates were used. Genetic variance for Angus and Hereford bulls was calculated using the Angus heritability estimates as the Hereford values were not publicly available, although the heritability estimate used by BreedPlan for Hereford bulls would likely be similar and any difference would mean only a small over- (if the Hereford heritability estimate was higher than for Angus) or under-estimation of the EBV calculated in the present experiment.

Conclusions

There was variation among the bulls used in this experiment for progeny birth weight, gestation length and age at weaning indicating selection of appropriate bulls could be used to improve performance of calves. The relationship between EBV based on progeny performance in this experiment and BreedPlan EBV was good for birth weight and gestation length traits and indicates that bulls can be selected based on the published BreedPlan EBV. Pre-weaning growth of progeny also varied between sires, however the relationship among the age at weaning EBV calculated in this experiment and the 200-day weight BreedPlan EBV was weak. The rate of assistance at birth in this experiment was very low, indicating that despite the variation among bulls for birth weight, the Angus and Hereford bulls used in this experiment were safe to use over mixed-aged dairy cows. When choosing bulls for using over mixed-aged dairy cows, dairy farmers should pick bulls with low birth weight and short gestation length EBV similar to those used in this experiment. The Angus bulls used in this experiment produced generally shorter gestation and lighter birth weight calves, although were slower to wean than calves sired by Hereford bulls.

Chapter 3 – Body condition score, milk production and rebreeding performance of mixed-aged dairy cows mated to Angus and Hereford bulls

This Chapter has been published in part elsewhere. It has been reformatted and presented here with permission:

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Abstract

Beef-breed bulls are used in dairy herds to produce a calf of greater value for finishing than calves sired by dairy bulls. There is limited research about which beef-breed bulls are most appropriate, and whether any negative impact on cow performance in terms of milk production and rebreeding should be considered, in addition to the increase in calf value. The aim of this experiment was to compare the body condition score, milk production and rebreeding performance of mixed-aged dairy cows mated to various Angus and Hereford beef-breed bulls. Body condition score, post-calving live weight, milk production, rebreeding performance, and survival of 952 mixed-aged dairy cows artificially bred to 31 Angus and 34 Hereford bulls were compared. There was no effect of service sire on post-calving live weight, days in milk, milk production or inter-calving interval of mixed-aged cows ($P > 0.05$). Milk production of the herd was 3338.8 L / 287.2 kg MS, which was low relative to the national average statistics. Service sire had an effect on the date of calving ($P < 0.001$), which was explained by the variation in gestation length ($P < 0.001$), although this did not translate into a service-sire effect on days in milk. The direct effect of service sire could not be determined for pregnancy rate and survival due to few empty or dead cows. However, a longer gestation length negatively influenced pregnancy rate ($P = 0.032$) and greater birth weight of the calf negatively influenced survival to rebreeding ($P = 0.003$) or to pregnancy detection ($P = 0.005$). The relationships with gestation length and birth weight of the calf indicate the potential for an effect of service sire. However, as lighter calves and shorter gestation lengths are preferable for beef-cross-dairy calves, selection of beef-breed service sires with these traits should minimise any negative effects. The cows in the present experiment were low producing, therefore, results should be applied with caution to high producing herds. The general lack of service sire effect on the parameters measured in this study indicates that any of the service sires used in this experiment would be appropriate for use over low-producing dairy cows.

Introduction

In most New Zealand dairy herds, approximately 72% of cows are artificially bred (AB), with the majority bred to genetically superior dairy-breed bulls to produce replacement heifers (DairyNZ, 2019). The remaining cows (approx. 1.4 million nationally) are available to mate to beef-breed bulls to generate a calf with value as a beef finishing animal. These cows would be typically the later-mated cows as it is more practical and desirable to keep calves as replacements from cows calving in the first 6-weeks (Johnson et al., 2018).

Beef-breed bulls are used to produce a calf of greater value for finishing than that of a calf sired by a dairy bull (Hickson et al., 2015). There is limited research about which beef-breed bulls are most appropriate to use as there is no information on any negative impact on cow performance in terms of milk production and rebreeding, which should be considered alongside calf value. Angus and Hereford are the predominant beef-breeds in New Zealand (Beef+LambNZ, 2019a), with Hereford bulls anecdotally used more commonly in the dairy industry than Angus (DairyNZ, 2019), and it is of interest to establish if there is any difference in the milk production or rebreeding success among cows mated to different Angus and Hereford bulls.

Milk production is the primary source of income for the dairy farm, with New Zealand farmers paid for milksolids sold which represents about 93% of dairy farm income (Cook, 2014). In order to lactate in the following season, and survive in the herd, the cow needs to get pregnant again within a tight timeframe, as breeding and calving are restricted to a limited period in order to match feed requirements to the seasonal pasture growth (Macmillan et al., 1990, Grosshans et al., 1997). Poor reproductive performance is undesirable because it delays the mean calving date and decreases the available days in milk, and total milk production (Roche et al., 1992, Xu and Burton, 1996, Grosshans et al., 1997).

Therefore, before making recommendations for sires based on calf performance in Chapter 2, the impact of bull on the body condition score, post-calving live weight, milk production and rebreeding performance of mixed-aged cows must be assessed.

The aims of this experiment were to compare the post-calving body condition score, post-calving live weight, survival, milk production and rebreeding performance of mixed-aged cows producing calves sired by different bulls. Where there was an effect of service sire, it was determined whether birth weight or gestation length of the calf, or calving assistance explained the sire effect on cow performance.

Materials and methods

This study was conducted at C. Alma Baker Trust NZ Ltd. Limestone Downs dairy farm, 16 km south of Port Waikato, New Zealand (latitude: 37.49 S, longitude: 174.77 E). The study and all handling procedures were approved by the Massey University Animal Ethics Committee (MUAEC 15/65).

Animals

This study used records from 952 lactations from mixed-aged cows bred to Angus (n=31) and Hereford (n=34) bulls over 2 years. There were 485 lactation records from 2016 calving cows, and 467 lactation records from 2017 calving cows. There were 270 cows which were present in both years of the experiment.

The herd was predominantly Holstein-Friesian and Holstein-Friesian-Jersey crossbred cows with small proportions of Jersey and Ayrshire (pure and crossed) breeds. The herd was a recently purchased herd (first season 2013-14), where the cows were sourced from multiple properties and had a low level of records (Lawrence et al., 2019). The cows have historically been low producing due to under nutrition and *Theileria Orientalis* infection outbreaks in previous years (Lawrence et al., 2019). Individual cow pedigree recording of the herd was incomplete, with only 68% recorded ancestry. At the beginning of the mating period in 2015 and 2016, cows were at a mean body condition score of 4.18 ± 0.47 (range 2.5 – 6.0) and 4.18 ± 0.49 (range 3.0 – 6.0), respectively. Average herd milk production for the season prior to the experiment (2015-16 lactation average, from herd recording software; MINDA™, LIC, Hamilton, New Zealand) was 2689 L per cow and 229 kg milksolids per cow. At the completion of the experiment (31 May 2018), the herd average milk production (2017-18 lactation average, from MINDA™) was 3191 L with 262 kg milksolids.

Management

Cows were managed under commercial dairy farm conditions. Cows were milked twice-a-day until at least after the rebreeding period. Once-a-day and 16-hour milking were implemented at the discretion of the farm to manage energy demand over summer, and as a management tool near the end of lactation.

The mating of the cows in each year (2015 and 2016) is outlined in Chapter 2. Briefly, cows were artificially bred to Angus or Hereford bulls over a 63- or 54-day period in 2015 and 2016 (Table 3.1), respectively. Bulls were used in mating teams, which were rotated each day of mating; cows submitted for insemination were randomly assigned to bulls available on the day. Semen was collected by commercial breeding companies, and all semen passed

quality control checks prior to freezing. All inseminations were performed by a Livestock Improvement Corporation (LIC) qualified technician. Throughout this chapter, the term ‘service sire’ is used to refer to the sire of the calf resulting from the experimental mating period, from which calving initiated the lactation, not the rebreeding period.

Table 3.1. Dates and lengths of the mating, calving, rebreeding and re-calving periods for cows in year 1 and 2 of the experiment.

	Year 1	Length (days)	Year 2	Length (days)
Mating Period	09/10/15 – 11/12/15	63	10/10/16 – 03/12/16	54
Calving Period	07/07/16 – 17/09/16	72	10/07/17 – 12/09/17	64
Rebreeding Period	10/10/16 – 24/01/17	106	10/10/17 – 19/12/17	70
Re-Calving Period	10/07/17 – 03/10/17	85	05/07/18 – 27/09/18	84

In 2016, calving was from 7 July to 17 September, and in 2017, from 10 July to 12 September. Rebreeding began on October 10 in both years and in 2016, included 10 weeks of AB followed by 5 weeks of natural mating. In 2017, the rebreeding period included 5 weeks of AB followed by 5 weeks of natural mating. Natural mating ratios were 1:26 and 1:18 bulls to non-pregnant cows for 2016 and 2017, respectively.

In 2016, the semen used during rebreeding period was a combination of experimental beef semen, used to generate the second year of experimental calves, followed by dairy-breed semen procured from LIC. In 2017, all semen used was dairy-breed semen sourced from LIC. All inseminations were performed by an LIC qualified technician.

An oestrous synchrony programme using progesterone controlled internal drug release inserts (CIDR) was used in 118 (2016; Cue-Mate 1.56g progesterone, Bayer Animal Health, Auckland, New Zealand) and 83 (2017; DIB-H 0.5g Progesterone, Agri-health, Auckland, New Zealand) cows. In 2016, CIDRs were used over two periods (AB dates 14/10/2016 and 29/10/2016) and only one period in 2017 (AB date 12/10/2017). CIDR allocation was reportedly used for low body condition score cows and later calvers, however, there was no relationship between body condition score and date of calving with whether or not a CIDR was used. On days where the CIDR cows were inseminated, multiple bull teams were used to allow for a maximum of 8 straws per bull in year 1, and 10 straws per bull in year 2. Straws were randomly allocated to cows on each day.

Pregnancy detection was carried out in late December (22/12/2016 and 21/12/2017) and in mid-February (17/02/2017 and 14/02/2018), using trans-rectal ultrasound by veterinarians (Franklin Vets, Pukekohe, New Zealand).

Measurements

Date of calving, date of mating (conception date), birth weight of calf, sex of calf, sire-breed of calf, calving assistance and gestation length were recorded as detailed in Chapter 2. Briefly, calves were weighed within 24 hours of birth, calving assistance was recorded as assisted (regardless of presentation) or not, parentage was determined by DNA and matched with mating records to determine mating date and gestation length.

Body condition score (BCS) was assessed 4 times during each season (Table 3.2). Body condition was scored on a 1-10 scale (DairyNZ, 2012a), and was assessed by the same qualified assessor at each time, in a rotary milking platform from a position behind the cows.

Table 3.2. Body condition score assessment dates over the two seasons

	Year 1 (2016-2017 season)	Year 2 (2017-2018 season)
Pre-calving	14/06/2016	29/06/2017
Rebreeding	28/09/2016	28/09/2017
Late summer	15/02/2017	20/02/2018
Late lactation	11/04/2017	24/04/2018

For the 30 days following calving, cows were weighed following each milking (twice daily) using a ProTrack walk-over-weigh scale (LIC, Hamilton, New Zealand).

Cow milk production data was collected using herd tests performed by LIC (Hamilton, New Zealand) either three (2016) or four (2017) times over the lactation (Table 3.3). Milk yield (MY) was measured using a milk meter, and a sample collected for lab analysis; fat and protein percentages were analysed using an infrared milk analyser (FTIR, Foss Electric, Hillerød, Denmark). Fat (FY) and protein (PY) yields were calculated as MY x fat or protein percentage, respectively; milksolids yield (MS) was calculated as FY + PY.

Table 3.3. Herd test measurement dates over the two seasons

	Year 1 (2016-2017 season)	Year 2 (2017-2018 season)
Pre-mating	02/10/2016	08/10/2017
Early summer	-	04/12/2017
Mid-summer	25/01/2017	21/01/2018
Late lactation	27/03/2017	03/04/2018

Any cow deaths and cows culled from the herd were recorded in herd management software (MINDA™), with date of death or culling. Pregnancy detection result and calving date in the following year (2017 or 2018 for 2016 and 2017 calving cows, respectively) were recorded. Pregnancy rate was recorded as a binary measure, with cows recorded as being pregnant at pregnancy detection, or calving in the following year recorded as '1' and cows not recorded as pregnant and not producing a calf recorded as '0'. Inter-calving interval was recorded as

the number of days from calving in 2016 or 2016 until the calving in the following year. Cows which did not calve in the following year were excluded from analysis. The cows receiving a progesterone CIDR were individually recorded.

Data cleaning

Of the 1450 mixed-aged cows mated (over 2 years), records from 952 mixed-aged dairy cow lactations were included in the analysis (Table 3.4), having been DNA matched to a calf with a DNA verified sire. Cows (within year) which did not get pregnant (n=397) or that did not have a singleton-calf assigned by DNA parentage were not included in the experiment (n=101) (Table 3.4).

Table 3.4. Number of cows present at different time points between mating and re-calving. The indented rows represent the number of cows excluded from the dataset or those which left the herd between two time points.

Time Point	Total number
Cows mated to experimental bulls	1450
excluded (no calf)	397
Cows calved	1053
excluded (non-experimental calf / twin)	101
Experimental dataset	952
left herd between calving and rebreeding	15
Cows in herd at rebreeding	937
left herd between rebreeding and pregnancy detection	27
Cows present in the herd at pregnancy detection	910
Re-calving Period	673

Cow age ranged from 3 to 13 years of age at calving. Due to low numbers of older cows, age groups of 3, 4, 5, 6 or 7+ years of age were used for analysis.

Deviation from median date of successful mating was calculated for all cows, within year, with a calf gestation length record. Cows mated before the median date were assigned a negative value.

Date of calving for individual cows was expressed as days from planned start of calving (2016: 17/07/2016; 2017: 19/07/2017).

The date which the cow was dried off (end of lactation) was taken as the recorded dry off date (n=709) or the date which the cow was removed from the herd, as recorded in MINDA™ (n=80); or, for cows that left the herd before the end of lactation and a removal date was not recorded, when the cow was last recorded as present on the ProTrack (LIC, Hamilton, New Zealand) recording system (n=163). The number of days in milk was calculated as the number of days from calving until the end of lactation.

Cow survival was recorded to rebreeding (October) and to pregnancy detection (February). Survival was recorded as a binary trait, with cows recorded as having survived (1) or not survived (0). Cows were recorded as having survived to mating or to pregnancy detection if they were alive at the beginning of the mating period or at the February pregnancy detection, respectively.

Body condition scores at pre-calving (PC BCS) and rebreeding (RB BCS) were grouped into ≤ 4 , 4.5 and ≥ 5.0 , and ≤ 3.5 , 4.0, 4.5, ≥ 5.0 , respectively, for adjusting for differences in body condition in the analysis of milk production and rebreeding.

A 30-day mean post-calving live weight for individual cows was calculated using all weights recorded in the 30 days post calving. Cows calving in 2016 and 2017 were treated separately. Live weights were cleaned to remove outliers by calculating the mean and standard deviation for each cow. Live weight records for individuals which were more than four standard deviations from the mean within year were removed, and the mean recalculated (Pietersma et al., 2006, Handcock et al., 2019b). This method was iterated until no more records were deleted (Pietersma et al., 2006, Handcock et al., 2019b). This left a dataset comprised of 36,751 live weight records (261 records removed) from 927 cows.

Total lactation milk production per lactation was calculated to a 253-day lactation, determined by the limits of the prediction data (15-267 days). The limits were determined by individual day of lactation at each herd test (across both years), the latest recorded calving was 15 days prior to the first herd test, and the earliest calving cow (therefore greatest day of lactation) was last herd tested on day 267 of lactation. A 253-day lactation yield of milk, fat, protein and milksolids was calculated using daily predicted milk production generated using a third order orthogonal polynomial. A single trait animal model was fitted to milk, fat, protein and milksolids yield data in ASReml (Version 4, Gilmour et al. (2009)). The dataset for milk production consisted of the individual cow herd test data as recorded in MINDA™ against the number of days in milk at each test specific for each cow and included 2949 records from 909 cow lactation records. The regression coefficients generated from these models were used to calculate a predicted daily value.

There were four 2016 calving cows not included in the analysis of milk production due to low milk volumes collected at herd tests leading to negative predicted milk production curves. These cows were all unassisted and calved to different bulls.

Pregnancy rate was calculated as the number of pregnant heifers over the number of heifers having calved. Pregnancy results were aged, however, due to mating records being deemed unreliable following DNA verification, pregnancy was simply recorded as pregnant or not.

Inter-calving interval was calculated as the number of days between the subsequent dates of calving. Cows which were not in the herd at pregnancy detection were not included in the analysis of pregnancy rate, and cows which were not pregnant or did not have a recorded calving in the following season were excluded from the analysis of inter-calving interval. Inter-calving interval was considered for a dataset with only cows which had a re-calving date, and with all cows in the dataset, where cows that failed to conceive were allocated a nominal calving date which was 21-days later than the last recorded date in the respective re-calving period (Morris et al., 2016). The service sire effect was not different between the two datasets, and so only the inter-calving interval using the cows which had a recorded re-calving date is presented.

As a measure of reproductive success during the rebreeding period, 21-day re-calving rate as the proportion of cows calving prior to 21 days following the planned start of calving (as 282 days from the mating start date; 19/07/2017 and 19/07/2018) was determined for the calving following the rebreeding period described in this Chapter and analysed as a binary trait.

As there was no association between CIDR allocation and body condition score, cows treated with a CIDR were not excluded from other measures of reproductive success.

Statistical analysis

Data were analysed using SAS (Version 9.4, SAS Institute Inc., Carey, North Carolina, USA). Body condition score, live weight, date of calving, days in milk, predicted milk production and inter-calving interval were analysed using mixed models while CIDR treatment, pregnancy rate, 21-day re-calving rate and cow survival were analysed using a glimmix model based on a binomial distribution.

The dataset was comprised of all cows which produced a calf in the relevant year (n=952), although cow records for some parameters were missing. For analysis which includes an effect for which a record is missing, individual lactation records were not included in the model.

The effect of service sire was investigated for BCS, post-calving live weight, calving date, days in milk, 253-day milk production, CIDR treatment, inter-calving interval and 21-day re-calving rate. The service sire least squares mean for each parameter were generated and are presented in Appendix B.1. The presented service sire mean date of calving is expressed as days from the planned start of calving. If the effect of service sire was significant ($P < 0.05$) further models were run to investigate whether the inclusion of birth weight, birth weight squared, or gestation length of the calf or calving assistance explained the service sire effect.

The effect of service sire on pregnancy rate and cow survival was unable to be investigated due to low numbers of cows, within service sire, not surviving to rebreeding or pregnancy detection, or not pregnant following the rebreeding period. Instead the effects of birth weight of calf and birth weight squared, gestation length of calf and calving assistance were fitted as characteristics of the service sire.

Models investigating the effect of service sire included the fixed effects of service sire nested within breed, breed of service sire, calving year, age of cow and sex of calf, with cow fitted as a random effect for all models except for CIDR treatment, and inter-calving interval. The fixed effects of PC BCS and RB BCS, and covariates of post-calving live weight and deviation from median date of mating (DOM deviation) were considered in the models indicated in Table 3.5 and were retained where significant ($P < 0.05$) as indicated in Table 3.5. Date of mating deviation and gestation length were fitted as a proxy for calving date, as gestation length was a trait of interest in this experiment.

Table 3.5: Description of the statistical models used, fixed effects, covariates and random effects considered and fitted in each analysis¹ describing the effect of service sire on the performance of mixed-aged cows.

Variable	Model ²	Fixed effects							Covariates		Random
		Service sire ³	Breed of Service sire	Calving year	Sex of calf	Grouped age of cow	PC BCS	RB BCS	Post-calving LWT	DOM deviation	Cow
Body condition score											
Pre-calving	Mixed	B	B	B	B	B			✓	X	B
Rebreeding	Mixed	B	B	B	B	B			X	✓	B
Late summer	Mixed	B	B	B	B	B			✓	✓	B
Late lactation	Mixed	B	B	B	B	B			X	✓	B
Post-calving liveweight	Mixed	B	B	B	B	B				X	B
Calving date ⁴	Mixed	B	B	B	B	B	X	X	X	✓	B
Days in milk	Mixed	B	B	B	B	B	X	X	✓	✓	B
Milk Production											
Milk Yield	Mixed	B	B	B	B	B	X	✓	✓	X	B
Fat Yield	Mixed	B	B	B	B	B	X	X	X	X	B
Protein Yield	Mixed	B	B	B	B	B	X	X	✓	X	B
Milksolids yield	Mixed	B	B	B	B	B	X	X	X	X	B
CIDR treatment	Glimmix	B	B	B	B	B		X	X	✓	
Inter-calving interval	Mixed	B	B	B	B	B		X	X	✓	
21-day re-calving rate ⁵	Glimmix	B	B	B	B	B		X	X	✓	

¹ 'B' illustrates effects that were fitted in each model regardless of the significance, '✓' illustrates effects that were considered and kept in the final model because they were significant at $P < 0.05$, 'X' illustrates effects considered then removed as not significant ($P > 0.05$). ² Glimmix models run specifying a binomial distribution. ³ Service sire nested within breed of service sire. ⁴ Calving date expressed as days from the planned start of calving. ⁵ 21-day re-calving rate: proportion of cows calving prior to 21-days after the planned start of calving. PC BCS: grouped body condition score pre-calving; RB BCS: grouped body condition score at rebreeding; DOMdev: deviation from median date of mating.

The two-way interactions of breed of service sire with calving year, sex of calf with calving year and breed of service sire with sex of calf were considered in all models and were not included in the final models as the interactions were not significant.

The models investigating the effects of service sire, as birth weight of calf, birth weight squared (quadratic effect of birth weight), gestation length of calf and calving assistance, the fixed and random effects, and covariates fitted in each model are indicated in Table 3.6. The models for rebreeding BCS and date of calving were the same as previously indicated in Table 3.5, with the addition of the service sire characteristics traits. An additional model was run to quantify the effect of any significant service sire characteristics removing the service sire traits which were not significant ($P>0.1$).

When fitted together, birth weight, birth weight squared, gestation length and calving assistance did not have an effect on the BCS at rebreeding, however the effect of service sire was explained, therefore, the sire characteristic effects of birth weight, gestation length and calving assistance were fitted separately.

For survival to rebreeding and to pregnancy detection, where birth weight had both a linear and quadratic effect, the estimate of survival and 95% confidence interval over the range of calf birth weights were generated using the estimate function in SAS for the model (birth weight graph) indicated in Table 3.6. The proportion of cows in each level for the fixed effects fitted in the model was specified.

Table 3.6: Description of the statistical models used, fixed effects, covariates and random effects considered and fitted in each analysis
¹ describing the effect birth weight of calf, gestation length of calf and calving assistance on the body condition score (BCS) at rebreeding, date of calving, pregnancy rate and survival to rebreeding and pregnancy detection.

Variable	Model ²	Fixed effects				Covariates			Random	Characteristics of service sire				
		Service sire ³	Breed of Service sire	Calving year	Sex of calf	Grouped age of cow	RB BCS	Post-calving LWT	DOM deviation	Cow	Calving assistance	Gestation length of calf	Birth weight of calf	Birth weight of calf squared
BCS at Rebreeding	Mixed	B	B	B	B	B		✓	B	X	X	X	X	
Birth weight effect	Mixed	B	B	B	B	B		✓	B			X		
Gestation length effect	Mixed	B	B	B	B	B		✓	B		X			
Calving assistance effect	Mixed	B	B	B	B	B		✓	B	X				
Calving date ⁴	Mixed	B	B	B	B	B		✓	B	X	✓	X	X	
Gestation length effect	Mixed	B	B	B	B	B		✓	B	X	✓			
Pregnancy rate	Glimmix		B	B	B	B	✓	X	✓		X	T	X	X
Gestation length effect	Glimmix		B	B	B	B	✓		✓			✓		
Survival to rebreeding	Glimmix		B	B	B	B		X	X		X	X	✓	✓
Birth weight figure	Glimmix		B	B	B	B							✓	✓
Survival to pregnancy detection	Glimmix		B	B	B	B		X	X		X	X	✓	✓
Birth weight figure	Glimmix		B	B	B	B							✓	✓

¹ 'B' illustrates effects that were fitted in each model regardless of the significance, '✓' Illustrates effects that were considered and kept in the final model because they were significant at P<0.05, 'T' Illustrates an effect that was considered and kept in the final model because it tended to be significant P<0.1, 'X' illustrates effects considered then removed as not significant (P>0.1). ² Glimmix models run specifying a binomial distribution. ³ Service sire nested within breed of service sire. ⁴ Calving date expressed as days from the planned start of calving. RB BCS: grouped body condition score at rebreeding; DOMdev: deviation from median date of mating.

Results

The service sire did not affect the BCS of cows at calving, pregnancy detection or late lactation, or post-calving live weight (Table 3.7). There was, however, an effect of service sire on the BCS of cows at rebreeding ($P=0.045$, Table 3.7; Figure 3.1), although the variation between service sire least squares means was 0.82 condition scores (3.64 to 4.46).

Table 3.7. Mean and standard deviation (SD) of the service sire mean cow body condition score, post-calving live weight, date of calving, days in milk, predicted 253-day milk production, CIDR use at rebreeding, the inter-calving interval, and the proportion of cows calved within 21-days of the planned start of calving.

	Mean	SD	P (service sire) ¹
Body condition score (1-10 scale)			
Pre-calving (June)	4.51	0.10	0.840
Rebreeding (September)	4.04	0.16	0.045
Late Summer (February)	4.15	0.10	0.653
Late lactation (April)	4.44	0.12	0.297
Post-calving live weight (kg)	463.1	7.1	0.207
Date of calving (days from planned start of calving)	21.1	2.8	<0.001
Days in milk (days)	260.3	9.0	0.888
Milk production			
253-day milk yield (L)	3338.8	143.6	0.518
253-day fat yield (kg)	157.2	6.3	0.596
253-day protein yield (kg)	129.9	5.3	0.478
253-day milksolids yield (kg)	287.2	11.1	0.516
Rebreeding			
CIDR treatment (%)	20.3		0.948
Inter-calving interval (days)	369.6	7.1	0.113
21-day re-calving rate (%)	52.3		0.870

¹ Service sire nested within service sire breed.

There was an effect of service sire on the date of calving, expressed as days from the planned start of calving, where the service sire least squares means ranged 13.2 days ($P<0.001$, Table 3.7; Figure 3.2), however this did not translate into a difference in the days in milk ($P=0.201$).

The service sire also had no effect on the milk production of the cows, nor the proportion of cows receiving CIDR treatment and the inter-calving interval ($P>0.05$; Table 3.7).

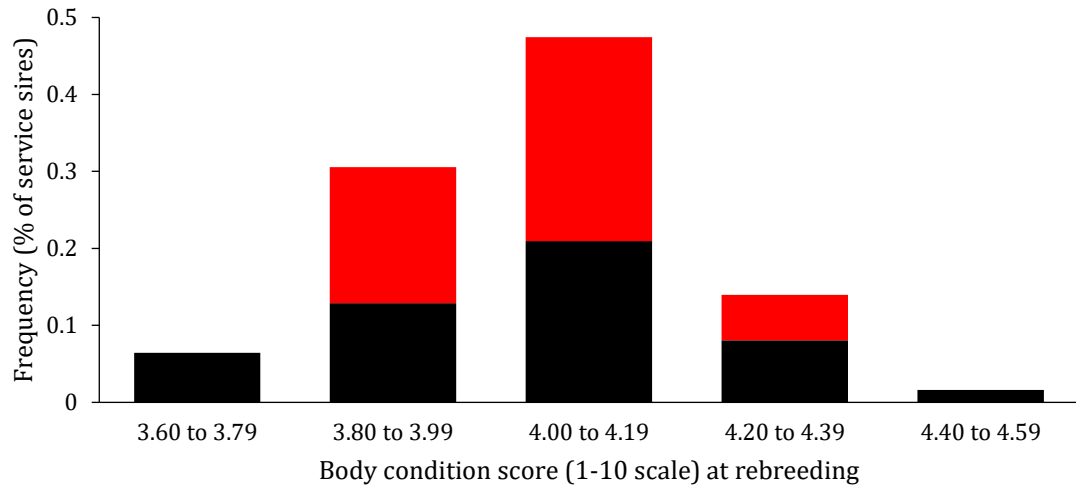


Figure 3.1. Distribution of least squares mean cow body condition score at rebreeding for each of the service sires, presented as a proportion of the Angus (black bar, 31 bulls) and Hereford (red bar, 34 bulls) bulls used.

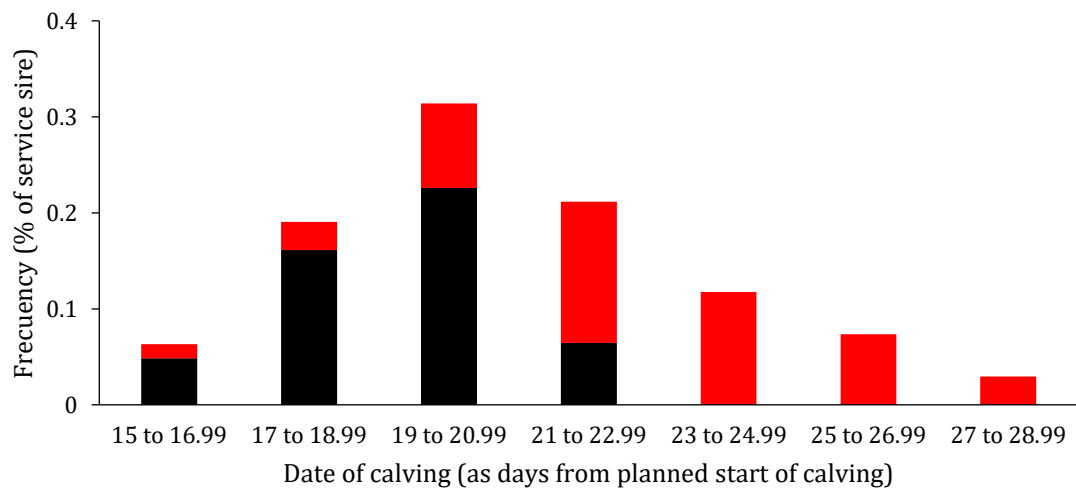


Figure 3.2. Distribution of least squares mean calving date, expressed as days from the planned start of calving for cows bred to each of the service sires, presented as a proportion of the Angus (black bar, 31 bulls) and Hereford (red bar, 34 bulls) bulls used.

Mean cow performance (for the parameters included in Table 3.7) for each of the service sires are presented in Appendix B.1. The proportion of cows requiring calving assistance was 1.37%. There were insufficient incidences of assisted calvings to investigate an effect of service sire.

There was an effect of service sire on BCS at rebreeding and date of calving. Therefore, birth weight, birth weight squared, and gestation length of the calf and calving assistance, as

characteristics of the service sire which could be contributing to the variation, were considered in order to identify which explained the effect of service sire.

Neither birth weight of calf, birth weight squared, gestation length of the calf, or calving assistance ($P>0.05$) had an effect on cow rebreeding BCS. However, the effect of service sire was no longer significant ($P=0.055$) when fitting the previously mentioned characteristics, therefore effects were considered separately. Neither birth weight, gestation length or calving assistance had an effect on BCS at rebreeding ($P>0.05$).

The effect of gestation length of the calf ($P<0.001$) explained the variation in service sire on the date of calving ($P=1.000$) as calves with longer gestation lengths were born later in the season. Birth weight, birth weight squared, and calving assistance had no effect on the date of calving ($P=1.000$).

Neither birth weight of calf, birth weight squared, nor calving assistance had an effect on pregnancy rate ($P>0.05$), however, gestation length of calf tended to be significant ($P=0.063$), therefore was considered without the other characteristics. For every day shorter the calf gestation, a cow was 1.049 times (odds ratio; 95% confidence interval 1.004 – 1.095) more likely to get pregnant in the following breeding season ($P=0.032$).

Birth weight of the calf had both a linear and quadratic effect on survival of the dam in the herd to rebreeding (linear: 1.205 ± 0.297 $P=0.003$, quadratic: -0.017 ± 0.005 $P<0.001$) and survival to pregnancy detection (linear: 0.779 ± 0.274 $P=0.005$, quadratic: -0.011 ± 0.004 $P=0.003$), where cows producing heavier calves had lower survival than cows producing medium sized calves (Figure 3.3). Gestation length of calf, and calving assistance had no effect on survival to rebreeding or pregnancy detection ($P>0.05$).

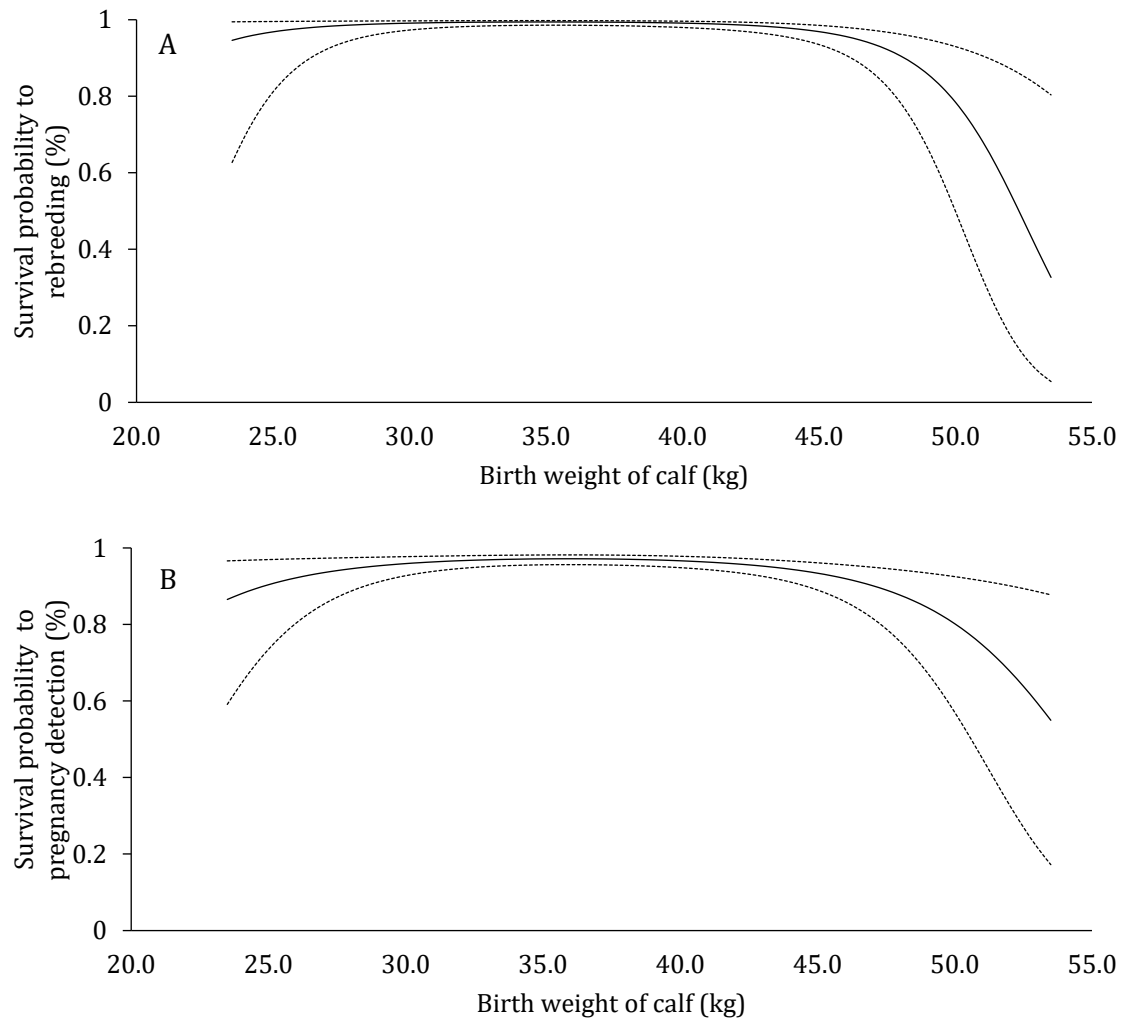


Figure 3.3. Probability of survival to rebreeding (A) and to pregnancy detection (B) of mixed-aged cows having produced calves of different birth weights, with 95% confidence intervals indicated by a dashed line.

For a cow producing a 25 kg calf, the likelihood of surviving in the herd to rebreeding was 96.8% and to pregnancy detection was 90.4%. For a 30 kg calf the survival likelihoods were 99.1% and 95.9%, for a 40kg calf likelihoods were 99.1% and 96.7%, and for a 45 kg calf likelihoods of 96.9% and 93.4%, for survival to rebreeding and pregnancy detection, respectively.

Discussion

This experiment showed that service sire did not affect milk production, inter-calving interval, date of calving and 21-day re-calving rate. Several authors report a relationship of birth weight and gestation length with milk production and reproductive performance, and studies that reported a service sire effect attribute it to sire-differences in these characteristics (Adkinson et al., 1977, Thatcher et al., 1980). Nevertheless, in the present experiment there was no effect of service sire effect in spite of differences in birth weight among sires (Chapter 2).

Of the eight key areas impacting reproductive performance in New Zealand dairy cattle (DairyNZ, 2017b): condition score & nutrition, heifer management, calving pattern, heat detection, rebreeding service bulls, cow health, non-cyclers and genetics; the only factor for which variation could be attributed to the service sire is the calving pattern through variation in gestation length. The effect of gestation length was evident on pregnancy rate, although gestation length did not appear to influence other reproductive traits. Given the main drivers of reproductive success in dairy herds are good oestrous (heat) detection, parity, a positive energy balance driven by good nutrition and artificial breeding technique (Claus et al., 1983, Westwood et al., 2002, Roche et al., 2011) rather than service sire, it is unsurprising that there was no service sire effect on rebreeding. The exception is difficult calving, which reduces subsequent in-calf rate (Laster et al., 1973, Gaafar et al., 2011) and can be influenced by sire through birth weight of calf (Burfening et al., 1978, Arthur et al., 2000, Hickson et al., 2008b, Mee, 2008). However, in the present experiment, assistance rate was low, and no bulls caused significant calving difficulty.

There was a service sire effect on BCS at rebreeding, which could not be explained by birth weight of calf, gestation length of calf or calving assistance. To the author's knowledge, there is no literature evaluating the effect of birth weight of the calf, gestation length of calf or calving assistance on the body condition score of cows after calving. The effect of service sire on BCS at rebreeding is therefore unable to be explained within the parameters of the data collected in the present experiment. It is possible that the relationship between service sire and BCS at rebreeding is spurious. More research would be needed to determine whether the effect is real, and if so, to determine the mechanism. There was no service sire effect on BCS pre-calving, late summer and the end of lactation.

There was variation in the calving date between the different service sires, where cows serviced by sires producing longer gestation calves, calved later in the season. However, this did not translate into a difference in the days in milk in this herd. The service-sire effect on

the date of calving was not unexpected given the variation in mean progeny gestation length of the service sires (Chapter 2) and the fixed breeding period. The effect of gestation length on the calving pattern is in agreement with studies in seasonal calving dairy cows (Macmillan and Curnow, 1976, Macmillan, 2002, Norman et al., 2009). Literature also suggests a relationship between gestation length and the number of days in milk, in seasonally calving dairy herds, which was not evident in the present experiment (Norman et al., 2009, Hess et al., 2016).

The influence of gestation length on subsequent reproductive performance was less clear – longer gestation was associated with a lower pregnancy rate in the following breeding season. However, there was no effect of service sire, indicating no gestation length effect on subsequent inter-calving interval or 21-day re-calving rate, which are typically related to the pregnancy rate. The variation in reproductive performance among cows bred to different service sires may have been masked by the set breeding period, where the majority of cows had calved early enough in the season to be cycling prior to the start of the breeding period. The post-partum anoestrous interval of New Zealand dairy cows is approximately 40 days with reported intervals ranging from 29 to 85 days (Fielden et al., 1973, Burke et al., 1995, McDougall et al., 1995); in the present experiment, 88% of cows had calved at least 40 days prior to the start of the rebreeding period. It was not clear why there was an effect of gestation length on pregnancy rate, but seemingly no variation in conception date. The results indicate that there may have been acyclic cows influencing this result, however, cyclic activity was not in the scope of this experiment. Additionally, the submission rate was unable to be determined from the data but would have been helpful information to identify acyclic cows. Therefore, further research is needed to identify the mechanism influencing pregnancy rate without affecting the inter-calving interval or 21-day re-calving rate.

The birth weight of the calf had a linear and quadratic effect on the survival of the cows, where, within the range of calf birth weights observed, cows producing heavier calves were less likely to survive. The association between birth weight of calf and cow mortality agrees with literature which indicates that dystocia can increase the risk of cow mortality (Philipsson, 1976, Maltecca et al., 2006, Stafford, 2011, Fouz et al., 2013), and calf birth weight is the primary factor affecting risk of dystocia (Philipsson, 1976, Mee, 2008, Stafford, 2011). There was no effect of calving assistance on the survival, however, there may have been cows that experienced a difficult calving which were not assisted in the present experiment. There was also a relationship between the calf surviving the calving period (Chapter 2) and the likelihood of the cow surviving to rebreeding and to pregnancy detection where if the calf did not survive, the cow was more likely to die also. It is possible

that these are not cause and effect, but rather that survival of both cow and calf are impaired by some other adverse effect, however, death rates were not high enough to warrant further investigation in this experiment.

The average predicted milk production for cows in this herd was 285.6 kg MS (1.13 kg MS/day) for the 253-day predicted period, which is less than the herd-test average of New Zealand dairy cows (381 kg MS, 1.41 kg MS/day, 271 day lactation (DairyNZ, 2019)). The results in this experiment were limited in that milk yield could not be predicted outside the period of day 15 to 267 of lactation, however it is clear that the cows in this experiment were producing below the national average indicating the cows were on a low plane of nutrition. This is supported by the mean body condition scores pre-calving (4.52 ± 0.42) and rebreeding (4.05 ± 0.49) which were less than or close to the industry recommended minimum BCS (5.0 at calving and 4.0 at mating for cows 4 years-of-age or older, 5.5 and 4.5 respectively for 3 year-old cows, DairyNZ (2012a)), indicating that a large proportion of cows were below target (78% below minimum at calving, 39% below at rebreeding). The low body condition scores and low plane of nutrition would likely prevent the animals from reaching their milk production potential, and limit their reproductive performance (Buckley et al., 2003, Valour et al., 2013).

The effect of underfeeding, causing a negative energy balance, on milk production and reproductive success has been studied, comparing similar genetic merit cows for milk production, where underfed cows produced less milk (Valour et al., 2013) and had lower pregnancy rates, conception rates and a longer post-partum anoestrous interval (Flux and Patchell, 1954, Grainger and Wilhelms, 1979, Randel, 1990, Valour et al., 2013). This depression of performance may contribute to any effects of service sire on milk production and reproduction being dimmed or overshadowed. Consequently, further work is needed to ascertain whether service sire effects are seen in higher producing cows.

The main measures of reproduction in the New Zealand dairy industry are the 6-week in-calf rate, the 3-week submission rate, and conception rate (DairyNZ, 2017b), which are used to compare performance between herds and determine a national average. In the second year of the present experiment, mating records were not available to determine 6-week in-calf rate, 3-week submission rate or conception rate. The mating records used to determine gestation length in previous years indicated poor oestrous detection in the herd with a high proportion of irregular returns, reducing the value of these parameters to assess sire impacts in this herd. There was an uneven distribution of bulls between the 2 years of the experiment, therefore an effect of service sire was not analysed for the rebreeding of just the first year of the experiment where the successful mating date was known for the cows

used in both years of the experiment. The pregnancy detection result and subsequent calving date, as recorded in MINDA™ were available, therefore, these measures were used to determine rebreeding success as pregnancy rate, inter-calving interval and 21-day re-calving rate as the proportion of cows calving in the first 3-weeks following the planned start of calving. The 21-day re-calving rate has been reported in the range 44.4 – 51.2% for New Zealand dairy cows for three- and four-year-old cows, indicating that the Limestone Downs herd was achieving average reproductive performance (Handcock et al., 2020).

The breed proportions of the individual cows in this experiment could not be accounted for, however, the bulls were randomly assigned to the cows in this experiment so any effect of cow breed should be small when considering differences among sires. The lack of difference in the cow milk production among service sires suggested that the cow breed distribution was similar among service sires because there is known variation in volume and milk composition among Friesian, Jersey and crossbred cows (Lopez-Villalobos et al., 2000). There were only 6 bulls that had fewer than 10 calves, therefore for the vast majority of bulls, the progeny group were from a reasonable sample of cows.

In conclusion, there were no differences in the post-calving, late summer or end of lactation body condition score, post-calving live weight, milk production, inter-calving interval or 21-day re-calving rate of cows serviced by the Angus or Hereford bulls used in this experiment. The lack of service sire effect on these parameters indicates that any of the service sires used in this experiment would be appropriate for use over low-producing dairy cows. Service sire did have an impact on the date of calving through variation in gestation length, however, this did not translate to a difference in the days in milk. There was also a negative effect of increased birth weight of the calf on cow survival, and of longer gestation length of the calf on pregnancy rate. The effects of heavy calves and long gestation indicates that the choices farmers are making regarding service sires are right in preferring bulls which produce calves that are not too heavy with shorter gestation lengths.

Chapter 4 – Body condition score, milk production and rebreeding performance of first-calving heifers mated to Angus, Hereford or Jersey bulls, and birth weight and pre-weaning growth and survival of their calves.

Abstract

The most prevalent bull breed for mating with dairy heifers in New Zealand is Jersey because it generates a lighter birth weight calf with lower calving difficulty. The calf born from a heifer is not often kept as a replacement dairy heifer as the calves are generally smaller than those born to mixed-aged cows as the heifer is still growing. Calves from heifers are typically sent for slaughter at less than 2 weeks old. The surplus calves born to heifers have the potential for rearing for beef production, which provides the opportunity of using beef-breed bulls and producing a calf of greater value than that of a dairy bull sired calf. Producing a greater value beef-sired calf must not be outweighed by compromising the level of milk production, rebreeding success, health or survival of the heifer. The objectives of this Chapter were to compare the body condition score, pre-calving live weight, milk production and rebreeding success of first calving heifers mated to Angus, Hereford and Jersey bulls; and to compare the calves during the calving and pre-weaning periods. The experiment included 304 heifers calving in either 2016 or 2017. Angus and Hereford bulls were chosen to be very low birth weight, within the lightest 15% of breed for birth weight estimated breeding value (EBV), with consideration given to the direct calving ease EBV. Jersey bulls were chosen to be breed average gestation length and live weight breeding value. The performance of the heifers and the resulting calf was measured from mating to the end of the resulting lactation (heifer) and from birth until weaning (calf). The aim of this experiment was to compare Angus, Hereford and Jersey bulls in terms of the performance of heifers mated to, and calves sired by bulls of each breed. Calves sired by Angus and Hereford bulls were 3.4–4.3 kg and 3.5–6.5 kg heavier at birth over the two years, respectively, than Jersey-sired calves. There was a 3.7% and 3.6–10% incidence of assistance at birth for Angus- and Hereford-sired calves, respectively, over the two years. No Jersey-sired calves were assisted. There was no difference in the body condition score, pre-calving live weight, milk production, pregnancy rate, inter-calving interval, re-calving date and 21-day re-calving rate of heifers mated to the different breeds of bulls. The results from this experiment suggest that Angus and Hereford bulls of low birth weight EBV can be used with low rates of calving assistance and without negative effects on the milk production and rebreeding of the heifer and may produce a calf of greater value than a Jersey-sired calf.

Introduction

The most prevalent bull breed for mating with dairy heifers in New Zealand is, anecdotally, Jersey because it generates a lighter birth weight calf, and lower calving difficulty (DairyNZ, 2007, Hickson et al., 2015). The majority of dairy heifers are bred by natural mating, with a small proportion artificially bred (20% of heifers, (DairyNZ, 2019)). Artificial breeding of heifers is often more difficult than natural mating due to the additional facilities, time, labour and heat detection requirements involved in inseminating non-lactating heifers around the time of puberty attainment (DairyNZ, 2017b, DairyNZ, 2020b). There is little selection in terms of genetic merit for bulls used for natural mating, as the main purpose of these matings is to achieve a pregnancy, rather than the characteristics of the resulting calf. The calf from a heifer calving is not often kept as a replacement dairy heifer as the calves are generally smaller than those born to mixed-aged cows as the heifer is still growing and will likely be of low or unknown genetic merit (Hickson et al., 2015, Handcock et al., 2019a). Surplus dairy-sired calves from the dairy industry are typically sent for slaughter at less than 2 weeks old (Thomas and Jordaan, 2013, Cook, 2014, Hickson et al., 2015, Handcock et al., 2019a). In 2014, c. 1.7 million calves were processed as bobby calves at less than 2 weeks of age, and 836,000 were reared and finished for beef (Cook, 2014, Hickson et al., 2015). The surplus calves born to heifers have the potential for rearing for beef production, which provides the opportunity of using beef-breed bulls and rearing progeny. Beef-breed bulls can be used to produce a calf of greater value than that of a dairy bull sired calf (Hickson et al., 2015), which would also be born early in the season. However, this must not be outweighed by compromising the level of milk production, rebreeding success, health or survival of the heifer.

Heifers in New Zealand are typically mated for the first time at 15 months-of age and calve at 22-24 months-of age (Handcock et al., 2018, Handcock, 2019). At two years-of-age, heifers have yet to reach mature weight, with industry targets of 60% of mature weight at first-mating and 90% at first-calving (McNaughton and Lopdell, 2012, Handcock et al., 2016, DairyNZ, 2017a, DairyNZ, 2017b). These live weight targets are set to ensure that heifers achieve good reproductive performance and milk production (McNaughton and Lopdell, 2012, Handcock et al., 2016). As heifers typically have the best genetics in the herd, it is beneficial to breed replacements from these heifers to maximise herd genetic gain (Handcock et al., 2019a), whether at first mating, or more commonly at the second mating.

Ensuring high reproductive success at the second mating of these heifers (at ~27 months-of-age) and ensuring survival of the first lactation is important for improving the genetics

of the herd. However, there is a high wastage of dairy heifers due to low rebreeding success (Kerslake et al., 2018, Handcock, 2019). Growth of heifers is important for minimising the risk of calving difficulty as an artefact of feto-maternal size disproportion (Lombard et al., 2007, Mee, 2008), and also for rebreeding success (Meijering, 1984, McNaughton and Lopdell, 2012, Fouz et al., 2013, Handcock et al., 2016, Handcock et al., 2019a, Handcock et al., 2019b). Calving difficulty also can have negative follow-on effects on rebreeding performance and milk production (Brinks et al., 1973, Laster et al., 1973, Meijering, 1984, Buckley et al., 2003, Mee, 2008, Hickson et al., 2010, Fouz et al., 2013). There is also a positive relationship between live weight and first lactation milk production (Handcock et al., 2018).

The objectives of this Chapter were to compare the body condition score, pre-calving live weight, milk production and rebreeding success of first calving heifers mated to Angus, Hereford and Jersey bulls; and to compare the calving and pre-weaning performance of the resulting calves.

Materials and Methods

This study was conducted at C. Alma Baker Trust NZ Ltd. Limestone Downs dairy farm, 16 km south of Port Waikato, New Zealand (latitude: 37.49 S, longitude: 174.77 E). The study and all handling procedures were approved by the Massey University Animal Ethics Committee (MUAEC 15/65).

Animals

This experiment included 304 singleton calves born to first-calving heifers over a three-month period (July to September) in each of two consecutive years (2016, n=183; 2017, n=121). Data from calves born alive or dead and their dam were included in the experimental analysis.

The herd was predominantly Holstein-Friesian and Holstein-Friesian-Jersey crossbred cows with small proportions of Jersey and Ayrshire (pure and crossed) breeds. However, individual cow breed recording of the herd was incomplete, with only 68% recorded ancestry (Chapter 3).

Angus and Hereford yearling bulls were chosen based on estimated breeding values (EBV) to be in the top 15% of breed for calving ease and low birthweight. Jersey bulls were breed average for live weight and gestation length breeding values (BV). The Breedplan birth weight, gestation length and direct calving ease EBV for each bull as at June 2019 are presented in Appendix C.1. for Angus and Hereford bulls. The LIC gestation length and live weight BVs for each Jersey bull as at January 2020 are also presented in Appendix C.1. Data from this experiment did not contribute to the calculation of the EBV or BVs for these bulls.

In 2015, the threshold for direct calving ease EBV was the top 15% of the breed, with the mean bull direct calving ease EBV 9.45% for Angus bulls and 8.08% for Hereford bulls, with birth weight EBV of 0.88 kg and 1.28 kg, respectively, with the 2015 Angus bulls in the top 5% of the breed and Hereford in the top 10% of the breed that year. For the 2016 breeding season, the mean direct calving ease EBV was 9.75% for Angus and 12.80% for Hereford bulls, with all bulls in the top 5% of their respective breed for that year. Mean birth weight EBV was 0.75 kg for the Angus bulls, and -0.5 kg for the Hereford bulls.

Management of heifers

Heifers were managed under commercial dairy farm conditions. Heifers were milked twice-a-day until at least after the rebreeding period. Once-a-day and 16-hour milking were implemented at the discretion of the farm to manage energy demand over summer, and as a management tool near the end of lactation. The heifers were grazed in a single mob prior

to and after mating until calving; with exception to 5 weeks prior to mating in year 2 (24/08/2016 – 28/09/2016), where heifers were split into a light (<250kg) and heavy (>250kg) grazing mob and the light heifers were preferentially fed.

Mating

The first mating of the heifers (2015, n=237; and 2016, n=135) was to generate experimental calves. Heifers were randomly allocated to mobs for mating with each breed. In the first year of the experiment (2015 mating, 2016 calving), 84, 74 and 79 maiden heifers were naturally mated to Angus (n=4), Hereford (n=4) and Jersey (n=4) bulls, respectively. The bulls were grazed with the heifers in separate mobs for 69 days (Table 4.1; 01/10/2015 – 09/12/2015). The calving period was from 04/07/2016 – 11/09/2016 (Table 4.1).

In year 2 (2016). In the second year of the experiment (2016 mating, 2017 calving), 57, 56 and 22 maiden heifers were naturally mated to Angus (n=2), Hereford (n=2) and Jersey (n=4) bulls, respectively. A 270 kg minimum weight threshold was imposed in the 2016 breeding period, where only heifers meeting the weight threshold were mated to Angus or Hereford bulls. The Jersey group contained the heifers (n=73) not meeting the minimum weight threshold, these heifers and their calves were not included in the experiment. The bulls were grazed with the heifers in separate mobs for 54 days (1/10/16 – 24/11/16) then all heifers were grazed in one mob with all 8 bulls for 12 days (24/11/16 – 06/12/16). The calving period was from 02/07/2017 – 08/09/2017 (Table 4.1).

Table 4.1. Dates and length of the mating, calving, rebreeding and re-calving periods for heifers in year 1 and 2 of the experiment.

	Year 1	Length (days)	Year 2	Length (days)
Mating Period	01/10/15 – 09/12/15	69	01/10/16 – 06/12/16	66
Calving Period	04/07/16 – 11/09/16	69	02/07/17 – 08/09/17	68
Rebreeding Period	10/10/16 – 24/01/17	106	10/10/17 – 19/12/17	70
Re-Calving Period	10/07/17 – 03/10/17	85	06/06/18 – 22/10/18	138

Rebreeding

The rebreeding performance of the heifers was recorded for the second mating of the heifers (2016 and 2017). Heifers were mated at the same time as the mixed-aged cows as outlined in Chapter 3. Briefly, rebreeding began on October 10 in both years and included 10 weeks of AB in 2016, and 5 weeks of AB in 2017 followed by 5 weeks of natural mating in each year (Table 4.1). Natural mating ratios were 1:26 and 1:18 non-pregnant cows for 2016 and 2017, respectively.

A CIDR (controlled internal drug release) programme was used in 28 (2016) and 17 (2017) heifers. In 2016, CIDRs were used over two periods (insertion dates 4/10/2016 and 19/10/2016) and only one period in 2017 (insertion date 2/10/2017), with the CIDRs removed after 7 days and insemination occurring 10 days after insertion. As outlined in Chapter 3, CIDR treatment was reportedly used for low body condition score and late calving heifers, however, there was no association between whether a CIDR was used and calving date or condition score.

Pregnancy detection was carried out in late December (22/12/2015, 21/12/2017) and in mid-February (17/02/2016, 14/02/2017), by trans-rectal ultrasound by a veterinarian (Franklin Vets, Pukekohe, New Zealand).

Heifer measurements

Body condition score (BCS) was assessed 6 times for each cohort (Table 4.2). Body condition was scored on a 1-10 scale (DairyNZ, 2012a), and was assessed by the same person throughout the experiment. For the measurements at mating, pregnancy detection and pre-calving, heifers were assessed in a raceway in cattle yards, where the heifer could be viewed from the top, side and behind. Post-calving, the milking heifers were assessed from behind when they were on a rotary milking platform.

Table 4.2. Body condition score assessment dates for each cohort

	Year 1 (2016-2017 season)	Year 2 (2017-2018 season)
Mating ¹	15/10/2015	28/09/2016
Pregnancy detection ¹	18/02/2016	15/02/2017
Pre-calving ¹	14/06/2016	29/06/2017
Rebreeding	28/09/2016	28/09/2017
Late summer	15/02/2017	20/02/2018
Late lactation	11/04/2017	24/04/2018

¹ All heifers were assessed in a raceway rather than the rotary platform, and liveweight was also measured at these timepoints.

Prior to calving live weight of heifers was measured, coinciding with BCS assessment at mating, pregnancy detection and pre-calving. Live weight was measured when heifer was standing upon a scale platform in a crate, using Tru-test weigh head (EziWeigh7i; Tru-Test, Auckland, New Zealand) and load cells.

Lactation

Heifers were herd tested by LIC (Hamilton, New Zealand) three (2016) or four (2017) times over the lactation (Table 4.3). Milk yield (MY) was measured using a milk meter, and a sample collected for lab analysis; fat and protein percentages were analysed using an infrared milk analyser (FTIR, Foss Electric, Hillerød, Denmark). Fat (FY) and protein (PY)

yields were calculated as MY x fat/protein percentage; milksolids yield (MS) was calculated as FY + PY.

Table 4.3. Herd test measurement dates over the two seasons

	Year 1 (2016-2017 season)	Year 2 (2017-2018 season)
Pre-mating	02/10/2016	08/10/2017
Early summer	-	04/12/2018
Mid-summer	25/01/2017	21/01/2018
Late lactation	27/03/2017	03/04/2017

Any heifer deaths and heifers removed from the herd were recorded in herd management software (MINDA™, LIC, Hamilton, New Zealand), with date of death or removal. Pregnancy detection result and calving date in the following year were recorded. Pregnancy rate was recorded as a binary measure, with heifers recorded as being pregnant at pregnancy detection, or producing a calf in the following year recorded as '1' and heifers not recorded as pregnant and not producing a calf were recorded as '0'. Inter-calving interval in days was recorded as date of subsequent calving less date of calving within each year of the experiment. Any heifers receiving a progesterone CIDR were recorded.

Calf management

Calving

All calves born in the previous 24 hours (alive or dead) were brought into the calf shed daily at approximately 10 am. Breed of the calf was estimated by visual assessment of the calf and reference to the mating record of the farmer recorded dam. Visual assessment of the calf consisted of looking at coat colour and checking if the calf was polled or had a white face. The live calves were tagged with a visual and electronic tag upon arrival at the shed.

Calving assistance was scored on a scale of 1-5, representing: no assistance (1), easy pull (2), hard pull or mechanical assist (3), vet assistance (4) and malpresentation (5). Guidelines for checking calving heifers was maximum 6 hours between checks. Heifers due to calve were at least checked first in the morning and last in the afternoon, with assistance given at the discretion of the farm staff. Parentage and therefore sire-breed was determined by DNA parentage assignment (Zoetis, Dunedin, New Zealand), using tissue samples obtained by taking a small section of an ear with a punch gun (Allflex).

Calf rearing

All calves were fed 2 litres of first milking colostrum within 24 hours of arrival in the calf shed. Jersey-sired calves were removed from the experiment after arrival in the calf shed. Angus- and Hereford-sired calves were reared until weaning.

In year 1 only, 68 of the first-born Angus- and Hereford-sired calves were sent to a professional calf rearer in Tirau (Top Notch Calves) at a minimum of 7 days old until weaning. The remainder of the calves born in year 1, and all Angus- and Hereford-sired calves born in year 2 were reared on the dairy farm. For the period from birth until weaning any deaths were noted, along with the date, and, if known, the cause of death.

Calves kept on the dairy farm were reared under commercial management until weaning. Calves were housed in pens of between 8 and 17 calves for between 2-6 weeks of age, dependent on shed availability and suckling ability. Calves were allocated to groups of similar age and size. Calves were group-fed 4 litres of whole milk per day over 2 feeds while housed. Calves were turned out to pasture into mobs of maximum 68 calves. Calves on pasture were group-fed from a mobile feeder 4 litres of whole milk per calf per day, initially over two feeds per day, then later one feed per day. All calves were offered *ad libitum* meal and water from birth until weaning

Calves sent to the commercial calf rearer were offered 3L/feed twice a day for the first 3 weeks, then 4L once a day until weaning. Calves were fed colostrum or whole milk for approximately 6 weeks, and a 50:50 mixture of stored colostrum and milk powder (Ancalf, NZAgBiz, Hamilton, New Zealand) for the remainder of the time until weaning. All calves were offered *ad libitum* meal until weaning and were housed in a calf shed for the entire pre-weaning period.

Weaning

Calves reared at the Limestone Downs dairy farm were weaned off milk at a target of 85 kg. Weaning began on October 5th in both years, with calves being weighed regularly as determined by the dairy farm (between 1- and 3-week intervals) until all calves were weaned. All calves at the calf rearer were weighed weekly and weaned to a minimum of 75 kg. Calves were weaned by progressively dropping milk fed by 0.5L/calf/day over a period of a week. Bull calves were castrated between 2 and 4 months of age.

Calf measurements

Date of birth was recorded as the date which the calf was brought into the rearing shed. Breed and sex of all calves (alive and dead) was also recorded upon entry.

Birth weight was recorded the morning that the calf was brought into the rearing shed prior to being fed that afternoon. Dead calves were also weighed when brought to the shed. Weight was recorded using a Pratley calf weigh crate (Prattley Industries LTD., Temuka, New Zealand) and a Tru-Test weigh-head (EziWeigh7i, Tru-Test, Auckland, New Zealand) and load bars (MP600, Tru-Test, Auckland, New Zealand).

Date and live weight at weaning was recorded for all calves. Age at weaning in days was calculated as the number of days between birth and weaning. Average daily gain (ADG) to weaning was calculated as weaning weight less birth weight divided by the age at weaning.

Data cleaning

Of the 372 experimental heifers bred, 35 did not produce a calf, 31 produced a calf that were not sired by an experimental bull and 2 heifers produced twins (Table 4.4). The data from these heifers and their calves were excluded from the experiment, leaving 304 heifer-calf pairs (Table 4.4).

Table 4.4. Number of heifers present at different time points between mating and re-calving. The indented rows represent the number of heifers excluded from the dataset or those which left the herd between two time points.

Time point	Total number
Heifers mated to experimental bulls	372
excluded (no calf)	35
Heifers calved	33
excluded (non-experimental calf / twin)	33
Experimental dataset	304
left herd between calving and rebreeding	5
Heifers in herd at rebreeding	299
left herd between rebreeding and pregnancy detection	6
Heifers present in the herd at pregnancy detection	293
Re-calving Period	196

Deviation from the median date of calving was calculated within year. Calving date was also expressed as days from the planned start of calving within year (2016: 09/07/2016, 2017: 10/07/2017).

Assistance at birth and survival were analysed as binary traits. Calving assistance was simplified from the 1-5 scale to classified as unassisted (0) or assisted (1; for correctly presented calves). Malpresented calves (incorrectly presented calves requiring assistance; Chapter 1, Figure 1.1), were treated as missing values and not included in the analysis of assistance for calves. Survival was described as died = 0 or survived = 1 for each period described below. Calf survival was recorded for the calving period (prior to calf collection) and rearing period (from collection of calf until weaning). Heifer survival was recorded to rebreeding, and to pregnancy detection. Heifers were recorded as having survived if they were in the herd at the beginning of the rebreeding period or at the last pregnancy detection date, respectively.

The date which the heifer was dried off (end of lactation) was taken as the recorded dry off date in MINDA™ for heifers which survived to the end of lactation (year 1: 05/05/2017; year

2: 10/05/2018), or the date which the heifer was removed from the herd. There were 93 (year 1: n=68; year 2: n=25) heifers for which a dry off date or removal date was not recorded. For these heifers, the ProTrack (LIC, Hamilton, New Zealand) electronic identification records were used to determine the last day the heifer was present in the milking herd, and this was used as the dry off date.

Body condition scores at pre-calving (PC BCS) and rebreeding (RB BCS) were grouped into ≤ 4.5 and ≥ 5.0 , and ≤ 4.0 , 4.5, ≥ 5.0 respectively, and used for adjusting for body condition in the analysis of heifer milk production and rebreeding, and calf survival and calving assistance.

Total lactation milk production per lactation was calculated to a 254-day lactation, determined by the limits of the prediction data (21-275 days). The limits were determined by individual day of lactation at each herd test (across both years), the latest recorded calving was 21 days prior to the first herd test, and the earliest calving heifer (therefore greatest day of lactation) was last herd tested on day 275 of lactation. A 254-day lactation yield of milk, fat, protein and milksolids was calculated using daily predicted milk production generated using a third order orthogonal polynomial. A single trait animal model was fitted to milk, fat, protein and milksolids yield data in ASReml (Version 4, Gilmour et al. (2009)). The dataset consisted of the individual heifer herd test data as recorded in MINDA™ against the number of days in milk at each test specific for each heifer and included 950 records from 294 heifers (data from both years of the experiment). There were three 2016 calving heifers not included in the analysis of milk production due to low milk volumes collected at herd tests leading to negative predicted milk production curves. The regression coefficients generated from the models were used to calculate a predicted daily value.

Pregnancy rate was calculated as the number of pregnant heifers over the number of heifers having calved. Inter-calving interval was calculated as the number of days between the subsequent dates of calving. Heifers which were not in the herd at pregnancy detection were not included in the analysis of pregnancy rate, and heifers which were not pregnant or did not have a recorded calving in the following season were excluded from the analysis of inter-calving interval. Inter-calving interval was considered for a dataset with only heifers which had a re-calving date (as a 3-year-old), and with all heifers in the dataset, where heifers that failed to conceive were allocated a nominal calving date which was 21-days later than the last recorded date in the respective re-calving period (Morris et al., 2016). The bull-breed effect was not different between the two datasets, and so only the inter-calving interval using the heifers which had a recorded re-calving date is presented.

As a measure of reproductive success during the rebreeding period, 21-day re-calving rate as the proportion of heifers (as 3-year-olds) calving prior to 21 days following the planned start of calving (as 282 days from the mating start date; 19/07/2016 and 19/07/2018) was determined for the calving following the rebreeding period described in this Chapter and analysed as a binary trait.

Calving date for the following calving season (re-calving date) was expressed as days from the planned start of calving within year (as 282-days from the mating start date; 19 July in both years). As a measure of reproductive success during the rebreeding period, 21-day re-calving rate as the proportion of heifers calving prior to 21 days following the planned start of calving (19/07/2017 and 19/07/2018) was determined for the calving following the rebreeding period described in this Chapter and analysed as a binary trait.

As there was no association between CIDR allocation and body condition score, cows treated with a CIDR were not excluded from other measures of reproductive success.

Statistical analysis

Data were analysed using SAS (Version 9.4, SAS Institute Inc., Carey, North Carolina, USA). The use of yearling heifers and yearling bulls each year prevented the use of common sires and heifers between years, therefore, for each of the models outlined below, data collected on the 2016- and 2017-calving heifers and their calves were analysed separately.

Calves born to first-calving heifers

Birth weight, age at weaning and pre-weaning average daily gain were analysed using linear mixed models with the MIXED procedure, while survival of the calving period and assistance at birth were analysed using a logit mixed model with the GLIMMIX procedure based on a binomial distribution. No calves died between the end of the calving period and weaning, therefore survival to weaning was not analysed.

The dataset was comprised of all calves born in the relevant year (2016 n=183; 2017 n=121), although records for some heifers for body condition score and live weight prior to calving were missing. For analysis which includes an effect for which a record was missing, individual records were not included in the model. The number of animals in each model is indicated in the tables.

All models included breed of sire, and sex of calf as fixed class effects; bull nested within breed was fitted as a random effect for mixed models. There were too few calves sired by each bull which did not survive or experienced assistance at birth to include sire in the models for these traits. Analysis of assistance at birth did not include Jersey-sired calves as

none were assisted in either year. Analysis of age at weaning and pre-weaning ADG did not include Jersey-sired calves as they were only included in the experiment for the calving period.

The models for age at weaning and pre-weaning ADG in 2016-born calves included the fixed effect of rearing location, and models for age at weaning in both years included the covariate of weaning weight. The fixed effect of heifer PC BCS, and covariates of heifer pre-calving live weight, deviation from median date of calving (DOB deviation), birth weight with linear and quadratic effects were considered in survival and assistance at birth models and were retained where significant ($P < 0.05$) as indicated in Table 4.5.

Table 4.5. Description of the statistical models used, and effects considered in the analysis describing the effect of sire-breed of calf on calves born to first-calving heifers. Calves born in 2016 and 2017 were analysed separately. 'B' illustrates effects fitted in the model regardless of significance; '✓' illustrates effects that were considered and fitted in the final model as significant at P<0.05; 'X' illustrates effects considered then removed as not significant at P<0.05.

	Model	Fixed effects		Random effect	Fixed effect		Covariates				
		Breed of bull	Sex of calf	Bull (within breed)	PC BCS	Rearing location ¹	LWT	DOC dev	Weaning weight	Birth weight	Birth weight squared
Birth weight	Mixed	B	B	B	X		✓	✓			
Survival of calving period	Glimmix ²	B	B		X		X	X		X	X
Assistance at birth ³	Glimmix	B	B		X		X	X		X	X
Age at weaning	Mixed	B	B	B		B	✓	X	B		
Pre-weaning ADG	Mixed	B	B	B		B	✓	✓			

PC BCS: grouped heifer body condition score pre-calving; LWT: heifer pre-calving live weight; DOC dev = deviation from median date of calving. ¹ Fitted for 2016 born calves only. ² Glimmix models run specifying a binomial distribution. ³ Jersey-sired calves not included in analysis of calving assistance as none were assisted, and survival in 2017 as all survived.

First-calving heifers

Body condition score, live weight, milk production, calving date, re-calving date, and intercalving interval were analysed using mixed models, and CIDR use, pregnancy rate, 21-day re-calving rate, and survival were analysed using a glimmix model based on a binomial distribution.

The dataset was comprised of all heifers that produced a calf in the relevant year, although heifer records for some parameters were missing for some heifers. For analysis which includes an effect for which a record is missing, individual records were not included in the model. The number of animals in each model is indicated in the tables.

All models included breed of bull, and sex of calf as fixed class effects; bull nested within breed was fitted as a random effect for traits analysed using mixed models only. There were too few heifers mated to each bull that were given CIDR treatment, did not get pregnant in the following breeding period, or that did not survive to include sire in the glimmix models for these traits. Due to low mortality rates of 2017 calving heifers, only survival in 2016 calving heifers was analysed.

The fixed effects of grouped pre-calving (PC BCS) and rebreeding (RB BCS), and covariates of live weight and deviation from median date of calving (DOB deviation) were considered in models and but were removed from the model if not significant in both years ($P>0.05$) as indicated in Table 4.6.

Pre-calving live weight was considered in all models as indicated in Table 4.6, except for mating and pregnancy detection body condition score where the live weight measured at the same time was considered instead.

Table 4.6. Description of the statistical models used, and effects considered in the analysis describing the effect of breed of bull on the performance of first-calving heifers. 2016 and 2017 calving heifers were analysed separately using the same model. 'B' illustrates effects fitted in the model regardless of significance; '✓' illustrates effects that were considered and fitted in the final model as significant in both years at P<0.05; 'X' illustrates effects considered then removed as not significant in both years at P<0.05.

	Model	Fixed effects		Random effect	Fixed effects		Covariates	
		Breed of bull	Sex of calf	Bull (within breed)	PC BCS	RB BCS	LWT	DOC dev
Body condition score								
Mating	Mixed	B ¹	B	B			✓	X
Pregnancy detection	Mixed	B	B	B			Y	X
Pre-calving	Mixed	B	B	B			✓	✓
Rebreeding	Mixed	B	B	B			X	X
Late summer	Mixed	B	B	B			✓	X
Late lactation	Mixed	B	B	B			X	X
Live weight								
Mating	Mixed	B	B	B				X
Pregnancy detection	Mixed	B	B	B				✓
Pre-calving	Mixed	B	B	B				X
Milk Production								
Days in milk	Mixed	B	B	B	X	X	X	✓
Milk yield	Mixed	B	B	B	✓	X	X	X
Fat yield	Mixed	B	B	B	✓	X	X	X
Protein yield	Mixed	B	B	B	✓	X	X	X
Milksolids yield	Mixed	B	B	B	✓	X	X	X
Rebreeding								
Calving date	Mixed	B	B	B			X	
CIDR treatment	Glimmix ¹	B	B			X	✓	X
Pregnancy rate	Glimmix	B	B				X	✓
Inter-calving interval	Mixed	B	B	B		✓	X	✓
Re-calving date	Mixed	B	B	B			X	X
21-day re-calving rate	Glimmix	B	B				X	X
Survival ²								
Survival to rebreeding	Glimmix	B	B				X	X
Survival to PD	Glimmix	B	B				X	✓

LWT = pre-calving liveweight for all models except BCS at mating and pregnancy detection which used LWT at mating and pregnancy detection, respectively; PC BCS: grouped body condition score pre-calving; RB BCS: grouped body condition score at rebreeding; DOCdev = deviation from median date of calving, PD = pregnancy detection. ¹ Glimmix models run specifying a binomial distribution. ² Survival only analysed for 2016 calving heifers due to low mortality in 2017 calving heifers.

Results

The birth weight of calves born to heifers differed between the breed of bull used (Table 4.7; $P < 0.05$). In 2016, the Hereford bulls used produced heavier calves than the Angus bulls, and the Jersey bulls produced the lightest calves. In 2017, there was no difference between the Hereford and Angus-sired calves, with the Jersey calves again lighter than the beef-breed breeds.

There was no difference in proportion of calving assistance of calves born to heifers mated to Angus or Hereford bulls ($P < 0.05$; Table 4.7). All calves which survived the calving period survived until weaning. There was no difference in the age at weaning, or pre-weaning average daily gain (ADG) of calves born to heifers mated to Angus or Hereford bulls ($P < 0.05$; Table 4.7). Calves were weaned at an average of 78.1 days of age in 2016, and 87.0 days of age in 2017, and grew at an average 0.70 kg/day in 2016 and 0.72 kg/day in 2017. The mean weaning weight was 89.6 kg in 2016, and 97.3 kg in 2017, due to the lower minimum weaning weight at the calf rearer in 2016.

Table 4.7. Birth weight, age at weaning, pre-weaning average daily gain (ADG), survival of the calving period and calving assistance of calves born to heifers in 2016 or 2017. Values are least squares means \pm standard error.

	n	Angus	Hereford	Jersey ⁴	P value
2016 calving					
Birth weight (kg)	155 ¹	34.0 \pm 0.6 ^b	36.2 \pm 0.7 ^c	29.7 \pm 0.7 ^a	<0.001
Calving assistance (%) ²	178	3.7 \pm 2.3	10.0 \pm 4.1	0	0.137
Survival of calving (%) ³	183	93 \pm 3.1	88.2 \pm 4.1	90.3 \pm 4.2	0.636
Age at weaning (days)	96	78.7 \pm 1.2	76.3 \pm 1.1		0.178
Pre-weaning ADG (kg/day)	96	0.71 \pm 0.01	0.69 \pm 0.01		0.129
2017 calving					
Birth weight (kg)	121	34.9 \pm 0.6 ^b	35.0 \pm 0.6 ^b	31.5 \pm 0.8 ^a	0.037
Calving assistance (%)	96	3.7 \pm 2.7	3.6 \pm 2.8	0	0.983
Survival of calving (%)	98	88.5 \pm 4.6	92.8 \pm 3.8	100	0.467
Age at weaning (days)	87	86.3 \pm 1.9	87.5 \pm 2.1		0.715
Pre-weaning ADG (kg/day)	87	0.72 \pm 0.01	0.72 \pm 0.01		0.971

^{a,b,c} Values within row with different superscripts are significantly different at $P < 0.05$.¹

Discrepancies in the number of records for birth weight compared to calving difficulty and survival is due to missing records for the covariates fitted in the model.² Calving assistance excludes malpresented calves.³ Survival to calving covers the period from birth to arrival in the rearing shed.⁴ Calves sired by a Jersey bull were not included in analysis as no calves were assisted in either year and all calves having survived in 2017.

There was no difference in the body condition score between mating and the end of the resulting lactation of heifers mated to Angus, Hereford or Jersey bulls ($P > 0.05$; Figure 4.1, Appendix C.2.). Body condition score decreased from ~ 5.5 at mating, to 4.9 (2016 calving

heifers) or 4.7 (2017 calving heifers) at calving (Figure 4.1). In both years body condition score increased to 4.4 near the end of lactation (Figure 4.1, Appendix C.2.).

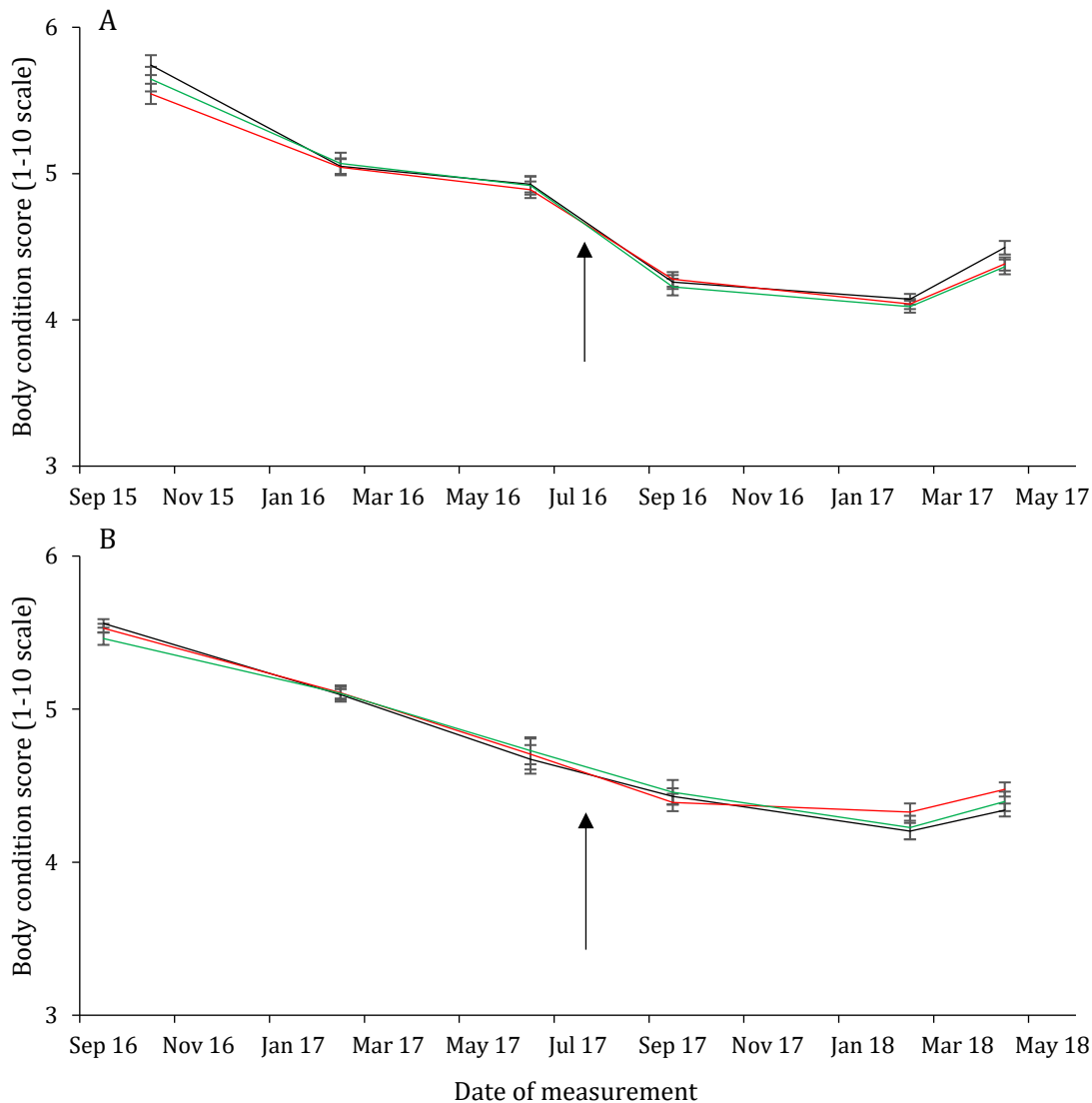


Figure 4.1. Body condition score between pre-mating and the end of the resulting lactation for heifers calving in 2016 (A) or 2017 (B) mated to Angus (black line), Hereford (red line) or Jersey (green line) bulls. Values are least squares means \pm standard error. Arrow indicates the mean calving date within year.

The live weight of heifers between mating and calving did not differ between heifers mated to Angus, Hereford or Jersey bulls ($P>0.05$; Figure 4.2, Appendix C.2.). The heifers were ~ 300 kg at mating and grew to 435 kg prior to calving in 2016, and 474 kg prior to calving in 2017 (Figure 4.2).

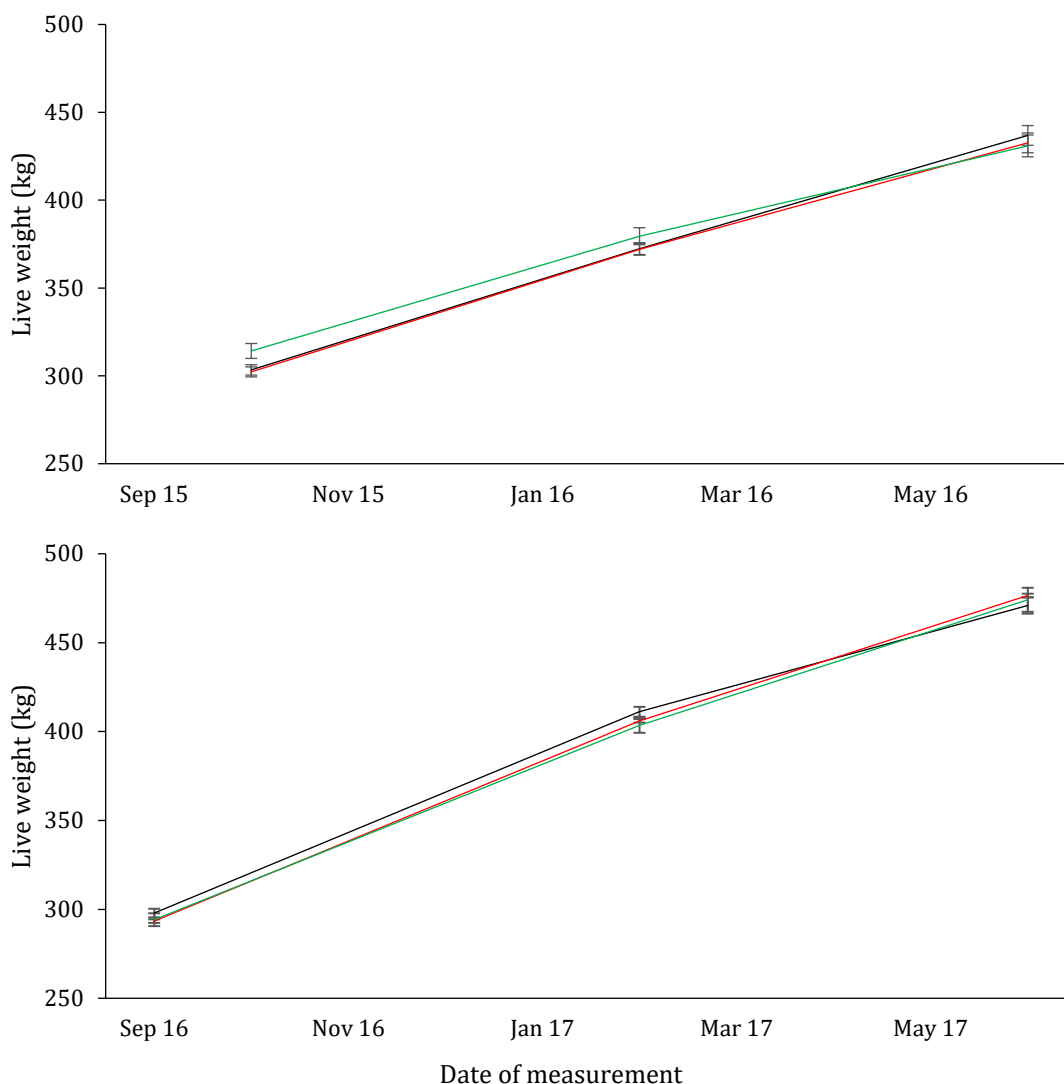


Figure 4.2. Live weight between mating and calving for heifers calving in 2016 (A) or 2017 (B) mated to Angus (black line), Hereford (red line) or Jersey (green line) bulls. Values are least squares means \pm standard error.

The days in milk and predicted 254-day milk production of heifers did not differ between those mated to Angus, Hereford or Jersey bulls ($P > 0.05$; Table 4.8). The average days in milk for heifers calving in 2016 was 271.0 days, and for 2017 calving heifers, 280.8 days. Heifers calving in 2016 produced an average of 2786.8 L of milk and 239.1 kg milksolids, the heifers calving in 2017 produced 3058.6 L of milk and 256.7 kg of milksolids.

Table 4.8. Days in milk and predicted 254-day milk production from heifers calving in 2016 or 2017 mated to Angus, Hereford or Jersey bulls. Values are least squares means \pm standard error.

	n	Angus	Hereford	Jersey	P value
2016 calving					
Days in milk (days)	175	267.0 \pm 3.1	275.5 \pm 3.2	271.3 \pm 3.6	0.217
Milk yield (L)	174	2730.3 \pm 94.6	2758.4 \pm 98.5	2737.1 \pm 101.6	0.977
Fat yield (kg)	174	131.2 \pm 3.6	130.5 \pm 3.8	130.6 \pm 3.9	0.989
Protein yield (kg)	174	104.2 \pm 3.1	106.6 \pm 3.2	104.4 \pm 3.3	0.837
Milksolids yield (kg)	174	235.2 \pm 6.6	237.1 \pm 6.9	235.2 \pm 7.1	0.976
2017 calving					
Days in milk (days)	119	280.9 \pm 3.9	279.5 \pm 4.2	283.8 \pm 5.9	0.840
Milk yield (L)	119	3096.1 \pm 56.6	3039.7 \pm 58.6	3076.4 \pm 81.1	0.785
Fat yield (kg)	119	146.2 \pm 2.3	140.3 \pm 2.4	143.5 \pm 3.3	0.268
Protein yield (kg)	119	114.5 \pm 1.9	112.2 \pm 1.9	114.3 \pm 2.7	0.675
Milksolids yield (kg)	119	260.8 \pm 4.0	252.6 \pm 4.1	257.9 \pm 5.7	0.393

For the rebreeding season following the calving seasons in 2016 and 2017, and the following calving season (2017 and 2018), there was no difference in the calving date, proportion of heifers receiving CIDR treatment, pregnancy rate, inter-calving interval, re-calving date or the 21-day re-calving rate of heifers mated to Angus, Hereford or Jersey bulls ($P > 0.05$; Table 4.9).

Table 4.9. The day of calving as a 2-year-old, proportion of heifers receiving CIDR treatment, pregnancy rate, inter-calving interval, day of calving as a 3-year-old and proportion of heifers calved in 21 days of the planned start of calving of heifers rebred following calving in 2016 or 2017 and being previously mated to Angus, Hereford or Jersey bulls. Values are least squares means \pm standard error.

	n	Angus	Hereford	Jersey	P value
2016 calving					
Day of calving (2-year-old) ¹	183	12.3 \pm 2.3	16.9 \pm 2.4	16.6 \pm 2.6	0.349
CIDR treatment (%)	155	25.3 \pm 6.2	8.33 \pm 3.6	13.18 \pm 5.2	0.057
Pregnancy rate (%)	175	57.1 \pm 6.3	70.72 \pm 6.0	73.66 \pm 6.6	0.157
Inter-calving interval (days)	109	385.8 \pm 4.7	387.65 \pm 4.0	381.64 \pm 4.7	0.578
Day of calving (3-year-old) ¹	111	26.3 \pm 3.5	28.51 \pm 3.5	24.61 \pm 4.0	0.763
21-day re-calving rate (%) ²	111	45.6 \pm 8.1	37.96 \pm 7.7	45.14 \pm 9.2	0.749
2017 calving					
Day of calving (2-year-old) ¹	121	13.9 \pm 2.1	15.9 \pm 2.1	19.1 \pm 3.1	0.423
CIDR treatment (%)	121	20.4 \pm 6.1	7.9 \pm 3.8	3.2 \pm 3.2	0.066
Pregnancy rate (%)	118	80.4 \pm 5.6	80.4 \pm 6.0	76.2 \pm 9.5	0.913
Inter-calving interval (days)	84	383.5 \pm 4.1	383.4 \pm 4.1	384.6 \pm 5.6	0.981
Day of calving (3-year-old) ¹	85	20.9 \pm 4.9	21.7 \pm 5.1	30.1 \pm 7.0	0.560
21-day re-calving rate (%) ²	85	54.1 \pm 8.5	57.9 \pm 8.7	53.2 \pm 12.1	0.932

¹ Day of calving expressed as days from the planned start of calving. ² 21-day re-calving rate for the following calving as a 3-year-old.

Heifers calved on average 14.8 (2016 calving) or 15.7 (2017 calving) days after the planned start of calving for their first calving. Heifers which calved for the first time in 2016 had a pregnancy rate to rebreeding of 66.9%, heifers calving in 2017 had a pregnancy rate of 79.6%. The intercalving interval between the first and second calf was 385.4 days for 2016 calving heifers and 383.7 days for 2017 calving heifers. The heifers calved for the second time, on average 26.4 (2016 calving heifers) or 23.0 (2017) days after the planned start of calving, with 44% and 55% of heifers calving within 3 weeks of the planned start of calving, respectively.

In 2016, Jersey-mated heifers were not included in the analysis of survival to rebreeding as all heifers survived. There was no difference in the survival to rebreeding of heifers mated to Angus ($97.1 \pm 2.0\%$) or Hereford ($96.9 \pm 2.2\%$) bulls ($P=0.930$). Similarly, there was no difference in the survival to pregnancy detection of heifers mated to Angus ($94.8 \pm 2.7\%$), Hereford ($97.9 \pm 1.7\%$) or Jersey ($97.4 \pm 2.1\%$) bulls ($P=0.554$). Survival in the 2017 calving heifers was not analysed as only 1 heifer did not survive to rebreeding, and an additional 2 heifers did not survive to pregnancy detection.

Discussion

The Angus and Hereford bulls sired heavier calves than the Jersey bulls and the Jersey-sired calves experienced fewer assisted births. The difference in the birth weight of Jersey-, Angus- and Hereford-sired-calves is in agreement with previous research (Burriss and Blunn, 1952, Baker et al., 1974, Long and Gregory, 1974, Smith et al., 1976, Gregory et al., 1978, Hickson et al., 2015). Some of the calves born to Angus and Hereford bulls experienced assistance at birth, whereas, the calves born to Jersey bulls were born without assistance. There was no effect of birth weight ($P > 0.05$) on assistance, however, the sample sizes were small in this experiment, with very few calves assisted.

In the second year of the experiment, the mean direct calving ease EBV for Hereford bulls was 4.7% greater, and the mean birth weight EBV for Hereford bulls 1.8 kg lighter. Consequently, Hereford calves were born 1.2 kg lighter, from heifers which were 44kg heavier, and the percentage of calves requiring assistance at birth decreased from 10% to 3.6%. The decrease in birth weight and assistance support literature which reports a strong relationship between birth weight and calving ease (Burfenig et al., 1978, Arthur et al., 2000, Johanson and Berger, 2003, Hickson et al., 2008b, Mee, 2008); and also indicates a favourable correlation between sire birth weight EBV and progeny birth weight and calving ease. The indicated relationship between EBV and progeny birth weight, which was also found in Chapter 3, indicates that the birth weight EBV should be considered when choosing beef-breed breed bulls to mate maiden dairy heifers to minimise assisted calvings, and that very low birth weight EBV are necessary.

Jersey bulls, which are the most commonly used bulls for mating dairy heifers (Hickson et al., 2015), produced the lightest calves with no incidences of calving difficulty. The Jersey breed is used in the dairy industry because it is associated with ease of calving (DairyNZ, 2007, Hickson et al., 2015), however the progeny of the bulls of are usually processed at ~4-10 days of age as bobby calves, and are of low value (Thomas and Jordaan, 2013, Cook, 2014, Hickson et al., 2015). The use of beef-breed bulls provides an alternative future for the surplus calves born in the dairy industry (Hickson et al., 2015). Using very low birth weight bulls to mate well grown heifers should result in calves which are born with ease, and with better rates of assistance than reported in the industry (5 - 15%) for dairy heifers (Xu and Burton, 2003, Mee, 2008, Stafford, 2011).

There was no difference in the pre-weaning growth of calves sired by Angus or Hereford bulls. This is in contrast to the limited literature published on straight-bred Angus and Hereford cattle which reported Angus calves tended to grow faster than Hereford sires

during the pre-weaning period (Long and Gregory, 1974), however agrees with the no difference seen in the artificially reared Angus- and Hereford-cross-dairy calves born to mixed-aged cows in Chapter 2. The lack of difference between the beef-cross calves could be due to the difference in rearing system to previous literature, particularly as artificially rearing calves reflects a restricted growth system where the genetic potential for growth cannot be fully expressed (Greenwood and Cafe, 2007).

A major concern of dairy farmers is that using beef-breed bulls results in difficult calving and impairment of heifer performance that would quickly outweigh any benefits from producing a higher value calf. However, bulls like those used in this experiment (high direct calving ease and low birth weight EBV) were acceptable in that there was no effect of the breed of bull on the body condition score, live weight, milk production or rebreeding performance of the first-calving heifers. Nevertheless, there was a small increase in assistance rate that required increased labour and skill. For calves born in 2016, there was a numerical difference in the proportion of Angus- and Hereford-sired calves requiring assistance at birth. Although the difference was not significant, however, did coincide with a 2.2 kg greater birth weight of the Hereford-sired calves. The numerical difference in assistance at birth did not result in a difference in the survival of the calves or a difference in the milk production or rebreeding success of the heifers.

There is no literature to suggest an effect of the birth weight of the calf, or of the breed of the bull on the body condition score of heifers. There is evidence to suggest an effect of birth weight of the calf on the milk production of the cow, where producing a heavier calf, influences the physiology of the mammary gland and increases the early milk production (Adkinson et al., 1977, Thatcher et al., 1980). The increased milk production may indirectly influence the body condition score through a drain on energy reserves if the increased milk production contributes to an energy deficit (Stockdale, 2001, Buckley et al., 2003, Dillon et al., 2003). However, there was neither a difference between bull breeds in the body condition score or milk production of heifers mated to different breeds in either year of the experiment. The lack of difference seen in the present experiment may be representative of the small variation in the birth weight of the calves, suggesting that for heifers producing calves with birth weights between 20.5 and 44 kg, there is no difference in the mammary gland development, milk production or body condition score.

There are no recommended pre-mating body condition scores for maiden heifers (~15 months-of-age) as body condition score is not typically recorded in young stock. Liveweight targets are used instead, with a target of 60% of mature weight at first mating and 90% at first calving (McNaughton and Lopdell, 2012, Handcock et al., 2016). The industry average

Holstein-Friesian-Jersey crossbred mature weight is 456kg (DairyNZ, 2019), therefore, the pre-mating target is 287 kg, which 72.5% of heifers in the experiment met, the pre-calving target liveweight of 410kg was met by 86.2% of heifers. Despite the majority of heifers seemingly meeting live weight targets prior to calving, in terms of body condition score pre-calving, 92% of the heifers in the experiment were below the New Zealand dairy cow target (5.5) body condition scores published by Dairy NZ (DairyNZ, 2012a). The decrease in condition between calving and rebreeding (average loss 0.47 units) was not greater than the DairyNZ recommendation of no more than 1 condition score unit for this period (DairyNZ, 2012a). Loss of body condition between calving and rebreeding can be a reason for lower pregnancy rates or longer anoestrous periods, and influence milk production (Buckley et al., 2003). The below-target BCS at first calving was countered by a better-than-target BCS low in early lactation, so that heifers were, on average, at target for mating.

Body condition score had an influence on the milk production of 2016 calving heifers in that heifers in better condition produced greater milk volume, and more milksolids over the lactation ($P < 0.05$). However, there was no indication of an effect of condition score on the rebreeding performance in the same year (CIDR, intercalving interval $P > 0.05$). There was an effect of body condition score at rebreeding on the intercalving interval for the 2017 calving heifers ($P < 0.001$), where heifers in greater condition had a longer intercalving interval, indicating that the heifers in greater condition took longer to resume cycling after calving and therefore, conceived later. Literature supports the effect of body condition score on milk production (positive) (Hutton and Parker, 1973, Rogers et al., 1979, Grainger et al., 1982, Stockdale, 2001, Buckley et al., 2003) and rebreeding success (negative) (Dillon et al., 2003, Harris and Pryce, 2004). The inconsistency between years, where BCS had a significant effect on milk production and rebreeding in 2016 heifers, but not for the 2017 heifers, may be an artefact of small numbers of heifers mated to each bull breed and/or little variation in the body condition score at pre-calving and rebreeding.

As in Chapter 3, data was not available to determine 6-week in-calf rate, 3-week submission rate or conception rate which are the main measures of reproductive performance in dairy cows. The herds pregnancy detection results and subsequent calving dates, as recorded in MINDA™ were available, therefore, these measures were used to determine rebreeding success as pregnancy rate, inter-calving interval, re-calving date and 21-day re-calving rate as the proportion of cows calving in the first 3-weeks following the planned start of calving in the following year. There is no literature which suggests a direct effect of sire on rebreeding success (pregnancy rate, intercalving interval, re-calving date or 21-day re-calving rate) of the heifers in this experiment. Rebreeding success may be indirectly affected

by service bull through the calving pattern (artefact of gestation length differences), as later calving heifers are less likely to be cycling at the beginning of the breeding period (Dillon et al., 2003, LIC, nd). However, as there was no difference between the mean calving date between the three bull breeds used, the lack of difference in rebreeding success between the three bull breeds was not unexpected.

There was, a numerical difference in the number of heifers mated to each bull breed receiving CIDR treatment, although this difference was not significant. More heifers mated to Angus bulls (n=25) received a CIDR than heifers mated to Hereford (n=11) or Jersey (n=9) bulls and is likely to result from the earlier mean calving date of heifers mated to Angus bulls in both years. This difference did not result in a difference in the pregnancy rate, intercalving interval or re-calving date of the heifers mated to different breeds.

This experiment was limited by not knowing the breed proportions of the individual heifers. The heifers were predominantly Holstein-Friesian-Jersey crossbred calves born on the farm where Holstein-Friesian-Jersey crossbred bulls were used. However, the breed recording on the farm was not complete and therefore, individual proportions of Holstein-Friesian and Jersey could not be accounted for. Literature suggests a difference between Holstein-Friesian and Jersey cows in terms of live weight, milk production (particularly fat %) and rebreeding success (Butler-Hogg and Wood, 1982, Grosshans et al., 1997, Burke et al., 1998, Lopez-Villalobos et al., 2000, Auld et al., 2007, Heins et al., 2008, Coffey et al., 2016, Spaans et al., 2018); however, as the heifers were randomly allocated to each mating mob, and the heifers in each mating mob had the same average weight throughout the experiment, and the same milk composition (fat %, data not presented), there was no indication of a heifer breed bias between the bull breed groups. Additionally, the small number of heifers, particularly in the second year meant that the sample sizes were small for some traits, particularly binomial traits, where not all heifers had a record, and resulted in a numerical difference in calving difficulty and proportion of heifers receiving a CIDR which were not significant. However, the number of heifers used in the analysis was greater than the sample size required for detecting power, for analysis of calving difficulty (2016 calves) and CIDR treatment (both years), indicating that with a larger sample size the numerical difference may result in a statistical difference between bull breeds.

The results from this experiment indicate no performance difference between heifers mated to Angus, Hereford or Jersey bulls, however, the heifers (and herd as a whole) in this experiment were low producing, and therefore it cannot be extrapolated with certainty to high producing heifers. The low milk production of the herd in the experiment was likely due to management as high genetic merit bulls had been used to breed the cows and heifers,

which does not support poor genetics as a reason for low production. The high proportion of heifers not meeting the industry target body condition score at calving indicated a degree of underfeeding leading up to calving, which would affect the development of the mammary gland and prevent the full expression milk production genetics (Buckley et al., 2003). Although there is no indication that there would be a difference in the milk production between the heifers mated to different breeds.

In conclusion, using Angus, Hereford and Jersey bulls over maiden heifers resulted in heavier calves born to heifers mated to Angus and Hereford bulls compared with Jersey bulls, however this did not translate into an effect on the heifer's milk production, body condition score or rebreeding success. The experiment therefore indicates that Angus and Hereford bulls with high direct calving ease (Angus: >4.1%, Hereford: >5.9%) and very low birth weight (Angus: <3.8kg, Hereford: <1.9kg) EBV, as in this experiment, can be used without negative effects on assistance at calving and the milk production and rebreeding of the heifer and may produce a calf of greater value than a Jersey-sired calf.

Chapter 5 – Identification characteristics of newborn Angus-cross-dairy and dairy calves

This Chapter has been published in part elsewhere. It has been reformatted and presented here with permission:

Coleman LW, Blair HT, Lopez Villalobos N, Back PJ, Hickson RE. 2017. Breed variation in tongue colour of dairy and beef-cross-dairy calves. Proceedings of the Association for the Advancement of Animal Breeding and Genetics, Volume 22.

Abstract

Dairy farmers can use a beef-breed bull to increase value of surplus calves. It is important that the farmer can identify the breed of newborn calves, to allow them to retain only dairy-breed calves as replacements. Angus bulls may offer advantages over Hereford bulls in terms of lighter birth weight and short gestation length which would add value to the dairy farm business. Using Angus bulls over a Holstein-Friesian-Jersey crossbred dairy herd results in calves that may look similar to the Holstein-Friesian-Jersey crossbred dairy calves, making identification of different breed calves difficult. DNA parentage identification is costly, and results take longer than the 4 days when calves can be sold, therefore, other phenotypic factors would be useful to identify these calves. The aim of this study was to identify methods of breed identification between newborn dairy (Holstein-Friesian-cross-Jersey) and Angus-sired calves using tongue colour and horn presence. The tongue colour of newborn Angus-sired and dairy calves born on a dairy farm was recorded over two seasons (n=894) as black, pink or spotted. Horn bud presence as horned or polled, was recorded in the second year (n=418) to improve the accuracy of identification. These parameters were used to compare the conditional probability of breed identification using solely tongue colour, then combinations of tongue colour and horn presence. Identifying the breed of newborn Angus-cross-dairy and dairy breed calves using solely tongue colour indicated practical usefulness, however, the calves with spotted tongues did not clearly fit Angus-sired or dairy calves. Combining tongue colour and horn status improved the accuracy of breed identification, with all calves with palpable horn buds being dairy breed, and 98% of polled calves with a black tongue being Angus-sired. Although breed is obvious in some cases, selection of new-born calves using tongue colour and horn presence will increase the accuracy of selection where breed is not obvious.

Introduction

For a dairy farmer using a beef-breed bull to increase the value of surplus calves, it is important to be able to identify the breed of calves born, so as to retain only dairy-breed calves as replacements. In a situation where a beef-breed bull is used to naturally mate the remainder of the cows after artificial breeding to a dairy bull, the variation in gestation length between breeds and individuals within breed mean that the calves born to different bulls and mating periods of artificial breeding and natural mating may be born at the same time.

Of beef-breed bulls used in the New Zealand dairy herd, the main breed is Hereford (DairyNZ, 2019), in part because the resulting calf will have a white face, making the beef-cross calf easy to identify (Holmes et al., 2007). Chapters 2 and 4 showed that there were Angus bulls with advantages in shorter gestation length and lighter birth weight calves that could add value to the dairy farm business. This is in agreement with the literature, indicating a lighter birth weight and shorter gestation length in Angus compared to Hereford calves (Burriss and Blunn, 1952, Wheat and Riggs, 1958, Baker et al., 1974, Long and Gregory, 1974, Smith et al., 1976, Gregory et al., 1978, Bourdon and Brinks, 1982, Baker et al., 1990, Jeyaruban et al., 2016)

Mating dairy cows to beef-breed bulls is ideal in a straight bred dairy herd, where the dairy calves (primarily Holstein-Friesian and Jersey) are easily identifiable from the beef-cross-dairy calves. However, with decreasing proportions of Holstein-Friesian and Jersey cows in the national dairy herd, and with close to half of the herd now being Friesian-Jersey crossbred (Muir et al., 2001, DairyNZ, 2019), the identification of calves is not as simple.

However, when an Angus bull is used, the resulting calves are usually completely black, and may look similar to Holstein-Friesian-Jersey crossbred and some Holstein-Friesian calves. As DNA sampling for parentage analysis is costly (in terms of financial cost and time to get results) and not widely used in commercial situations, other phenotypic factors may be useful to identify these beef-cross-dairy calves. The use of colour of coat markings, ears and noses to identify different genotypes in adult cattle and sheep has previously been reported (Pitt, 1920, Dry, 1924, Ibsen, 1933, Dry, 1936, Bogart and Ibsen, 1937).

Identifying the breed of calf at birth is important, so that the dairy farmer is able to retain appropriate dairy-breed heifers as replacements, and dairy-beef calf rearers are able to purchase beef-cross calves for rearing. The dairy farmer wants to retain only dairy-breed heifers, and to identify all the available dairy-breed heifers to maximise the opportunity for selection among potential replacements. In contrast, the dairy-beef calf rearer is generally

less concerned with the need to identify all available beef-cross calves but does not want to mistakenly rear Friesian-Jersey calves in place of beef-cross calves. Calves which the buyer is confident are beef-cross-dairy are worth more to the dairy-beef calf rearer. Calves are usually sold from the dairy farm at 4 days of age, so the breed of the calf needs to be identified within this timeframe.

The white face markings of Hereford-cross-dairy calves make the calves easily distinguishable from dairy breed calves, for this reason, this Chapter will focus on identifying Angus-cross-dairy calves from dairy breed calves. Therefore, the objective of this experiment was to identify characteristics that can be used to distinguish between newborn calves born to dairy cows and Angus or dairy (Jersey, Friesian or Friesian-Jersey crossbred) bulls.

Materials and methods

This study was conducted at C. Alma Baker Trust NZ Ltd. Limestone Downs dairy farm, 16 km south of Port Waikato, New Zealand (latitude: 37.49 S, longitude: 174.77 E). The study and all handling procedures were approved by the Massey University Animal Ethics Committee (MUAEC 15/65).

The identification of new-born dairy and beef-cross dairy calves was conducted over two years. The first-year data was collected to test the identification of Angus-cross-calves from dairy calves solely using tongue colour. In the second year, data was collected to combine the presence of horns with tongue colour to improve the accuracy for identification of Angus-cross-calves.

Animals

Eight hundred and ninety-four dairy and Angus-cross-dairy breed calves born over two consecutive years (2016, 2017) were included in this analysis (Table 5.1). Calves were born to dairy cows for which the individual breeds were not accurately recorded, however the herd was Holstein-Friesian, and Holstein-Friesian-Jersey-crossbred based. Calves in this experiment were sired by either an Angus, Jersey, Holstein-Friesian, or Holstein-Friesian-Jersey crossbred bull (Table 5.1). The Jersey-sired, Holstein-Friesian-sired and Holstein-Friesian-Jersey crossbred-sired calves are referred to as 'dairy' throughout this Chapter. Holstein-Friesian-sired calves were born in year 1 only, and Holstein-Friesian-Jersey crossbred-sired calves born in year 2 only.

Table 5.1. Number of calves from each sire-breed included in the calf identification analysis. Dairy-sired calves are those sired by Jersey, Friesian or Friesian-Jersey crossbred bulls.

Sire-breed	Tongue colour	Tongue colour and Horns
Angus	629	281
Dairy	265	137
Jersey	164	85
Friesian	49	-
Friesian-Jersey crossbred	52	52

Management

Calves were identified to dams by the farmer at the time of calf removal, typically within 24 hours of birth. Calves were identified as being Angus-, Jersey-, Holstein-Friesian-, or Holstein-Friesian-Jersey crossbred-sired by visual assessment of the animal and through mating records for the probable dam. Calves sired by Angus and Jersey bulls, and any calves for which breed was unknown or doubtful, were tissue sampled within 24h of birth for

parentage analysis (Chapters 2 and 4). The calves sired by Holstein-Friesian and Holstein-Friesian-Jersey crossbred bulls were not included in the experiment as outlined in Chapter 2 and 4, therefore, the calves were not matched to a bull. Sire breed was DNA verified for the Angus- and Jersey-sired calves by assigning parentage to a bull of the respective breed. Calves for which breed was doubtful were considered to be dairy breed if parentage was not assigned to an experimental sire.

Identification characteristics

During both years of the experiment, tongue colour of all calves was recorded. In addition, during the second year of the experiment the presence of horn buds was also recorded.

Tongue colour of all calves was assessed by opening the mouth of the calf and looking at the top of the tongue. Tongue colour was recorded as being either completely pink, completely black or having a combination of black and pink patches (spotted) (Figure 5.1). No attempt was made to quantify the proportion of pink and black for calves with spotted tongues.

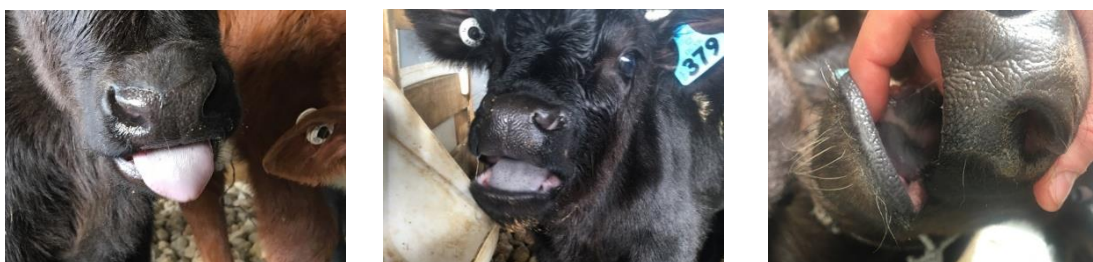


Figure 5.1. Examples of tongue colour, L-R: pink, black, spotted

Presence of horn buds was recorded as horned or polled. The presence of horn buds was felt for on the frontal bone either side of the occipital protuberance. Horns cannot be diagnosed with absolute certainty until 3 months of age and as such it is possible that some horn buds could not be felt at such an early age (Cole and Johansson, 1948).

Statistical analysis

Data were analysed using conditional probabilities, that were calculated using Microsoft Excel (Microsoft Office 2016).

Results

Using tongue colour to differentiate Angus-sired calves from dairy breed calves

Seventy-eight percent of Angus-sired calves had a black tongue, while only 21% of dairy calves had a black tongue (Table 5.2). A pink tongue was the most common colour for dairy calves (0.55) (Table 5.2). Pink was the least common tongue colour in Angus-sired calves (0.03; Table 5.2). A spotted tongue was more common in dairy calves (0.24) than Angus-sired calves (0.19) (Table 5.2).

Table 5.2. Proportion of each sire-breed of calf having a specific coloured tongue.

Sire-breed	n	Black Tongue	Spotted tongue	Pink Tongue
Angus	629	0.78	0.19	0.03
Dairy	265	0.21	0.24	0.55

A calf with a black tongue was highly likely (0.90) to be Angus-sired (Table 5.3). A calf with a pink tongue was most likely to be Dairy (0.87) (Table 5.3). Calves with tongues showing pink and black spotting had a greater probability of being an Angus-sired (0.65) than a dairy (0.35) calf (Table 5.3).

Table 5.3. Conditional probability of a calf being each sire-breed given that it possesses a specific coloured tongue.

Sire-breed	Black Tongue	Spotted tongue	Pink Tongue
Angus	0.90	0.65	0.13
Dairy	0.10	0.35	0.87

The number of calves with spotted tongues raises a question of whether spotted tongue calves should be sold (Angus-sired) or kept (dairy) when imposing tongue colour as a selection criterion. If dairy and Angus-sired calves were to be identified solely on tongue colour, and any calf with a black tongue was sold, this experiment indicates that 79% of the dairy calves would be correctly retained, however, 22% of the Angus-sired calves would also be retained as replacement dairy calves (Table 5.4). If calves were to be sold if they had a black, or a spotted tongue, this study suggests 97% of Angus-sired calves would be correctly identified, along with 45% of dairy calves unnecessarily culled (Table 5.4).

Table 5.4. Comparison of the chance of keeping or selling a calf on tongue colour given the sire-breed.

	Selling on black tongue only		Culling on black or spotted tongue	
	Dairy	Angus	Dairy	Angus
Keep	0.79	0.22	0.55	0.03
Cull	0.21	0.78	0.45	0.97

Combining tongue colour with the presence of horns

The majority (0.94) of dairy breed calves had palpable horn buds at birth, while only 1 Angus-sired calf did (Table 5.5). Ninety percent of Angus-sired calves were polled with a black tongue, with smaller proportions being polled with a spotted (0.08) or pink (0.02) tongue (Table 5.5). A greater proportion of dairy breed calves with horns had pink tongues (0.47) than spotted and black tongues (0.28 and 0.20 respectively) (Table 5.5). The one Angus-sired calf with palpable horn buds at birth had a black tongue.

Table 5.5. Proportion ¹ of each sire-breed of calf being polled or having horns and the combination of tongue colour and horned status.

	Any colour	Black tongue	Spotted tongue	Pink tongue
Horns				
Angus-sired	0.00	0.00	0.00	0.00
Dairy	0.94	0.28	0.08	0.47
Polled				
Angus-sired	1.00	0.89	0.20	0.02
Dairy	0.06	0.03	0.01	0.01

¹P (phenotype | breed)

It was extremely unlikely that a calf with horns was Angus-sired (0.01) regardless of tongue colour (Table 5.6). If the calf was polled, there was a greater probability that the calf is Angus-sired (0.97) than dairy, and the likelihood is greater for calves with a spotted tongue (0.92) than a pink tongue (0.75) (Table 5.6). The probability of a polled calf with a black tongue being Angus-sired was 0.98, whereas a calf with horns and a black tongue was more likely to be dairy (0.97) (Table 5.6).

Table 5.6. Conditional probability ¹ of a calf being a specific sire-breed given a specific tongue colour and/or whether the calf is polled or has horns.

Sire-breed	Horns	Polled				
Angus	0.01	0.97				
Dairy	0.99	0.03				
	Black tongue & Horns	Black tongue & Polled	Spotted tongue & Horns	Spotted tongue & Polled	Pink tongue & Horns	Pink tongue & Polled
Angus	0.03	0.98	0.00	0.92	0.00	0.78
Dairy	0.97	0.02	1.00	0.08	1.00	0.22

¹P (Breed | phenotype)

For a dairy farmer wanting to pick replacement heifers in the absence of DNA testing or calving those cows mated to an Angus bull separately, only picking those calves with horns will result in 99% accuracy of the selected heifers with no Angus-calves selected, and only 6% of dairy calves being missed (Table 5.7). However, in a situation which results in a large selection pool, the farmer may choose only the calves which have horns and a pink or

spotted tongue, increasing the proportion of correctly identified calves chosen to 100%, but missing 34% of potential dairy heifers (Table 5.7).

Table 5.7. Probability that the selected calf is the desired breed and the proportion of correctly identified dairy calves or incorrectly identified dairy calves for a dairy farmer or beef producer selecting dairy or Angus-sired calves, respectively, on tongue colour and horn status.

Dairy Farmer ¹	P (selected = Dairy) ²	Dairy calves missed ³
Horned calves only	0.99	0.06
Horns + Pink/Spotty tongue	1.00	0.34
Beef producer ¹	P (selected = Angus-cross) ²	Dairy calves selected ⁴
Polled calves only	0.97	0.06
Polled + Black/Spotty tongue	0.98	0.04
Polled + Black tongue	0.98	0.03

¹ Assuming a 50:50 ratio of Angus-sired and dairy calves available to choose from. ² Probability of the calf selected being the correct breed: $P(\text{desired breed} | \text{desired phenotype})$. ³ Proportion of dairy calves not having the desired phenotype and therefore not selected: $P(\text{undesired phenotype} | \text{desired breed})$. ⁴ Proportion of dairy calves having the desired phenotype and therefore selected: $P(\text{desired phenotype} | \text{undesired breed})$.

A dairy-beef calf rearer can greatly reduce the chances of inadvertently purchasing dairy calves in place of Angus-sired calves if they only purchase polled calves. Unfortunately, this phenotype does not completely prevent the purchase of Friesian-Jersey crossbred calves.

Assuming that the proportions of Angus-sired and dairy calves sold together are equal, for a beef-cross-dairy calf rearer, only wanting to choose Angus-sired calves, selecting only polled calves would result in a group of calves that were 97% Angus-sire, however 6% of dairy calves also had the desired phenotype and could therefore be incorrectly selected. To decrease the proportion of dairy calves, the dairy-beef rearer could select calves that were polled and that had a black tongue. This would result in a group of calves that were 98% Angus-sired, reducing the proportion of unwanted dairy calves.

These probabilities are based on the assumption there is an equal proportion of Angus-sired and dairy calves at the sale. However, in reality, the proportion of Angus-sired calves at a calf sale is likely to be greater than dairy calves. If the ratio of Angus-sired to dairy calves was assumed to be 9:1 then the proportion of Angus-sired calves purchased using the polled criteria would be 99.4%.

Discussion

The differentiation between Angus-sired and dairy calves solely by tongue colour indicated that tongue colour was a useful trait for breed identification. The Angus-sired calves were more likely to have black tongues and less likely to have pink tongues than dairy calves. However, the high incidence of calves in all breeds with a spotted tongue means that identifying those with a spotted tongue as either Angus-sired or dairy resulted in a large proportion of falsely identified calves.

Ibsen (1933) reported that there is a relationship to Angus having a black colouring gene and possessing a black tongue. However, in the experiment reported here, a proportion of Angus-sired calves had a spotted tongue (0.19), which may indicate that tongue colour is more affected by the white-spotting gene from the dam's Holstein-Friesian genetics, than the coat colour is. There was a small proportion of Angus-sired calves possessing a pink tongue (0.03), which may be a result of extreme white-spotting, as the tongues were assessed *in vivo* it cannot be said with certainty that there were no black spots deep in the mouth.

Ibsen (1933) hypothesised that the black-spotting gene causing black tongues in Jersey cattle is dominant over the Friesian white-spotting. While this may be true of the 5 white points (four feet and forehead) typical of a Friesian being black pigmented in the crossbreed, the theory does not hold up with pigmentation of the tongue. The results from this study suggest that inheritance of tongue colour is more complicated than suggested by Ibsen (1933). The cows in the dairy herd used to produce the calves varied in proportion of Friesian and Jersey genetics. There were a small number of cows in the herd which had breeds other than Friesian and Jersey in their pedigree, and not all cows had a fully recorded pedigree. Consequently, the full pedigree of each calf could not be identified, and it is likely that differing proportions of Friesian and Jersey genes contribute to the different tongue colours observed.

The results of the year 1 experiment, looking solely at tongue colour, indicated that tongue colour may provide useful clues for breed identification because black tongue calves were highly likely to be Angus-sired and pink tongue likely to be dairy calves. Although, alone it was not infallible, the occurrence of spotted tongues raised an issue of how to identify the calves with spotted tongues as they were no more likely to be Angus-sired than dairy. As tongue colour was not reliable as a sole indicator, it could be combined with other visual assessments to help inform cull/keep decisions. In the second year of the experiment, as the

Angus breed is polled, and the dairy breeds are not, horn status was added to tongue colour to increase the likelihood of correct breed identification.

Results presented here showed that the addition of horn presence, into the identification criteria, provided a more reliable method in which to identify Angus-sired and dairy calves. The majority of Angus-sired calves were polled with a black tongue, with a small proportion (8%) being polled with a spotted tongue. Whereas 94% of the dairy breed calves had palpable horn buds at birth.

As the horned phenotype was exclusive (aside from one Angus-sired calf) to the dairy breed, the presence of horns can be used for identification of potential replacement heifers. Although the selection criteria for dairy calves excluded 6% of the dairy calves as potential replacements for not having palpable horn buds at birth, no Angus-sired calves would be incorrectly classified as dairy breed. In terms of identifying Angus-sired calves the most reliable criteria was choosing only those calves which were polled with a black tongue, minimising the number of dairy calves being incorrectly identified.

The present experiment focussed on calves less than 4-days-of-age, which is the minimum age at which unwanted calves can be transported to slaughter, and often the time which other calves are traded for rearing. However, as the calves aged, their breed became more obvious, in terms of distinguishing between beef-cross-dairy and dairy breed calves. Therefore, any mistakenly identified calves that were reared would be able to be identified and sold. The mistakenly identified calves includes the dairy breed calves which did not have palpable horn buds at birth and may have been mistaken for Angus-sired calves and reared as such. The dairy calves mistakenly identified as Angus-sired in this experiment (n=9) had all developed horns prior to weaning.

Scurs, which are small rudimentary horns, develop later in life in heterozygous polled cattle (Cole and Johansson, 1948, Brenneman et al., 1996). Scur presence may cause confusion and mistaken identification in Angus-sired cattle when checking for horn buds on weaned calves. The development of scurs is reported to be sex linked, with male cattle more likely to develop scurs than female cattle due to only needing one copy of the scur gene as opposed to female cattle needing to be homozygous (Gowen, 1918, Blackwell and Knox, 1958, Long and Gregory, 1978, Frisch et al., 1980, Prayaga, 2007). Although the Angus-sired calves were polled at birth, there were a few Angus-sired calves which developed scurs prior to weaning (average age at weaning was 84 days), and more identified later in the life of the cattle (~200 and 400 days of age) when measurements outside of the scope of this experiment

and thesis were taken. These calves were not individually recorded because the identification of calves beyond 4 days-of-age was outside the scope of this experiment.

The dominance of the polled condition over the horned condition suggests that the identification of Angus-sired calves in a dairy herd using presence of horns would be more accurate than looking at coat colour alone. However, with the possible delayed development of horns and delayed development of scurs, the presence of horns is not as accurate as DNA testing to determine breed by parentage analysis. Regardless, the cost of DNA parentage to determine breed is unlikely to outweigh the cost and inconvenience of rearing a few additional calves which may later be correctly identified and sold.

In reality, there were a proportion of the calves (number unknown, as outside of the scope of this experiment) which were identifiable by coat colour alone, without needing to check the tongue colour or feel for horns. Therefore, the proportion of unidentified calves would be less than assumed in this experiment, where the coat colour was not considered. However, there were others for which coat colour alone was misleading.

In conclusion, using tongue colour and presence of horn buds at birth provides a useful tool in the identification of Angus-sired and dairy calves. Dairy farmers wishing to identify potential replacement heifers should only choose calves with horn buds. Beef farmers wishing to select Angus-sired calves should choose polled calves with a black tongue.

Chapter 6 – Sale income of beef-cross-dairy calves, mating strategies to generate beef-sired calves and considerations for dairy farmers regarding the use of beef genetics in their herd.

Abstract

The most common mating strategy for the period in which non-replacement calves are generated, following a period of artificial breeding to generate dairy replacements, is using a Jersey bull. Jersey-sired calves are of low value; therefore, beef-breed bulls could be used to generate a higher value calf. The value of Angus, Hereford and Jersey sired calves was determined using sale reports. Beef-sired calves were of more value to the dairy farm than Jersey-sired calves. Data was collected regarding the colour of Angus and Hereford-sired calves, which was used to estimate the proportion of 'right' and 'wrong' coloured calves. Calves which appear to be born to Holstein-Friesian dams are generally preferred by purchasers and are of greater value. Hereford-sired calves were worth more than Angus-sired calves, with bull calves of greater value than heifer calves. All Jersey-sired calves were considered surplus dairy calves and valued according to the bobby calf schedule regardless of sex or appearance. Mating strategies for generating beef-sired calves from the dairy herd were considered, and the strength, weaknesses and any other factors requiring consideration for each strategy were compared. The strategies considered in this chapter included natural mating and artificial breeding. The natural mating strategies considered beef-breed bulls purchased with unknown genetics, or with recorded genetics. The artificial breeding strategies considered using beef semen following a dairy AB period or alongside the dairy AB period mating a select proportion of cows, yearling AB mating and the use of sexed semen. For each strategy, an estimated number of beef-sired calves generated was obtained using a herd modelled on New Zealand averages for reproductive performance. The number of beef-sired calves born can be increased by using strategies which increased the proportion of cows bred to beef bulls or semen: by using selective beef AB alongside dairy AB, using yearling AB and sexed semen. The value proposition of beef-breed mating strategies will vary between farms, depending on the different considerations needed for each scenario. Utilising a combination of mating strategies potentially increases the proportion of beef-sired calves produced, however, the ability to incorporate some of these strategies requires a sufficient level of reproductive performance to be worthwhile.

Introduction

Following a period of artificial breeding (AB) to generate dairy replacements, the most common mating strategy in New Zealand, for the period in which non-replacement matings occur, is to use Jersey bulls (Holmes et al., 2007, Hickson et al., 2015). The resulting non-replacement Jersey-sired calves are of low value for rearing, whereas beef-breed bulls could be used to generate calves with greater potential for beef finishing.

There are a number of mating strategies which can be used to incorporate beef-breed matings into the dairy herd. Beef mating options can include natural mating or AB cows using semen from beef-breed bulls. The simplest use of beef-breed mating strategies is using natural mating following a period of dairy-breed AB. Nevertheless, the use of beef-breed AB has the opportunity to further integrate beef-breed mating, either after or alongside dairy-breed AB.

For bulls used for natural mating, there are different options around the type of beef-breed bulls, i.e. breed and whether the bull is unrecorded or recorded in terms of genetic merit, which need consideration. Additionally, consideration of whether to use natural mating or beef-breed AB is needed, as the suitability of each type of strategy will differ between farms.

There are many beef-breed breeds used in New Zealand that could be used to mate dairy cows. Anecdotally, the most commonly used breed is Hereford (DairyNZ, 2019), with Angus bulls also frequently used. These breeds represent the most populous beef breeds in the New Zealand beef industry (Beef+LambNZ, 2019a), and semen from Angus and Hereford bulls are offered by breeding companies for AB (LIC, 2020a).

The aim of this Chapter was to compare the income from the sale of surplus calves using Angus, Hereford or Jersey bulls; and to identify possible options for incorporation of beef-breed semen or bulls into dairy herds and consider factors contributing to their suitability to the system.

Value of beef-cross-dairy calves relative to Jersey-sired calves

Four-day-old, beef-sired, calves were valued as being sold for rearing. Beef-sired calf sale prices were derived from prices from weekly feeder calf sales published in the Farmers Weekly publication from late-August to late-September 2018, 2019 and 2020. Beef-cross calf value is less for calves which appeared to have Jersey parentage. Sale prices for Angus-, Hereford- and Jersey-sired calves are presented in Table 6.1.

Table 6.1. Four-day-old feeder calf prices (\$/head) for Hereford and Angus sired bulls and heifer calves and Jersey-sired calves. Price per head is dependent on whether the calf was 'right' or 'wrong' coloured indicating a Holstein-Friesian or Holstein-Friesian-crossbred dam, respectively.

	Angus		Hereford		Jersey
	Bull	Heifer	Bull	Heifer	
'Right' colour	\$110	\$80	\$210	\$110	\$28
'Wrong' colour	\$70	\$50	\$110	\$60	\$28

Beef-cross-dairy calf sale prices were split into 'right' and 'wrong' colour as indicative of how calves in New Zealand are sold at feeder calf sales (Oliver and McDermott, 2005, Burggraaf, 2017). 'Right' coloured calves represent those which suggest Holstein-Friesian parentage, and have a black coat, with Hereford-sired calves showing a clean white face and four clean white feet (Appendix D.1). 'Wrong' coloured Angus- or Hereford-sired calves represent calves that have a brown, red or brindled coat, have patchy coloured feet, and in the case of Hereford-sired calves, do not have a clean white face, or solid (non-white) coloured feet (Appendix D.1), because these traits are generally indicative of Jersey parentage. Based on data collected from calves born to Angus and Hereford sires in Chapter 2 and 4, the proportion of 'right' and 'wrong' coloured calves were estimated for a crossbred herd. The coat colour and markings of 593 calves were recorded and used to classify calves using the characteristics above. Calves born in a crossbred herd, similar to the experimental herd used in chapters 2-5, would be 76% 'right' coloured Angus-sired and 38% 'right' coloured Hereford-sired calves. The vast majority of calves born in a Holstein-Friesian herd would be coloured as Angus- or Hereford-cross-Friesian, and therefore, be 'right' coloured.

Jersey-sired calves were valued assumed to be sold for processing ('bobby calves'). Income from calves sold as bobby calves was derived from the bobby calf kill sheets from calves born in 2017 on the dairy farm used in Chapters 2-5 and using the 2019 bobby calf schedule price from Greenlea (Greenlea Premier Meats Limited, Hamilton, New Zealand).

To represent the region where the herd used in Chapters 2 – 5 was based, the Frankton and Tirau calf sales (Waikato region) were used. The calf sale price is influenced greatly by the

number of calves at each sale, therefore, an average from a 5-week period, from 20 sales over 3 years, was used to give a representative individual calf price. The 5-week period where surplus calves were born was assumed using the mean planned start of calving for a Waikato herd (18 July) (DairyNZ, 2019), as Waikato is the region which the farm used in Chapters 2-5 is located), and a 6-week period where replacement calves are generated, with a 11 week total mating period (NZ average) (LIC, 2018).

Beef-cross-dairy calves are sold both at feeder calf sales and privately. Beef-cross-dairy calves are likely to incur additional costs associated with transport to feeder calf sales and fees at sales. These costs were not factored into the values above as these are varied between sale and are dependent on the location of the farm relative to the sale and would not apply to calves sold privately.

Additionally, the cost of feeding the calves until sale may differ, due to variation in age at sale, due to multiple factors, for example, sale type and sale frequency. It is likely that beef-cross-dairy calves sold privately or via a feeder calf sale would be held on farm for longer than those collected by the bobby truck. Feeder calf sales typically occur weekly, whereas bobby calf pick up can be as often as daily. Therefore beef-cross-dairy calves may be aged 4 – 9 days old at sale, if sold weekly, whereas daily bobby calf pick up would mean few Jersey-sired calves would be kept after 4 days-of-age. The age at sale will also vary dependent on sale frequency for feeder calf sales, and the number of companies and/or frequency of calf pick up for bobby calves.

Options for generating beef-cross-dairy calves and factors contributing to their suitability to the dairy system

Mating strategies are identified in Table 6.2 below, with strengths, weaknesses and other considerations derived for each.

Table 6.2. Mating strategies to incorporate and increase proportion of beef-breed mating to generate beef-cross-dairy calves from a dairy herd.

Strategies to incorporate beef-breed mating		
Strengths	Weaknesses	Other considerations
Unrecorded beef-breed natural mating		
<ul style="list-style-type: none"> • Bulls are easy to obtain • Bulls are relatively cheap (Angus \$1,350, Hereford \$1,550¹), usually a small premium above their current processing value • Bulls are effective at heat detection 	<ul style="list-style-type: none"> • Bulls on farm • Bulls are unknown – they may have undesirable genetics (i.e. increase risk of calving difficulty) which could quickly outweigh the savings in purchasing a cheaper bull instead of a recorded bull 	<ul style="list-style-type: none"> • Facilities to manage bulls on farm, staff health and safety • Sufficient bull power (team size) needed. • Animal health and biosecurity considerations when bringing bulls onto farm
Recorded beef-breed natural mating		
<ul style="list-style-type: none"> • Can select bulls based on desirable genetics (i.e. minimising calving difficulty risk) • Bulls are effective at heat detection 	<ul style="list-style-type: none"> • Bulls on farm • Recorded bulls may be expensive (Angus \$2,500, Hereford \$2,600²), a large premium above their current meat value 	<ul style="list-style-type: none"> • Facilities to manage bulls on farm, staff health and safety • Sufficient bull power team size) needed. • Animal health and biosecurity considerations when bringing bulls onto farm
Beef-breed AB mating following dairy-breed AB period		
<ul style="list-style-type: none"> • No bulls on farm • Cost of breeding likely to be less than using bulls • Access to better beef-breed genetics through AB 	<ul style="list-style-type: none"> • Increased length of AB • Increased labour cost • Long period of heat detection 	<ul style="list-style-type: none"> • Staff need to have good heat detection capabilities • Plan to manage heat detection fatigue.
AB a select percentage to beef-breed semen alongside usual dairy-breed AB period		
Cows selected as those with poorer genetics or poor producers (bottom %)		
<ul style="list-style-type: none"> • Generate replacement heifer calves from top cows, improved genetic merit of replacements • More early-born beef-breed calves with potential for a greater sale value • Access to better beef-breed genetics through AB 	<ul style="list-style-type: none"> • Beef calves born alongside dairy calves – need to be able to easily tell them apart to prevent retaining beef-cross calves as replacements 	<ul style="list-style-type: none"> • Need to have good recording to identify top cows • May need to extend the AB period to generate enough replacement heifers, more so for herds with lower reproductive performance (6-week in-calf rate) • Shed space for calves as beef calves will be retained longer than bobby calves and are arriving at the peak of calving

Strategies to increase the proportion of beef-breed mating

Strengths	Weaknesses	Other considerations
Sexed semen (dairy-breed)		
<ul style="list-style-type: none"> Select which cows to generate replacement heifers from, improved genetic merit of replacements Less dairy AB may be needed, more mixed-aged cows available to mate to beef Potential for a shorter dairy-breed AB period 	<ul style="list-style-type: none"> Lower conception rate compared with conventional semen (Xu, 2014) May increase not-in-calf rate or conversely mating period May lengthen the following calving period and reduce days in milk 	<ul style="list-style-type: none"> Sexed straw cost is 2-3 times greater than conventional semen Need to have good herd reproductive performance Good record keeping needed to identify top cows Need good heat detection to maximise conception rate
Yearling heifer dairy-breed AB		
<ul style="list-style-type: none"> Increased genetic gain Allows for more mixed-aged cows to be bred to beef May need a shorter dairy-breed AB period for mixed-aged cows Option to use sexed semen 	<ul style="list-style-type: none"> Additional costs associated with heat detection aids Cost of synchrony programme (if using) Additional labour requirement 	<ul style="list-style-type: none"> Location of heifers (farm or grazier) Need suitable facilities to AB yearlings Heat detection skills on farm Labour availability Heifers need to have met target live weights prior to mating.

¹ Unrecorded bull purchase costs derived from 2019 August and September sale reports for yearling bulls, from Farmers weekly publications. ² Recorded bull purchase costs were estimated using the median sale price from 2019 yearling bull sales, Totaranui Angus and Craigmore Hereford.

Estimated number of beef-sired pregnancies for each strategy

The first four strategies outlined in Table 6.2 detail methods of integrating beef-breed mating into the mating period following a dairy AB period and alongside the initial AB period. Assuming an initial AB mating period of 6-weeks (Period 1), and a second mating period of 5-weeks (Period 2; based on the national average 11 week total mating period), the expected proportion of pregnancies using each mating strategy, split into carrying a dairy-sired heifer, dairy-sired bull or beef-sired calf (heifer and bull), is outlined in Table 6.3 below.

Table 6.3. Estimated proportion (%) of cows pregnant with a dairy-sired heifer, dairy-sired bull or beef-sired calf, for each mating strategy used to incorporate beef-breed mating into a dairy herd. Pregnancies are split into period 1, based on the first 6 weeks of mating, and period 2, based on the last 5 weeks of mating.

Mating strategy	Period 1 – 6 weeks			Period 2 – 5 weeks	Not-in-calf
	Dairy-sired heifer calves	Dairy-sired bull calves	Beef-sired heifer and bull calves	Beef-sired heifer and bull calves	
Natural mating – unrecorded bull	34.0	34.0		16.0	16.0
Natural mating – recorded bull	34.0	34.0		16.0	16.0
Beef-breed AB following dairy AB	34.0	34.0		16.0	16.0
Bottom 20% to beef alongside dairy AB	27.2	27.2	13.6	16.0 ¹	16.0

¹ Assuming the period 2 mating used a beef-breed bull or semen.

The proportion of expected pregnancies in Table 6.3 were broadly estimated using the following assumptions based on NZ dairy averages and industry information.

- The proportion of pregnancies in period 1 and 2 were determined using the New Zealand average 6-week in-calf rate (68%), not-in-calf rate (16%) and mating length (rounded up to 11 weeks) for the 2018-2019 season (LIC, 2018).
- The sex ratio of pregnancies was assumed to be 50:50
- The proportion of cows bred to beef-breed AB was set at 20%. This percentage could vary between herds and would be determined by reproductive performance of the herd and management practices. There are no published average proportions of cows bred to beef at the same time as dairy-breed AB.

The final two strategies identified in Table 6.2, using sexed semen and yearling AB, provide an opportunity to increase the proportion of beef-sired pregnancies, given that the required number of replacement heifers could be generated in a shorter AB period. Table 6.4 outlines the estimated proportions of pregnancies in Period 1 and 2. A shorter AB length of 3 weeks (Period 1) was used followed by 8 weeks (Period 2), assuming that all matings in Period 2 were to a beef-breed.

Table 6.4. Estimated proportion (%) of cows pregnant with a dairy-sired heifer, dairy-sired bull or beef-sired calf, for each mating strategy used to increase the proportion of beef-breed mating into a dairy herd. Pregnancies are split into period 1, based on the first 3 weeks of mating, period 2, based on the last 8 weeks of mating, or from yearling heifer AB mating.

Mating strategy	Yearling AB		Period 1 – 3-weeks		Period 2 – 8 weeks	Not-in-calf
	Dairy-sired heifer calves	Dairy-sired bull calves	Dairy-sired heifer calves	Dairy-sired bull calves	Beef-sired heifer and bull calves ¹	
Sexed semen			25.1	18.1	40.8	16.0
Yearling AB	5.5	5.5	21.6	21.6	40.8	16.0

¹ Assuming all period 2 matings were to a beef-breed bull or semen.

The number of expected pregnancies in Table 6.4 were estimated using the following assumptions based on NZ dairy averages and industry information.

- The adjusted period 1 mating length was shortened to 3-weeks in order to use the national 3-week submission rate average. Consideration was given to the proportion of replacement heifers generated in each scenario. A minimum 25% dairy heifer replacement pregnancies was used, allowing for pre- and post-natal calf mortality, not pregnant or not bred heifers, binomial variation in the sex ratio and the average proportion of 2-year old heifers in the milking herd (20% of the herd, derived from the number of herd tested cows, (DairyNZ, 2019).
- The New Zealand average 3-week submission rates (80%) and conception rate (54%) (LIC, 2018) were used to estimate the proportion of pregnancies in the first 3-weeks (Period 1, 43.2%). The New Zealand average not-in-calf rate and mating length was again used to determine the number of pregnancies in the second period (40.8%).
- The sex ratio of pregnancies was assumed equal for the yearling AB scenario, the sex ratio for pregnancies to sexed semen was assumed to be 90% female, as is the target for the liquid sexing technology used by LIC (Xu, 2014).
- The proportion of cows bred to sexed semen, was set at 20%. This number will vary between herds and would be determined by reproductive performance of the herd and management practices. There are no published average proportions for the proportion of cows bred to sexed semen.
- The number of yearlings bred (20% of the herd size) was estimated using the average proportion of 2-year-old cows herd tested relative to the total number of cows tested (DairyNZ, 2019), with 55% conception rate to a single AB insemination (Xu and Burton, 1999) and half of those pregnancies expected to be carrying a heifer calf (5.5% of the herd size).

The number of cows pregnant to each mating strategy and carrying each calf type identified in tables 6.3 and 6.4 above (dairy-sired heifer, dairy-sired bull and beef-sired calves) would vary depending on the culling protocols on the farm. When selective culling is applied, industry recommendations are to cull the lower producing cows and cows with later expected calving dates (DairyNZ, 2015), which would be biased towards the cows pregnant to a beef-breed mating for the strategies in Tables 6.3 and 6.4. Additionally, the number of calves born and sold to each of the pregnancy types will depend on the pre- and post-natal mortality rates on the farm.

The estimation of pregnancies in the sexed semen strategy does not take into account the reduced conception rate of sexed semen. For frozen sexed semen, the conception rate can be 10-15% lower than conventional semen, LIC has reported a 3-5% decrease in conception rate with use of their fresh product (Wilson, 2014, Xu, 2014, CRVAmbreed, 2019).

Discussion

Price differentiation between calves at sale is based primarily on breed, sex, weight and appearance of the calf (Oliver and McDermott, 2005, Burggraff, 2017) rather than the calf growth potential or estimated breeding values (EBV) for carcass and meat quality. Commercial feeder calf sale prices are reflective of a decreased value for smaller and calves with 'wrong' colouring, as heavier calves appearing to have Holstein-Friesian parentage are preferred (Muir et al., 2001, Morris and Kenyon, 2014). Because of the size and colour value difference at sale, some farmers may choose not to send some smaller or 'wrong' coloured calves to a feeder calf sale, choosing instead to send the calf for processing as a 'bobby' calf. Selling beef-sired calves as bobby calves will likely decrease the value of using beef-breed mating strategies. Bull-breed selection could be used to maximise the value proposition of the beef-sired calves born. A farm with a crossbred herd may benefit from using an Angus bull rather than a Hereford bull to generate a greater proportion of 'right' coloured calves. Conversely, a farm with a Holstein-Friesian herd will benefit more from a Hereford bull as a greater proportion of calves will be 'right' coloured, and Hereford-sired calves tend to be more valuable than Angus-sired.

The calf values compared in this Chapter are solely based on the sale price of the calf. Rearing the beef-cross calves, particularly for sale at a feeder calf sale would likely incur additional rearing costs as many sales are on a weekly or twice-weekly basis, therefore, calves aged 4-10 days old. Calves sold privately may be sold more regularly, and bobby calves can be collected for slaughter daily, once reaching 4 days-of-age. The magnitude of the additional costs is dependent on the management practices on the farm i.e. milk volumes fed, and whether surplus milk, whole milk from the vat, or milk replacer is used, capacity to accommodate the extra calves in the shed, and the availability of labour to feed them.

Similarly, the calf values identified in this chapter do not take into account additional costs of transporting calves to sale. Bobby calf collection is paid for by the meat processing company, and private sale costs are typically at the cost of the buyer. Feeder calf sales have fees associated with selling calves, and transport to the sale is at the cost of the farm, and therefore, decreasing the value of the beef-sired calf. The transport costs will vary between farms as they depend on the number of calves, the method of transport used and the location of the farm relative to the sale.

When recorded into dairy farm management software, calves of dairy origin are assigned EBV for dairy traits and breeding and production worth at birth (average of the dam and sire values). There is an opportunity to assign calves with an expected production value for

beef finishing, enabling calves to be sold on their genetic potential in addition to the size and appearance price differentials used at present. A premium for calves from recorded bulls, with growth potential, at sale would add value to the use of recorded over unrecorded bulls. Recorded beef-breed bulls have EBV for growth, carcass and meat quality, giving an indication to how offspring will grow and the likely income at slaughter. However, added value due to genetics would require the calves to have a known sire. Selling beef-sired calves based on expected production (growth and finishing) would fit into the current market of online sales, as dairy calves are currently traded online this way. However, it would likely change the way 'sale yard' calf sales currently operate and would require a way for the genetic data to be transferred to a non-dairy farmer which is currently not available.

The greater purchase cost of Hereford compared with Angus bulls represents the market share of Hereford bulls in the dairy industry, with Hereford the most commonly used beef-breed breed bull for dairy herds (DairyNZ, 2019) and, therefore, having the greatest demand. The primary reason for this difference is the "white-faced advantage" of the Hereford breed, wherein the calves born to Hereford bulls are easily identified as beef-cross-dairy. Aside from sale income of calves, there are also breed differences between Angus and Hereford bulls for calf birth weight and gestation length, which on average favour Angus bulls (Chapter 2), in terms of minimising calving difficulty. There is greater uncertainty around the breed of the calf when using an Angus bull (Chapter 5) because the calf may be difficult to differentiate from a Holstein-Friesian-Jersey crossbred calf. However, identifying calves with black tongues and no horn buds as Angus-sired calves will largely alleviate this issue (Chapter 5). As detailed in Chapter 1, there are a great number of beef-breed bulls available to the dairy industry, although the sale price of other breeds of beef-sired calves are not as well documented as Hereford and Angus.

Of the 6 strategies identified in this chapter, three are based on using beef-breed mating following a period of dairy AB. The first two strategies to integrate beef-breed mating involved a natural mating period following a dairy AB period. For many farms, the calving and mating periods represent the busiest times on the dairy farm. For herds with a long calving spread there is little time to rest between the busy calving and mating periods. Using physical bulls is a strategy which allows for reducing the labour associated with heat detection, as there is no need to detect cows on heat daily for inseminations. A benefit for many farmers is that bulls are adept at heat detection, allowing for less responsibility for the staff.

Considerations for using bulls for natural matings include ensuring enough bull power (team size), having the on-farm facilities for managing bulls (staff health and safety), and

animal health and biosecurity considerations for bringing bulls onto the farm. Industry recommendations are to have 1 bull per 30 non-pregnant cows, with at least 2 bulls running with the herd at all times (DairyNZ, 2020b, DairyNZ, 2020a). In addition, there are recommendations to have spare bulls available, with some reports recommending allowance for 2 full teams of bulls. Spare bulls allow for the rotation of teams and switching out of bulls which are not serving correctly or become ill (e.g. lame).

Having bulls on farm poses a health and safety risk to staff. Bulls can be temperamental and difficult to manage. There is an increased risk of injury to cattle and staff when having bulls on farm. Having sufficient facilities on farm is recommended to allow for a quarantine of bulls when arriving onto the farm, before being put into the herd for mating. A quarantine period allows for an adjustment period, particularly for teams of bulls from different properties, and to observe unfavourable behaviour (aggression, dominance) or any injuries that will affect the performance of the bulls (DairyNZ, 2020a).

Animal health considerations for using natural mating bulls include (but are not limited to) ensuring the bulls are healthy, well grown and having a known disease exposure and vaccination protocol (DairyNZ, 2020a). Introducing bulls into the herd risks also introducing diseases such as Bovine Viral Diarrhoea (BVD), Theileria and Johnes into the herd. Yearling bulls are preferable as there is a lower risk of introducing venereal disease and limit the temperamental issues and size differences that are associated with mature bulls. Bulls will require monitoring throughout the mating process to ensure that they are serving correctly.

The primary differences between the unrecorded bull and recorded bull mating strategies identified in this chapter are the cost of purchase, in favour of the unrecorded bull, and the confidence in the expected level of performance, in favour of the recorded bull. Bulls, with recorded genetic information (EBV) purchased at yearling bull sales (September/October) are more expensive than bulls purchased without genetic information. Considering representative median bull price from 2019 yearling bull sales for Angus and Hereford, recorded bulls are over \$1,000 more expensive than unrecorded bulls. The difference in price between the two bull options, especially when purchasing a number of bulls to make up a team, could mean that a team of recorded bulls may be too expensive relative to the number and value of the calves generated.

The predictable performance based on EBV of the recorded bull, however, is a huge advantage of purchasing a recorded bull. The genetic merit of the unrecorded bulls could fall anywhere in the range of the breed, and on average, will lag behind the recorded bulls

(Beef+LambNZ, 2017, Dechow and Rogers, 2018). Therefore, the unrecorded bulls are associated with risk of generating heavier calves that may result in increased calving difficulty, which has the potential for increasing morbidity and mortality of the cow and/or calf (Burfenig et al., 1978, Berg, 1979, Meijering, 1984, Naazie et al., 1989, Arthur et al., 2000, Pryce et al., 2006, Hickson et al., 2008b, Mee, 2008, Hickson et al., 2010). Additionally, a longer gestation length may decrease the days in milk of the cow, thereby decreasing milk production, and potentially increase the calving spread. Recorded beef-breed bulls offer a degree of reliability due to having EBV for the performance of the bulls. As illustrated in Chapter 2, the relationship between EBV and progeny birth weight and gestation length indicate that the buyer can use EBV to purchase bulls that suit their farming system in terms of calf birth weight and gestation length.

The level of risk aversion of the farmer will also influence choice of beef-breed bulls. The difference between unrecorded and recorded bull purchase cost is ~\$1000 greater for the recorded bull compared to an unrecorded bull. The difference is less than the value of replacing a single cow (~\$1800, based on September 2019 online sales of in-milk dairy cows), if an unrecorded bull sired one calf that resulted in the loss of the cow from calving difficulty. In addition, calving difficulty has been associated with a decrease in milk production and a decrease in fertility caused by an increase in time taken to begin cycling, which may result in the cow not getting pregnant in the breeding season and subsequently being culled (Brinks et al., 1973, Laster et al., 1973, Meijering, 1984, Buckley et al., 2003, Mee, 2008, Hickson et al., 2010, Fouz et al., 2013). Additionally, calving difficulty increases the risk of death of the calf, which at ~\$100 per calf, the death of multiple calves in the unrecorded bull mating strategies would greatly reduce the value proposition of the unrecorded bull.

The third strategy identified in this chapter, and final strategy utilising beef-breed mating in the period following an initial AB period, is using beef-breed AB. This strategy replaces the need for having bulls on the farm, but requires whole season AB. Using whole-season AB is likely to be a cheaper alternative in terms of cost of breeding relative to purchasing bulls for natural mating. LIC 2020 straw prices, exclusive of technician fees, range from \$9.95 for a 'no-choice pack' to \$18 for individual Angus and Hereford bulls. Different breeds are available by breeding companies although the straw cost increases with the rarer, less commonly used breeds (LIC 2020 prices, up to \$40 per straw) (LIC, 2020a). There are also advantages of being able to access better beef-breed genetics, which are offered by breeding companies or can be sourced from beef-bull breeders. However, whole season AB increases the labour cost associated with longer AB periods and requires an extended period of heat

detection. Extending AB requires detection of heat and management of cows put up for AB, and for many farms, lengthens the busy period on the farm which starts at calving. Recommendations to combat heat detection fatigue as signs of heat become less obvious, due to lower numbers of cycling cows, smaller sexually active groups and potentially less obvious signs of heat, include having multiple trained staff members detecting heat, or using a heat detection aid, or for some properties where an detection aid is used throughout mating, an additional aid may be used (e.g. tail paint plus a heat mount detector) (DairyNZ, 2017b). The additional labour requirement for extending AB, including the extended heat detection is not a uniform cost for all herds. The cost of labour is variable, differing between herringbone and rotary shed types, and affected by management, herd size, staffing levels and ownership structure, which vary among farms. The mating period also represents a busy time for dairy farms and extending the period of AB can be a strain on the staff, creating a disproportionate cost beyond the additional time taken. Therefore, for some farming operations a breeding period consisting entirely of AB is not a feasible option.

Whole-season AB herds represent only a small proportion of New Zealand dairy herds (2014: 2.4%; 2017: 3.6%), however the number of herds is increasing over time (LIC, 2019b). Statistics produced by LIC indicated that whole-season AB herds tended to have a similar or slightly better reproductive performance (+1.4% 6-week in-calf-rate; +4.6% 3-week submission rate) compared to other herds, although the not-in-calf rate also tended to be higher in all AB herds (LIC, 2019b), particularly when heat detection is poor. A benefit of using bulls for natural mating includes identifying cows in oestrus, which may be missed in a whole-season AB herd when the number of cycling cows decreases, especially if oestrous behaviours are not exhibited or unable to be identified because of a low number of sexually active cows. The benefit of using bulls is supported by greater 1.3% greater conception rate and a 0.6% lower not-in-calf rate (for the same mating length) compared to whole-season AB herds (LIC, 2019b).

One strategy identified in this chapter considered using beef-breed AB mating alongside the typical dairy AB period, where this option utilises breeding the lower genetic cows to beef, from which generating replacement heifers is not desirable. This strategy has the potential to further improve the genetic merit of the herd by selecting the best cows to breed the next generation from. Benefits of mating a proportion of cows to beef-breed semen include generating earlier-born beef-sired calves which may correspond with feeder calf sales where demand exceeds supply, increasing the value of the calf. Utilising beef-breed AB also creates the opportunity of accessing better beef-breed genetics including calving difficulty information. Having beef-sired calves born at the same time as potential replacement dairy

calves requires the calves to be easily identified; as detailed in Chapter 5, this may be difficult when using Angus semen in a crossbred herd. Additionally, a sufficient level of herd recording is needed to identify the bottom performing cows to mate to beef-breed semen, and a suitable level of reproductive performance (high submission and conception rates) is required to ensure enough replacements will be generated from a potentially smaller population of cows in the same time period. Considering the 6-week in-calf rate, the minimum level of reproductive performance required to generate sufficient (25%) dairy-AB-sired heifers, when breeding 20% of the herd to beef, is 63%. The average 6-week in-calf rate of the bottom 25% of New Zealand dairy herds is 58%, therefore suggesting that the 'breeding a proportion of the herd to beef' option would not be suitable for a large number of New Zealand herds.

The final two strategies identified in this chapter, using sexed semen and yearling AB, increase the proportion of beef-sired calves generated from the dairy herd. Using sexed semen to generate dairy replacement heifers would reduce the number of cows needing to be mated to generate heifer replacements. This in turn would increase the proportion of cows available to mate to beef-breed bulls. At present, the cost of sexed semen (\$56/straw, excluding technician fee) is significantly more than non-sexed semen (maximum cost of \$34.95/straw), as such, best results would be obtained by herds with excellent heat detection (LIC, 2020a). Additionally, the accuracy of sexing the semen is ~90%, and conception rates of fresh sexed semen tend to be 3-5% lower than non-sexed semen (Xu, 2014, LIC, 2020a). Therefore, for some farms, the added benefit of less surplus calves sired by dairy bulls, may be outweighed by the greater cost of insemination and lower conception rate to sexed semen.

Breeding yearling heifers to dairy AB allows a portion of replacement heifers to be generated from, typically, the proportion of the herd with the best genetics, maximising the genetic gain in the herd (Handcock et al., 2019a). A yearling AB strategy allows for a greater proportion of mixed-aged cows to be bred to a beef-breed mating strategy. There is also the option to use sexed semen to mate yearling heifers, further increasing the proportion of cows which could be bred to a beef-breed mating strategy. Yearling AB requires suitable facilities, and as many farms do not have yearling heifers on the dairy farm for mating, this may not be a feasible option. Where the yearling heifers are on the dairy farm, the same facilities as used for the milking herd can be used, minimising the additional requirement (facilities and labour) for heat detection. However, as industry recommendations are to mate heifers earlier than the milking herd (DairyNZ, 2020b), there are likely to be additional labour (including for heat detection) requirements. Additionally, using a synchrony

programme which would condense the period of AB, reducing labour requirements and heat detection also incurs additional costs. For heifers located at a different property, the logistics of AB may not be a financially or logically viable option. A factor requiring consideration when breeding yearling heifers in general, but of particular importance when using AB, due to the increased logistical considerations, is that heifers need to be well grown, meeting live weight targets (McNaughton and Lopdell, 2012, Handcock et al., 2016, DairyNZ, 2017a, DairyNZ, 2017b, DairyNZ, 2020b). Well grown heifers have a better chance of successful conception and better reproductive success the following year (McNaughton and Lopdell, 2012, Handcock et al., 2016).

Alone, each of the six strategies identified in this chapter have the potential to generate beef-sired calves from the dairy herd. Utilising a combination of strategies would further increase the proportion of beef-sired calves generated. Each of the strategies alone are dependent on the reproductive performance of the herd, a higher 6-week in-calf rate and lower not-in-calf rate will give more options to incorporate and increase the proportion of beef-breed matings into the herd, while still allowing for the generation of sufficient replacement heifers.

The outcome of this chapter indicates using beef-breed bulls has the potential to generate a greater value calf compared to using a Jersey bull. Six options for integrating and increasing the proportion of beef-breed matings into a dairy herd, each with their own strengths and weaknesses, were identified. The value of each strategy will differ between farms, and no one strategy is likely to work for all farms. Natural mating using a recorded beef-breed bull is worth considering over an unrecorded bull, as the recorded bull offers reliability around the performance of the bull, whereas the unrecorded bulls are associated with a greater risk of heavier birth weight calves and calving difficulty. Incorporating beef-breed mating into the same period as dairy AB will increase the number of beef-sired calves produced in the herd, while enabling selection of which cows to breed replacement heifers from. Utilising a combination of the strategies identified in this chapter would enable the greatest proportion of beef-sired calves to be produced. The combination of strategies used by an individual farmer will depend on the goals and constraints that a particular farm is operating under. A key factor for the dairy farmer is to select a strategy that will still generate sufficient replacement dairy heifers. Consequently, farmers achieving top quartile reproductive performance have more options to incorporate beef-breed mating into their dairy herd.

Chapter 7 – Concluding discussion

Introduction

The key interest of dairy farmers when choosing a service bull for dairy cows is the health and production of the dairy cow or heifer (Cook, 2014). In New Zealand, AB is used for approximately 72% of mixed-aged cows, with the majority bred to genetically superior dairy-breed bulls (DairyNZ, 2019). Most herds then use a period of natural mating, although a period of non-dairy AB is also popular prior to natural mating (LIC, 2019a, LIC, 2019b, LIC, 2020c). Artificial breeding is used to a lesser extent in dairy heifers, with the majority naturally mated (DairyNZ, 2017b, DairyNZ, 2020b). Anecdotally, the most prevalent bull breed used for mating with dairy heifers, and mixed-aged cows after the AB period is finished, in New Zealand, is Jersey as the breed is associated with a lighter birth weight calf, and has a lower risk of calving difficulty (DairyNZ, 2007, Hickson et al., 2015).

There is an opportunity to repurpose the surplus dairy calves born every year by using beef-breed bulls and rearing the progeny for beef production. The progeny from beef-breed bulls are generally of greater value than that of surplus dairy bull sired calves (Hickson et al., 2015). Furthermore, generating beef-sired calves instead of low value dairy-sired surplus calves (bobby calves) may address negative welfare and sustainability connotations associated with bobby calf production (Cook, 2014, Fisher et al., 2017). The opportunity for using beef-breed bulls exists both as AB to beef-breed semen and using live bulls following a period of AB for mixed-aged cows or for mating maiden heifers.

Limited research exists regarding which beef-breed bulls are most appropriate for mating to dairy cows and heifers, and whether there are any negative impacts of the bull on cow and heifer performance in terms of milk production and rebreeding, which should be considered alongside a change in calf value. Angus and Hereford are the predominant beef breeds in New Zealand (Beef+LambNZ, 2019a), with Hereford bulls anecdotally more commonly used in the dairy industry than Angus (DairyNZ, 2019).

It is of value to the dairy sector to establish if there is any difference in the performance of cows and heifers mated to different beef-breed bulls, and their progeny. Therefore, the overarching objective of this thesis was to identify what type, in terms of EBV, of beef-breed bulls are appropriate for mating to dairy cows, in terms of assistance at birth/calving, birth weight, gestation length and pre-weaning growth of the beef-cross-dairy calf and the milk production and rebreeding success of the dairy cow.

Appropriate bulls for using over mixed-aged dairy cows

In Chapters 2 and 3, mixed-aged dairy cows were artificially bred to beef-breed bulls that had a range of birth weight, gestation length and 600-day weight BreedPlan EBV. The progeny performance was evaluated in Chapter 2, and the effect of the bull on indices of cow production evaluated in Chapter 3.

In addition to the overlying objective of the thesis, Chapter 2 was designed to: a) evaluate the birth weight, gestation length and progeny growth to weaning of individual Angus and Hereford bulls for beef-cross-dairy calf production, and b) to evaluate the relationship between EBV and beef-cross-dairy progeny performance for birth weight, gestation length and pre-weaning growth for individual Angus and Hereford bulls.

The risk of assisted births is the main reason for farmers being cautious about using beef-breed bulls to mate dairy cows (Mee, 2008). Assisted births can have detrimental effects on the survival of calves, health and survival of the dam, and milk production and subsequent reproductive success of the dam (Brinks et al., 1973, Laster et al., 1973, Meijering, 1984, Buckley et al., 2003, Mee, 2008, Hickson et al., 2010, Fouz et al., 2013). There were very few assisted births in the calves born to mixed-aged cows in this experiment (<1%), less than the 2 – 10% reported in literature (Xu and Burton, 2003, Mee, 2008, Stafford, 2011). Birth weight of the calf is the primary risk factor for increased rate of calving assistance (Burfening et al., 1978, Arthur et al., 2000, Hickson et al., 2008b, Mee, 2008), therefore, the lower assistance rate is likely due to the bulls being selected in the lightest 50% of the respective breed for birth weight EBV, and consequently the calves born were light enough to not result in increased risk of assistance. The calves born to mixed-aged cows in Chapter 2 were of similar birth weight to female dairy calves born to Holstein Friesian bulls (32.5 – 36.1 kg) (Hickson et al., 2015) and lighter than the recommended weight of at least 40 kg for purchasing Holstein Friesian bull calves for beef production (Muir et al., 2002, Beef+LambNZ, 2018).

Calf birth weight is negatively related to pre-weaning growth; therefore, restriction of birth weight should negatively impact the days to reach weaning weight and consequently, rearing costs. The pre-weaning growth rate of calves born to mixed aged cows in this experiment was consistent with pre-weaning growth rates (0.61 – 0.82 kg/day) reported in artificially reared dairy-origin calves in New Zealand (Muir et al., 2000a, Muir et al., 2001, Muir et al., 2002, Cardoso et al., 2015, Back et al., 2016, Back et al., 2019). Therefore, rather than smaller is better, recommendations should be based on using bulls with an appropriate birth weight (≤ 40 kg for the experimental herd). These recommendations should produce

calves comparable to the expected birthweight when using dairy bulls, that are small enough to not increase the risk of dystocia, while minimising the disadvantage of smaller calves taking longer to reach weaning weight.

The rate of assisted births was low, therefore, all the bulls in the experiment were deemed safe for mating to dairy cows. Some bulls used in the experiment described in Chapters 2 and 3, had advantages of shorter gestation length, which in turn, benefits the dairy herd by reducing the calving spread (Winkelman and Spelman, 2001, Norman et al., 2011, Donkersloot, 2014, Stachowicz et al., 2015), and increasing the days in milk. However, these advantages would be dependent on the breeding objectives of the individual farm and the mating structure, as shorter gestation length bulls would be more desirable when used later in the breeding period. The bulls varied in progeny birth weight and gestation length, and there was a good relationship between progeny performance through an EBV calculated using the data from the present experiment, and the BreedPlan EBV of the bulls. As there was a good relationship between birth weight and gestation length EBV and the progeny performance, there is no need for a genetic evaluation specific for beef-breed bulls used to mate dairy cows.

The minimum standard beef-breed bull for using to mate dairy cows would produce calves with an equal or lighter birth weight and gestation length than average alternative Holstein-Friesian bull (straight-bred Holstein-Friesian calves are likely to average around 40 kg at birth, based on the reported values from Hickson et al. (2015) on female dairy calves; and have a gestation length of 281 days, (Donkersloot, 2014)). The 40 kg birth weight also coincides with the ideal weight for dairy-beef calf purchase recommendations (Muir et al., 2002, Beef+LambNZ, 2018). The relationship between progeny performance and BreedPlan EBV in Chapter 2 was used to generate what threshold EBV the bulls would need, to produce comparable calves to Holstein-Friesian bulls. Under the BreedPlan genetic evaluation, the EBV of an ideal Angus bull would therefore be $\leq +7.64$ kg for birth weight and ≤ -2.37 days for gestation length; and for a Hereford bull, the EBV thresholds would be $\leq +6.93$ kg for birth weight and ≤ -4.60 days for gestation length. Searching for active bulls (born between 2016 and 2019) with these EBV on the Agriculture Business Research Institute (ABRI) database of BreedPlan EBV (as at May 2020) shows that there are 829 Hereford bulls that meet this criteria, whereas, there are far more Angus bulls available in the industry, with the search returning 25,505 bulls. While there are a far greater number of appropriate Angus bulls than Hereford, good bulls exist within both breeds. Of the bulls used in the experiment, 28/31 Angus bulls met the birth weight and gestation length EBV thresholds, along with 7/34 Hereford bulls. This difference was due to the gestation length EBV, as all bulls in the

experiment met the birth weight EBV threshold. Depending on the farm and mating scenario, the previously mentioned EBV thresholds may not be completely suitable, and the ideal birth weight and/or gestation length EBV may need to be lower, however, the results from Chapter 2 indicate that EBV can be used to select bulls with desirable traits.

As there are bulls which exist in both breeds that are suitable for mating to dairy mixed-aged cows, there is the opportunity for breed preference. There is a greater preference for Hereford bulls in the industry currently, in part because the resulting calf is easily identified by the presence of a white head. However, based on findings reported in this thesis (Chapters 2), if bulls of lighter birth weight and shorter gestation length are required, there are a far greater number of suitable Angus than Hereford bulls. It is important for the dairy farmer to be able to identify the breed of calves born in order to select replacement heifers from dairy breed calves and sell beef-cross-dairy calves. When Angus bulls are used, the resulting calves are usually completely black, which means they may look similar to Holstein-Friesian-Jersey crossbred and some Holstein-Friesian calves. As DNA sampling for parentage analysis is costly and not widely used in commercial situations, the aim of Chapter 5 was to identify characteristics which could be used to identify breed in dairy and Angus-cross-dairy calves. The tongue colour and presence of horn buds at birth were useful for identifying Angus-sired calves from dairy breed calves. The combination of a black tongue and no palpable horn buds (polled) was identified as a means of differentiating Angus-sired calves from dairy-sired calves with high accuracy (Chapter 5).

Based on the results from Chapters 3 and 4, there was very little effect on the milk production and rebreeding success of dairy cows from breeding to Angus or Hereford bulls. The specific objective of Chapter 3 was to identify whether there was an effect of service sire on the body condition score, milksolids yield and rebreeding success of mixed-aged dairy cows serviced by Angus and Hereford bulls. The present experiment did not find any effect of the service sire on the milk production or rebreeding success of the cows. There is no literature that indicates a direct effect of the service sire on milk production or rebreeding success, however, the negative effect of dystocia on milk production or rebreeding success is documented (Brinks et al., 1973, Laster et al., 1973, Meijering, 1984, Buckley et al., 2003, Mee, 2008, Hickson et al., 2010, Fouz et al., 2013). Provided the service sire does not cause an increase in assisted calvings, there should not be any detrimental effects on milk production or rebreeding.

The results from Chapters 2 and 3 indicated that there is scope for using high genetic merit beef-breed bulls over mixed-aged dairy cows. The potential value of beef-cross-dairy calves were identified in Chapter 6, the use of Angus and Hereford bulls, which could be

extrapolated to other beef breeds, would generate a higher value calf than using a Jersey bull, and the value of Hereford-sired calves is generally greater than Angus-sired calves. For a crossbred herd, the preferable bull-breed choice may be a Hereford bull, because their replacement heifer calves are easily differentiated, whereas this is not the case when using an Angus bull. However, with increasing proportions of Jersey ancestry in the herd, the proportion of calves classed as 'wrong' coloured would also theoretically increase. Angus-bulls may offer an advantage over Hereford bulls where a greater proportion of calves born to crossbred dams are classified as being 'right' coloured and a higher value. Mastering the horns and tongue-colour technique identified in Chapter 5, would assist with distinguishing the breed of calves.

Methods of incorporating beef-breed mating into a dairy herd were identified in Chapter 6. Options were considered which included the use of high genetic merit beef-breed bulls for natural mating and use through artificial breeding. Methods of increasing the proportion of cows bred to beef-breed bulls in dairy herds by using sexed semen or yearling AB were also identified. Although not all options identified would be suitable for use in all herds, in particular herds with poorer than average reproductive performance, there are options for using high genetic merit beef-bulls to mate mixed aged cows.

Ideal bulls for using over maiden dairy heifers

In Chapter 4, maiden dairy heifers were naturally mated to Angus, Hereford or Jersey bulls which were chosen for very high calving ease and low birth weight (Angus and Hereford) or breed average live weight and gestation length (Jersey). In addition to identifying what type of Angus and Hereford bulls are suitable for mating to heifers, Chapter 4 was designed to: a) compare the birth weight, calving assistance and survival of calves born to first-calving heifers mated to Angus, Hereford or Jersey bulls; b) compare the pre-weaning growth of Angus- and Hereford-sired calves; and c) to identify whether there were differences in the body condition score, milk production and rebreeding success of first-calving heifers mated to Angus, Hereford or Jersey bulls.

The calves born to Angus and Hereford bulls were heavier at birth than those born to Jersey bulls and experienced more assisted births. This was not an unexpected result given the breed produces light calves with little risk of assistance (DairyNZ, 2007, Hickson et al., 2015). Although the Angus and Hereford bulls were associated with increased incidences of assisted births, there was no difference in the pre-weaning growth of the calves (Angus and Hereford bulls only), or the survival, milk production or rebreeding success of heifers mated to Angus, Hereford or Jersey bulls. Therefore, providing the cost of the increase in assistance

(direct costs of labour and possible veterinary assistance, indirect costs of the welfare implications, which were not within the scope of this experiment) is outweighed by the additional sale value of the calf, it is worth considering the use of Angus and Hereford bulls to mate heifers. The bulls used in Chapter 4 were selected to minimise risk of calving difficulty, however, 8/12 beef-breed bulls used in the experiment still resulted in some calving assistance. Within the bulls used in the present experiment, selecting bulls with greater direct calving ease and lighter birth weight EBV resulted in a decreased proportion of assisted births. Therefore, choosing bulls with high direct calving ease and low birth weight EBV will reduce the risk of calving assistance in first-calving heifers.

The findings in Chapter 6 illustrated that both Angus and Hereford bulls will generate more income from calf sales than using Jersey bulls,. There was no difference in the milk production or rebreeding performance of heifers mated to Angus, Hereford or Jersey bulls, which combined with the greater value calf, supports the use of beef-breed bulls to mate dairy heifers. However, the findings of Chapter 4 highlight the risk of beef-breed bulls compared with Jersey bulls. The beef-breed bulls used in Chapter 4 were associated with increased calving assistance, in comparison to no assistance from heifers bred to Jersey bulls. The value proposition of a beef-sired calf would decrease where the beef-breed bull used is associated with an increase in calving difficulty. The calving period represents a busy time on dairy farms and risk aversion around calving difficulty may lead to reluctance of farmers to use beef-breed bulls. Literature provides evidence towards a decrease in production and survival of dairy cows and the calf following a difficult calving (Anderson and Bellows, 1967, Brinks et al., 1973, Laster et al., 1973, Laster and Gregory, 1973, Meijering, 1984, Buckley et al., 2003, Lombard et al., 2007, Mee, 2008, Hickson et al., 2010, Fouz et al., 2013), therefore the use of beef-breed bulls over heifers should be with caution. Further research is needed before recommendations of individual bulls for breeding to maiden heifers can be determined.

Although the number of suitable beef-breed bulls for breeding to maiden heifers cannot be determined without first identifying suitable EBV thresholds, there is likely to be insufficient suitable bulls to service all naturally bred dairy heifers in New Zealand. To naturally breed approximately 750,000 -800,000 heifers, (derived from proportion of 2-year old heifers herd tested as a proportion of the herd, and the number of yearling heifers bred to AB, DairyNZ (2019)), around 100,000 bulls would be needed (mating ratio of 1:15-20 with two bull teams as recommended by DairyNZ (2020b)). As the demand for bulls is likely to exceed the supply of suitable bulls if all farmers were to use beef-breed bulls to

mate heifers, the cost of acquiring a bull is likely to be a limiting factor of using beef-breed bulls to mate yearling heifers.

Considerations for application of beef-cross-dairy calf production

Improving beef-cross-dairy production in New Zealand requires participation from three parts of the industry: the AB companies providing semen to dairy farmers, bull breeders providing live bulls to dairy farmers and breeding companies for AB, and finally the dairy farmers who mate their cows to beef-breed bulls or breed them to beef-breed semen. The considerations for dairy farmers are outlined in the previous sections illustrating the ideal EBV for bulls to breed to mixed-aged cows and maiden dairy heifers.

Additionally, the practical application of beef-cross-dairy production requires the participation of beef finishers to grow the cattle from point of sale (4-day old or weaning) to slaughter. Traits of importance to beef finishers include growth, carcass and meat quality. Therefore, the bulls used in Chapter 2 and 3 were selected to represent a range of EBV for 600-day weight and Intramuscular fat. While the post-weaning growth and the carcass and meat quality evaluation of beef-cross-dairy cattle is outside of the scope of this thesis, it still needs to be evaluated to ensure this mating strategy provides a saleable product.

Dairy AB companies

The primary breeding companies in New Zealand are Livestock Improvement Corporation (LIC), CRV Ambreed (CRV) and Samen. All three breeding companies provide beef-breed bulls from a range of breeds. However, not all individual bull information, regarding their expected performance are available on the breeding company websites, unlike the dairy breed bulls. The dearth of easily available information, and limited choice of individual bulls mean that there are limited options for dairy farmers to choose an individual bull which suits their system. Additionally, the minimal amount of information available on individual bulls on the company websites raises the question of the different trait EBV of these bulls and whether there is an opportunity to improve the quality of these bulls.

Improving the uptake of beef-cross-dairy production would require the breeding companies to offer bulls with estimated breeding values. BreedPlan provides this information for most breeds, or it can be obtained by progeny testing bulls as is done with the dairy-breed bulls the breeding companies currently offer, allowing the farmers to choose which bull would suit their system and their selection objectives. Allowing the choice of individual bulls rather than a no-choice pack may also increase the use of the beef-breed semen from these companies, as the farmers would have more confidence in the expected performance of the bulls they are selecting. Progeny testing a range of beef-breed bulls

together would help to compare the bulls of different breeds and provide justification for the selection of specific bulls. Although useful, the BreedPlan EBV system has a disadvantage of keeping the breeds separate, resulting in EBV that are not comparable across breeds. This will be misleading for dairy farmers used to the across-breed genetic evaluation system used in the New Zealand dairy industry. For example, a farmer with a herd of smaller cows may place more emphasis on lower birth weight than a farmer with large Holstein cows. Similarly the timing of mating, whether the cows mated to beef-breed semen are those mated towards the end of the breeding season in which more emphasis may be placed on gestation length than if beef-breed semen was used to mate selected cows such as those with lower production or lower breeding worth, concurrently with those mated to dairy semen, which would make gestation length less important.

Beef-breed bull breeder

The primary breeding objective of many beef-breed bull breeders is to provide 2-year-old bulls to beef herds, of less importance to these breeders is providing bulls to dairy herds. Many bull breeders do market bulls towards dairy herds at the yearling sales. Often, these bulls are those which are not selected to be kept for sale as a 2-year-old. The yearling bulls not kept are typically those with lighter birth weights and lower growth, and the lighter birth weight makes these bulls acceptable for using to mating dairy cows.

Beef cows are primarily naturally mated (McFadden et al., 2005, Morris and Kenyon, 2014) rather than being artificially bred, as is common in the dairy industry. The recommended ratio of bulls to cows is lower for beef cows (1:50) (Beef&LambNZ, 2017) than for dairy cows (1:32) (DairyNZ, 2006) when used following a period of artificial breeding. The national dairy herd (4.95 million cows) is far larger than the national beef herd (1 million cows) (Beef+LambNZ, 2019a, DairyNZ, 2019). While, 20,000 bulls are required to breed beef cows, the number of bulls required for the 30% of dairy cows that are not pregnant following the AB period is 46,400, although dairy breed bulls are also used. Beef-breed bulls are often retained for multiple years of mating, whereas dairy farmers frequently replace bulls after a single season. This means a greater number of bulls are required for the dairy industry than the beef industry.

With increasing interest in the use of sexed semen in the dairy industry, the potential for beef-cross-dairy production increases, as less cows are required to generate dairy replacements. With sexed semen, there is an option for mating the top cows to dairy bulls and mating the remaining cows to beef-breed semen through AB alongside the rest of the cows, or natural mating could be used. Or, alternatively, having a reduced mating period to dairy semen, then natural or AB mating the later cows to beef-breed bulls. Both options

would increase the number of beef-cross-dairy calves produced, although with greater numbers of cow to mate, additional beef-breed bulls would be needed on top of the 46,400 mentioned previously.

Although, the primary objective for many bull breeders is to produce bulls for beef herds, the number presented in the previous paragraph shows that there is an opportunity for breeders to produce bulls for dairy herds as their primary objective. Bull breeders can hold more yearling bulls than 2-year-old bulls on the farm if fewer bulls are held beyond one year of age as there is little overlap with previous and subsequent years' bulls. Sale reports from bull breeders illustrate that 2-year-old bulls sell for 2-3 times more than yearling bulls; although, the total costs associated with grazing/feeding for an additional 8-12 months, relative to the greater sale income from older bulls may be reduced for yearling bulls. Additionally, there is greater scope for the number of bulls sold to dairy herds per year to increase, compared to the limited scope for selling more bulls to beef herds, as the national beef cow herd is declining and an increasing proportion of beef is originating from the dairy industry (Morris and Kenyon, 2014, Beef+LambNZ, 2017).

Limitations of thesis

The general aim of this thesis was to investigate the suitability of using high genetic merit beef-breed bulls to mate dairy cows. This thesis provides evidence that high genetic merit beef-breed bulls can be used over dairy cows, and what traits these bulls need to have. However, some limitations of the data arose, which may affect the results, and therefore, justify additional research.

The individual cow breeds were unknown in this experiment, and so the likely differences in dam or cow breed contributing to variation, particularly in calf growth, milk production and rebreeding success of the cow, were unable to be accounted for. The herd was predominantly Holstein-Friesian, and Holstein-Friesian-Jersey crossbred, with first calving heifers primarily sired by Holstein-Friesian-Jersey crossbred bulls. Although the individual breed proportions were unknown, the bulls were randomly assigned to the cows in this experiment so any effect of cow breed should be small when considering possible differences in milk production and rebreeding performance among service sires. The lack of difference in the mating and pre-calving live weight (heifers), the post-calving live weight (mixed-aged cows) and cow milk production among service sires suggested that the cow breed distribution was similar among service sires, as there is known variation among Friesian, Jersey and crossbred cows in live weight, milk volume and milk composition (Butler-Hogg and Wood, 1982, Burke et al., 1998, Lopez-Villalobos et al., 2000, Heins et al.,

2008, Spaans et al., 2018). There were only 6 bulls that had fewer than 10 calves to mixed-aged cows, therefore for the vast majority of bulls used in Chapter 2 and 3, the progeny group were from a reasonable sample of cows and theoretically, a similar representation of breeds.

The EBV calculated in Chapter 2, for bulls used over mixed-aged cows, were limited by the unknown breed proportions of the dam and ancestry of the dam, therefore relationship links between the dams could not be accounted for unlike the sire. The unknown dam breed and lack of dam pedigree meant that heritabilities were unable to be calculated from this dataset, and some genetic variation in the population was unable to be determined. The standard errors of the genetic correlations in Chapter 2 were large reflecting a large genetic variation in the dataset. The standard errors of the phenotypic correlations were much lower indicating that the phenotypic variation among the data was smaller. Being able to account for the breed proportions of the dam, and a pedigree of the dam in the calculation of the correlations between traits would result in lower standard errors for the genetic correlations but may not change the value of the correlations.

The average predicted milk production for mixed-aged cows (Chapter 3) and heifers (Chapter 4) in this herd was less than the herd-test average of New Zealand dairy cows (DairyNZ, 2019). The body condition scores of the cows (Chapter 3) and heifers (Chapter 4) were lower than the industry recommended minimum BCS prior to calving (DairyNZ, 2012a). The low body condition scores and low plane of nutrition would likely prevent the animals from reaching their milk production potential, and limit their reproductive performance (Buckley et al., 2003, Valour et al., 2013). The depression of milk production and reproductive performance may contribute to any effects of service sire on milk production and reproduction being reduced or overshadowed. Consequently, further work is needed to ascertain whether service sire effects are seen in higher producing cows.

Recommendations for future research

The focus of beef-cross-dairy production in this thesis is on the effect of the beef-breed bulls on the dairy cow, and the performance of the beef-cross-dairy calf until weaning. The Angus- and Hereford-sired calves generated in Chapter 2 and 4 were followed in a second PhD (Natalia Martin, Massey University). The scope of the second PhD was from weaning of the calves through to slaughter and evaluated progeny growth, carcass characteristics and meat quality of the Angus and Hereford bulls. Further progeny testing to identify suitable beef-breed bulls will require a whole production chain approach including beef-finishing farms and beef processing plants.

Although the Angus and Hereford breeds used in this experiment represent the most populous beef breeds in New Zealand, there are other breeds which are being used in the dairy industry and offered by the breeding companies LIC, CRV Ambreed and Samen. Therefore, selected bulls from other breeds should and are being included in the subsequent cohorts of bulls evaluated in the Beef + Lamb NZ Genetics Dairy-beef progeny test, for which the first 2 years provided the data evaluated in this thesis. The required number of bulls, as calculated for breeding mixed-aged cows above, indicates that there are insufficient Angus and Hereford bulls in the current population to meet the needs of the dairy industry. Incorporating additional beef breeds into the beef-cross-dairy progeny test evaluation will allow for the comparison of different breeds, which the current within breed genetic evaluations by BreedPlan do not allow. The practical application of beef-cross-dairy production is reliant on the incorporation of the top standard of beef-breed bulls identified by the evaluation, in order to get an accessible product to farmers.

The suitability of using beef-breed bulls to mate maiden dairy heifers also requires further investigation. Further research would focus on the economic differences between using beef-breed and Jersey bulls, initially, in terms of the economic impact of increased calving difficulty and potential flow on impacts on heifer milk production and rebreeding success. Additional data would be needed to compare the cost of calving assistance, and to determine if, and at what point the calving assistance rate, likely driven by feto-maternal disproportion (calf birth weight and heifer live weight) (Meijering, 1984, Hickson et al., 2006, Hickson et al., 2008a, Hickson et al., 2008b, Mee, 2008), negatively impacts on the survival and production of the heifer and the resulting calf (Anderson and Bellows, 1967, Brinks et al., 1973, Laster et al., 1973, Laster and Gregory, 1973, Meijering, 1984, Buckley et al., 2003, Lombard et al., 2007, Mee, 2008, Hickson et al., 2010, Fouz et al., 2013). Further investigation would offer more information to the suitability of beef-breed bulls for using over dairy heifers and for identification of suitable individual bulls.

Conclusion

The results presented in this thesis provide evidence towards the suitability of using beef-breed bulls over mixed-aged dairy cows. Indications towards suitable birth weight and gestation length EBV for Angus and Hereford bulls, and consequently suitable individual bulls were identified. Correlations between birth weight and age at weaning indicated that suitable bulls are not the lightest that the breed can offer, rather that beef-breed bulls which produce comparable calves to the alternative dairy bulls are most appropriate. In low producing mixed-aged dairy cows the service sire had little or no effect on the subsequent milk production, rebreeding performance or survival of the cow, with very low rates of

calving difficulty. Using beef-breed bulls provides a greater difference in calf sale income relative to Jersey bulls. Additionally, the increased purchase cost of a recorded bull, suitable for minimising calving difficulty, is likely balanced by the unknown risk of difficult calvings from an unrecorded bull. Therefore, using high genetic merit recorded beef-breed bulls should be considered for mating to mixed-aged cows. For maiden dairy heifers, the suitability of beef-breed bulls is reliant on minimising calving difficulty, which Chapter 4 provided evidence that lighter birth weight EBV bulls tended to decrease calving assistance. However, provided the beef-breed bull does not contribute to an increase in calving difficulty, the lack of difference in milk production, rebreeding performance and survival provides sufficient evidence for the use of beef-breed breed bulls over maiden dairy heifers. Additional research is needed to provide recommendations for suitable beef-breed bulls to mate maiden heifers. Overall, the results presented in this thesis provide evidence towards the successful use of high genetic merit beef-breed bulls in New Zealand dairy herds.

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Appendices

Appendix A: Supplementary tables for Chapter 2

Appendix A.1: Estimated breeding values of Angus and Hereford Bulls

Appendix A. Table 1. Birth weight, gestation length and 200-day weight BreedPlan¹ estimated breeding values (with accuracy in parentheses, %) for Angus bulls artificially bred to mixed-aged cows. Values current as at January 2020.

Name	Sire ID	Herd book number	Year used	Birth weight (kg)	Gestation length (days)	200-day weight (kg)
BLUE MOUNTAIN BRILLIANZ O5	715061	210530135	Link	3.6 (81)	-8.8 (86)	47 (79)
EARNSCLEUGH BARTEL 144307	716043	210130144307	Year 2	2.9 (96)	-6.9 (94)	56 (92)
FOCUS PROGRESSION 110178	714046	145720110178	Year 1	0.3 (91)	-3.3 (86)	31 (86)
FOCUS PROTOGE 110002	712171	145720110002	Year 1	1.4 (88)	-9.1 (85)	51 (83)
GLANWORTH WAIGROUP 1213	714004	1215401213	Link	1.0 (97)	-4.4 (94)	35 (95)
GRAMPIANS LOTTERY K13	716073	21150014K13	Year 2	5.7 (78)	-3.8 (82)	39 (81)
KAKAHU 13059	715103	13300013059	Year 1	3.3 (91)	-2.8 (94)	48 (86)
KAKAHU FOR BOND 13007	715058	13300013007	Link	3.3 (94)	-5.3 (96)	50 (91)
KAKAHU JUBILANT 13054	715060	13300013054	Year 1	0.6 (90)	-3.0 (93)	37 (85)
MATAURI REALITY 839	710016	14647008839	Year 1	1.1 (99)	-10.1 (99)	41 (99)
MATAURI RESOLUTION F030	712080	14647010F030	Link	3.9 (98)	-7.1 (97)	43 (96)
MEADOWSLEA F540	715105	19134010540	Year 2	2.4 (97)	-6.5 (83)	33 (96)
MT LINTON 13041	715102	20305013041	Link	-0.4 (91)	-8.0 (86)	41 (88)
PINEBANK 1/06	708031	119900061	Link	3.2 (93)	-5.8 (84)	31 (91)
RENNYLEA EDMUND E11	711067	AUNORE11	Year 1	1.0 (99)	-7.2 (99)	36 (99)
SEVEN HILLS 161-06	708057	21159006161	Year 1	0.6 (94)	-7.3 (84)	42 (91)
SEVEN HILLS 173-06	715104	21159006173	Link	1.9 (71)	-6.6 (68)	42 (70)
SHALOM WAIGROUP 101/01	703057	10596001101	Year 1	1.9 (97)	-1.4 (92)	23 (95)
SHALOM WAIGROUP 319/07	715088	10596007319	Link	2.8 (84)	-1.0 (61)	33 (79)
STORTH OAKS ANGUS PRIME K5	716058	19507014K5	Year 2	2.4 (90)	-6.2 (88)	38 (85)
STORTH OAKS EVEREST J20	715038	19507013J20	Link	2.5 (96)	-8.7 (96)	53 (93)
STORTH OAKS H41	714042	19507012H41	Link	4.4 (95)	-7.6 (96)	47 (92)
STORTH OAKS J29	715099	19507013J29	Link	2.5 (76)	-7.1 (85)	42 (72)

Name	Sire ID	Herd book number	Year used	Birth weight (kg)	Gestation length (days)	200-day weight (kg)
STORTH OAKS K134	716084	19507014K134	Year 2	5.7 (79)	-7.4 (84)	56 (75)
STORTH OAKS K154	716086	19507014K154	Year 2	4.6 (94)	-3.6 (92)	41 (90)
TE MANIA UNLIMITED U3271	702140	AUS0VTMU3271	Link	3.1 (99)	-0.4 (99)	29 (99)
THOMAS UP RIVER 1614	713089	US17091363	Year 2	3.4 (98)	-5.9 (99)	59 (98)
TOTARANUI 13007	715098	12922013007	Link	3.1 (92)	-5.1 (94)	50 (91)
TURIHAUA LIBERATION C27	712005	17691007C27	Year 1	1.2 (95)	-3.9 (66)	27 (92)
WAITANGI D213	710091	18954008D213	Link	3.0 (98)	-3.9 (96)	45 (97)
WOODBANK BLACK POWER	704170	15009000006	Year 1	4.9 (95)	-3.8 (90)	36 (93)

¹ From NZ Angus, ABRI database, current as at January 2020. Data from the use of the bulls in this experiment did not contribute to the calculation of the BreedPlan EBV.

Appendix A. Table 2. Birth weight, gestation length and 200-day weight BreedPlan¹ estimated breeding values (with accuracy in parentheses, %) for Hereford bulls artificially bred to mixed-aged cows. Values current as at January 2020.

Name	Sire ID	Herd book number	Year used	Birth weight (kg)	Gestation length (days)	200-day weight (kg)
ARDO ACHILLES 120	715106	0277100120	Year 1	1.3 (97)	-1.3 (85)	25 (96)
ARDO BISMARCK 4256	716017	0277144256	Year 2	-0.6 (97)	-3.2 (94)	23 (95)
ARDO EZICALVE CASPIAN	711022	0277066159	Year 2	-2.5 (97)	-0.1 (76)	18 (95)
ARDO FARGO 1154	715086	0277111154	Year 1	-0.3 (97)	5.3 (81)	30 (96)
BEECHWOOD DOUBTLESS	716098	0051140527	Year 2	2.3 (94)	-3.3 (87)	36 (91)
BEECHWOOD TURK	714037	0051100094	Link	2.8 (95)	-1.6 (94)	35 (93)
BLUESTONE 080014	715091	1683080014	Link	1.4 (96)	-2.3 (91)	31 (94)
BLUESTONE 120061	714003	1683120061	Year 1	1.9 (92)	-9.9 (87)	30 (88)
BLUESTONE 140015	716087	1683140015	Year 2	5.3 (90)	-7.7 (83)	36 (86)
BLUESTONE 140027	716088	1683140027	Year 2	1.1 (91)	-8.2 (82)	34 (87)
BURNFOOT PLAYBOY	666325	0735P0007	Link	3.5 (97)	-0.4 (86)	21 (95)
COLRAINE CODE WORD 13 139	715101	1660130139	Year 1	2.5 (79)	-5.2 (73)	34 (76)
CRAIGMORE OPIUM 10214	716016	0169100214	Year 2	3.2 (89)	0.1 (66)	30 (86)
FLAGSTAFF BIG RED E8	715073	0759090008	Year 1	2.0 (96)	-2.7 (81)	27 (92)
FLAGSTAFF DYNAMO G6	715084	0759110006	Link	0.3 (86)	-4.5 (79)	29 (80)
KAIRAUMATI COAL FACE 1482	715092	1483140082	Year 1	4.1 (76)	0.8 (71)	35 (77)
KOANUI BEDFORD 4081	715108	0216144081	Year 1	2.6 (74)	0.0 (74)	28 (69)
KOANUI BRITON 2044	716097	0216122044	Year 2	2.1 (95)	-1.4 (89)	36 (92)
KOANUI ROCKET 0219	703131	0216000219	Link	-0.9 (99)	0.3 (99)	29 (99)
KOANUI UNANIMOUS 0408	715093	0216100408	Year 1	3.0 (97)	2.6 (89)	38 (96)
LIMEHILLS AWESOME X117	715107	0677020117	Year 1	2.1 (95)	0.7 (84)	21 (93)
LIMEHILLS STAMPER 20719	715082	0677120719	Link	6.7 (96)	1.5 (89)	45 (94)
MARANUI HICK 11-62	715095	0659110062	Year 1	1.4 (96)	1.9 (45)	24 (94)
MATAPOURI KOA 09 99	715094	0251090099	Year 1	1.7 (97)	0.4 (55)	22 (95)
OKAWA MARSHALL 0109	715089	0617100109	Link	2.5 (96)	2.8 (69)	33 (93)
ORARI GORGE MISCHIEF 120083	716044	0400120083	Year 2	2.5 (96)	-3.8 (94)	35 (94)
OTAPAWA SPARK 3060	705090	0347033060	Link	5.3 (99)	-5.0 (98)	49 (98)

Name	Sire ID	Herd book number	Year used	Birth weight (kg)	Gestation length (days)	200-day weight (kg)
OTENGI WISCO 23	715090	0816040023	Year 1	3.7 (82)	2.7 (58)	18 (79)
PLATFORM QUEBEC	666931	0813Q0344	Year 2	3.0 (98)	3.1 (96)	20 (97)
RIVERTON BALTIC 09 183	715087	0091090183	Link	0.8 (98)	-2.0 (85)	32 (96)
TE TAUMATA DELUXE 12520	714043	0308120520	Year 2	3.9 (94)	-5.2 (74)	43 (91)
WESTHOLM KOALA K13	715085	0421090013	Link	2.3 (94)	-3.5 (75)	30 (87)
WIRRUNA DAFFY	710087	AUWNAD1	Year 1	2.0 (98)	0.2 (98)	21 (98)
WIRRUNA ECHUCA E99	712049	AUWNAE99	Link	0.3 (98)	-1.4 (98)	38 (97)

¹ From NZ Hereford, ABRI database, current as at January 2020. Data from the use of the bulls in this experiment did not contribute to the calculation of the BreedPlan EBV.

Appendix A.2: Progeny means for Angus and Hereford sires

Appendix A. Table 3. Number of progeny (n), sire mean (least squares mean \pm standard error) and rank within breed (across both breeds in parentheses) for birth weight and gestation length, for Angus sires.

Sire ID	Birth weight (kg)			Gestation length (days)		
	n	Mean	Rank	n	Mean	Rank
A1	20	36.0 \pm 0.9	17 (25)	18	281.9 \pm 0.9	29 (40)
A2	10	34.5 \pm 1.2	3 (4)	10	283.1 \pm 1.3	3 (4)
A3	14	38.1 \pm 1.1	26 (46)	13	280.4 \pm 1.1	21 (26)
A4	18	34.9 \pm 1.0	7 (9)	14	278.8 \pm 1.1	11 (14)
A5	10	36.0 \pm 1.2	16 (24)	10	280.0 \pm 1.3	20 (23)
A6	15	34.9 \pm 1.0	8 (10)	14	277.2 \pm 1.1	2 (3)
A7	16	34.7 \pm 1.0	5 (7)	12	282.6 \pm 1.2	30 (45)
A8	18	36.8 \pm 0.9	21 (35)	17	279.3 \pm 1.0	14 (17)
A9	23	35.5 \pm 0.8	14 (18)	22	281.3 \pm 0.9	28 (36)
A10	16	38.0 \pm 1.0	25 (45)	15	279.2 \pm 1.0	13 (16)
A11	12	35.5 \pm 1.1	13 (17)	12	278.7 \pm 1.2	8 (11)
A12	12	35.1 \pm 1.1	9 (12)	9	278.7 \pm 1.3	9 (12)
A13	20	34.7 \pm 0.9	4 (6)	19	279.9 \pm 0.9	19 (22)
A14	15	38.4 \pm 1.0	28 (50)	14	279.5 \pm 1.1	16 (19)
A15	12	34.0 \pm 1.1	2 (2)	11	280.4 \pm 1.2	2 (2)
A16	22	36.6 \pm 0.9	19 (32)	21	277.9 \pm 0.9	4 (5)
A17	16	35.8 \pm 1.0	15 (22)	15	281.2 \pm 1.0	27 (35)
A18	5	39.3 \pm 1.9	30 (58)	4	279.5 \pm 2.0	15 (18)
A19	21	39.3 \pm 0.9	29 (57)	19	279.0 \pm 0.9	12 (15)
A20	12	36.4 \pm 1.2	18 (30)	11	280.7 \pm 1.2	23 (31)
A21	16	35.5 \pm 1.0	12 (16)	16	278.6 \pm 1.0	7 (10)
A22	16	35.4 \pm 1.0	11 (15)	16	279.8 \pm 1.0	18 (21)
A23	21	33.3 \pm 0.8	1 (1)	20	281.1 \pm 0.9	1 (1)
A24	13	37.3 \pm 1.3	23 (40)	10	281.0 \pm 1.3	25 (33)
A25	13	36.7 \pm 1.2	20 (34)	10	276.1 \pm 1.3	1 (1)
A26	4	37.6 \pm 1.9	24 (42)	4	277.4 \pm 2.0	3 (4)
A27	16	35.4 \pm 1.0	10 (14)	15	279.7 \pm 1.1	17 (20)
A28	13	34.9 \pm 1.1	6 (8)	11	278.2 \pm 1.2	5 (7)
A29	21	37.2 \pm 0.9	22 (39)	19	278.5 \pm 0.9	6 (9)
A30	13	40.3 \pm 1.2	31 (62)	5	278.8 \pm 1.8	10 (13)
A31	15	38.2 \pm 1.0	27 (48)	8	280.8 \pm 1.4	24 (32)

Appendix A. Table 4. Number of progeny (n), sire mean (least squares mean \pm standard error) and rank within breed (across both breeds in parentheses) for birth weight and gestation length, for Hereford sires.

Sire ID	Birth weight (kg)			Gestation length (days)		
	n	Mean	Rank	n	Mean	Rank
H1	17	38.5 \pm 0.9	24 (52)	17	283.2 \pm 1.0	19 (50)
H2	13	38.0 \pm 1.1	19 (43)	13	285.8 \pm 1.1	28 (59)
H3	26	35.6 \pm 0.8	6 (20)	25	282.9 \pm 0.8	17 (47)
H4	24	38.4 \pm 0.8	22 (49)	18	280.7 \pm 0.9	8 (30)
H5	19	38.8 \pm 0.9	25 (53)	15	286.1 \pm 1.1	29 (60)
H6	16	35.0 \pm 1.0	3 (11)	9	282.6 \pm 1.3	16 (46)
H7	16	36.3 \pm 1.0	12 (29)	16	283.1 \pm 1.0	18 (48)
H8	13	36.1 \pm 1.1	9 (26)	13	280.3 \pm 1.1	4 (24)
H9	19	36.2 \pm 0.9	11 (28)	15	281.4 \pm 1.0	9 (37)
H10	15	38.9 \pm 1.0	28 (56)	9	281.6 \pm 1.3	11 (39)
H11	12	37.2 \pm 1.1	17 (38)	12	283.3 \pm 1.2	21 (52)
H12	18	40.9 \pm 0.9	33 (64)	17	285.0 \pm 1.0	27 (58)
H13	20	35.2 \pm 0.9	4 (13)	18	278.2 \pm 0.9	3 (8)
H14	16	36.2 \pm 1.0	10 (27)	15	282.2 \pm 1.0	12 (41)
H15	13	34.4 \pm 1.1	1 (3)	12	284.3 \pm 1.2	1 (3)
H16	16	37.0 \pm 1.0	16 (37)	15	284.2 \pm 1.0	23 (54)
H17	9	40.9 \pm 1.3	32 (63)	8	288.6 \pm 1.4	34 (65)
H18	6	39.8 \pm 1.6	31 (61)	6	287.2 \pm 1.7	33 (64)
H19	20	38.0 \pm 0.9	20 (44)	15	282.3 \pm 1.0	13 (42)
H20	12	38.5 \pm 1.1	23 (51)	12	284.5 \pm 1.2	25 (56)
H21	17	38.9 \pm 1.0	27 (55)	15	283.3 \pm 1.1	20 (51)
H22	14	37.4 \pm 1.1	18 (41)	13	286.9 \pm 1.1	32 (63)
H23	7	38.8 \pm 1.6	26 (54)	6	286.5 \pm 1.6	30 (61)
H24	16	35.7 \pm 1.0	7 (21)	16	282.5 \pm 1.0	15 (44)
H25	14	36.0 \pm 1.1	8 (23)	12	283.6 \pm 1.2	22 (53)
H26	16	41.4 \pm 1.0	34 (65)	16	286.8 \pm 1.0	31 (62)
H27	13	39.4 \pm 1.1	30 (60)	12	282.4 \pm 1.2	14 (43)
H28	15	36.7 \pm 1.0	14 (33)	15	280.6 \pm 1.1	7 (29)
H29	12	34.6 \pm 1.2	2 (5)	9	280.4 \pm 1.3	5 (25)
H30	12	39.4 \pm 1.1	29 (59)	12	281.5 \pm 1.2	10 (38)
H31	21	38.2 \pm 0.9	21 (47)	19	278.1 \pm 0.9	2 (6)
H32	11	36.9 \pm 1.2	15 (36)	8	276.1 \pm 1.4	1 (2)
H33	10	35.5 \pm 1.3	5 (19)	8	284.6 \pm 1.4	26 (57)
H34	14	36.6 \pm 1.1	13 (31)	14	280.5 \pm 1.1	6 (28)

Appendix A. Table 5. Number of progeny (n), sire mean (least squares mean \pm standard error) and rank within breed (across both breeds in parentheses) for age at weaning and pre-weaning average daily gain (ADG), for Angus sires.

Sire ID	n	Age at weaning (days)		Pre-weaning ADG (kg/day)	
		Mean	Rank	Mean	Rank
A1	17	84.3 \pm 2.3	22 (48)	0.66 \pm 0.018	27 (54)
A2	8	88.3 \pm 3.4	3 (4)	0.65 \pm 0.026	30 (60)
A3	13	83.6 \pm 2.6	20 (44)	0.63 \pm 0.021	31 (64)
A4	17	87.0 \pm 2.4	30 (62)	0.65 \pm 0.019	29 (58)
A5	9	81.9 \pm 3.2	15 (32)	0.71 \pm 0.025	7 (15)
A6	14	80.3 \pm 2.5	12 (28)	0.70 \pm 0.020	11 (20)
A7	13	86.2 \pm 2.6	25 (56)	0.70 \pm 0.021	13 (22)
A8	17	80.5 \pm 2.4	13 (29)	0.70 \pm 0.018	12 (21)
A9	19	86.4 \pm 2.2	27 (58)	0.66 \pm 0.017	28 (55)
A10	16	81.1 \pm 2.4	14 (31)	0.69 \pm 0.019	17 (28)
A11	11	78.1 \pm 2.9	6 (14)	0.71 \pm 0.022	8 (16)
A12	12	80.1 \pm 2.8	10 (25)	0.73 \pm 0.022	3 (7)
A13	20	86.3 \pm 2.2	26 (57)	0.66 \pm 0.017	24 (50)
A14	11	77.7 \pm 2.9	5 (13)	0.70 \pm 0.022	9 (18)
A15	10	86.5 \pm 3.0	2 (2)	0.68 \pm 0.023	19 (35)
A16	20	85.0 \pm 2.1	23 (52)	0.67 \pm 0.017	21 (41)
A17	15	79.2 \pm 2.5	8 (19)	0.72 \pm 0.019	4 (10)
A18	4	79.9 \pm 4.7	9 (23)	0.69 \pm 0.037	18 (29)
A19	18	77.5 \pm 2.2	3 (11)	0.71 \pm 0.017	5 (13)
A20	10	76.3 \pm 3.0	1 (8)	0.73 \pm 0.023	2 (6)
A21	15	80.1 \pm 2.5	11 (26)	0.70 \pm 0.019	9 (18)
A22	13	82.7 \pm 2.7	18 (38)	0.68 \pm 0.021	20 (36)
A23	21	85.5 \pm 2.1	1 (1)	0.69 \pm 0.016	16 (27)
A24	10	77.5 \pm 3.0	2 (10)	0.75 \pm 0.023	1 (2)
A25	10	86.4 \pm 3.0	28 (59)	0.67 \pm 0.023	22 (42)
A26	3	78.3 \pm 5.5	7 (15)	0.70 \pm 0.043	14 (23)
A27	16	82.6 \pm 2.5	17 (36)	0.71 \pm 0.019	6 (14)
A28	12	82.7 \pm 2.8	19 (39)	0.69 \pm 0.022	15 (26)
A29	17	83.8 \pm 2.4	21 (46)	0.67 \pm 0.019	23 (47)
A30	11	77.7 \pm 2.9	4 (12)	0.66 \pm 0.023	26 (53)
A31	15	82.2 \pm 2.5	16 (34)	0.66 \pm 0.020	25 (51)

Appendix A. Table 6. Number of progeny (n), sire mean (least squares mean \pm standard error) and rank within breed (across both breeds in parentheses) for age at weaning and pre-weaning average daily gain (ADG), for Hereford sires.

Sire ID	n	Age at weaning (days)		Pre-weaning ADG (kg/day)	
		Mean	Rank	Mean	Rank
H1	14	83.3 \pm 2.5	21 (40)	0.66 \pm 0.020	27 (52)
H2	12	79.5 \pm 2.8	12 (20)	0.69 \pm 0.022	13 (31)
H3	26	81.9 \pm 1.9	18 (33)	0.71 \pm 0.015	8 (12)
H4	23	78.4 \pm 2.1	9 (16)	0.69 \pm 0.016	11 (25)
H5	18	82.7 \pm 2.3	20 (37)	0.65 \pm 0.018	31 (61)
H6	16	86.4 \pm 2.5	32 (60)	0.67 \pm 0.019	20 (40)
H7	12	79.2 \pm 2.8	11 (18)	0.69 \pm 0.021	10 (24)
H8	12	84.5 \pm 2.8	27 (49)	0.65 \pm 0.021	30 (59)
H9	18	76.8 \pm 2.3	8 (9)	0.72 \pm 0.018	5 (8)
H10	13	83.4 \pm 2.7	22 (41)	0.67 \pm 0.021	23 (45)
H11	10	81.0 \pm 3.0	17 (30)	0.69 \pm 0.023	15 (33)
H12	17	74.1 \pm 2.3	4 (4)	0.73 \pm 0.018	4 (5)
H13	18	84.1 \pm 2.3	26 (47)	0.67 \pm 0.018	22 (44)
H14	15	78.5 \pm 2.5	10 (17)	0.70 \pm 0.019	9 (17)
H15	13	87.8 \pm 2.7	1 (3)	0.67 \pm 0.021	21 (43)
H16	15	83.5 \pm 2.5	23 (42)	0.68 \pm 0.019	19 (39)
H17	7	70.3 \pm 3.6	1 (1)	0.74 \pm 0.028	3 (4)
H18	5	85.8 \pm 4.2	31 (55)	0.63 \pm 0.033	34 (65)
H19	18	79.9 \pm 2.2	15 (24)	0.68 \pm 0.017	18 (38)
H20	10	73.9 \pm 3.0	2 (2)	0.74 \pm 0.023	2 (3)
H21	14	76.3 \pm 2.6	7 (7)	0.72 \pm 0.020	6 (9)
H22	10	80.2 \pm 3.0	16 (27)	0.69 \pm 0.024	16 (34)
H23	6	82.4 \pm 3.9	19 (35)	0.66 \pm 0.030	28 (56)
H24	15	83.6 \pm 2.5	24 (43)	0.65 \pm 0.019	29 (57)
H25	13	84.7 \pm 2.6	29 (51)	0.67 \pm 0.021	24 (46)
H26	12	74.0 \pm 2.8	3 (3)	0.68 \pm 0.022	17 (37)
H27	11	75.9 \pm 2.9	6 (6)	0.69 \pm 0.022	12 (30)
H28	15	85.7 \pm 2.5	30 (54)	0.64 \pm 0.020	32 (62)
H29	11	87.5 \pm 2.9	33 (63)	0.66 \pm 0.023	26 (49)
H30	10	79.8 \pm 3.1	14 (22)	0.69 \pm 0.024	14 (32)
H31	18	84.6 \pm 2.3	28 (50)	0.63 \pm 0.018	33 (63)
H32	10	83.7 \pm 3.1	25 (45)	0.66 \pm 0.024	25 (48)
H33	9	74.8 \pm 3.2	5 (5)	0.76 \pm 0.025	1 (1)
H34	13	79.8 \pm 2.7	13 (21)	0.72 \pm 0.021	7 (11)

Appendix A.3: Calculated estimated breeding values

Appendix A. Table 7. Birth weight, gestation length and age at weaning estimated breeding values (EBV), for Angus bulls used in the experiment based on the data collected from the beef-cross-dairy progeny. Accuracy of the EBV is presented in parentheses.

Sire ID	Birth Weight (kg)	Gestation Length (days)	Age at weaning (days)
A1	-3.18 (0.78)	-3.50 (0.86)	4.73 (0.57)
A2	-3.99 (0.67)	-2.70 (0.80)	5.91 (0.44)
A3	0.13 (0.72)	-6.08 (0.83)	4.00 (0.52)
A4	-3.17 (0.76)	-8.20 (0.84)	7.26 (0.57)
A5	-2.78 (0.69)	-7.73 (0.81)	4.80 (0.49)
A6	-2.98 (0.75)	-10.83 (0.84)	2.42 (0.56)
A7	-5.00 (0.74)	-2.62 (0.82)	5.77 (0.52)
A8	-1.92 (0.80)	-8.08 (0.87)	3.65 (0.64)
A9	-3.02 (0.79)	-4.76 (0.88)	6.31 (0.59)
A10	-1.09 (0.76)	-7.75 (0.85)	2.69 (0.58)
A11	-3.14 (0.70)	-8.61 (0.82)	0.89 (0.49)
A12	-3.49 (0.70)	-7.29 (0.78)	2.37 (0.51)
A13	-4.06 (0.78)	-6.26 (0.87)	5.95 (0.60)
A14	0.05 (0.74)	-7.15 (0.84)	1.08 (0.49)
A15	-5.12 (0.70)	-6.22 (0.81)	5.79 (0.48)
A16	-2.63 (0.80)	-9.43 (0.88)	5.18 (0.62)
A17	-2.76 (0.75)	-4.19 (0.85)	1.60 (0.56)
A18	-2.13 (0.54)	-7.11 (0.65)	3.40 (0.33)
A19	0.58 (0.78)	-7.72 (0.87)	0.26 (0.58)
A20	-2.24 (0.70)	-5.19 (0.81)	0.81 (0.48)
A21	-3.25 (0.75)	-8.23 (0.85)	1.46 (0.56)
A22	-3.18 (0.76)	-6.93 (0.86)	5.37 (0.56)
A23	-6.14 (0.78)	-4.13 (0.87)	5.18 (0.61)
A24	-1.60 (0.71)	-5.00 (0.80)	1.53 (0.50)
A25	-3.15 (0.72)	-11.75 (0.81)	5.89 (0.50)
A26	-2.11 (0.50)	-8.60 (0.65)	3.07 (0.29)
A27	-3.79 (0.74)	-5.84 (0.84)	4.07 (0.56)
A28	-3.36 (0.73)	-8.57 (0.82)	3.01 (0.55)
A29	-0.70 (0.77)	-8.03 (0.86)	4.02 (0.57)
A30	3.22 (0.71)	-7.27 (0.69)	0.67 (0.49)
A31	0.23 (0.75)	-5.28 (0.78)	3.51 (0.58)
Angus Mean EBV	-2.44	-6.81	3.63

Appendix A. Table 8. Birth weight, gestation length and age at weaning estimated breeding values (EBV), for Hereford bulls used in the experiment based on the data collected from the beef-cross-dairy progeny. Accuracy of the EBV is presented in parentheses.

Sire ID	Birth Weight (kg)	Gestation Length (days)	Age at weaning (days)
H1	1.58 (0.76)	0.19 (0.86)	1.57 (0.54)
H2	0.20 (0.71)	4.33 (0.83)	-0.96 (0.51)
H3	-3.23 (0.81)	-0.34 (0.89)	1.27 (0.65)
H4	0.75 (0.81)	-3.95 (0.87)	-0.67 (0.64)
H5	0.91 (0.77)	4.03 (0.84)	1.46 (0.58)
H6	-3.32 (0.74)	-0.23 (0.78)	3.46 (0.56)
H7	-1.72 (0.75)	-0.04 (0.85)	-0.70 (0.52)
H8	-1.21 (0.71)	-4.56 (0.83)	1.59 (0.51)
H9	-1.25 (0.78)	-3.13 (0.85)	-3.20 (0.60)
H10	0.96 (0.73)	-1.13 (0.78)	1.64 (0.52)
H11	1.05 (0.70)	-0.24 (0.82)	-0.14 (0.48)
H12	3.21 (0.76)	2.47 (0.86)	-4.57 (0.58)
H13	-1.79 (0.79)	-7.35 (0.87)	1.17 (0.61)
H14	-1.45 (0.75)	-1.78 (0.85)	-1.81 (0.55)
H15	-3.30 (0.71)	1.06 (0.82)	4.18 (0.52)
H16	-1.03 (0.75)	1.75 (0.85)	2.03 (0.55)
H17	2.46 (0.65)	6.60 (0.77)	-3.77 (0.42)
H18	1.37 (0.57)	4.07 (0.72)	1.56 (0.36)
H19	1.13 (0.78)	-1.78 (0.85)	-1.07 (0.59)
H20	0.61 (0.70)	1.35 (0.82)	-2.70 (0.47)
H21	0.66 (0.75)	-0.13 (0.84)	-2.38 (0.54)
H22	-0.95 (0.72)	4.99 (0.83)	-0.41 (0.48)
H23	0.68 (0.60)	3.18 (0.72)	0.73 (0.39)
H24	-2.12 (0.75)	-1.41 (0.85)	1.45 (0.55)
H25	-2.28 (0.74)	-0.11 (0.83)	3.20 (0.55)
H26	6.42 (0.74)	4.94 (0.85)	-3.27 (0.51)
H27	1.80 (0.71)	-1.66 (0.82)	-2.51 (0.49)
H28	-0.95 (0.73)	-3.63 (0.84)	2.39 (0.55)
H29	-3.47 (0.72)	-2.44 (0.80)	3.64 (0.53)
H30	0.60 (0.70)	-1.43 (0.82)	-0.58 (0.48)
H31	2.37 (0.78)	-7.71 (0.86)	1.72 (0.58)
H32	-0.44 (0.69)	-8.12 (0.77)	0.48 (0.49)
H33	-2.06 (0.67)	2.02 (0.77)	-3.27 (0.46)
H34	-1.06 (0.74)	-3.82 (0.84)	-1.72 (0.55)
Hereford mean EBV	-0.14	-0.41	-0.01

Appendix A.4. Calf sex and calving year or rearing location means

Appendix A. Table 7. Number of progeny (n), mean (least squares mean \pm standard error) birth weight, gestation length age at weaning and pre-weaning average daily gain (ADG), for bull or heifer calves born in 2016 or 2017, and reared at different locations.

	Birth weight (kg)	Gestation length (days)	Age at weaning (days)	Pre-weaning ADG (kg/day)
n	927	869	873	873
Sex of calf				
Bull	38.2 \pm 0.2 ^b	281.9 \pm 0.2 ^b	78.8 \pm 0.5 ^a	0.69 \pm 0.004
Heifer	35.7 \pm 0.2 ^a	280.9 \pm 0.2 ^a	84.1 \pm 0.5 ^b	0.68 \pm 0.004
P-Value	<0.001	<0.001	<0.001	<0.001
Calving year				
2016	36.4 \pm 0.2 ^a	281.3 \pm 0.2		
2017	37.5 \pm 0.3 ^b	281.5 \pm 0.3		
P-Value	0.012	0.598		
Rearing location				
Limestone 2016			80.7 \pm 0.7	0.70 \pm 0.005 ^b
Tirau 2016			81.7 \pm 1.0	0.66 \pm 0.008 ^a
Limestone 2017			81.9 \pm 0.7	0.70 \pm 0.005 ^b
P-Value			0.408	<0.001
P-Values				
Sire ID	<0.001	<0.001	<0.001	<0.001
Dam age	<0.001	<0.001		
DOB deviation	<0.001			<0.001
Weaning weight			<0.001	
Dam pre-calving live weight	<0.001			

^{a,b,c} Means with differing superscripts within variable and column differ at $P < 0.05$.

Appendix A.5: Relationship between sire BreedPlan EBV and progeny mean birth weight and gestation length

The relationship between the progeny mean birth weight or gestation length and the BreedPlan EBV for birth weight or gestation length respectively was calculated using a linear regression model in SAS. The relationship was calculated separately for Angus and Hereford breeds, with each model weighted by the number of progeny for each sire.

The suitable EBV, which would generate progeny equal or better (lower birth weight or shorter gestation length) to an alternative Holstein-Friesian bull was calculated using an average birth weight of 40 kg (Hickson et al., 2015) and a gestation length of 281 days (Donkersloot, 2014) fitted into the regression equation. The 40 kg birth weight coincides with the recommended purchase price for dairy-beef (Holstein-Friesian) bull calves (Muir et al., 2002, Beef+LambNZ, 2018).

Appendix A. Table 11. Relationship between Breedplan EBV and progeny mean birth weight and gestation length for Angus and Hereford bulls, with the threshold BreedPlan EBV for generating progeny the same birth weight or gestation length as an average Holstein-Friesian (HF) bull.

	Intercept	Gradient	P value	R ²	HF average ¹	Suitable EBV
Birth weight						
Angus	34.12 ± 0.46	0.77 ± 0.15	<0.001	0.48	40	7.64
Hereford	36.19 ± 0.38	0.55 ± 0.13	<0.001	0.37	40	6.93
Gestation length						
Angus	281.90 ± 0.53	0.38 ± 0.08	<0.001	0.42	281	-2.37
Hereford	283.85 ± 0.35	0.62 ± 0.1	<0.001	0.55	281	-4.60

¹ Holstein-Friesian bull average progeny birth weight from Hickson et al. (2015); and average progeny gestation length from Donkersloot (2014).

Appendix B: Supplementary tables for Chapter 3

Appendix B.1. Mean post-calving performance of mixed aged cows by service sire

Appendix B. Table 1. Service sire mean (\pm SE) cow body condition score (1-10 scale) at 4 time points for mixed-aged cows, with the number of cows per sire for each measurement.

Bull ID	n	Pre-calving (June)	n	Rebreeding (September)	n	Late Summer (February)	n	End of lactation (April)
A1	19	4.56 \pm 0.09	17	4.03 \pm 0.10	16	4.13 \pm 0.09	14	4.48 \pm 0.09
A2	10	4.64 \pm 0.13	10	4.30 \pm 0.14	10	4.39 \pm 0.12	7	4.61 \pm 0.14
A3	13	4.53 \pm 0.11	13	4.02 \pm 0.12	12	4.10 \pm 0.11	12	4.37 \pm 0.10
A4	16	4.37 \pm 0.10	12	3.96 \pm 0.12	11	4.02 \pm 0.11	8	4.39 \pm 0.12
A5	10	4.61 \pm 0.12	10	4.26 \pm 0.13	9	4.17 \pm 0.12	8	4.61 \pm 0.12
A6	15	4.52 \pm 0.10	14	4.04 \pm 0.12	14	4.19 \pm 0.10	12	4.50 \pm 0.10
A7	15	4.50 \pm 0.10	12	3.74 \pm 0.13	12	4.14 \pm 0.11	11	4.29 \pm 0.11
A8	17	4.45 \pm 0.10	17	4.16 \pm 0.11	17	4.17 \pm 0.09	15	4.46 \pm 0.09
A9	22	4.51 \pm 0.09	22	4.07 \pm 0.10	21	4.08 \pm 0.08	18	4.33 \pm 0.09
A10	14	4.51 \pm 0.10	14	4.13 \pm 0.11	12	4.34 \pm 0.10	11	4.51 \pm 0.10
A11	12	4.63 \pm 0.12	11	4.20 \pm 0.13	11	4.19 \pm 0.11	9	4.56 \pm 0.12
A12	12	4.60 \pm 0.12	9	4.09 \pm 0.15	9	3.98 \pm 0.12	9	4.17 \pm 0.12
A13	20	4.52 \pm 0.09	17	3.95 \pm 0.11	17	4.05 \pm 0.09	14	4.37 \pm 0.09
A14	15	4.49 \pm 0.10	13	3.97 \pm 0.12	12	4.17 \pm 0.10	9	4.45 \pm 0.12
A15	12	4.65 \pm 0.11	9	4.09 \pm 0.14	10	4.36 \pm 0.11	6	4.19 \pm 0.13
A16	20	4.46 \pm 0.09	19	3.89 \pm 0.10	18	4.09 \pm 0.08	15	4.41 \pm 0.09
A17	16	4.45 \pm 0.10	15	4.07 \pm 0.11	15	4.02 \pm 0.09	14	4.30 \pm 0.09
A18	4	4.52 \pm 0.20	4	4.46 \pm 0.23	4	4.25 \pm 0.18	4	4.46 \pm 0.18
A19	19	4.42 \pm 0.09	17	3.88 \pm 0.10	16	4.20 \pm 0.09	14	4.63 \pm 0.09
A20	11	4.57 \pm 0.12	11	4.20 \pm 0.14	11	4.27 \pm 0.11	10	4.47 \pm 0.11
A21	16	4.53 \pm 0.10	15	4.02 \pm 0.11	15	4.15 \pm 0.09	12	4.39 \pm 0.10
A22	15	4.70 \pm 0.10	15	3.95 \pm 0.11	14	4.27 \pm 0.09	11	4.50 \pm 0.10
A23	21	4.48 \pm 0.09	20	4.16 \pm 0.10	17	4.26 \pm 0.09	16	4.40 \pm 0.09
A24	9	4.58 \pm 0.13	10	4.08 \pm 0.14	8	4.03 \pm 0.13	8	4.42 \pm 0.12
A25	10	4.54 \pm 0.13	9	3.92 \pm 0.14	7	4.11 \pm 0.14	6	4.38 \pm 0.14
A26	4	4.28 \pm 0.20	4	3.78 \pm 0.22	4	3.94 \pm 0.18	3	4.46 \pm 0.20
A27	15	4.52 \pm 0.10	15	3.97 \pm 0.11	14	4.12 \pm 0.10	12	4.42 \pm 0.10
A28	13	4.52 \pm 0.11	11	4.30 \pm 0.13	9	4.22 \pm 0.12	8	4.70 \pm 0.12
A29	17	4.25 \pm 0.10	18	4.01 \pm 0.11	15	4.03 \pm 0.10	15	4.45 \pm 0.10
A30	10	4.52 \pm 0.13	5	3.71 \pm 0.19	5	3.98 \pm 0.16	5	4.37 \pm 0.16
A31	13	4.58 \pm 0.11	8	3.64 \pm 0.16	5	4.12 \pm 0.17	5	4.26 \pm 0.16
H1	17	4.47 \pm 0.09	17	4.09 \pm 0.10	17	4.22 \pm 0.09	17	4.63 \pm 0.08
H2	13	4.34 \pm 0.11	13	3.85 \pm 0.13	10	3.95 \pm 0.12	8	4.33 \pm 0.13
H3	26	4.50 \pm 0.08	25	4.15 \pm 0.09	24	4.30 \pm 0.07	18	4.50 \pm 0.08
H4	23	4.54 \pm 0.08	18	4.00 \pm 0.10	18	4.08 \pm 0.08	17	4.39 \pm 0.08
H5	17	4.43 \pm 0.10	14	4.02 \pm 0.12	14	4.08 \pm 0.10	13	4.35 \pm 0.10
H6	16	4.58 \pm 0.10	9	4.23 \pm 0.15	9	4.28 \pm 0.12	9	4.47 \pm 0.12
H7	16	4.62 \pm 0.10	14	3.86 \pm 0.12	13	4.25 \pm 0.10	13	4.32 \pm 0.10

Bull ID	n	Pre-calving (June)	n	Rebreeding (September)	n	Late Summer (February)	n	End of lactation (April)
H8	12	4.59 ± 0.12	13	4.21 ± 0.13	13	4.17 ± 0.10	12	4.70 ± 0.11
H9	18	4.57 ± 0.09	15	4.38 ± 0.12	15	4.29 ± 0.09	13	4.47 ± 0.10
H10	15	4.33 ± 0.10	9	4.02 ± 0.15	8	4.12 ± 0.13	7	4.23 ± 0.13
H11	12	4.46 ± 0.12	11	4.02 ± 0.14	9	4.11 ± 0.12	8	4.55 ± 0.13
H12	16	4.65 ± 0.10	17	4.04 ± 0.11	16	4.07 ± 0.09	15	4.30 ± 0.09
H13	19	4.41 ± 0.09	18	3.93 ± 0.11	15	4.12 ± 0.09	14	4.38 ± 0.10
H14	15	4.45 ± 0.10	14	3.84 ± 0.12	14	4.13 ± 0.10	9	4.26 ± 0.12
H15	12	4.53 ± 0.11	11	4.10 ± 0.13	11	4.18 ± 0.11	11	4.41 ± 0.11
H16	16	4.60 ± 0.10	14	3.84 ± 0.11	13	4.18 ± 0.10	11	4.35 ± 0.10
H17	9	4.64 ± 0.14	8	3.98 ± 0.17	8	4.24 ± 0.13	6	4.61 ± 0.15
H18	6	4.31 ± 0.17	5	3.99 ± 0.20	5	4.03 ± 0.16	4	4.38 ± 0.18
H19	17	4.56 ± 0.09	14	4.16 ± 0.11	11	4.09 ± 0.11	7	4.55 ± 0.13
H20	12	4.46 ± 0.11	12	4.01 ± 0.13	12	4.02 ± 0.11	11	4.39 ± 0.11
H21	15	4.73 ± 0.11	15	3.94 ± 0.12	13	4.18 ± 0.10	10	4.42 ± 0.11
H22	13	4.38 ± 0.11	13	4.03 ± 0.12	12	4.06 ± 0.11	12	4.33 ± 0.10
H23	6	4.60 ± 0.16	6	4.19 ± 0.19	6	3.99 ± 0.15	6	4.40 ± 0.15
H24	16	4.63 ± 0.10	16	4.28 ± 0.12	15	4.07 ± 0.10	12	4.49 ± 0.10
H25	13	4.41 ± 0.11	11	3.93 ± 0.13	11	4.19 ± 0.11	8	4.53 ± 0.12
H26	15	4.58 ± 0.10	15	4.17 ± 0.12	14	4.17 ± 0.10	11	4.67 ± 0.11
H27	12	4.51 ± 0.12	10	4.10 ± 0.14	10	4.15 ± 0.12	8	4.49 ± 0.13
H28	15	4.43 ± 0.10	15	3.84 ± 0.11	14	4.13 ± 0.10	14	4.45 ± 0.09
H29	11	4.51 ± 0.12	9	4.17 ± 0.15	6	4.16 ± 0.15	6	4.47 ± 0.15
H30	12	4.40 ± 0.12	11	3.81 ± 0.13	11	4.11 ± 0.11	10	4.59 ± 0.11
H31	18	4.39 ± 0.09	17	4.19 ± 0.11	13	4.26 ± 0.10	11	4.48 ± 0.11
H32	10	4.60 ± 0.13	8	4.08 ± 0.16	7	4.35 ± 0.14	5	4.43 ± 0.16
H33	9	4.49 ± 0.14	7	3.85 ± 0.18	7	4.11 ± 0.14	7	4.30 ± 0.14
H34	12	4.41 ± 0.12	12	4.10 ± 0.13	11	4.10 ± 0.11	7	4.58 ± 0.14

Appendix B. Table 2. Service sire least squares mean (\pm SE) date of calving (in relation to the planned start of calving (PSC)), post-calving live weight and mean days in milk for mixed-aged cows, with the number of cows per sire for each measurement.

Bull ID	n	Date of calving (in relation to PSC) (days)	n	Post-calving live weight (kg)	n	Days in milk (days)
A1	18	21.7 \pm 0.9	19	464.5 \pm 4.8	17	260.0 \pm 7.3
A2	10	22.7 \pm 1.3	10	474.3 \pm 7.7	10	251.5 \pm 9.6
A3	12	20.2 \pm 1.1	13	467.1 \pm 6.6	12	268.5 \pm 8.8
A4	14	18.5 \pm 1.0	16	462.1 \pm 6.1	12	259.5 \pm 8.7
A5	10	19.7 \pm 1.2	10	472.6 \pm 6.3	10	245.4 \pm 9.6
A6	14	16.9 \pm 1.1	15	470.8 \pm 5.6	14	264.3 \pm 8.2
A7	12	22.6 \pm 1.1	15	456.2 \pm 6.8	12	264.1 \pm 8.7
A8	17	18.9 \pm 1.0	17	459.0 \pm 6.2	17	261.6 \pm 7.4
A9	22	20.9 \pm 0.9	22	462.3 \pm 5.4	22	252.7 \pm 6.6
A10	14	19.3 \pm 1.0	14	463.3 \pm 6.1	14	254.2 \pm 8.0
A11	12	18.5 \pm 1.1	12	457.3 \pm 7.1	11	250.8 \pm 9.2
A12	9	18.7 \pm 1.3	12	456.0 \pm 6.7	9	277.7 \pm 10.1
A13	19	19.4 \pm 0.9	20	464.5 \pm 5.1	18	265.0 \pm 7.1
A14	14	19.2 \pm 1.0	15	461.5 \pm 6.5	13	261.2 \pm 8.3
A15	11	20.1 \pm 1.2	12	466.0 \pm 6.2	9	233.4 \pm 10.1
A16	20	17.9 \pm 0.9	20	456.9 \pm 5.1	19	259.4 \pm 6.9
A17	15	21.2 \pm 1.0	16	468.1 \pm 6.1	15	271.1 \pm 7.7
A18	4	19.0 \pm 2.0	4	469 \pm 14.8	3	266.9 \pm 17.3
A19	19	18.9 \pm 0.9	19	453.8 \pm 5.2	17	262.7 \pm 7.3
A20	11	20.8 \pm 1.2	11	455.1 \pm 7.6	11	266.2 \pm 9.1
A21	16	18.1 \pm 1.0	16	450.1 \pm 5.8	15	266.5 \pm 7.8
A22	16	19.4 \pm 1.0	16	456.3 \pm 5.6	15	255.1 \pm 7.7
A23	20	20.9 \pm 0.9	21	464.9 \pm 5.6	20	253.7 \pm 6.8
A24	8	20.6 \pm 1.4	9	464.3 \pm 7.4	8	255.8 \pm 10.7
A25	10	15.5 \pm 1.2	10	466.0 \pm 7.6	9	252.1 \pm 10
A26	4	16.8 \pm 2.0	4	466.1 \pm 14.9	4	274.8 \pm 15
A27	15	20.0 \pm 1.0	16	464.9 \pm 5.5	15	265.7 \pm 7.9
A28	11	17.8 \pm 1.2	13	457.0 \pm 6.3	11	266.6 \pm 9.2
A29	17	18.2 \pm 1.0	18	458.3 \pm 6.1	17	267.4 \pm 7.6
A30	5	18.5 \pm 1.7	10	460.0 \pm 7.8	5	279.2 \pm 13.5
A31	7	20.0 \pm 1.5	14	471.5 \pm 6.3	7	241.7 \pm 11.4
H1	17	22.8 \pm 0.9	17	462.6 \pm 5.2	17	269.0 \pm 7.3
H2	13	25.6 \pm 1.1	13	457.1 \pm 7.4	13	239.6 \pm 8.5
H3	25	22.6 \pm 0.8	26	470.2 \pm 4.9	25	256.9 \pm 6.0
H4	18	20.5 \pm 0.9	23	461.5 \pm 4.8	18	271.1 \pm 7.1
H5	14	26.0 \pm 1.1	18	460.1 \pm 6.1	14	260.1 \pm 8.1
H6	9	22.3 \pm 1.3	16	460.9 \pm 5.8	9	269.8 \pm 10.2
H7	16	23.1 \pm 1.0	16	470.2 \pm 6.4	14	257.0 \pm 8.0
H8	13	19.9 \pm 1.1	13	464.5 \pm 7.3	13	260.7 \pm 8.5
H9	15	21.0 \pm 1.0	18	466.0 \pm 5.7	15	268.1 \pm 7.8
H10	9	21.9 \pm 1.3	15	460.3 \pm 6.1	9	255.7 \pm 10.1
H11	12	22.8 \pm 1.2	12	485.5 \pm 8.0	10	252.0 \pm 9.6
H12	17	24.9 \pm 1.0	17	450.2 \pm 5.7	17	263.8 \pm 7.4
H13	17	17.8 \pm 1.0	19	469.9 \pm 6.5	17	262.4 \pm 7.3

Bull ID	n	Date of calving (in relation to PSC) (days)	n	Post-calving live weight (kg)	n	Days in milk (days)
H14	15	21.7 ± 1.0	15	468.3 ± 6.2	14	251.3 ± 8.0
H15	12	23.8 ± 1.1	12	464.5 ± 6.4	11	257.7 ± 9.1
H16	15	24.2 ± 1.0	16	463.9 ± 5.3	14	245.6 ± 8.0
H17	8	28.7 ± 1.4	9	459.8 ± 10	8	255.9 ± 10.7
H18	6	27.1 ± 1.6	6	463.6 ± 11.1	5	251.8 ± 13.6
H19	15	22.0 ± 1.0	17	469.7 ± 5.4	14	232.8 ± 8.0
H20	12	24.1 ± 1.1	12	460.8 ± 6.4	12	259.4 ± 8.8
H21	15	23.1 ± 1.0	15	460.8 ± 7.4	15	230.4 ± 7.9
H22	13	26.8 ± 1.1	13	457.9 ± 6.6	12	257.7 ± 8.8
H23	6	26.2 ± 1.6	6	464.4 ± 9.9	6	263.1 ± 12.4
H24	16	22.2 ± 1.0	16	466.0 ± 6.4	16	246.0 ± 7.7
H25	12	23.1 ± 1.1	13	475.6 ± 6.7	11	256.3 ± 9.2
H26	15	25.8 ± 1.0	15	479.8 ± 6.3	15	251.6 ± 8.1
H27	12	22.1 ± 1.2	12	444.5 ± 6.7	10	250.9 ± 9.6
H28	15	19.9 ± 1.0	15	465.4 ± 5.8	15	261.5 ± 7.9
H29	8	20.2 ± 1.4	11	455.6 ± 7.1	8	253.6 ± 10.7
H30	12	21.9 ± 1.1	12	448.5 ± 6.6	12	261.5 ± 8.8
H31	17	17.2 ± 1.0	19	462.8 ± 5.4	17	249.6 ± 7.4
H32	7	16.1 ± 1.5	10	466.8 ± 8.3	7	275.4 ± 11.4
H33	8	24.1 ± 1.4	9	458.9 ± 10.1	7	266.9 ± 11.5
H34	12	20.7 ± 1.1	12	467.8 ± 7.4	12	259.4 ± 8.8

Appendix B. Table 3. Service sire mean (\pm SE) 253-day predicted milk production of mixed-aged cows, with the number of cows per sire for each measurement.

Bull ID	n	Milk yield (L)	n	Fat yield (kg)	n	Protein yield (kg)	n	Milksolids yield (kg)
A1	18	3314.2 \pm 115.0	18	158.5 \pm 5.2	18	128.8 \pm 4.1	18	287.4 \pm 8.9
A2	10	3308.6 \pm 158.9	10	152.6 \pm 7.3	10	125.3 \pm 5.6	10	278.7 \pm 12.3
A3	13	3490.3 \pm 139.4	14	165.6 \pm 6.2	13	136.2 \pm 4.9	14	301.3 \pm 10.4
A4	14	3484.6 \pm 132.2	14	162.3 \pm 6.1	14	134.8 \pm 4.7	14	298.0 \pm 10.3
A5	10	3459.0 \pm 154.1	10	163.6 \pm 7.1	10	135.1 \pm 5.5	10	299.3 \pm 12
A6	15	3417.1 \pm 128.8	15	162.1 \pm 5.9	15	132.1 \pm 4.6	15	295.3 \pm 10.0
A7	15	3294.8 \pm 130.5	16	156.8 \pm 5.7	15	129.6 \pm 4.6	16	285.2 \pm 9.7
A8	17	3698.0 \pm 124.8	17	176.1 \pm 5.7	17	142.1 \pm 4.4	17	318.2 \pm 9.6
A9	22	3330.7 \pm 109.7	22	157.7 \pm 5.0	22	130.4 \pm 3.9	22	288.3 \pm 8.5
A10	14	3480.3 \pm 131.6	15	160.9 \pm 5.8	14	135.7 \pm 4.7	15	293.8 \pm 9.9
A11	11	3386.8 \pm 152.1	11	152.2 \pm 6.9	11	130.4 \pm 5.4	11	283.7 \pm 11.8
A12	12	3468.0 \pm 145.7	12	163.2 \pm 6.7	12	137.2 \pm 5.1	12	299.9 \pm 11.3
A13	17	3317.9 \pm 120.6	18	156.6 \pm 5.3	18	129.9 \pm 4.1	18	286.8 \pm 9.0
A14	13	3218.4 \pm 137.9	13	150.9 \pm 6.3	13	125.2 \pm 4.9	13	276.7 \pm 10.6
A15	9	3107.5 \pm 164.9	10	147.3 \pm 7.2	10	126.9 \pm 5.5	10	274.5 \pm 12.1
A16	19	3475.5 \pm 113.2	19	161.9 \pm 5.2	19	135.6 \pm 4.0	19	296.3 \pm 8.8
A17	16	3418.4 \pm 125.1	16	165.0 \pm 5.7	16	134.0 \pm 4.4	16	299.5 \pm 9.6
A18	2	3656.0 \pm 351.9	3	175.7 \pm 13.4	3	143.3 \pm 10.3	3	319.1 \pm 22.6
A19	17	3236.6 \pm 119.3	17	153.8 \pm 5.5	17	127.7 \pm 4.2	17	281.1 \pm 9.2
A20	11	3394.4 \pm 154.1	11	157.6 \pm 7.1	11	133.1 \pm 5.4	11	290.0 \pm 11.9
A21	15	3159.2 \pm 127.9	15	149.4 \pm 5.9	15	122.7 \pm 4.5	15	272.6 \pm 9.9
A22	15	3425.9 \pm 127.1	15	160.0 \pm 5.8	15	132.2 \pm 4.5	15	292.4 \pm 9.9
A23	21	3265.9 \pm 110.1	21	149.6 \pm 5.0	21	126.6 \pm 3.9	21	276.2 \pm 8.5
A24	9	3430.8 \pm 165.4	11	157.6 \pm 6.9	9	129.2 \pm 5.9	11	286.8 \pm 11.7
A25	9	3247.4 \pm 164.6	9	148.8 \pm 7.5	9	125.5 \pm 5.8	9	276.0 \pm 12.7
A26	4	3306.5 \pm 253.9	4	158.2 \pm 11.5	4	128.3 \pm 9.0	4	286.9 \pm 19.4
A27	16	3234.8 \pm 125.2	16	153.7 \pm 5.7	16	128.2 \pm 4.4	16	281.5 \pm 9.7
A28	12	3243.0 \pm 144.8	12	157.1 \pm 6.7	12	128.2 \pm 5.1	12	285.2 \pm 11.3
A29	17	3359.4 \pm 124.3	20	160.0 \pm 5.3	18	130.5 \pm 4.3	20	290.3 \pm 8.9
A30	9	3685.8 \pm 167.5	11	164.3 \pm 7.0	9	139.5 \pm 5.9	11	303.4 \pm 11.8
A31	14	3190.2 \pm 134.6	15	147.7 \pm 6.0	14	122.5 \pm 4.8	15	271.9 \pm 10.1
H1	17	3288.5 \pm 119.4	17	155.7 \pm 5.5	17	128.8 \pm 4.2	17	284.9 \pm 9.3
H2	13	3467.5 \pm 141.7	13	162.3 \pm 6.5	13	134.5 \pm 5.0	13	296.2 \pm 11
H3	26	3230.4 \pm 98.4	26	152.3 \pm 4.5	26	124.3 \pm 3.5	26	276.7 \pm 7.7
H4	23	3401.8 \pm 104.6	23	161.8 \pm 4.7	23	132.9 \pm 3.7	23	294.2 \pm 8.0
H5	17	3370.8 \pm 123.5	17	157.6 \pm 5.7	17	131.6 \pm 4.4	17	289.0 \pm 9.6
H6	16	3489.1 \pm 126.8	16	163.2 \pm 5.8	16	134.9 \pm 4.5	16	297.6 \pm 9.8
H7	14	3210.0 \pm 133.7	14	152.5 \pm 6.1	14	124.3 \pm 4.7	14	277.0 \pm 10.3
H8	13	3674.3 \pm 142.1	13	166.4 \pm 6.5	13	140.2 \pm 5.0	13	307.2 \pm 11
H9	18	3328.1 \pm 118.5	18	154.2 \pm 5.5	18	128.2 \pm 4.2	18	282.6 \pm 9.2
H10	14	3119.6 \pm 134.4	15	144.1 \pm 6.0	15	121.2 \pm 4.6	15	264.3 \pm 10.1
H11	10	3072.8 \pm 160.5	10	145.6 \pm 7.4	10	118.9 \pm 5.7	10	267.0 \pm 12.4
H12	17	3323.6 \pm 121.2	17	158.4 \pm 5.5	17	129.0 \pm 4.3	17	286.4 \pm 9.4
H13	18	3142.7 \pm 120.8	20	149.0 \pm 5.2	19	125.9 \pm 4.1	20	275.1 \pm 8.8
H14	14	3320.8 \pm 132.6	14	155.4 \pm 6.1	14	127.2 \pm 4.7	14	282.8 \pm 10.3

Bull ID	n	Milk yield (L)	n	Fat yield (kg)	n	Protein yield (kg)	n	Milksolids yield (kg)
H15	11	3274.5 ± 148.6	11	157.0 ± 6.8	11	128.8 ± 5.3	11	285.3 ± 11.6
H16	15	3305.0 ± 126.6	15	156.7 ± 5.8	15	127.9 ± 4.5	15	284.7 ± 9.8
H17	9	3351.6 ± 169.3	9	157.4 ± 7.8	9	126.8 ± 6.0	9	283.6 ± 13.2
H18	5	3525.7 ± 225.3	5	162.6 ± 10.4	5	139.3 ± 8.0	5	301.7 ± 17.5
H19	16	3353.8 ± 123.7	16	160.6 ± 5.6	16	130.4 ± 4.4	16	292.1 ± 9.5
H20	12	3385.4 ± 144.8	12	157.8 ± 6.6	12	132.5 ± 5.1	12	290.4 ± 11.2
H21	14	3242.2 ± 137.7	15	154.9 ± 6.1	15	129.4 ± 4.7	15	283.7 ± 10.2
H22	12	3351.5 ± 145.3	12	159.1 ± 6.7	12	131.8 ± 5.1	12	290.0 ± 11.3
H23	6	3261.3 ± 204.5	6	164.3 ± 9.4	6	129.1 ± 7.2	6	294.7 ± 15.9
H24	16	3387.6 ± 128.0	16	158.3 ± 5.8	16	132.9 ± 4.5	16	291.3 ± 9.9
H25	12	3157.8 ± 145.4	12	150.2 ± 6.7	12	122.5 ± 5.1	12	274.0 ± 11.3
H26	15	3056.0 ± 132.2	15	150.9 ± 6.0	15	119.7 ± 4.7	15	273.0 ± 10.2
H27	10	3218.1 ± 157.5	10	148.3 ± 7.2	10	124.2 ± 5.6	10	272.3 ± 12.3
H28	15	3326.6 ± 129.4	15	155.6 ± 5.9	15	127.6 ± 4.6	15	283.0 ± 10.1
H29	11	3102.7 ± 152.2	12	154.1 ± 6.7	11	124.5 ± 5.4	12	277.8 ± 11.3
H30	11	3443.3 ± 151.5	12	161.7 ± 6.7	12	132.4 ± 5.2	12	291.8 ± 11.3
H31	19	3361.3 ± 117.4	19	156.1 ± 5.4	19	128.4 ± 4.1	19	284.8 ± 9.1
H32	10	3255.3 ± 159.9	11	154.8 ± 7.0	10	127.1 ± 5.7	11	283.0 ± 11.8
H33	8	3503.0 ± 183.0	9	163.9 ± 7.9	8	136.1 ± 6.4	9	301.6 ± 13.3
H34	12	3216.4 ± 146	14	150.7 ± 6.2	12	123.6 ± 5.2	14	274.0 ± 10.5

Appendix B. Table 4. Service sire mean (\pm SE) post-calving live weight, inter-calving interval and proportion of cows treated with CIDRs for mixed-aged cows, with the number of cows per sire for each measurement.

Bull ID	n	CIDR treatment (%)	n	Inter-calving interval (days)	n	Proportion calved within 21d from PSC (%)
A1	18	16.51 \pm 8.96	15	364.1 \pm 4.9	18	66.39 \pm 12.69
A2	10	22.31 \pm 12.39	6	354.7 \pm 7.9	10	75.32 \pm 16.46
A3	13	23.73 \pm 11.34	9	381.0 \pm 6.5	13	14.72 \pm 13.52
A4	14	26.14 \pm 11.83	11	376.9 \pm 5.8	14	49.58 \pm 15.64
A5	10	12.40 \pm 8.81	9	364.6 \pm 6.5	10	57.24 \pm 17.07
A6	14	24.41 \pm 11.49	11	363.1 \pm 5.9	14	68.99 \pm 14.08
A7	12	31.16 \pm 13.80	8	367.1 \pm 6.8	12	66.39 \pm 16.93
A8	17	11.91 \pm 6.90	13	369.6 \pm 5.5	17	70.15 \pm 12.56
A9	22	7.34 \pm 4.41	13	356.4 \pm 5.5	22	83.89 \pm 9.36
A10	15	14.58 \pm 9.60	11	375.9 \pm 5.8	15	41.37 \pm 15.30
A11	12	12.91 \pm 8.94	8	366.1 \pm 6.9	12	68.76 \pm 16.31
A12	9	49.66 \pm 17.59	6	373.3 \pm 8.0	9	45.11 \pm 20.97
A13	19	30.97 \pm 11.11	14	376.0 \pm 5.2	19	49.43 \pm 14.01
A14	14	36.5 \pm 13.65	10	373.8 \pm 6.1	14	54.12 \pm 16.60
A15	11	22.23 \pm 12.21	11	369.0 \pm 5.9	11	49.98 \pm 15.94
A16	21	8.85 \pm 6.03	14	363.4 \pm 5.1	21	73.18 \pm 11.91
A17	15	14.26 \pm 9.35	13	378.7 \pm 5.3	15	36.15 \pm 13.41
A18	4	0.00 \pm 0.01	3	361.9 \pm 11.1	4	70.95 \pm 26.03
A19	19	17.21 \pm 9.16	14	372.9 \pm 5.1	19	37.99 \pm 13.17
A20	11	41.97 \pm 15.94	10	369.1 \pm 6.1	11	45.31 \pm 16.15
A21	16	29.31 \pm 11.85	13	380.3 \pm 5.4	16	40.56 \pm 14.44
A22	16	6.97 \pm 6.68	14	360.5 \pm 5.1	16	84.69 \pm 10.07
A23	20	10.46 \pm 7.09	11	362.9 \pm 5.9	20	69.44 \pm 15.02
A24	10	7.94 \pm 7.78	7	371.7 \pm 7.3	10	45.18 \pm 19.59
A25	10	25.81 \pm 13.86	6	374.6 \pm 7.8	10	55.43 \pm 21.05
A26	4	30.23 \pm 24.85	2	356.5 \pm 13.6	4	100.00 \pm 0.24
A27	15	18.03 \pm 11.56	11	378.1 \pm 5.9	15	36.39 \pm 14.78
A28	11	0.00 \pm 0.01	7	375.8 \pm 7.3	11	52.60 \pm 19.94
A29	19	4.73 \pm 4.74	9	375.9 \pm 6.6	19	36.58 \pm 17.13
A30	5	29.13 \pm 23.50	3	370.9 \pm 11.2	5	55.38 \pm 30.84
A31	8	41.79 \pm 18.61	6	375.4 \pm 7.9	8	27.58 \pm 18.04
H1	17	17.31 \pm 9.31	15	368.5 \pm 5.0	17	54.13 \pm 13.32
H2	13	40.38 \pm 15.23	7	362.2 \pm 7.3	13	60.63 \pm 20.46
H3	25	20.50 \pm 7.95	21	377.2 \pm 4.3	25	34.74 \pm 11.38
H4	18	23.37 \pm 10.58	13	369.3 \pm 5.4	18	59.09 \pm 14.24
H5	15	13.49 \pm 7.82	9	365.2 \pm 6.5	15	52.85 \pm 17.63
H6	9	0.00 \pm 0.01	8	379.5 \pm 6.9	9	36.55 \pm 17.76
H7	16	16.86 \pm 9.22	11	357.3 \pm 5.8	16	77.85 \pm 12.00
H8	13	39.74 \pm 14.12	10	366.1 \pm 6.2	13	60.58 \pm 15.90
H9	15	23.03 \pm 11.82	14	370.5 \pm 5.2	15	51.47 \pm 14.12
H10	9	0.00 \pm 0.01	4	377.0 \pm 9.7	9	25.85 \pm 22.48
H11	12	24.82 \pm 11.99	8	377.1 \pm 6.9	12	32.49 \pm 18.47
H12	17	36.31 \pm 12.91	12	388.8 \pm 5.6	17	18.40 \pm 10.33
H13	18	6.20 \pm 5.94	13	372.3 \pm 5.3	18	50.61 \pm 14.34

Bull ID	n	CIDR treatment (%)	n	Inter-calving interval (days)	n	Proportion calved within 21d from PSC (%)
H14	15	6.14 ± 5.97	8	362.2 ± 6.8	15	75.12 ± 15.55
H15	12	11.69 ± 8.18	12	364.1 ± 5.6	12	58.44 ± 14.75
H16	15	25.34 ± 11.45	11	359.7 ± 5.8	15	54.39 ± 15.69
H17	8	38.65 ± 17.96	4	374.7 ± 9.6	8	20.28 ± 18.88
H18	6	14.15 ± 13.60	3	369.8 ± 11.2	6	0.00 ± 0.12
H19	15	26.07 ± 11.80	7	368.8 ± 7.2	15	58.64 ± 19.63
H20	12	27.51 ± 12.90	9	370.4 ± 6.5	12	44.74 ± 17.40
H21	15	14.98 ± 8.55	9	369.3 ± 6.5	15	56.80 ± 17.24
H22	13	12.48 ± 8.64	8	357.8 ± 6.9	13	66.26 ± 17.14
H23	6	15.22 ± 14.39	4	370.2 ± 9.7	6	45.84 ± 25.58
H24	16	19.48 ± 9.47	10	368.4 ± 6.2	16	57.96 ± 15.98
H25	12	12.90 ± 8.91	8	368.6 ± 6.9	12	44.21 ± 18.73
H26	16	18.04 ± 9.91	12	370.4 ± 5.7	16	47.09 ± 15.34
H27	12	13.02 ± 9.01	8	364.9 ± 6.9	12	57.55 ± 17.96
H28	15	15.69 ± 10.32	11	367.1 ± 5.9	15	69.39 ± 14.82
H29	9	24.90 ± 15.42	6	363.0 ± 7.9	9	64.50 ± 20.28
H30	12	33.60 ± 15.53	11	366.4 ± 5.9	12	65.39 ± 15.86
H31	19	25.38 ± 11.19	10	374.5 ± 6.2	19	57.22 ± 16.52
H32	8	41.64 ± 18.55	4	381.4 ± 9.7	8	40.46 ± 25.17
H33	8	15.41 ± 14.20	6	377.8 ± 8.0	8	31.12 ± 19.44
H34	14	15.53 ± 10.30	9	362.5 ± 6.5	14	63.91 ± 16.85

Appendix C: Supplementary tables for Chapter 4

Appendix C.1. Estimated breeding values of Angus and Hereford Bulls

Appendix C. Table 1. Direct calving ease, birth weight and gestation length (Angus and Hereford; BreedPlan¹) estimated breeding values, and live weight and gestation length (Jersey, LIC²) breeding values (with accuracy in parentheses, %) for Angus, Hereford and Jersey bulls naturally mated to maiden heifers. Values current as at January 2020

Bull name	Herd book number	Breed	Year	Direct calving ease (%)	Birth weight (kg)	Gestation length (days)
PUKETI REGAN 14123	21149014123	Angus	2016	13.2 (53)	-0.4 (73)	-6.1 (83)
PUKETI REGAN 14134	21149014134	Angus	2016	4.1 (53)	3.8 (72)	-2.3 (76)
TE ATARANGI KESSLERS K098	19241014K098	Angus	2016	9.0 (50)	1.0 (72)	0.2 (56)
TE ATARANGI TURI K026	19241014K026	Angus	2016	11.5 (53)	-0.9 (73)	-8.4 (51)
HEATHER DELL L72	19928015L72	Angus	2017	7.8 (53)	1.2 (73)	-2.7 (60)
TE ATARANGI WAI L027	19241015L027	Angus	2017	11.7 (54)	0.3 (74)	-5.4 (54)
CRAIGMORE BATON 140323	169140323	Hereford	2016	6.9 (47)	1.4 (74)	-1.9 (47)
CRAIGMORE BATON 140337	169140337	Hereford	2016	5.9 (45)	1.9 (74)	2.5 (46)
HAUMOANA ACCENT 14032	511140032	Hereford	2016	9.2 (45)	1.7 (74)	-0.9 (37)
MAHUTA KIMO 4029	828144029	Hereford	2016	10.3 (50)	0.1 (74)	-1.9 (52)
ARDO EXTRACT 5298 (EZI)	277155298	Hereford	2017	14.1 (48)	-1.4 (73)	-0.3 (39)
CRAIGMORE OPIUM 150206	0169150206	Hereford	2017	11.5 (44)	0.4 (73)	-0.6 (40)

Bull ID	LIC animal code	Breed	Year	Live weight (kg)	Gestation length (days)
CFWP-14-14	33078860	Jersey	2016	-49 (35)	-1.1 (60.1)
CFWP-14-22	33208712	Jersey	2016	-45 (39)	-2.5 (64.2)
DRVH-14-371	33428384	Jersey	2016	-51 (33)	-1.6 (64.4)
DRVH-15-311	34528994	Jersey	2017	-51 (33)	-1.8 (64.8)
DRVH-15-312	34528988	Jersey	2017	-55 (33)	-1.8 (42.5)
DRVH-15-319	34529008	Jersey	2017	-46 (33)	-2.1 (42.0)
DRVH-15-344	34674810	Jersey	2017	-52 (33)	-2.5 (64.2)

¹ Estimated breeding values (EBV) from NZ Angus and NZ Hereford, ABRI database, current as at January 2020. ² Breeding values (BV) from Livestock Improvement Corporation (LIC) database, current as at January 2020. Data from the use of the bulls in this experiment did not contribute to the calculation of the BreedPlan EBV or the LIC BV.

Appendix C.2: Heifer body condition score and live weight

Appendix C. Table 2. Body condition score (1-10 scale) between mating and the end of the resulting lactation and live weight (kg) prior to calving for heifers calving in 2016 or 2017 mated to Angus, Hereford or Jersey bulls. Values are least squares means \pm standard error.

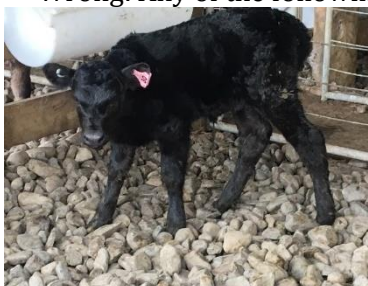
	n	Angus	Hereford	Jersey	P Breed
2016 calving					
Body condition score					
Mating	145	5.74 \pm 0.07	5.54 \pm 0.07	5.66 \pm 0.09	0.219
Pregnancy detection	146	5.05 \pm 0.05	5.04 \pm 0.06	5.07 \pm 0.07	0.958
Pre-calving	155	4.93 \pm 0.06	4.89 \pm 0.06	4.92 \pm 0.06	0.887
Rebreeding	176	4.26 \pm 0.05	4.28 \pm 0.05	4.22 \pm 0.06	0.790
Late summer	174	4.14 \pm 0.05	4.14 \pm 0.05	4.09 \pm 0.05	0.743
Late lactation	146	4.49 \pm 0.05	4.38 \pm 0.05	4.36 \pm 0.05	0.167
Live weight					
Mating	144	303.4 \pm 2.9	302.3 \pm 2.8	314.2 \pm 4.3	0.109
Pregnancy detection	147	372.4 \pm 3.4	372.0 \pm 3.3	379.5 \pm 4.8	0.434
Pre-calving	155	436.8 \pm 5.6	432.6 \pm 5.6	430.9 \pm 6.2	0.765
2017 calving					
Body condition score					
Mating	121	5.56 \pm 0.03	5.53 \pm 0.03	5.46 \pm 0.04	0.235
Pregnancy detection	120	5.09 \pm 0.04	5.11 \pm 0.04	5.10 \pm 0.05	0.973
Pre-calving	121	4.66 \pm 0.09	4.70 \pm 0.10	4.75 \pm 0.09	0.785
Rebreeding	118	4.43 \pm 0.05	4.39 \pm 0.06	4.46 \pm 0.08	0.777
Late summer	114	4.20 \pm 0.05	4.33 \pm 0.06	4.23 \pm 0.08	0.339
Late lactation	99	4.34 \pm 0.04	4.48 \pm 0.05	4.40 \pm 0.06	0.198
Live weight					
Mating	121	297.9 \pm 2.4	293.4 \pm 2.5	294.2 \pm 3.6	0.463
Pregnancy detection	121	411.1 \pm 2.7	406.0 \pm 2.9	403.7 \pm 4.1	0.330
Pre-calving	121	470.9 \pm 4.6	476.5 \pm 4.7	474.1 \pm 6.8	0.710

Appendix D: Supplementary material for Chapter 6

Appendix D.1: Right and wrong colour characteristic examples for Angus- and Hereford-cross-dairy calves (Chapter 6)

Angus

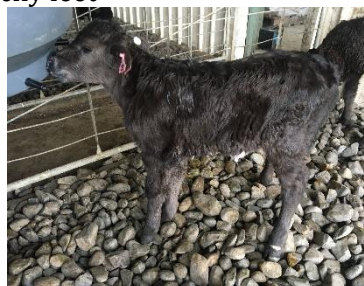
- Right: black coat, 4 either solid white or black feet
- Wrong: Any of the following: Brown, grey or red coat, patchy feet



RIGHT:
Black coat, no white face or body patches, white inguinal patch. No white feet.



WRONG:
Brownish-black coat, no white face, no white feet, no white patches. No white feet.



WRONG:
Grey coat, white inguinal spot, and no additional white markings. Rear left foot exhibiting Jersey marking.

Hereford

- Right: Black coat, 4 solid white feet, clean white face
- Wrong: Any of the following: Red or brown coat, patchy face, patchy or solid (non-white) feet



RIGHT:
Black coat, clean white face, 4 Friesian feet, white body spotting, white inguinal area tail tip and forehead.



WRONG:
Black coat, partial white face, 4 Jersey feet, white forehead and body spots.



WRONG:
Red coat, barely white face markings, white forehead patch.



WRONG:
Red coat, clean white face,
white body patches, white
inguinal area and forehead.
All feet with Friesian
marking.



WRONG:
Red coat, no white face, no
white forehead.



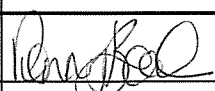
WRONG:
Red coat, partial white face,
white body patches.



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Please select one of the following three options:		
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Candidate's Signature:	Lucy Wesley Coleman	<small>Digitally signed by Lucy Wesley Coleman Date: 2020.06.17 14:49:02 +12'00'</small>
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