Viability of Dairy-origin calves for a New Beef Production Enterprise in New Zealand

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Abstract

The New Zealand dairy industry produces approximately 4.2 million calves annually, of which about 30% are retained within the dairy industry, while a further 20% are utilised in the beef industry. The remainder are surplus to requirements, and the majority (1.7 million per annum) are processed in the low value bobby calf trade. This model appears sub-optimal, with an estimated opportunity cost in excess of NZD $1 billion annually, and numerous animal welfare and ethical issues. Farming surplus dairy calves in an accelerated-cycle beef production enterprise for slaughter prior to one-year of age, could generate favourable outcomes, and the current study aimed to investigate this opportunity.

Experimental growth and carcass data for Hereford x Friesian-Jersey steers slaughtered at 8-, 10- and 12- months of age was obtained in a live-animal trial. Simulation models (referred to as NGB^{8}, NGB^{10} and NGB^{12} where the figures refer to monthly ages at slaughter) utilising Microsoft EXCEL feed budgets, gross margin analysis and the OVERSEER nutrient budget model were developed from the experimental data to estimate the physical, financial, and environmental performance of accelerated-cycle beef production at each slaughter age. Results were compared to a simulated high and low performing bull-beef enterprise based on the literature, with slaughter occurring at 18- or 24-months, to determine the relative performance of accelerated-cycle beef production. The model comparators are referred to as Bull^{18} and Bull^{24}.

In the trial, the accelerated-cycle beef production (NGB) steers achieved slaughter weights of 252, 303 and 348 kg at 8-, 10- and 12-months of age (119, 146 and 174 kg carcass weight). The dressing out percentage was the same in the 8- and 10-month treatments ($P>0.05$) but increased in the 12-month treatment ($P<0.001$). Using the 'prime' beef price, NGB^{8} and NGB^{10} generated a loss, while NGB^{12} was profitable. To be financially competitive with Bull^{18} or Bull^{24}, NGB production required a price premium of 11 – 29% above the 'prime' beef schedule. There was insufficient evidence to suggest NGB production had a lower nutrient loss footprint, or reduced greenhouse gas output compared to bull-beef production. Further analysis showed weaner genetic merit for growth had a positive relationship with profitability, but no interaction with environmental output under NGB production. Overall, this study demonstrated that Hereford x Friesian-Jersey steers can grow well under typical beef finishing conditions. Given that accelerated-cycle beef production's environmental output is similar to bull-beef production, profitability is the key determinant of the concept's viability. Although NGB production with slaughter occurring at 12-months of age was profitable under

the ‘prime’ beef classification, a premium of 11 – 29% (depending on slaughter age) would be required for the proposed enterprise to be financially competitive with bull-beef production. However, research has shown the meat derived from this production system is of high quality, therefore there is potential for a price premium if suitable markets are located. Finally, the procurement of weaners with high genetic merit for growth represents an opportunity to further enhance the proposed enterprises overall performance.

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List of Abbreviations

Abbreviation	Meaning
ADG	Average daily gain
APC	Average pasture cover level
ASC	Anion storage capacity
DO%	Dressing out percentage
EMA	Eye muscle area
FCE	Feed conversion efficiency
FOB	Free-on-board
GHG	Greenhouse gas
GM	Gross margin
Ha	Hectare
HF	Holstein-Friesian
kgDM	Kilograms of dry matter
ME	Metabolisable energy
NGB	New Generation Beef
N	Nitrogen
OBH	Once-bred heifer
P	Phosphorous
PGR	Pasture growth rate
pH	Acidity
RBY	Retail beef yield
R1	Rising-one-year-old
R2	Rising-two-year-old
Sheep:cattle	Ratio of total sheep stock units to cattle stock units
SEM	Standard error of the mean
S.U.	Stock unit
UK	United Kingdom
WFGM	Whole-farm gross margin

Chapter 1. Introduction

The New Zealand beef industry is founded on pastoral agriculture as the temperate climate provides a year-round supply of pasture as a low-cost source of feed (Morris and Kenyon, 2014). In the year ending September 2017 New Zealand produced 633,000 tonnes of beef and veal with a total value of NZD $ 3.26 billion (B+LNZ, 2018). Key export markets for New Zealand beef were North America (51% by weight) and North Asia (35%) respectively. In recent years the beef industry has become increasingly reliant on the dairy sector as a source of cattle for meat production (Burggraaf, 2016, Lineham and Thomson, 2017).

The New Zealand dairy industry produces a significant surplus of calves each season, as a byproduct of requiring cows to produce a calf to produce milk. It has been estimated that 1.7 million calves are slaughtered within 4 - 8 days of birth in the bobby calf trade (Thomas and Jordaan, 2013, Archer *et al.*, 2014). The ongoing consumer concern pertaining to the ethics and sustainability of these practices means there is growing industry interest in identifying a viable alternative.

It has been suggested that growing these surplus calves in a novel accelerated-cycle beef production enterprise where processing occurs between 8 – 12 months of age may overcome some of the perception issues associated with the current model. Accelerated-cycle beef production can be defined as beef production where cattle are grown rapidly from weaning to slaughter and processed at less than one-year of age. There is potential for accelerated-cycle beef production to perform well given the greater growth efficiency associated with growing young animals (Brody, 1946, Richards, 1959, Aguilar *et al.*, 1983).

The physical, financial, and environmental performance of traditional beef production enterprises where cattle are processed between 18 - 36 months has been researched extensively (Barton *et al*, 1994, Landcare Research, 2015, Smeaton *et al*, 2011). However, in the New Zealand context little is known about the performance of cattle grown in enterprises utilising a yearling slaughter age. The performance of a yearling beef production enterprise would have to be comparable or superior to that of currently implemented forms of beef production so, quantifying the performance of cattle grown for yearling beef production is the first step in investigating the broader concept.

This dissertation aims to compile the missing performance-based data through a modeling exercise, which utilised industry average hypothetical physical farm data along with experimental growth and carcass data (for dairy-origin steers slaughtered at 8-, 10- and 12- months of age) obtained in a parallel but independent live-animal trial. With this data three accelerated-cycle beef production enterprise models with slaughter occurring at 8-, 10- and 12- months of age were developed alongside a 'typical' breeding sheep enterprise. In addition, two traditional bull beef models, one of which was high performing (18-month slaughter) and one of which was low performing (24-month slaughter) were developed alongside the same breeding sheep enterprise. This approach enabled fair comparisons between all models.

The dissertation is structured to first provide the reader with relevant background information through a detailed review of the literature. The methodology chapter then outlines the specific approach taken in the modeling exercise and provides context for the subsequent results and discussion chapter. Finally, the key findings and implications are outlined in the conclusion chapter, along with limitations of the study, and the suggested direction for future research in the field of accelerated-cycle beef production.

1.1 Objectives and Research Question

1.1.1 Objectives

The objective of this dissertation was to investigate the viability of growing surplus dairy-origin calves (from weaning to slaughter) in a accelerated-cycle beef production enterprise utilising a yearling slaughter age. It set out to consider if comparable physical and financial performance to traditional forms of bull beef production was possible and to identify any constraints to the applicability of a yearling beef production system. The comparison against bull finishing was chosen as this production enterprise is often recognized as one of the highest performing forms of beef production in New Zealand (Morris and Kenyon, 2014). The study also aimed to quantify the environmental footprint (nutrient losses and GHG emissions) associated with the model scenarios, thus enabling comparisons between yearling beef production and traditional bull beef production on this increasingly important parameter. Overall this study aimed to bring together physical, financial, and environmental performance data on accelerated-cycle (yearling) beef production between weaning and slaughter at the farm systems level. The study did not examine any post farm-gate or pre-weaning considerations such as production risk, market risk or calf rearing regimes, however these topics are all relevant to the broader concept and are important areas for future research.

1.1.2 Hypothesis

It is hypothesized that the accelerated-cycle beef production enterprises will be capable of growing greater numbers of cattle than the traditional bull beef enterprises, and that this will necessitate the provision of more supplementary feed to maintain realistic average pasture cover levels. It is expected that across all examined slaughter ages, yearling beef production will have a greater feed conversion efficiency than the traditional bull beef scenarios. It is predicted that financial return (across all measures) will show a positive relationship with slaughter age within the accelerated-cycle scenarios, and that returns will be similar between the accelerated-cycle scenarios and the high performing bull scenario, thus the breakeven price required for accelerated-cycle production will not differ significantly from the price point used in the analysis. It is theorized that due to growth efficiencies at a younger age, accelerated-cycle beef production will result in lower nutrient losses and greenhouse gas emissions compared to the traditional bull beef scenarios and an increased genetic merit for growth in weaners grown to a yearling age will increase meat production and profit obtained.

1.1.3 Research questions

This dissertation will attempt to answer the following questions:

1. How many cattle can be grown under accelerated-cycle beef production with slaughter occurring at 8-, 10- and 12- months of age, relative to traditional bull beef production with slaughter occurring at 18- and 24- months of age?

2. What are the supplementary feeding requirements for accelerated-cycle beef production to maintain average pasture cover levels within a realistic range when slaughter occurs at 8-, 10- and 12- months of age?

3. At each examined slaughter age, what is the feed conversion efficiency of accelerated-cycle beef production relative to traditional bull beef production?

4. What is the financial return (per head, hectare, and kilogram of dry matter eaten) for an accelerated-cycle beef production enterprise when slaughter occurs at 8-, 10- and 12- months of age, and how does this compare to the profitability of the traditional bull scenarios?

5. What is the breakeven meat price for accelerated-cycle beef production (at each examined slaughter age) to be financially competitive with traditional bull beef production?

6. What is the relative environmental footprint (nutrient losses and greenhouse gas emissions) of accelerated-cycle beef production compared to traditional bull beef production?

7. What is the impact differing degrees of genetic merit for growth (proxied with average daily growth rate) within weaners grown in the accelerated-cycle beef enterprises

have on physical, financial and environmental performance relative to traditional bull beef production.

1.2 Disclaimer

During the review process two important errors in the feed budget model background calculations were identified. The decision was made not to correct these errors given the significant amount of work involved. These errors affect the accuracy of many model outputs, as such all readers should be aware of the following points when interpreting the reported results.

1. Weaner steer maintenance energy requirements are overestimated in the accelerated-cycle beef enterprise models. Mature cattle maintenance energy requirements were mistakenly used when calculating feed requirements in the accelerated-cycle beef enterprise scenarios. As such, feed requirements are overstated in these scenarios. This has implications for the physical, financial and environmental findings presented in this study. The impacts of this error and likely direction of bias are explained in the results and discussion chapter.

2. The maximum average pasture cover constraint level (3000 kgDM/ha) used in the feed budget models was too high for Class 4 land (Beef + Lamb NZ classification). This meant that during some periods average pasture cover levels became unrealistically high in the feed budget models. This error has implications for the accuracy of the physical, financial and environmental performance data presented in this dissertation. The likely effect of this error and direction of resulting bias is outlined where possible, however overall it is difficult to estimate the impact of this error without a full rerun of the models (which was not possible).

Chapter 2. Literature Review

2.1 Beef production systems in New Zealand

Efficiency in the beef industry can be defined as the total value of outputs (e.g. meat, leather, bone, and offal) divided by the total value of inputs (e.g. feed, labour, land, and transport). Efficiency is a key determinant of profit on beef farms, and as a result potential for profit is the main criteria beef cattle are selected for in New Zealand (Morris and Smeaton, 2009). The profitability of various beef finishing policies is influenced by factors such as feeding requirements, growth rates, stocking rate, carcass yield, feed utilization, and market prices (McRae, 2003, Pettigrew *et al.*, 2017). New Zealand's beef industry can be categorized into three main production systems, each utilising unique inputs to produce a beef or veal product targeting a specific market: heifer and steer finishing; bull-beef finishing: and cattle from the dairy industry.

2.1.1 Heifer and steer finishing for 'prime' beef production

Heifer and steer finishing is the most common 'prime' beef production system in New Zealand. In this system, beef and dairy-beef origin weaners are generally purchased from other farms or bred on farm, this decision is usually determined by the farm's topography and potential to grow feed. After procurement in October – December (from dairy cows) or March – May (from beef cows), weaners are finished to suitable carcass condition and typically processed at 18 – 36 months of age (Coleman, 2016).

Heifer and steer finishing targets 'prime' classification, to optimize the price per kilogram of carcass weight (New Zealand Meat, 2004). 'Prime' classification requires a carcass weighing 260 – 330 kg (510 – 650 kg live weight), a muscling score of at least two, and 3 - 10mm of fat cover over the eye muscle (New Zealand Meat, 2004, Coleman, 2016). Seasonal feed supply patterns commonly lead to feed shortages in winter and late summer, respectively (White and Hodgson, 1999, Rattray *et al.*, 2007). This makes it difficult to achieve 'prime' classification within the 16 to 24-month timeframe, which requires an average live weight gain of 0.70 – 1.2 kg/day from weaning to slaughter. In heifers and steers, typically about 54% (by weight) of the carcass is marketed as 'prime', whilst the remainder is sold as 'manufacturing' grade (B+LNZ 2017).

2.1.2 Bull-beef finishing

In 2018 bulls accounted for 12% of New Zealand's national cattle slaughter by headcount (Figure 1, Statistics New Zealand, 2018), however by weight the bull-beef industry's contribution to beef throughput is likely much higher. In this system intact male weaners are procured at approximately 100 kg live weight in spring aged 3 – 4 months old (between October and November) (Morris and Kenyon, 2014). These bulls are then grown through to the following summer and sold between December and April at 550 – 580 kg live weight (Morris and Kenyon, 2014, Pettigrew *et al.*, 2017). This results in a 16 – 24 month production cycle capable of generating carcasses in the order of 280 – 310 kg (Purchas *et al.*, 2002, Morris and Kenyon, 2014).

Bull-beef finishing has two major advantages over traditional steer and heifer finishing. Firstly, high growth rates can be achieved with intact male cattle, due to their naturally higher concentrations of anabolic androgens, notably testosterone (Fritsche and Steinhart, 1998). Average live weight gains of 1.10 – 1.50 kg/day are now common place on bull finishing farms across the country (Purchas *et al.*, 2002, McRae, 2003, Morris and Kenyon, 2014). The bull-beef industry in New Zealand is founded almost completely on Holstein-Friesian bulls procured from dairy farms (Morris and Kenyon, 2014). These animals are generally cheaper to purchase than traditional beef breed weaners (Cook, 2014, Jolly, 2016), and have sufficient genetic merit in regard to lean growth and carcass conformation (Bown *et al.*, 2016)

By default, bull carcasses are classified as 'manufacturing' due to their lower fat cover levels, which typically results in a discounted price per kilogram compared to carcasses attaining 'prime' classification (Coleman, 2016). Bull carcasses are graded based on fat depth (typically < 3mm), muscling score, and hot weight (New Zealand Meat, 2004). Finishing bulls is financially competitive with many land uses, and like other finishing systems, its profitability is dependent on the stocking rate (stock units per hectare) which can be achieved (Cassells and Matthews, 1988, McRae, 2003, Pettigrew *et al.*, 2017).

2.1.3 Cull cows and surplus calves from the dairy industry

The national dairy herd directly contributes to New Zealand's beef and veal production in the form of cull dairy cows and the disposal of surplus calves (Morris and Kenyon, 2014).

Cull cows

Cull cows are dairy cows that have come to the end of their production life. In New Zealand approximately one million dairy cows are culled each year and marketed as beef products (B+LNZ, 2017), directly contributing to the beef industry. Under the New Zealand meat classification framework, cows are either graded as ‘manufacturing’ or ‘prime’ depending on their degree of finish (New Zealand Meat, 2004, Coleman, 2016). Cull cows (both beef and dairy-origin) accounted for 23% of all cattle slaughtered in 2018 (Figure 1, Statistics New Zealand, 2018).

Surplus dairy calves

In order to initiate lactation and produce milk, dairy cows must give birth to a calf (NZVA, 2014). Under current practice about 50% of the calf crop (approximately 2.10 million calves annually) are surplus to the requirements of the dairy and beef industries (Figure 1, Table 1, Archer *et al.*, 2014, Hickson *et al.*, 2015). This surplus of calves constitutes New Zealand’s bobby calf trade for veal meat and other co-products (Biss and Hathaway, 1994), however not all surplus calves are processed (Archer *et al.*, 2014, Cook, 2014).

Surplus dairy calves are collected from farms around the country and transported to slaughter plants at 4 – 8 days of age (Biss and Hathaway, 1994, Thomas and Jordaan, 2013). The traditional calving period for dairy cattle is during spring (García and Holmes, 2001), however, increasingly farmers are electing to calve a proportion of their herd in autumn (Garcia and Holmes, 1999, Clark *et al.*, 2007). As a result, the peak throughput period for processing bobby calves is in spring, with a smaller volume being processed in autumn.

A bobby calf is worth approximately $25 - $70 per head, which means for some farmers the costs of transport and feeding exceed the financial return at processing (Cook, 2014, Jolly, 2016). In the year ending September 2018, 1.82 million bobby calves were processed (Figure 1, Statistics New Zealand, 2018). Over the same period 19,977 tonnes of veal meat was exported, with a free-on-board (FOB) value of NZD $103 million (4% of beef and veal exports) (B+LNZ, 2018). The annual calf slaughter has been on a long-term increase, and in the last 35 years has risen by almost 900,000 animals (47%) (Figure 1, Statistics New Zealand, 2018).

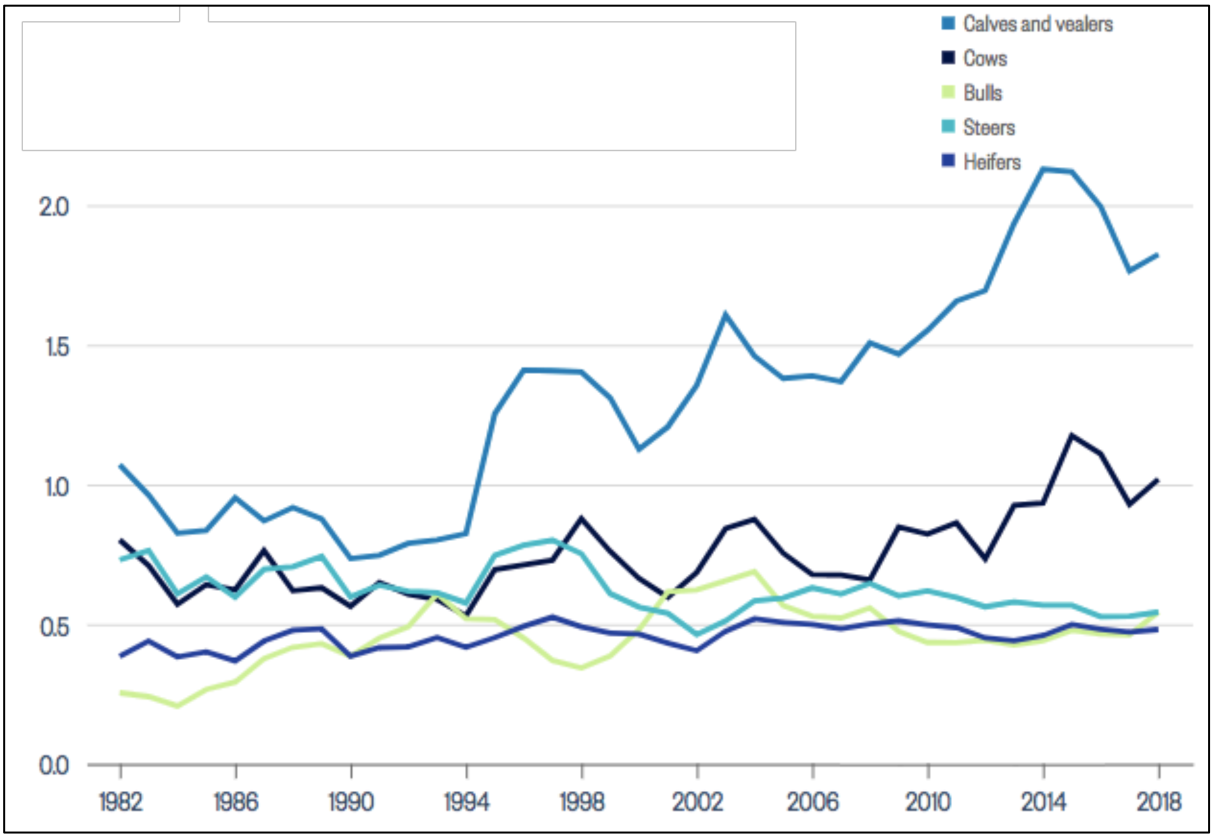

Figure 1: Total cattle slaughter (by animal type) from 1982 - 2018 in New Zealand (Statistics New Zealand, 2018).

2.2 Importance of the dairy industry for beef production

The distinction between beef and dairy breed cattle has become increasingly blurred in recent years, with research highlighting the benefits of crossbreeding (Burke *et al.*, 1998, Hickson *et al.*, 2014, Coleman *et al.*, 2016) and scientific evidence refuting some of the traditional prejudice associated with dairy-origin cattle for beef production (Burggraaf, 2016). These developments have culminated in the beef industry becoming increasingly reliant on the dairy industry to grow throughput (Table 1). In the 2013-14 season 50 - 55% of beef products by weight (45% by value) originated from the dairy industry (Morris and Kenyon, 2014). More recent estimates suggest in excess of 65% of beef products are derived from dairy-origin cattle (Burggraaf, 2016, Lineham and Thomson, 2017).

Cattle utilised for beef production in New Zealand are procured from either the beef or dairy cow herds (Table 1). Beef-origin cattle are born in the national beef herd comprising approximately one million breeding cows and heifers (Figure 2). The key breeds in the beef herd are Angus (37%), mixed (17%), Friesian (14%), Angus x Hereford (12%), Hereford (10%), Friesian x Hereford (4%) and other (6%) (B+LNZ, 2018). Beef-origin cattle are typically weaned at six to eight months of age (Barton and Pleasants, 1997, Clarke *et al.*, 2009, Morris and Smeaton, 2009), thereafter being transitioned to a pasture-based diet destined for either breeding or finishing. Relative to dairy-origin calves which are typically artificially reared, beef-origin calves are traditionally reared by their dam ('suckled') enabling them to achieve comparatively heavier weaning weights. This makes beef-origin calves particularly sought after by heifer and steer finishers and is reflected in the relative value of these animals at weaner sales and on the store market (Cook, 2014, Jolly, 2016).

Table 1: Number of calves born annually in New Zealand, and the volume used in each destination (by origin). Percentages indicate proportion of each sex class.

	Beef-origin	**Dairy-origin**	**Total**
No. calves born annually	880,000 (50% F, 50% M)	4,170,112 (50% F, 50% M)	5,050,112
Total no. by destination			
Breeding replacements	169,798 (94% F, 6% M)	1,143,074 (96% F, 4% M)	1,312,872
Finishing heifers/ steers	632,321 (40% F, 60% M)	417,275 (47% F, 53% M)	1,049,596
Finishing bulls	27,881 (100% M)	371,973 (100% M)	399,854
Live export heifers	0	43,517 (100% F)	43,517
Bobby calves	0	1,695,601 (34% F, 66% M)	1,695,601
Deaths (Estimate)	50,000 (50% F, 50% M)	62,552 (50% F, 50% M)	112,552
Killed on farm (Estimate)	0	436,120 (34% F, 66% M)	436,120

Sourced from (Archer *et al.*, 2014).

Dairy-origin cattle are born in the national milking herd comprised of approximately five million cows and heifers. The key breeds in the dairy herd are Holstein-Friesian x Jersey (often termed Kiwi cross) (47%), Holstein-Friesian (34%), Jersey (9%), other (9%) and Ayrshire (1%) (B+LNZ, 2018). Dairy-origin calves used for beef production are typically sold to a rearer at four days of age, when they are artificially reared to 100 kg live weight and weaned at 2 - 3 months of age (Barton and Pleasants, 1997, Clarke *et al.*, 2009). At this point calves are sold to beef finishing farmers, and on a per head basis prices are often discounted relative to beef-origin cattle, reflecting the lighter weaning weights and relative difficulty to finish dairy-origin cattle (Cook, 2014, Jolly, 2016). However, due to the comparatively early weaning age and restrictive pre-weaning environment, dairy-origin calves often exhibit more compensatory growth later on in life than calves of less restricted rearing (Everitt *et al.*, 1978, Barton and Pleasants, 1997).

2.2.1 Trends in the New Zealand cattle industry

A declining beef herd and growing dairy herd have long been features of New Zealand's cattle industry (Figure 2, Figure 3, Cook, 2014, Burggraaf, 2016, Jolly, 2016). Between 2007 and 2017 national beef cattle numbers decreased from 4.39 to 3.61 million (-18%), whilst dairy cattle numbers increased from 5.26 to 6.47 million (23%) (B+LNZ, 2018). Over the last five years the number of beef breeding cows and heifers has remained stable, yet over the same period total beef production has increased by 15% (61,000 tonne) (B+LNZ, 2018). An increase in the per head productivity of beef cattle may be partially responsible for this trend, however a growing number of dairy-origin cattle slaughtered for beef products is likely the main driver.

The supply of dairy-origin cattle for beef production is sensitive to milk price and industry outlook. Between the 2014 - 2016 seasons when the milk price fell to a 10-year low of $3.90 per kilogram of milk solids (Interest, 2018a), the number of calves slaughtered in that period increased reaching its all-time peak of 2.13 million animals (2014 - 2015 season) (Figure 1, Statistics New Zealand, 2018). In 2018 the Micoplasma Bovis outbreak caused more uncertainty in the dairy value chain (MPI, 2018), however the impact this could have on the supply of dairy-origin cattle for beef processing is unclear.

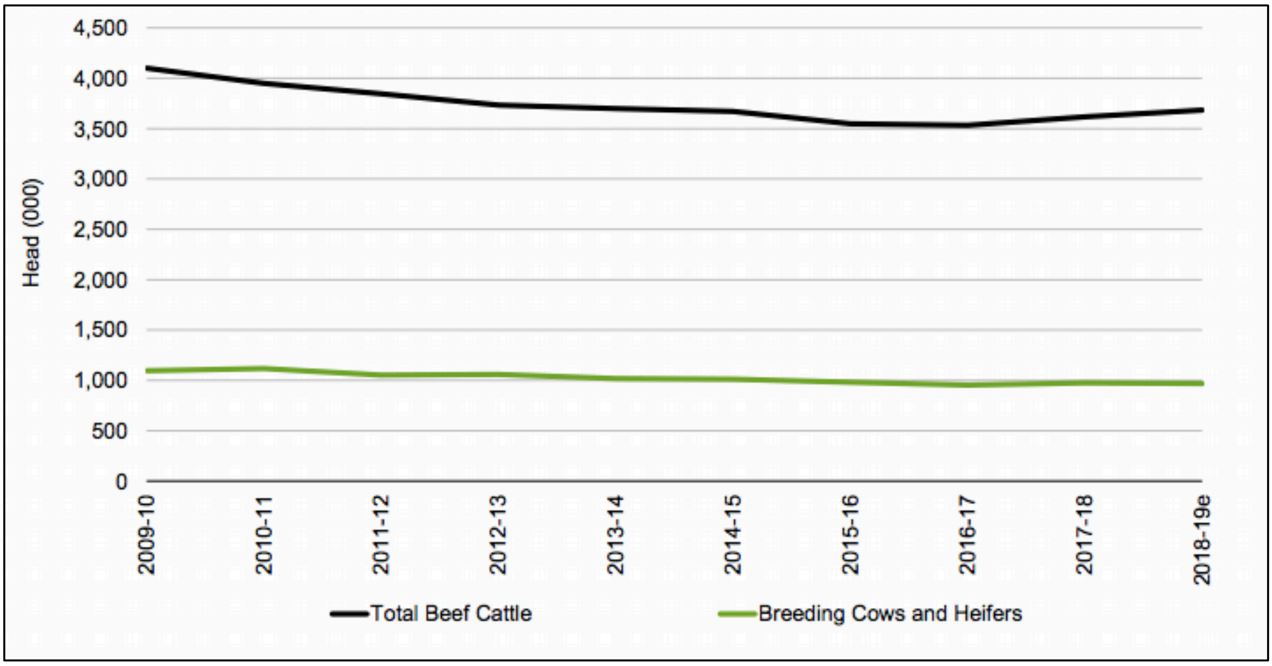

Figure 2: Trend in total number of beef cattle, breeding beef cows and heifers farmed in New Zealand over the last decade (year ending June) (B+LNZ, 2018).

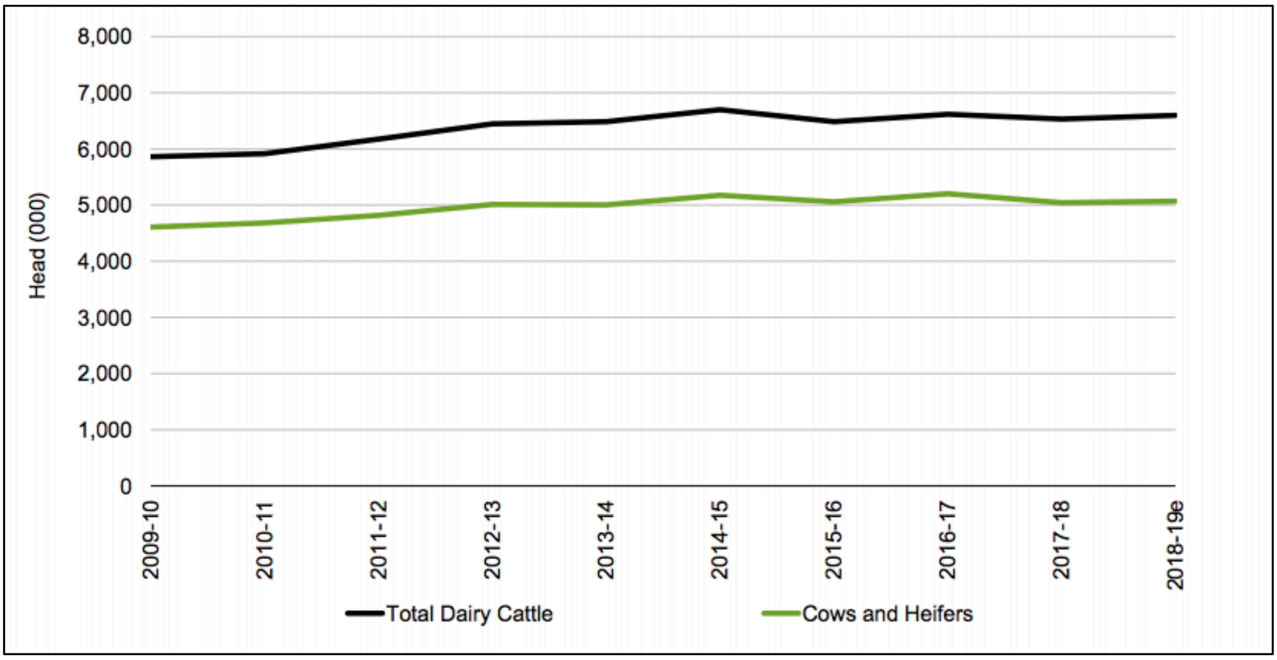

Figure 3: Trend in total number of dairy cattle, breeding dairy cows and heifers over the last decade in New Zealand (year ending June) (B+LNZ, 2018).

2.2.2 Current dairy industry model for disposing of surplus calves

Each year the dairy industry produces approximately 4.2 million calves as a byproduct of lactating cows. Under current practice about 30% of these calves are retained within the dairy industry as replacement milking and breeding stock. A further 20% are utilised in the beef industry, either as crossbred breeding stock or grown out for 'prime' or 'manufacturing' beef (Hickson *et al.*, 2015). However, due to competition between agricultural land uses, the remaining 50% (2.10 million calves per annum) are surplus to requirements (Figure 4, Archer *et al.*, 2014). The majority of these calves are slaughtered in the bobby calf trade, and there is a lack of data recording the fate of the remainder of surplus calves (Cook, 2014).

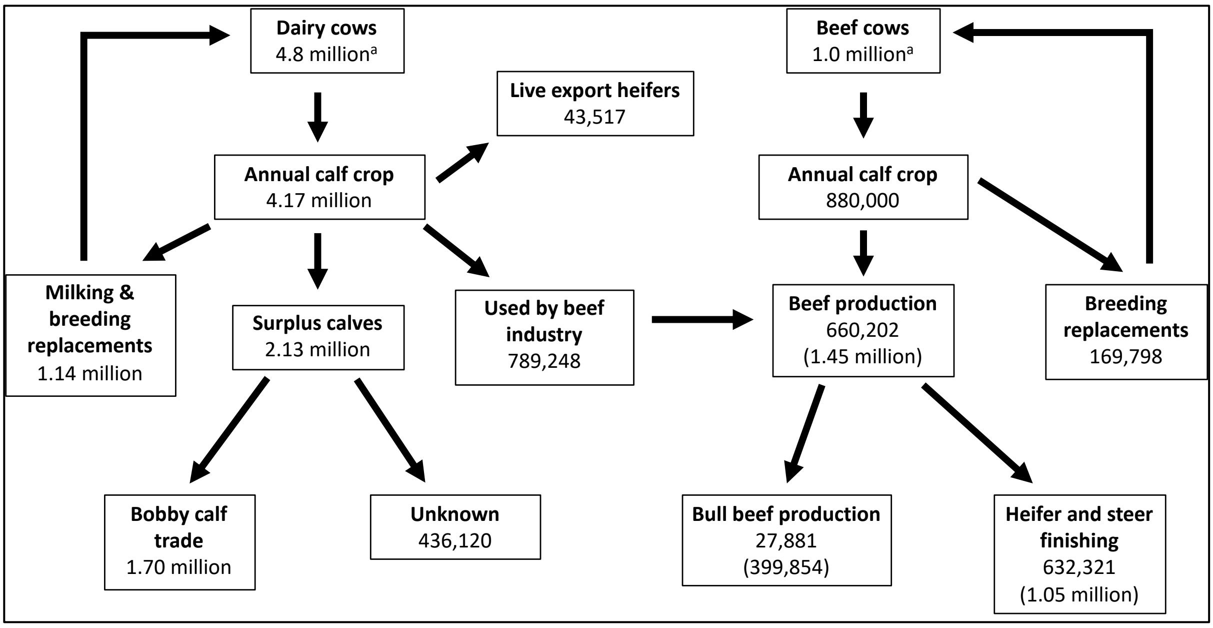

Figure 4: Flow diagram showing the pathway and end uses of the annual dairy and beef herd's calf crop. Adapted from (Archer *et al.*, 2014).

[a] – Sourced from (B+LNZ, 2018).

Values in brackets are totals (including contributions from the dairy industry).

The current mode of operation (Figure 4) regarding surplus dairy calves has a number of potential flaws. From an economic standpoint, the fate of surplus dairy calves represents a significant under utilisation of a potentially valuable resource. In the existing value chain, a dairy calf at four days of age is typically worth between \$25 (bobby calf) and \$250 (higher genetic merit calf for breeding) per head depending on its genetic makeup, whereas a finished bull can be worth up to \$1500 – \$1800, a difference of at least \$1250 (Cook, 2014, Interest, 2018b). On a national scale the opportunity cost of the bobby calf trade has been estimated to exceed NZD \$1 billion annually (Jolly, 2016), however it is unclear how the author estimated the cost of the additional feed required to net this benefit.

In addition, there are a number of ethical issues pertaining to the treatment of surplus dairy calves (Mellor and Webster, 2014). In particular, animal welfare during transport and handling enroute to the abattoir has been identified as a problem area (McCausland *et al.*, 1977, Mackle, 2016). Furthermore, the public's attitude towards potential welfare compromises is compounded by the young age of calves which elevates their vulnerability to adverse treatment (Mellor *et al.*, 2000). Ongoing media scrutiny in conjunction with the release of several graphic video's depicting the mistreatment of bobby calves makes the ethical argument particularly topical (Mackle, 2016). Recent regulatory changes under the Animal Welfare Act 1999 have attempted to address some of these problems. These include the prohibition of killing calves with blunt force to the head, and the tightening of rules around calf transportation, for example all calves must be "free from signs of any injury, disease, disability, or impairment" prior to transportation (MPI, 2018a).

However, New Zealand farmers still risk losing their 'social license' to farm if the fundamental ethical issue (slaughtering 4 – 8 day old calves in the bobby calf trade) is not resolved (Jolly, 2016). In practice this could mean a deterioration in the public's attitude towards agriculture, in particular dairy farming. It has already been asserted that "if the pollution caused by the dairy industry was properly accounted for, it would exceed the industry's total economic value" (Joy, 2017), and animal welfare issues only further compromise the industry's already unstable public image (Mellor, 2015). On the domestic front, the consequences of not getting this right in future could lead to negative sentiment towards farming, making it difficult for the industry to remain sustainable. On the international front, the marketability of New Zealand produce could become compromised which would carry significant ramifications, as demonstrated in other agri-food controversies such as the 2013 botulism scare (Pang, 2017).

2.3 Breed effects on growth and carcass traits for beef production

The comparative suitability of dairy and beef breed cattle for beef production has been researched extensively (see the review of Bown *et al.*, 2016). This section will attempt to summarize the key literature pertaining to growth and carcass characteristics in both dairy and beef breed types and identify the strengths and weaknesses of each for beef production. Overviews at the end of each section summarize the literature presented in each sub section.

2.3.1 Growth characteristics

Average daily gain (ADG)

Barton *et al.* (1994) found Holstein-Friesian (HF) steers were heavier at slaughter than HF x Jersey steers and pure Jersey steers when raised on a pasture-based diet and slaughtered at 22 - 23 months of age (Table 2). Similarly, in heifers examined from 3 - 22 months of age grown in pasture-based systems, HF heifers were heaviest at any given point, followed by HF x Jersey heifers, with pure Jersey breed heifers being the lightest (Handcock *et al.*, 2019). While, Cundiff *et al.* (1993) examining the offspring of Hereford and Angus dams, produced similar results with Jersey sired progeny having 14%, 10%, and 6% lower average daily gains (ADG) compared to Simmental, HF, and Limousin sired progeny respectively. Furthermore, in once-bred heifer (OBH) systems Hereford x HF heifers achieved higher ADGs and live weights compared to Hereford x Jersey heifer’s (Table 2, Burke *et al.*, 1998).

Further work by Coleman *et al.* (2016) compared the growth of steers fed a pasture-based diet from Angus, Angus × HF, Angus × HF-Jersey, and Angus × Jersey cows when sired by a Hereford bull. Coleman *et al.* (2016) found that dairy-beef steers were heavier than steers from pure beef breed dams at weaning (168 days old) (Table 2), this was attributed to the greater lactation performance of the dairy breed dams. Steers born to pure beef breed dams achieved greater post weaning growth rates compared to steers born to dairy cross dams (Table 2). This was attributed to beef breed effects. Overall the Hereford x Angus-HF steers had the highest ADGs over their lifespan and achieved the heaviest slaughter and carcass weights of the breeds examined. This was attributed to these animals benefiting from three breed heterosis, and the HF component enabling higher pre-weaning ADGs as a result of their dam’s increased lactational performance.

Growth efficiency

Cattle of high milking potential (dairy breed) are less efficient at live weight maintenance than cattle of lower milking potential (Montano-Bermudez *et al.*, 1990, Archer *et al.*, 1999). This suggests dairy breeds may have inferior growth efficiency compared to beef breeds, making dairy breeds less efficient for beef production. When slaughtered at 18-months of age, Charolais bulls had a 13% lower energy cost per kilogram of live weight gain compared to German HF bulls (Pfuhl *et al.*, 2007). Furthermore, Charolais bulls achieved a 13% higher ADG compared to HF bulls and were also heavier at slaughter (Table 2). In addition, Burke *et al.* (1998) reported that Hereford x HF OBH’s produced 7% more carcass weight than Hereford x Jersey heifers per tonne of dry matter consumed (Table 2).

Table 2: Summary of literature comparing the growth characteristics of different cattle breeds under a range of; sex class, slaughter age and feeding regimes.

Dam breed	Sire breed	Sex class	Number (*n*)	Slaughter age (days)	ADG (gram/day)	Slaughter weight (kg)	Reference
Friesian	Friesian	Steer	10	688	673	463.3	(Barton *et al.*, 1994)
Jersey	Jersey	Steer	10	691.5	512	354.2	
Jersey	Friesian	Steer	10	688	628	432.3	
Holstein-Friesian	Unknown	Heifer	48,026		584		(Handcock *et al.*, 2019)
Holstein-Friesian x Jersey	Unknown	Heifer	129,503		567		
Jersey	Unknown	Heifer	12,407		529		
Angus-Hereford	Jersey	Steer	130		1066	457.2	(Cundiff *et al.*, 1993)
Angus-Hereford	Simmental	Steer	172		1238	520.7	
Angus-Hereford	Holstein	Steer	72		1175	494.0	
Angus-Hereford	Limousin	Steer	173		1129	489.9	
Angus	Hereford	Steer	25	714	715	595.0	(Coleman *et al.*, 2016)
Angus-Holstein Friesian	Hereford	Steer	21	714	711	624.0	
Angus-Holstein Friesian-Jersey	Hereford	Steer	11	709	658	589.0	
Angus-Jersey	Hereford	Steer	21	712	668	587.0	
Friesian	Hereford	Heifer	57		400	456.8	(Burke *et al.*, 1998)
Jersey	Hereford	Heifer	45		300	407.6	
German Holstein	German Holstein	Bull	18	547.5	1196	588.2[a]	(Pfuhl *et al.*, 2007)
Charolais	Charolais	Bull	18	547.5	1377	675.4[a]	
Friesian	Friesian	Bull	43		970	501.0	(Muir *et al.*, 2001)
Jersey	Unknown	Bull	46		900	465.7	
Unknown	Wagyu x [b]	Heifers + steers	120	912.5	708	667.0	(Greenwood *et al.*, 2006)
Unknown	Piedmontese x [b]	Heifers + steers	120	912.5	730	684.0	

Angus–Murray Grey (Fast growth)	Angus [b]	Heifers + steers			1110	490.3	(McIntyre *et al.*, 2009)
Angus–Murray Grey (Slow growth)	Angus [b]	Heifers + steers			710	507.3	
Hereford	Limousin [bc]	Steer	28	404 – 523	750	646	(Wilkins *et al.*, 2009)
Hereford	Charolais [bc]	Steer	29	404 – 523	780	680	
Hereford	Angus [bc]	Steer	59	404 – 523	740	644	
Hereford	Red Wagyu [bc]	Steer	29	404 – 523	690	606	
Hereford	Black Wagyu [bc]	Steer	36	404 - 523	700	631	

[a] - Empty live weight, (all digesta removed from body).

[b] - Feedlot system.

[c] - Fast growth treatment.

Per hectare production

Muir *et al.* (2001) compared the growth of rising one-year old HF and Jersey x bulls when farmed in a TechnoGrazing™ system, which is an intensive, high utilization, and efficient pastoral grazing system capable of high animal performance levels (Charlton and Wier, 2001). This study reported that HF bulls were heavier than Jersey bulls on a per head basis, but Jersey bulls produced 1% more live weight gain per hectare than HF bulls (Table 2). These findings concur with earlier work (Cundiff *et al*., 1993, Barton *et al*., 1994), and go one step further by examining productivity on a per hectare basis, thus identifying a potential opportunity to farm young Jersey x bulls. Muir *et al.* (2001) concluded that Jersey x bulls can be as profitable as HF bulls on a per hectare basis, provided their purchase price is discounted to reflect them typically being lighter than beef breeds at a given slaughter age.

Combined these studies suggest that when fed a pastoral diet Jersey and Jersey crossbred cattle have lower ADGs than HF and beef breed cattle in both steer finishing and OBH systems. Beef breed steers are capable of higher post weaning ADGs than dairy breed steers, but dairy breed steers are typically heavier at weaning if they are reared on a dairy dam. Hereford x Angus-HF crossbred steers display heterosis resulting in higher ADGs over their lifespan compared to Hereford x Angus, Hereford x Angus-HF-Jersey, and Hereford x Angus-Jersey steers respectively. In regard to growth efficiency, dairy breed bulls and OBH's are less efficient compared to beef breeds. This is attributed to the dairy breeds having higher maintenance and weight gain energy requirements, along with a lower feed intake:carcass weight conversion ratio compared to beef breeds. On a per hectare basis, Jersey x bulls produce more live weight than HF bulls as rising one-year olds, however further research is required to determine whether the same relationship exists in heifers and steers, and with other breeds.

2.3.2 Carcass characteristics

Dressing out percentage, carcass weight, and eye muscle area

Barton and Pleasants (1997), compared beef breed steers (Angus, Beef Shorthorn, Galloway, Hereford, and Red Poll) with dairy breed steers (HF, Milking Shorthorn, Ayrshire, and Jersey) and found that dairy breeds had lower DO%, carcass weight and eye muscle area (EMA) relative to the beef breeds (Table 3). In particular, Jersey steers had the lowest carcass weight, DO%, and one of the lowest EMA's, while Beef Shorthorn and Angus steers were top performers on these parameters (Table 3). HF steers achieved a modest carcass weight and EMA, however they had a lower DO% compared to Beef Shorthorn and Angus steers (Table 3). Similar results were produced in other studies (Gifford, 1977, Cundiff *et al.*, 1993), and Carroll *et al.* (1964) noted that differential pre-weaning environments between dairy and beef breeds may be acting as a covariate for the observed breed effects on carcass characteristics (Table 3). Furthermore, Burke *et al.* (1998) found Hereford x Jersey OBHs have lighter and shorter carcasses compared to Hereford x HF heifers (Table 3), however no differences in DO% or EMA were observed in this study. In addition, Clarke *et al.* (2009) compared dairy-origin Holstein bulls and Friesian steers with beef bred bulls and steers and found that in both sex classes the beef breeds achieved greater DO% and heavier carcasses than Holstein and Friesian animals (Table 3). EMA was not recorded in this study. These results concur with Purchas (2007). More recently Coleman *et al.* (2016) found Hereford x Angus steers have higher DO% and carcass weights compared to Angus × HF, Angus × HF-Jersey and Angus × Jersey, steers from cows sired by a Hereford bull and slaughtered at 24-months of age, whilst steers with Jersey genetics had the lowest DO% and carcass weights respectively (Table 3). The EMA's of Hereford x HF-Jersey and Hereford x Angus-Jersey steers were greater than those of Hereford x Angus-HF steers (Table 3).

Lean meat yield, fat cover, intramuscular fat and bone

Relative to beef breed steers, dairy breed steers have more non-carcass fat (kidney and channel), less fat cover above the 12th rib, and heavier bones (Table 3, Barton and Pleasants, 1997). Jersey steers had the most non-carcass fat and second least fat cover over the 12th rib, whilst HF steers had a moderate amount of non-carcass fat and the least fat above the 12th rib (Table 3). By contrast Beef Shorthorn and Angus steers had the most fat above the 12th rib, and one of the lowest non-carcass fat measurements (Table 3). There were no differences in lean meat yield between the dairy and beef breeds, and neither intramuscular fat nor marbling score were documented in this trial. Similar observations were made in earlier works (Table 3, Carroll *et al.*, 1964, Gifford, 1977).

Cundiff *et al.* (1993) reported that Jersey x steers had the most fat cover, highest marbling score, and least bone (by weight and %). However, these steers also had the most non-carcass fat (kidney, heart, and pelvic fat) and considerably less saleable meat compared to the other breeds examined (Table 3). Holstein x steers achieved the greatest retail beef yield (RBY), Simmental steers had the second highest RBY and marbling score, while Limousin x steers had the second greatest fat cover (Table 3). Furthermore, in OBHs Hereford × Jersey cattle have more fat cover above the 12th rib, a higher IMF%, and more kidney and pelvic fat compared to Hereford × HF heifers (Burke *et al.*, 1998). The same study found Hereford x Jersey cattle have a higher muscle:bone ratio and lighter femur bone weight relative to

Table 3: Summary of literature comparing the carcass traits of different cattle breeds under a range of; sex class, slaughter age and feeding regimes.

Dam breed	Sire breed	Sex class	Slaughter age (days)	Carcass weight (kg)	DO%	Fat over 12^{th} rib (mm)	Fat %	Lean yield (kg)	Bone %	EMA (cm^2)	IMF %	Conformation score	Reference
Angus	Angus	Steer	~912	271.0[a]	52.7[a]	9.4[a]		169.2[a]		10.6[a]			(Barton and
Beef Shorthorn	Beef Shorthorn	Steer	~912	275.5[a]	53.6[a]	11.7[a]		158.3[a]		9.1[a]			Pleasants,
Hereford	Hereford	Steer	~912	288.0[a]	54.1[a]	11.4[a]		171.4[a]		10.1[a]			1997)[a]
Friesian	Friesian	Steer	~912	280.0[a]	51.2[a]	4.0[a]		166.8[a]		9.8[a]			
Jersey	Jersey	Steer	~912	212.0[a]	48.3[a]	4.0[a]		165.0[a]		8.9[a]			
Holstein	Holstein	Steer	864	383.7	58.0	26	35.1	225.0	13.4			15.5	(Carroll *et al.*,
Hereford	Hereford	Steer	681	325.2	62.0	33	40.0	182.8	10.7			20.6	1964)
Friesian	Friesian	Steer	938	218.9	47.4	51.6	12.0	135.3	19.9	51.6			(Gifford, 1977)
Friesian	Charolais	Steer	939	228.4	48.0	58.6	11.4	148.5	19.8	58.6			
Friesian	Hereford	Steer	940	214.1	47.3	53.3	14.7	132.1	19.0	53.3			
Jersey	Friesian	Steer	1102	287.1	52.4	58.4	15.5	170.0	17.9	58.4			
Jersey	Charolais	Steer	1095	309.0	53.6	66.2	14.9	193.7	17.7	66.2			
Jersey	Hereford	Steer	1104	288.7	52.6	63.2	19.0	167.4	17.2	63.2			
Angus-Hereford	Jersey	Steer		273.5	59.8	11.2	20.7	176.4	12.4	66.6			(Cundiff *et al.*,
Angus-Hereford	Simmental	Steer		315.2	60.5	9.4		216.8	13.4	76.6			1993)
Angus-Hereford	Holstein	Steer		299.8	59.1	10.2	16.5	212.7		69.5			
Angus-Hereford	Limousin	Steer		302.5	61.7	9.9	15.9	208.2	12.6	79.2			
Friesian	Hereford	Heifer		234.8	50.0	5.6				59.4	3.2		(Burke *et al.*,
Jersey	Hereford	Heifer		209.9	50.0	7.6				60.3	3.8		1998)

Beef breed	4 beef breeds	Bull	470	353.0	58.8	1.9	9.1	257.3	18			11.1	(Clarke *et al.*,
Holstein	Holstein	Bull	428	248.0	52.0	1.5	10.7	167.2	21.9			5.8	2009)
Beef breed	4 beef breeds	Steer	786	413.0	56.6	4.6	12.4	291.2	17.1			9.7	
Friesian	Friesian	Steer	792	351.0	52.3	4.3	14.4	232.0	19.4			6.1	
Friesian	Friesian	Steer	688	241.5	52.1	2.0	8.3	163.0	22.7	59.5			(Barton *et al.*,
Jersey	Jersey	Steer	691.5	181.4	51.2	2.6	9.4	116.4	22.6	51.0			1994)
Jersey	Friesian	Steer	688	225.6	52.2	3.3	8.9	149.0	22.3	58.1			
Angus	Hereford	Steer	714	302.0	50.7	5.8				75.0	5.8		(Coleman *et al.*,
Angus-Holstein Friesian	Hereford	Steer	714	312.0	50.1	4.9				73.0	4.4		2016)
Angus-Holstein Friesian-Jersey	Hereford	Steer	709	293.0	49.7	4.8				73.8	5.2		
Angus-Jersey	Hereford	Steer	712	289.0	49.3	5.7				75.3	5.2		
German	German	Bull	547.5	356.7	53.9		5.6	269.0	15.8	82.1			(Pfuhl *et al.*,
Holstein	Holstein	Bull	547.5	450.3	60.3		4.7	355.6	13.3	125.8			2007)
Charolais	Charolais												

[a] - Average of multiple year's results.

Hereford x HF heifers (Table 3). These findings contradict earlier work (Cundiff *et al.*, 1993), however these differences could be due to the respective sires used.

Clarke *et al.* (2009) found that in both steers and bulls the Holstein and Friesian breeds had less fat above the 12th rib, a lower conformation score, more kidney and channel fat, a higher bone %, and a lower meat yield (grams/kg) relative to their beef breed counterparts (Table 3), supporting earlier work (Cundiff *et al.*, 1993, Barton and Pleasants, 1997, Purchas, 2007). Coleman *et al.* (2016) reported that Hereford x Angus steers had more fat above the 12th rib and a greater IMF% compared to Hereford x Angus-HF, Hereford x Angus-HF-Jersey and Hereford x Angus-Jersey steers (Table 3). A limitation of this study was that it did not report muscle:bone ratio, bone %, kidney and channel fat, lean meat yield, or RMY.

Combined the literature suggests Jersey and Jersey x steers have lower DO%, carcass weights and EMA compared to beef breed and HF steers. In OBHs, crossbred cattle with Jersey genetics are likely to generate lighter carcasses compared to crossbred heifers with HF genetics, however there is no evidence to suggest DO% or EMA will differ between these breeds. In addition, dairy breed cattle are associated with more non-carcass fat, higher amounts of bone (by weight or %), less lean or saleable meat, and either more or less fat above the 12th rib relative to beef breeds.

2.4 New Zealand’s accelerated-cycle beef production opportunity

Although carcasses from accelerated-cycle systems can be comparatively light, efficiency can be high as greater numbers of cattle can be grown, and multiple production cycles can be completed in the same timeframe as a single longer cycle enterprise. Because of these attributes, accelerated-cycle beef production could finish more cattle per hectare compared to traditional beef production systems. This is a vital advantage, as limited agricultural land is a key constraint leading to the current industry model (Figure 4) where surplus dairy calves are underutilised. Theoretically growing these animals in an accelerated-cycle (8 – 12 months of age at slaughter) production enterprise could reduce input costs in the efficiency equation, whilst adding value, thus providing a viable alternative pathway for surplus dairy calves.

2.4.1 International examples of accelerated-cycle beef production

Although New Zealand doesn’t currently have any accelerated-cycle beef production enterprises, the international cattle industry has demonstrated the potential of slaughtering cattle at less than one-year of age (Table 4). Veal production, also known as ‘baby beef’ in parts of Europe, is distinct from beef production. Under European Union legislation veal is defined as bovine meat derived from animals slaughtered at eight months of age or less, whereas beef comes from bovines a minimum of 12-months old (European Parliment, 2013, Domaradzki *et al.*, 2017). Furthermore, meat can be marketed as 'rose veal' when it is derived from cattle slaughtered at less than one-year of age, farmed in a welfare-friendly environment and from eight weeks of age onwards fed a mixed *ad libitum* diet (European Parliment, 2013, Domaradzki *et al.*, 2017). However, for both veal and beef meat, management practices, feeding regimes and meat characteristics are not regulated. In Argentina cattle are regularly slaughtered at less than one-year of age (Boyer, 2016), yielding a red meat product favoured on the domestic market (Joseph, 2015).

The United Kingdom (UK) veal industry has demonstrated the achievable physical performance of dairy-origin cattle (predominantly HF), when slaughtered at less than a year of age. Currently two systems are implemented, whereby calves are fed a combination of milk and concentrates, and either slaughtered at 6 - 7 months (270 - 300 kg live weight) or 10-months (400 – 420 kg live weight) of age generating carcasses in the ranges of 130 – 150 kg and 200 – 215 kg, respectively (AHDB, 2011, Domaradzki *et al.*, 2017). The Polish veal industry undertakes a small amount of 'suckler beef' production where calves are raised on milk alone (provided by their dam) and slaughtered at 250 - 350 kg live weight (Domaradzki *et al.*, 2017). However, the majority of veal produced in Poland is derived from calves artificially fed whole milk until they reach 80 kg live weight when their diet is transitioned to milk replacer and they are slaughtered once they reach a minimum of 120 kg live weight to produce white veal (Florek *et al.*, 2012).

Belgium's veal industry is similar. Calves (typically dairy-origin but also some crossbred and Belgian Blue animals) are fed solely milk which minimises iron levels, and slaughtered and marketed as 'white veal' (Pardon *et al.*, 2014). In Spain a range of accelerated-cycle cattle production enterprises are implemented (Domaradzki *et al.*, 2017), the most intensive enterprise consists of crossbred calves which are grown rapidly for slaughter at 8 – 9 months of age (Table 4). Spanish farmers also produce suckler beef where calves are naturally suckled prior to slaughter at 6 - 7 months of age (Vieira *et al.*, 2005). In North West Spain (Galicia) HF, Limousin, Belgian Blue and Rubia Gallega calves are grown in a 7 – 9 month production cycle and processed at 300 – 400 kg live weight (Bispo *et al.*, 2010). These international examples (Table 4) demonstrate the achievable performance levels when slaughtering cattle at less than one-year of age.

Table 4: Carcass and growth characteristics of a range of breeds raised in veal and yearling beef systems and slaughtered at different ages. Adapted from (Domaradzki *et al.*, 2017).

Dam breed	Sire breed	Slaughter age (months) and sex	Growth rate (grams/ day)	Slaughter weight (kg)	DO%	Carcass weight (kg)	Reference
Holstein-Friesian	Holstein-Friesian	6 – 7 (F & M)		270 - 300	49	130-150	(AHDB, 2011)
Holstein-Friesian	Holstein-Friesian	10 (F & M)	1300 - 1500	400 - 420	50.6	200-215	(AHDB, 2011)
Limousin	Limousin	6 (F & M)	1221	255	63.3	148	(Litwinczuk and Stanek, 2013)
Limousin	Limousin	8 (M)		294	61.7	182	(Florek, 2013)
German Angus	German Angus	7 – 8 (F & M)	989	277	53.3	147	(Golze, 2001)
Tudanca	Charolais	7 (M)		256	56.2	144	(Aldai *et al.*, 2012)
Limousin-Simmental		9 (F & M)	1355	399	57.4	228	(Terler *et al.*, 2014)
Parda de Montaina		8 (M)	790	227			(Ripoll *et al.*, 2013)

2.4.2 Advantages of an accelerated-cycle beef system utilising dairy-origin calves

The emergence of alternative proteins onto the market (B+LNZ, 2018b), along with ongoing regulatory reform (Veissier *et al.*, 2008) and a trend in consumer preferences towards welfare 'friendlier' foodstuffs (Blokhuis, 2004) is making animal welfare increasingly topical in the red meat industry (Verbeke, 2009). Favourable animal welfare practices can increase the productivity of cattle, and also enhance the palatability of the derived meat products (Hemsworth *et al.*, 1993). Accelerated-cycle beef production may overcome some of the inherent animal welfare challenges associated with the bobby calf trade (Mellor *et al.*, 2000). Cattle would be sent for slaughter at older ages, and therefore may be better able to cope with the stress associated with transport and handling prior to slaughter.

Nutrient losses (notably nitrogen and phosphorus) (Monaghan *et al.*, 2007) and greenhouse gas (GHG) emissions (particularly methane accounting for 80% of biological losses (Hammond *et al.*, 2009)) are externalities associated with pastoral agriculture in New Zealand. Pressure is mounting on the agricultural sector to account for the environmental costs of production (Caradus, 2007). In 2016, pastoral agriculture accounted for 49% of New Zealand's total emissions (Ministry for the Environment, 2018). Accelerated-cycle beef production may help address some of these contemporary environmental issues.

Slaughtering cattle within one-year of age may reduce pugging which can limit pasture growth and impair soil physical properties (Drewry, 2006), as there would be fewer cattle on farm during late winter and early spring, when soils are wet and more susceptible to damage. Sheath and Boom (1997) compared 200 kg live weight steers with 390 kg steers, and found the heavier animals consistently caused more pugging damage. In addition, using lysimeters, a positive relationship between urine volume (a proxy for cow age/size) and urine nitrate leaching levels was found (Stout, 2003), suggesting the lighter and younger animals used in accelerated-cycle beef production may reduce nitrate leaching compared to the heavier cattle used in traditional enterprises.

Furthermore, there is a positive relationship between slaughter age and GHG emissions in steers and bulls under indoor concentrate feeding and outdoor pastoral grazing conditions (Murphy *et al.*, 2017b), suggesting accelerated-cycle beef production may generate less GHGs compared to traditional forms of beef production. Regional Councils in New Zealand have begun introducing nutrient loss limits in an attempt to combat water quality issues (Horizons Regional Council, 2014). Therefore, the productivity per unit of N lost between different production systems is becoming an increasingly important consideration around land use decisions. Collectively these findings suggest on a per head basis, accelerated-cycle beef production utilising young, light cattle may reduce N losses compared to traditional forms of beef production, whilst also achieving a lower GHG footprint per kilogram of carcass weight produced.

So far, no studies have quantified the nutrient losses and GHG emissions of accelerated-cycle beef production relative to traditional forms of beef production. Moreover, the number of animals grown in an accelerated-cycle enterprise would likely differ to traditional enterprises, as more light cattle could be grown, relative to traditional heavier animals at a given stocking rate. This adds an additional level of complexity and necessitates further modelling to determine the equivalent carrying capacity of each stock class within a given farm system. Additional research into the comparative efficiency of beef production systems in terms of nutrient losses and GHG emissions is warranted.

Accelerated-cycle beef production may use feed more efficiently than traditional enterprises. Research across a number of taxa suggests that animals grow at their fastest rate when young due to evolutionary pressures (Figure 5, Brody, 1946, Richards, 1959, Aguilar *et al.*, 1983). This is known as the accelerated growth phase phenomenon (Metcalfe and Monaghan, 2003). On an energy partitioning basis, live weight and maintenance energy requirements are positively correlated (Rattray *et al.*, 2007). Therefore, lighter animals have comparatively lower maintenance energy requirements, meaning a greater proportion of total energy ingested can be used for growth. In a livestock production setting this suggests farming young animals could increase feed conversion efficiency (FCE) which is a measure of how effectively feed is converted into a given output. In the context of beef production carcass weight is the desired output (Equation 1).

Equation 1: Beef production feed conversion efficiency formula (Arthur *et al.*, 1996).

$$\frac{kg\ dry\ matter\ eaten}{kg\ carcass\ weight\ produced}$$

The relationship between breed and FCE is well understood in adult cattle (Hanset *et al.*, 1987, Pfuhl *et al.*, 2007, Nielsen *et al.,* 1990, Richardson *et al*., 1999), yet little work has been done to quantify the FCE of young cattle (particularly during their first year of life). Therefore, a gap in knowledge exists in this area, and further research is needed before comparisons between accelerated-cycle and traditional beef production can be made.

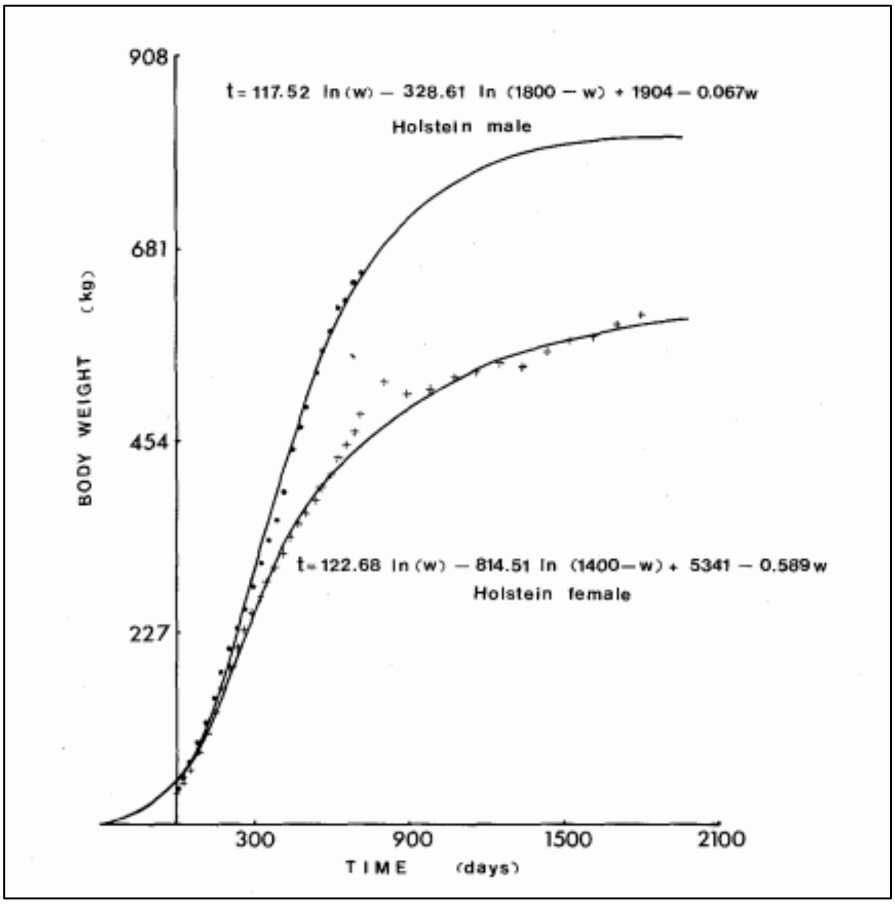

Figure 5: Growth curve of Holstein cattle of both sexes from peri-natal period to 2100 days (Aguilar *et al.*, 1983).

2.4.3 Barriers for accelerated-cycle beef production

In the current study it was assumed that all 'post farm gate' barriers for accelerated-cycle beef production were overcome, thus the focus was on better understanding the on-farm barriers. Nevertheless, it is important to identify both pre- and post- farm gate barriers, as this helps establish the scope of this study and identify potential areas for future research. Key barriers include: resource limitations; infrastructural incompatibilities; and a lack of supporting research relative to the performance of young (8 – 12-month-old) dairy-origin cattle when grown in an accelerated-cycle beef production system.

Resource limitations

Calf rearing is a seasonal, capital intensive activity that carries considerable market and animal health risk (Ormond *et al.*, 2002). Rearers typically purchase calves at a minimum of four days of age and raise them for 2 - 3 months before sale to a beef finisher (Muir *et al.*, 2000, Ormond *et al.*, 2002). Profitability is principally driven by the purchase price of 4 - 8 day old calves, feeding costs (Muir *et al.*, 2000), and finally the market for 100 kg calves which is strongly correlated with the bull schedule price (Ormond *et al.*, 2002). At present, there is capacity to rear approximately 2.8 million calves per year in New Zealand, however in excess of 5 million calves are born (Archer *et al.*, 2014). For accelerated-cycle beef production to be viable, New Zealand's calf rearing capacity may need to grow, in order to meet the demand for additional calves every year. The extra number of calves that would need to be reared for accelerated-cycle beef production each year is currently unknown and would be difficult to estimate.

The finite land area available for agriculture is another resource barrier hindering the adoption of accelerated-cycle beef production. Of New Zealand's 26.7 million hectares, agricultural land comprises 12.1 million hectares, of which dairy farming occupies 2.6 million hectares (21%) while sheep and beef farming utilises 8.5 million hectares (70%) (Statistics New Zealand, 2016). The balance (1 million hectares) is occupied by a mixture of deer, pig, horse and poultry farms. Assuming that all agricultural land is being farmed to its full capacity (within the limitations of the owner's ability), it is clear that accelerated-cycle beef production would have to directly compete with and displace some existing land uses. Overcoming this barrier will be heavily dependent on the physical, financial, and environmental performance of accelerated-cycle beef production relative to alternative agriculture land uses. Presently this relative competitiveness is unknown, so identifying values around these parameters was one of the major objectives of the current study.

Infrastructural incompatibilities

Although comparatively minor, infrastructural and processing incompatibilities for slaughtering young cattle exist in many New Zealand cattle slaughter plants. The difference in size between 18 – 24 month-old and 8 – 12 month-old cattle is significant and may cause issues in processing both pre- and post-mortem. Anecdotal evidence suggests the dimensions (particularly height) of the stun box at many slaughter plants is unsuitable for processing cattle aged 8 - 12 months, making humane slaughter difficult. Post-mortem mechanised skinning devices and transport rails are designed to handle the larger carcasses of older animals, which again makes processing smaller carcasses difficult. It may be possible for deer slaughter plants to process a proportion of the cattle grown in accelerated-cycle beef systems, however, this is dependent on deer plants having surplus capacity. In order for accelerated-cycle beef production to become commercially viable, the New Zealand Meat Classification Authority would likely need to develop a new classification scheme recognising carcasses produced under accelerated-cycle beef production systems, as distinct from existing carcass classifications.

Research limitations

Being a novel concept, there is limited research comparing the relative performance of accelerated-cycle beef production, in particular there is a lack of profit-oriented research outputs. It is important to consider these uncertainties holistically across the value chain including the perspectives of all parties including the dairy farmer, calf transporter, calf rearer, beef producer, and meat processor. The main objective for most dairy farmers is to maximise milk production, as milk typically accounts for more than 90% of farm income (AgFirst, 2017). As a result, dairy farmers select sires based on traits such as milk production, short gestation length, and calving ease. This means only 20% of dairy-origin progeny are sired by beef breed bulls (Burggraaf, 2016). Therefore, increasing the genetic merit for growth of surplus dairy calves is a significant opportunity. Financially oriented research may identify incentives to enable dairy farmers to reconsider their policies regarding surplus calves.

From the beef farmer's perspective, the key questions are 'will accelerated-cycle beef production make more money than other forms of beef production?', and 'what other implications will this enterprise have on my farm system'? Before this study, the answers to these questions were unknown, as they depended on a large number of variables such as; the price per kilogram of meat required to breakeven, achievable stocking rates, relative environmental footprint, and the physical performance of cattle processed at 8 – 12 months of age.

2.5 Farm management decision making tools

The broad role of farm management professionals, a group comprised of farmers, farm consultants, farm managers, and many individuals working in the agricultural support sector (Shadbolt and Martin, 2005) is to help farms meet their performance goals. These goals are not exclusively economic. Other considerations such as physical performance levels, environmental sustainability, susceptibility to risk, and perception of the general public and consumers are also important. A range of decision support tools (Hammond, 2017) are available to farm management professionals to help predict, estimate, forecast, or otherwise infer information about the nexus of biological, market, and environmental processes operating within the farm system. This section will review contemporary decision support tools with relevance to analysing physical, financial, and environmental farm performance parameters.

Mathematical programming such as linear programing, and simulation modeling are common methodologies used to model agricultural production systems (Crosson *et al.*, 2006). Linear programming has the ability to identify optimal systems under a given set of constraints. It has also been shown to be effective in identifying inefficiencies and opportunities in a range of agricultural systems (Kahlon and Johl, 1962, Ridler *et al.*, 2001, Hedley *et al.*, 2006). A limitation of linear programing is that it requires an extensive database of variables (linear inequalities) which are often difficult to measure, for example pasture growth responses to fertilizer application at various rates. By comparison, simulation modeling has the potential to accurately simulate and compare complex biological processes and economic interactions operating within agricultural production systems (Shadbolt and Martin, 2005, Crosson *et al.*, 2006). EXCEL feed budget models are a form of simulation modeling and have been used extensively in the fields of farm management and consultancy (Gray, 1987, Duranton and Matthew, 2018). Feed budgeting can be used for the development and evaluation of farm systems and management strategies (Brookes *et al.*, 1993), as well as making comparisons between different systems under a set of status quo input parameters. Feed budgets can function in two directions too, estimate pasture growth based on user defined feed demand parameters and known average pasture cover levels (APC), or project monthly APC's from user defined pasture growth and feed demand data (Frengley, 1973, Parker, 1973, Brookes *et al.*, 1993).

Feed budgets are a versatile decision support tool, as the user can manipulate variables, making them a popular choice for researchers. The downside of this versatility is that there is increased scope for error, and users require an understanding of the biological processes being modeled. Therefore, the commercial use of feed budgeting among farmers and industry professionals is limited. In addition, unlike some decision tools, standalone feed budgets do not provide financial analysis for given farm system models, therefore additional analysis is required to determine profitability. Gross margin analysis is an effective economic assessment tool that can be used for comparing alternative agricultural production systems (Penfold *et al.*, 1995). Gross margins are a function of revenues less the cost of goods sold. In agricultural studies gross margins are typically presented on a whole farm or enterprise specific basis, and units include $/head (Murphy *et al.*, 2017a), $/hectare (Crosson *et al.*, 2006), and $/stocking unit (Dynes *et al.*, 2019).

Recently FARMAX (a commercially available linear program), formerly StockPol (Marshall *et al.*, 1991), emerged (Marshall *et al.*, 1991, Bryant *et al.*, 2010) which combines physical and financial farm data. FARMAX is a specialist software package with the ability to process sheep, cattle and deer or dairy farm systems (Bryant *et al.*, 2010). FARMAX was developed with farmers and industry professionals as the target users, as such its operation is streamlined and user-friendly compared to feed budgeting. Fundamentally, FARMAX provides the same base capability as feed budgeting, forecasting APC based on user defined feed demand parameters. However, a key point of difference with FARMAX is that it is a whole farm system's model, with financial analysis (using contemporary market data) conducted on all models. In addition to its following in the commercial sector, FARMAX has been used in numerous scientific farm system's studies (Smeaton *et al.*, 2011, Williams *et al.*, 2014, Rowarth *et al.*, 2016, Dynes *et al.*, 2019) and thus is a useful decision support tool for researchers. A weakness of FARMAX relative to Microsoft EXCEL feed budgets is that there is less transparency and flexibility in regard to model assumptions. This is a particular limitation when modeling novel systems, as the FARMAX data library is based on currently implemented commercial systems.

The OVERSEER nutrient budget programme is a nutrient management tool taking into account nitrogen (N), phosphorus (P), sulfur, potassium, calcium, magnesium, sodium, acidity (pH), and emissions (methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), capable of reporting outputs on a block specific or whole farm scale (Wheeler *et al*., 2006, Wheeler *et al*., 2008). In order to produce valid outputs OVERSEER requires detailed input data pertaining to the farm system's climate, physical features, and livestock policies. OVERSEER has been used to quantify nutrient losses (Monaghan *et al.*, 2008) and GHG emissions (Wheeler *et al.*, 2008) across a broad range of farm system types, and can also help identify strategies to optimise the environmental efficiency of systems (Dynes *et al.*, 2019). Furthermore, OVERSEER has been used in a regulatory capacity (Shepherd *et al.*, 2009) to develop limits and quantify the outputs of individual farm systems.

Chapter 3. Materials and Methods

3.1 Approach

This study took a mixed modeling approach utilising: EXCEL feed budgets; gross margin analysis; and the OVERSEER nutrient budget model sequentially, thus combining the methodologies used singularly in a number of previous studies (Brookes, 1993, Frengley, 1973, Shepherd, 2009, Taylor, 2018, Wheeler, 2008). The models drew upon contemporary literature (B+LNZ, 2018, Morris and Kenyon, 2014, Pettigrew *et al.*, 2017) to provide the base assumptions for the bull beef models, while the accelerated-cycle beef production models were based on experimental data obtained in a recent independent live animal trial. This experiment provided raw data on the: growth potential; feeding requirements; and carcass characteristics of dairy-origin steers when slaughtered at less than one-year of age.

Initially, Microsoft EXCEL feed budget models were developed from experimental data (for the accelerated-cycle scenarios) and contemporary literature (for the traditional 'base' beef production scenarios). Microsoft EXCEL feed budget models were prefered over FARMAX, as this approach enabled greater transparency around model assumptions and the accurate inputting of data obtained in the live animal experiment. All model parameters (with the exception of cattle enterprise policy) were identical between feed budget models enabling fair comparisons. Gross margin analysis was then conducted, providing a financial appraisal for each scenario so profitability could be compared. In addition, OVERSEER nutrient budget models were developed to quantify the environmental footprint of the respective scenarios. Finally, variation analysis simulated the impact various degrees of weaner genetic merit for growth had on the performance of the accelerated-cycle scenarios. Overall this methodology enabled comparisons on the physical, financial, and environmental performance of accelerated-cycle beef production relative to traditional bull-beef production.

3.2 Animals and management

In the live animal trial eighty Hereford x Friesian-Jersey castrated male (steer) calves born in the spring of 2017 were procured from commercial calf rearers located in the Taranaki region at approximately three-months of age at an average of 103 kg live weight (SEM 1.10). The steers were managed as a single mob for the duration of the experiment, and allocated into four (balanced for live weight at 8-months of age) groups, for slaughter at 8-, 10-, 12- and 18- (omitted from this study due to their late slaughter date) months of age (Table 5). As birth date data could not be obtained, a mean birth date of August 15th 2017 (LIC, 2016) was assumed for modeling purposes.

Table 5: Summary of the independent trials design showing group size, mean start live weight, slaughter date and mean slaughter age by treatment

	Treatment (monthly age at slaughter)		
	8	**10**	**12**
Number (*n*)	20	20	20
Start weight (kg) ± SEM	102±2.00	105±2.87	104±2.28
Slaughter date	16/05/18	17/07/18	04/09/18
Days of age at slaughter	269	332	380

The steers were grazed from November 2017 to mid-May 2018 on Massey University's Keeble Farm (B+LNZ (2018a) Class 4 land) located 7km southeast of Palmerston North (latitude 40.40°S, longitude 175.60ºE) as one group. Between December 2017 and January 2018, the diet consisted of a herb-clover mix comprising plantain (*Plantago lanceolate*), chicory (*Cichorium intybus*), white clover (*Trifolium repens*), and red clover (*Trifolium pratense*). In addition, Sharpes earlywean 16% crude protein meal (approximately 0.5 kg/day @ 12 MJME/kilogram of dry matter (kgDM), (Sharpes, 2019)) was provided over this period to compensate for the unusually dry season, and help the weaners transition onto a full forage diet. From February 2018 the steers were break fed (allocated a fresh ungrazed section of crop daily) a crop of Hunter Brassica (*Brassica campestris ssp. rapifera*) until March, at which point they were fed a final round of the herb-clover mix and transitioned to a perennial ryegrass (*Lolium*) and white clover based pasture. In mid-May the steers were transported to Massey University's Haurongo Farm located 5km south of Palmerston North (latitude 40.39°S, longitude 175.63° E) where their diet remained a perennial ryegrass and white clover-based pasture until slaughter. From 3 – 12 months of age all steers were treated with a monthly oral drench (Coopers: Alliance) to control internal parasites. In addition, monthly fecal egg counts (Levecke *et al.*, 2012) were conducted to ensure the anthelmintic was effective.

3.3 Growth and slaughter measurements

Steers were weighed unfasted fortnightly from November 24th 2017 to September 4th 2018, using electronic Gallagher™ SmartTSi scales (accuracy ±1%) (Gallagher, 2018) and Tru – Test™ MP load bars (accuracy ±1%) (Tru - Test, 2018). Prior to slaughter all steers were weighed unfasted (Table 5). Commercial slaughter occurred at Feilding Venison Packers

Limited, located 25km (approximately 0.5 hours) from the farm. Hot carcass weights were obtained at slaughter.

3.4 Feed budget model design

Simulation modeling (Crosson *et al.*, 2006) in the form of Microsoft EXCEL feed budgeting (Gray, 1987, Duranton and Matthew, 2018) was performed. Two status quo base farm systems were developed using B+LNZ (2018a) Class 4 farm survey data and modeled in EXCEL with feed budgets. The use of B+LNZ (2018a) Class 4 farm survey data in the base models enabled fair comparisons with the accelerated-cycle models (outlined below), as the physical performance data used in these models was obtained from trial work conducted on the same land class. The base systems consisted of a high performing bull-beef (256 bulls) and sheep (2284 breeding ewes) system where bulls were processed at 17–19 months of age (referred to as Bull^{18}), and a lower performing bull-beef (213 bulls) and sheep (2284 breeding ewes) system where bull slaughter occurred at 22 – 24 months of age (referred to as Bull^{24}). The physical farm features and self-replacing sheep enterprise were identical in both base models. The only differences between these models were within their respective bull enterprises. The base models (Bull^{18} and Bull^{24}) were designed to replicate commercial Class 4 (rolling to easy terrain) farming systems located in the Manawatu region, and formed the basis for comparisons with the proposed accelerated-cycle beef production enterprises. Feed budgets for Bull^{18} and Bull^{24} can be found in Appendix A.

To enable comparisons with the proposed accelerated-cycle beef enterprises, hereon referred to as New Generation Beef (NGB), the base farm model was duplicated, and the original bull-beef enterprises were substituted by an NGB production enterprise. Growth rate and live weight data obtained in the live animal experiment were used in the NGB models to estimate maintenance and growth energy requirements. Overall this process was replicated three times to develop a unique model representing the 8-, 10-, and 12-month (referred to as NGB^{8}, NGB^{10} and NGB^{12} respectively) slaughter options of the NGB production enterprise.

The sheep enterprise, overall stocking rate (11.1 – 11.4 stock units/hectare), and sheep-to-cattle (sheep:cattle) ratio (63:37 – 62:38) remained similar between models, meaning any differences in performance were attributable to differences between the beef enterprises. Stocking rate calculations were based on the assumption that a stock unit consumes 620 kgDM (6240MJME) annually, similar to Woodford and Nicol (2004) (Appendix E). Carcass weight production per hectare (ha) (carcass weight/ha) for the respective beef enterprise scenarios was calculated as the total amount of carcass weight sold during the modeled period divided by the area allocated to cattle.

3.4.1 Physical farm features and feed supply

The model farm comprised 425 ha effective (B+LNZ 2018a) and grew 7.2 t DM/ha/yr, of the total effective area 53 ha was regrassed annually (8-year pasture renewal program) (Stevens *et al.*, 2000). Monthly pasture growth rates (PGR) ranged from 10 – 36 kgDM/ha/yr, and the metabolisable energy (ME) content of feed was between 8 - 12 MJME/kgDM (Table 6).

Table 6: Monthly pasture growth rate data for Massey University's Keeble farm (Wood, 1999), monthly pasture metabolisable energy content values for Manawatu hill country (MPI, 2013) and minimum and maximum average pasture cover constraint levels

Month	**Keeble[a] PGRs** (kgDM/ha/day)	**PGRs used in model[b]** (kgDM/ha/day)	**Metabolisable energy [c]** (MJME/kgDM)	**APC constraints** (kgDM/ha ending)[d]
July	15.0	9.8	10.6	> 1200 < 3000 Opening = Closing
August	24.0	15.6	12.3	
September	33.0	21.5	10.2	
October	51.0	33.2	11.3	
November	55.0	35.8	10.7	
December	44.0	28.6	9.6	
January	32.0	20.8	9.3	
February	23.0	15	8.0	
March	26.0	16.9	8.9	
April	21.0	13.7	8.4	
May	23.0	15.0	10.8	
June	16.0	10.4	10.7	

[a] - Sourced from Wood (1999).

[b] - Keeble farm PGRs were reduced equally by a factor of 35% to give a stocking rate within 8.0 – 13.0 stock units/ha specified by B+LNZ (2018a) as representative of Manawatu Class 4 land. This approach meant that the annual growth pattern, and overall pasture production level was representative of a Class 4 farm located in the Manawatu.

[c] – Sourced from MPI (2013).

[d] – Sourced from Korte *et al.* (1982), Waghorn and Clark (2004), Brock (2006).

The pasture species consisted of a ryegrass and white clover-based sward. In addition, silage could be cut between October and December, and fed back into the system during deficit periods at cost of $400/ha (Askin and Askin, 2016), with 15% wastage (DairyNZ, 2016) and a lower (compared to fresh pasture) ME content (Appendix A, McGrath *et al.*, 1998). Excessive APC's are associated with reduced pasture quality, while insufficient APC's can impair net pasture production (Korte *et al.*, 1982, Waghorn and Clark, 2004, Brock, 2006). Therefore, in all models APC constraints were established, whereby APC had to remain between 1200 – 3000 kgDM/ha throughout the year (Table 6). Finally, all models were calibrated to a status quo condition, meaning that starting APC was equal to ending APC to show that the system was sustainable for the provision of pasture. These key physical assumptions remained identical across all models and meant that any differences in output values were not confounded by physical farm features.

3.4.2 Animal components

The animal components of the model were complex, and combined data from the experiment with data from existing literature. Animal energy requirements were calculated on a daily basis, and considered body maintenance, live weight gain, pregnancy, and lactation energy costs (reproductive energy costs were only relevant to breeding sheep) (Appendix A, Rattray *et al.*, 2007). In the feed budget, stock numbers (Appendix B, Appendix D) were reported as a monthly average, to enable the simulation of stock being bought or sold during the monthly time step. For clarity the animal components of the sheep enterprise, bull enterprises, and NGB steer enterprises will be explained in succession.

Sheep enterprise

The self-replacing sheep enterprise comprised Romney breeding ewes based on B+LNZ (2018a) Manawatu Class 4 farm data. The models used a mature ewe replacement rate of 23% and drew upon the literature for breed and age class specific values such as lambing rate and date (Kenyon *et al.*, 2004). These data were combined to form a representation of a 'typical' sheep enterprise (Table 7, Appendix B). The sales policy was to sell all 'surplus' (not required as replacements) lambs (2094 head) finished direct for slaughter into the autumn market at 41.6 kg live weight (18.7 kg carcass weight) (B+LNZ, 2018). Lamb sales were staggered between March 15th (50%) and April 15th (50%) to account for the normal distribution of lamb live weights exhibited on commercial farms. Sheep energy calculations were based on (Rattray *et al.*, 2007, Cranston *et al.*, 2017), see Appendix A.

Table 7: Physical performance features of the modelled breeding sheep enterprise (Kenyon *et al.*, 2004, B+LNZ 2018a)

Age class	Lambing rate	Mean mating date	Mean lambing date
Mixed age ewes	131%	April 9th	Sept 3rd
Two tooth ewes	131%	April 9th	Sept 3rd
Hogget ewes	60%	May 11th	Oct 5th

Bull-beef enterprise

The bull-beef enterprises were designed to reflect a ‘typical’ high and lower performing bull-beef enterprise operating on Class 4 land in the Manawatu and were based on the literature (Morris and Kenyon, 2014, Pettigrew *et al.*, 2017). HF bull calves were purchased at 100 kg live weight on November 23rd each year (Morris and Kenyon, 2014) and grown out to 576.6 kg live weight (305.6 kg carcass weight) (B+LNZ, 2018) with a 53% dressing out rate (Pfuhl *et al.*, 2007, Clarke *et al.*, 2009). In the high performing enterprise, the bulls ADG was 1.14 kg/day, and sales were staggered through summer occurring in December (33.3%), January (33.3%), and February (33.3%). In the lower performing enterprise, the bulls ADG was 0.84 kg/day, and slaughter occurred prior to the second winter in May (33.3%), June (33.3%), and July (33.3%). It was assumed both bull enterprises had death rates of 3.00% (B+LNZ 2018a). Energy calculations (Rattray *et al.*, 2007) and monthly bull growth rates are appended (Appendix A, Appendix C).

New Generation Beef steer enterprise

The NGB steer enterprise models (NGB^{8}, NGB^{10} and NGB^{12}) were based on the experimental data. Each model utilised growth data to accurately reflect steer growth profiles for each slaughter option (Appendix C). Statistical analysis found no difference in ADGs between cattle that were in the slaughter treatment, compared with cattle in the treatments that remained on farm, meaning this approach was statistically valid. In each model, steers were bought onto the farm on November 23rd (weighing 100 kg) (Morris and Kenyon, 2014), and slaughtered on either May 15th, July 17th or September 4th.The cattle death rate across all NGB models was assumed to be 3.00% (B+LNZ 2018a, Appendix B). Daily energy calculations (Rattray *et al.*, 2007) and monthly steer growth rates are appended (Appendix A, Appendix C).

3.5 Financial analysis

Gross margin ($/ha) analysis was used to compare the financial performance of the respective scenario models. Costs, returns, and gross margins (GMs) were estimated on both an enterprise specific, and whole farm (WFGM) basis. B+LNZ (2018a) Manawatu Class 4 farm survey cost per stock unit (S.U.) data for the 2018-19 period was used to estimate farm working expenses for each scenario (Appendix F). The cost per S.U. was multiplied by the total number of S.U.s, then allocated to the respective enterprises according to the sheep:cattle ratio (with the exception of enterprise specific costs such as shearing) (Appendix F). In the WFGM, regrassing and silage making costs were based on the literature (Lee, 2014, Askin and Askin, 2016).

A three-year average of the monthly bull and steer schedule prices (292 – 320 kg) were calculated (Figure 6, AgBrief, 2016-18), thus reflecting recent market conditions. The former was used in conjunction with B+LNZ (2018) average carcass weight data to determine revenues in the bull scenarios, and the later in conjunction with experimental carcass weight data for the steer scenarios. Differences in objective meat quality between cattle processed at 8-12 months of age are unlikely to effect meat value (Pike *et al.*, 2019), therefore there is potential for cattle within this age range to be classed and processed under a single new classification category. However, because the market value of carcasses produced in NGB systems is not known, in the financial analysis they were valued through the existing ‘prime’ classification. This representing the ‘worst case’ scenario where cattle processed at 8-12 months are not recognized in a unique classification category, and the meat attains no price premium for its tenderness and high eating quality (Pike *et al.*, 2019).

Readers should note schedule prices vary throughout the year (Figure 6), so the findings of this study are sensitive to sales timing. Furthermore, farmgate beef prices are influenced by processing costs and saleable meat yield, neither of which have yet been quantified for the proposed system. As such, if sold through the ‘prime’ schedule the price/kg of carcass weight attained for cattle processed at 8 - 12 months of age would likely differ from those attained from cattle slaughtered at traditional ages. It is outside the scope of this dissertation to quantify these differences.

A three-year average of Feilding weaner fair prices in November were used to determine the purchase cost of 100 kg HF bulls and dairy-origin steers respectively (Table 8, AgriHQ, 2016-18). Stock valuations (IRD, 2018) were used to calculate the change in inventory levels, and the opportunity cost of capital (discount rate) was 6.0% (New Zealand Treasury, 2018). For stock that were on the farm for less than one-year, their purchase cost was divided by 12 and multiplied by the number of months they were on farm, to accurately reflect their opportunity cost within the one-year timestep. All financial outputs are given in New Zealand dollars, and GMs are expressed in terms of net and $/ha.

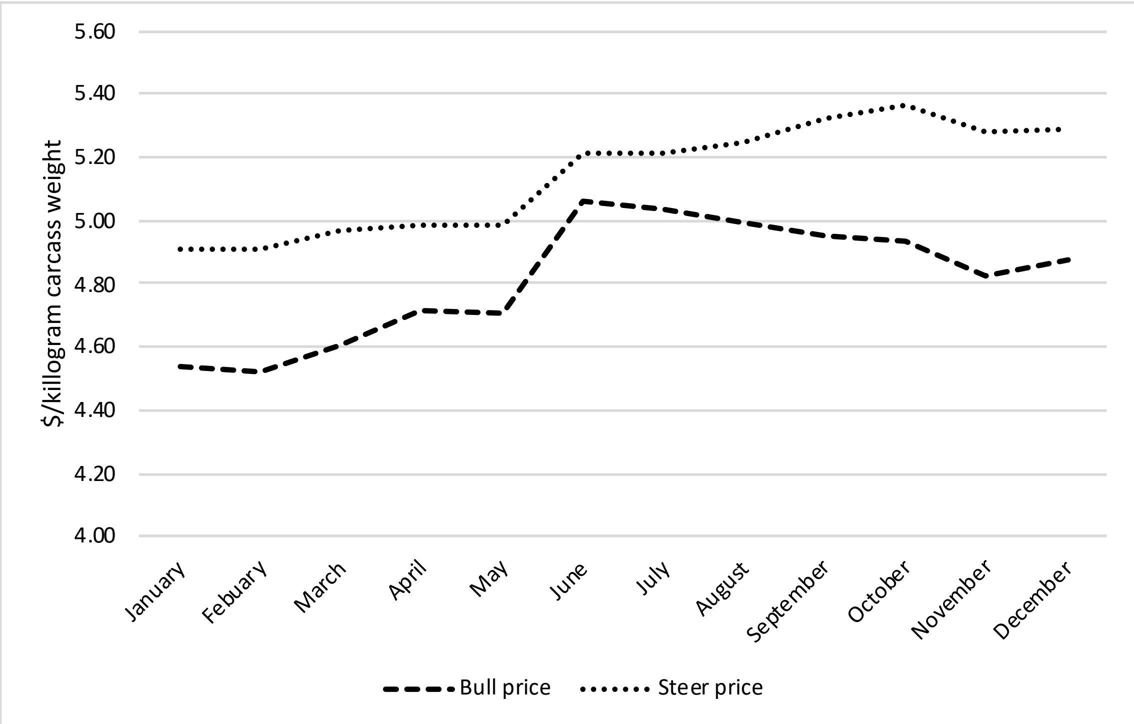

Figure 6: Average bull and steer (292 – 320 kg) monthly schedule prices ($/kg carcass) between 2016 and 2018 (AgBrief, 2016-18).

Table 8: Feilding Weaner Fair average 100 kg live weight calf prices between 2016 – 2018

Sex class	2018	2017	2016	Average
Bull	$ 457.00	$ 510.00	$ 449.00	$ 472.00
Steer	$ 489.00	$ 532.00		$ 510.50

Sourced from AgriHQ (2016-18).

3.6 Overseer analysis

OVERSEER (version 6.3.1) analysis was conducted on all scenario models, to quantify the effect different beef enterprises had on nutrient losses and GHG emissions, and thus provide a picture of overall environmental efficiency. The model farm's climate and soil properties are detailed in Appendix G and remained identical in all nutrient budgets. Manawatu silt loam (Waim_45a.1) (Waimakariri family) was chosen as the soil type for the model. Manawatu silt loam is a recent, well-drained soil that is present on Keeble farm where the PGR data for the model was sourced (Table 6, Centre for Precision Agriculture, 2019). Furthermore, this soil is commonly found in the Horizons (Manawatu) region (Landcare Research, 2019), therefore results from the current study will have relevance to farms in the region.

Farm area, supplement harvest (and use), and stock performance levels were all drawn from the respective feed budgets (Appendix A). Stock numbers were initially drawn from the feed budgets, and then proportionately adjusted (Appendix D) to achieve a similar (±1 kgDM/ha/yr) total pasture yield estimate, thus enabling fair comparisons between scenarios. Maintenance fertiliser and lime were applied in accordance with industry best practice (Table 10) to maintain soil test and pH levels (Table 9), so all nutrient budgets were status quo. In addition, urea was applied at 22 kg/ha (10 units of N/ha) in August, reflecting typical sheep and beef farming practice based on survey data (MPI, 2012).

Table 9: Soil test values (units)[a] and anion storage capacity % (ASC) for Manawatu silt loam

Olsen P	QT K	QT Ca	QT Mg	QT Na	Organic S	ASC[b]
16	7	7	21	8	7	19%

[a] - The soil test values are defaults derived from the OVERSEER library, (means of aggregated farm data, derived from comparative farms).

[b] - Anion storage capacity (measure of soil's ability to retain anions, for example phosphate and sulphate).

Table 10: Nutrients and lime (kg/ha/year) applied via fertiliser to maintain soil test and pH levels (by scenario)

Model	N	P	K	S	Ca	Mg	Na	Lime
NGB[8]	10[a]	14[b]	0	18[b]	46[bc]	0	0	40
NGB[10]	10[a]	13[b]	0	15[b]	42[bc]	0	0	40
NGB[12]	10[a]	14[b]	0	18[b]	50[bc]	0	0	50
Bull[18]	10[a]	15[b]	0	19[b]	48[bc]	0	0	40
Bull[24]	10[a]	15[b]	0	19[b]	48[bc]	0	0	40

[a] – Nitrogen provided from urea fertiliser applied in August.

[b] – Phosphorus, sulphur and some calcium from superphosphate fertiliser (November).

[c] – Balance of calcium provided from lime application in November.

3.7 Variation analysis

Variation in the genotype of dairy-origin calves (Clark *et al.*, 2007, Bown *et al.*, 2016) represents a source of uncertainty for NGB production, as it may affect efficiency and profitability. Research has shown that steers with Jersey genetics grow 4% (Cole, 1975), 5% (Coleman *et al.*, 2016), 7% (Barton *et al.*, 1994) or 9% (Cundiff *et al.*, 1993) slower than their contemporaries without Jersey genetics (Table 2). Therefore, of particular interest is the impact genotype has on physical, financial, and environmental performance for the proposed enterprise. To quantify this, ADG was used as a proxy for genotype. ADG is influenced by nutritional, environmental, and genetic factors. Therefore, in the variation analysis scenarios, it was presumed that the increases/decreases in ADG were solely attributable to genetics.

It was assumed the calves used in the experiment (Table 5) represent 'average' genetic value for growth. Additional simulation models were developed to quantify the impact a 10% increase or decrease in ADG (compared to the experimental data), had on the performance of NGB production with slaughter occurring at 8-, 10- and 12-months of age. The +10% scenarios are hereon referred to as NGB^{8+}, NGB^{10+} and NGB^{12+}, and the -10% scenarios are referred to as NGB^{8-}, NGB^{10-} and NGB^{12-}. The physical, financial, and environmental performance attributes of the high and low genetic merit for growth scenarios were then quantified, using the same methodology as with the base scenarios.

Chapter 4. Results and Discussion

This section presents results from the live animal experiment and modeling exercise, with model outputs being separated into physical, financial, and environmental attributes. The impact of cattle genotype (proxied with ADG) on the performance of NGB production is quantified with additional analysis. Finally, findings are discussed and compared to the literature, and the implications for New Zealand's cattle industry are outlined.

4.1 Growth and carcass characteristics of steers grown in the NGB system

As expected, given the experimental design, and the fact that all steers were managed together, there was no difference (P>0.05) in start live weight between treatments. Similarly, no differences in ADG between treatments for the duration of the experiment (Table 11, P>0.05) or within growth periods (Table 12, P>0.05) were observed. At slaughter the 8-month steers were lighter than the 10-month steers (P<0.001), which were lighter than the 12-month steers (Table 11, P<0.001). Days to slaughter differed between treatments as per the experimental design (P>0.05). In regard to carcass attributes, carcass weights got heavier, as slaughter age got older (Table 11, P<0.001). No differences in DO% between the 8- and 10-month treatments were observed (P>0.05), however the DO% of the 12-month treatment was higher (Table 11, P<0.001).

Table 11: Mean (±SEM) physical performance of steers in 2017/18 trial slaughtered at 8-,10- and 12-months.

	Treatment group		
	8	10	12
Start weight (kg)	102±2.00	105±2.87	104±2.28
ADG (kg/day)*	0.88±0.02	0.86±0.01	0.87±0.01
Slaughter weight (kg)	252±5.59^{a}	303±3.95^{b}	348±4.93^{c}
Days to slaughter	169±1.20^{a}	232±1.09^{b}	280±1.20^{c}
Hot carcass weight (kg)	119±2.76^{a}	146±2.91^{b}	174±2.45^{c}
Dressing out %	47.2%±0.3^{a}	47.4%±0.3^{a}	50.0%±0.3^{b}

^{abc} - Differing superscripts within a row indicate significant differences between treatments (P<0.05).

* – Average daily gain from start of study to slaughter.

Table 12: Average daily growth rate (±SEM) between slaughter treatments by growth period

	Treatment group		
	8	**10**	**12**
Growth period	*n*=20	*n*=20	*n*=20
Start - 8 months	0.88±0.02	0.88±0.02	0.89±0.02
8 - 10 months		0.80±0.03	0.75±0.03
10 - 12 month			1.08±0.02

No significant differences within rows (P>0.05).

Hereford x Friesian-Jersey steers haven't been studied when slaughtered at 8 – 12 months of age before in New Zealand, however, studies have been conducted on dairy-cross-beef cattle when farmed in traditional systems and slaughtered at 18 – 24 months of age (Barton *et al.*, 1994, Coleman *et al.*, 2016). Compared to traditional systems (Table 3, Table 4), slaughtering at 8 - 12 months of age results in lighter carcasses as expected, a 0 - 5% lower DO% associated with the cattle being further from their mature age, and no difference in ADG. In addition, the ADGs, carcass weights and DO% recorded in the current study (Table 11) were comparable to the international literature pertaining to pasture-based yearling beef systems (see review of Domaradzki *et al.* 2017).

Compared to intensive yearling production systems utilising a predominantly milk-based diet or concentrate feeds, the steers in the current study achieved lower ADGs, a lower DO%, and lighter carcass weights when slaughtered at the same ages (Table 4, AHDB, 2011, Florek, 2013). The relative intensities of the production systems, and breed effects likely confounded results. Overall, findings from the current study indicate that ADGs in excess of 0.8 kg/day are possible with dairy-origin steers slaughtered at less than one-year of age, while the carcass traits were comparable to pasture-based international yearling production systems.

4.2 Physical performance of modeled farm system scenarios

Table 13 presents the physical assumptions, drawing upon data from the live animal experiment (Table 11) and outputs for each cattle enterprise scenario model. Cattle slaughter weights and days on farm differed between scenarios (Table 13), reflecting the different slaughter ages and growth rates between models. The amount of silage harvested varied (Table 13) because of unique feed supply and demand patterns in each of the different scenarios (Figure 7, Figure 8). The ADGs for the NGB scenarios were synonymous with experimental data (Table 11), while $Bull^{18}$ and $Bull^{24}$ ADGs were similar to the literature relating to high (Morris and Kenyon, 2014) and low (Muir *et al.*, 2001) performing bull systems. The number of cattle purchased differed between scenarios (Table 13), reflecting the greater lifetime feed demand associated with slaughtering cattle at older ages. Cattle death rate was the same in all scenarios, with cattle sales to the meat processor being 97% of purchases (B+LNZ, 2018a).

Table 13: Key assumptions and outputs for simulated farm system physical performance parameters (by scenario)

	Model scenario:				
	NGB^{8}	NGB^{10}	NGB^{12}	Bull^{18}	Bull^{24}
Inputs					
Total farm area (ha)[a]	425	425	425	425	425
Silage area (ha)	16	4	60	0	0
Cattle start weight (kg)[b]	100	100	100	100	100
Cattle end weight (kg)	252	303	348	577	577
Days on farm	173	236	285	418	569
ADG (kg/day)	0.88	0.86	0.87	1.14	0.84
Cattle purchased (head)	742	572	441	256	213
Cattle sold (head)	719	555	428	248	206
Outputs					
Stocking rate (S.U/ha)[c]	11.3	11.4	11.1	11.3	11.3
Sheep-to-cattle ratio	63:37	62:38	64:36	63:37	63:37
Area allocated to cattle (ha)	159	160	154	158	159
Total cattle stock units	1804	1824	1705	1787	1805
Cattle feed demand tDM/yr	1118	1131	1057	1108	1119
Live weight/ha at slaughter (kg)[d]	1139	1048	969	1166	1091
Carcass production/ha (kg)[e]	537	503	484	479	395
Feed conversion efficiency[f]	7.7%	7.1%	7.0%	6.8%	5.6%
Carcass weight/ha/tDM eaten (kg)	75	70	67	67	55

[a] - Sourced from B+LNZ (2018a).

[b] – Sourced from Morris and Kenyon (2014).

[c] – Stocking rate caclulations can be found in Appendix E.

[d] – Total cattle live weight per/ha (inclusive of start live weight).

[e] – Total cattle carcass weight/ha (inclusive of start carcass weight) for animals slaughter within the 12-month modeled period.

[f] – Total carcass weight sold/total feed eaten.

The stocking rate (±0.3 S.U/ha) and sheep:cattle ratio (±2%) varied between scenarios (Table 13), because of feed supply and demand relationships, and differences in total cattle feed demand, respectively. Implementing a suitable sheep:cattle ratio and stocking rate helps match feed supply with demand (Gray *et al.*, 2008), and enhances the farm system's ability to cope with various sources of risk including financial, climatic, and regulatory (Shadbolt and Martin, 2005). The sheep:cattle ratio of the NGB scenarios remained within ±1% of the average described in the B+LNZ (2018a) farm survey data, whilst the stocking rates were within the reported range for Class 4 farms in the Manawatu. The area allocated to cattle (calculated from the percentage of total feed consumed by cattle) and total cattle S.U.'s varied (±6.5%) between the scenarios, this was attributable to small differences in total cattle feed demand. Live weight per/ha (at slaughter) was the greatest in Bull^{18} closely followed by NGB^{8}, with Bull^{24}, NGB^{10} and NGB^{12} all producing progressively less live weight per/ha (Table 13).

Both carcass weight/ha and FCE increased as slaughter age decreased, in favor of the NGB enterprises (Table 13), reflecting the greater growth efficiency associated with younger cattle (Aguilar *et al*., 1983). The NGB scenarios generated 5 – 58 kg more carcass weight/ha, and achieved a 0.2 – 0.9% higher FCE ratio compared to the Bull^{18} scenario (depending on slaughter age) and yielded 89 – 142 kg more carcass weight/ha and had a 1.4 – 2.1% higher FCE ratio compared to the Bull^{24} scenario (Table 13). This was due to cattle being lighter, and on farm for less time in the NGB scenarios, meaning their daily and lifetime maintenance feeding requirements were lower (Koch *et al.*, 1963, Rattray *et al.*, 2007). Maintenance feed has no financial value as it doesn't contribute to carcass weight production (Koch *et al.*, 1963), and therefore represents a loss of efficiency in livestock production systems.

Research suggests bull-beef finishing systems can produce 275 – 483 kg carcass weight/ha (38 – 50 kg carcass weight/tDM eaten) (Ogle and Tither, 2000). Cosgrove *et al.* (2003) showed Friesian bulls can generate up to 1000 kg carcass weight/ha (77kg carcass weight/tDM eaten), while McRae, (2003) suggests 500 – 600 kg carcass weight/ha (46 kg carcass weight/tDM eaten) is representative of 'average' performance. In the model, NGB^{8} generated 537 kg carcass weight/ha (75kg carcass weight/tDM eaten), NGB^{10} generated 503 kg carcass weight/ha (70 kg carcass weight/tDM eaten), and NGB^{12} generated 484 kg carcass weight/ha (67 kg carcass weight/tDM eaten). Annual pasture yield is a key determinant of carcass weight/ha, as it affects the number of animals that can be grown and achievable ADGs. To enable comparisons between studies, carcass weight/ha/tDM eaten can be examined. On this basis, Bull^{18} and Bull^{24} performed above the 'average' defined in the literature, while the NGB scenarios showed strong performance, with NGB^{8} being at the high performing level (Table 13).

During review it was noticed that cattle maintenance energy requirements were overestimated in the NGB scenarios (section 1.2). As such the model's outputs for cattle purchased, cattle sold, and stocking rate are underestimated in these scenarios. Therefore, in reality it may be possible to grow more cattle in the NGB scenarios than indicated in Table 13, and thus achieve a higher stocking rate. This also raises questions around the accuracy of per/ha carcass weight production and feed conversion efficiency in the NGB scenarios. Further research is needed to improve the accuracy of the aforementioned outputs in the NGB scenarios.

4.2.1 Feed supply and demand relationships

Figure 7 depicts the per ha feed demand profile of each scenario from the modeling exercise, while Figure 8 shows the unique monthly (end of period) APC patterns which are a function of whole farm feed demand, PGRs and supplement use. NGB^{8} had a distinctive peak in feed demand during February, attributable to the high numbers of cattle in this scenario, combined with moderate ADGs (Figure 7, Table 13, Appendix C). The absence of cattle during winter (May 15th - November 23rd) in NGB^{8} meant that by early spring, APC levels were high. Therefore, to remain under the 3000 kgDM/ha APC constraint (Figure 8), 16 ha of silage was harvested in December. This silage was fed back into the system in February (33.3%), March (33.3%) and April (33.3%) when feed demand levels exceeded supply (Appendix A, Figure 8). NGB^{10} also had a peak in per ha feed demand during February (Figure 7), however it was lower than the peak in NGB^{8}, as less cattle were on farm (Table 13). In NBG^{10}, cattle were absent from the farm from July 17th – November 23rd, which coincided with low PGRs in late winter (Table 6). Therefore, remaining under the maximum APC constraint was less of a challenge in NGB^{10} (Figure 8). As a result, only 4 ha of silage was harvested (Table 13) and fed back into the system in February and July (equally), to remain above the 1200 kgDM/ha APC constraint in July (Figure 8).

Compared to NGB^{8} and NGB^{10}, NGB^{12} had a relatively steady per ha feed demand profile due to lower cattle numbers on-farm in this scenario (Figure 7, Table 13). As a result, the annual APC pattern for NGB^{12} was comparatively less variable, and had a similar profile to Bull^{24} (Figure 8). Maintaining APC levels within the upper constraint was not an issue in NGB^{12}, however meeting the minimum APC constraint in winter was a challenge (Figure 8). Slaughtering at 12-months of age, meant feeding steers throughout the winter feed deficit

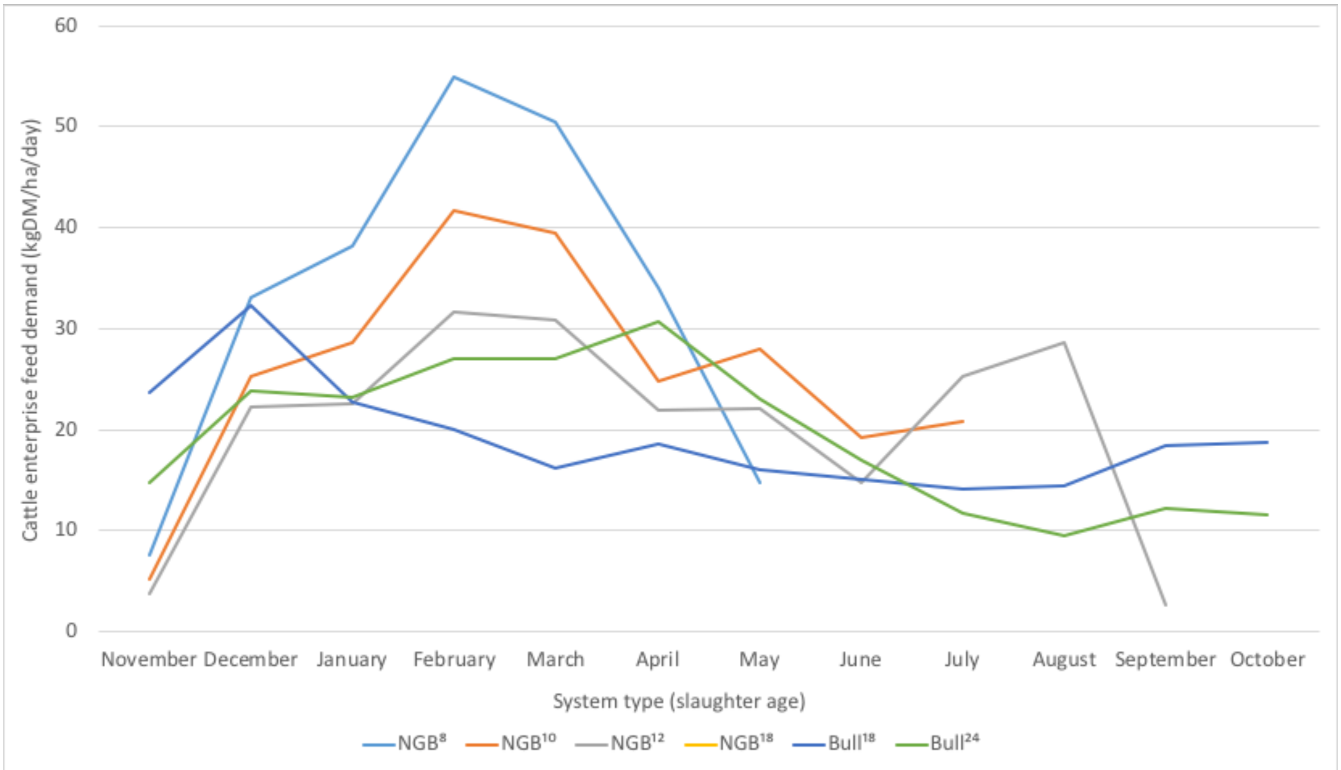

Figure 7: Annual feed demand pattern (per hectare) of each simulated cattle enterprise

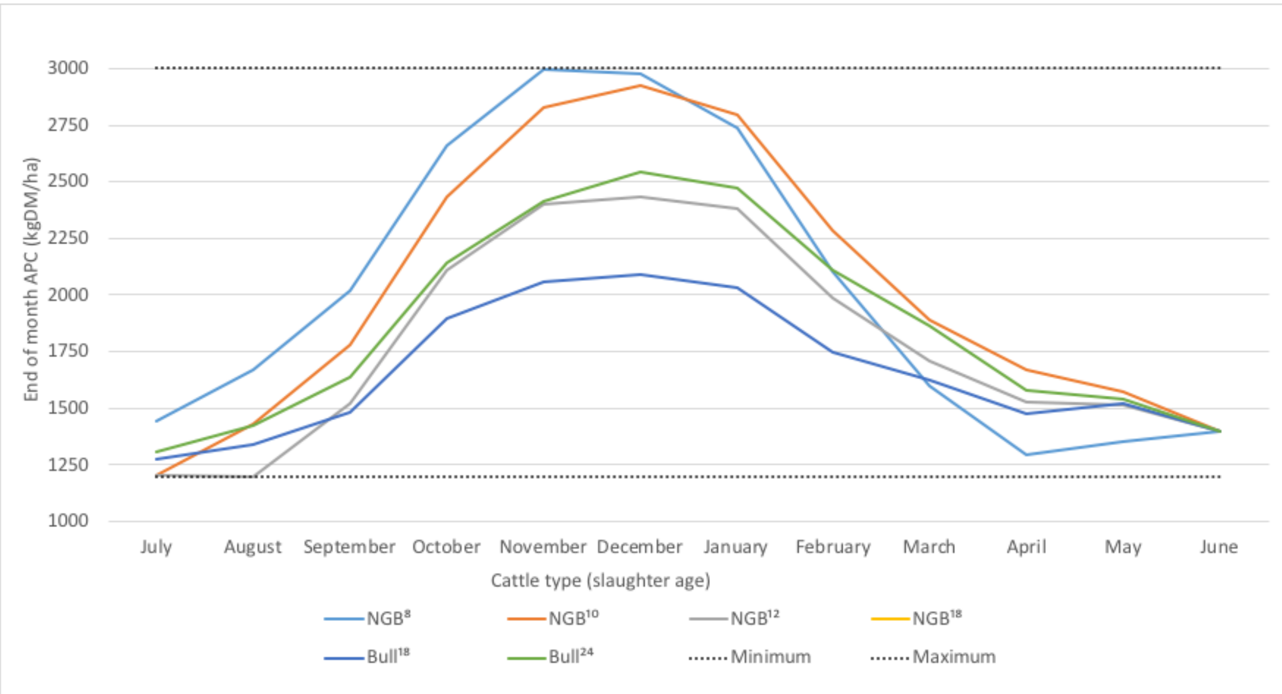

Figure 8: Farm system monthly average pasture cover (kgDM/ha) levels for each scenario model and minimum/maximum constraints.

period, which was difficult and necessitated the harvest of 60 ha of silage between October and December (Table 13, Figure 8). This silage was fed out in July (32%) and August (62%) respectively, to maintain APC levels above the minimum constraint (Figure 8).

The per ha feed demand profile of $Bull^{18}$ peaked in December (Figure 7). This was driven by rising 1-year old bulls growing rapidly at this time (Appendix C), and new weaners being bought into the system in late November (Table 13, Appendix A). For the remainder of the year feed demand was steady, and APC levels remained within the constraints without the provision of silage (Figure 8, Table 13). The feed demand profile of $Bull^{24}$ was smoothest, with a small peak in April prior to the sale of finished bulls (Figure 7). Feed supply and demand were well matched in this scenario as cattle feed demand was consistent throughout the year, and APC levels remained within constraint levels (Figure 8) without the provision of silage (Table 13).

The match between feed supply and demand is a critical determinant of efficiency in pasture-based agricultural production systems. PGRs vary across New Zealand (White and Hodgson, 1999), so each region has unique strengths and weaknesses for production. The proposed NGB enterprise has a unique feed demand profile, in that cattle may be absent from the farm system for up to four months of the year (Figure 7), taking pressure off feed supply during the critical winter and pre-lambing periods (Figure 8). This has implications for winter feed availability, pasture quality, complementarity with other livestock enterprises, and ultimately ease of management and resource utilisation.

The feed demand profiles of $Bull^{18}$ and $Bull^{24}$ were consistent with the literature. ADGs (Appendix C) peaked between spring and summer, before decreasing in late autumn as feed became scarce going into winter (Doyle *et al.*, 1989, Muir *et al.*, 2001, Purchas *et al.*, 2002). New Zealand literature on NGB production is scarce. In terms of feed demand profile, the closest match to NGB might be a trade lamb enterprise where store lambs are purchased in spring or early summer and grown for slaughter in autumn and winter. Many farmers operating such enterprises utilise high ME crops such as forage brassicas (Judson *et al.*, 2013), or herbs or legumes (Golding *et al.*, 2011) as these feeds have been shown to increase animal performance (Rattray *et al.*, 2007). There is potential to use forage crops in a similar way for NGB production, enabling higher stocking rates, greater levels of animal performance, or a reduced silage feed requirement, all of which could enhance profitability. However, on farms already conducting intensive lamb finishing, using crops for NGB production may result in direct competition between these two enterprises and therefore may not be feasible.

Achieving high ADGs (0.8 – 1.0 kg/day) during summer, in 100 kg weaners sourced in spring is challenging (Morris and Kenyon, 2014), as low moisture levels and high proportions of dead matter in the sward (White and Hodgson, 1999) combine to limit pasture availability and ME content. As a result, weaner growth is generally restricted to 0.6 – 0.7 kg/day during this time (Morris and Kenyon, 2014). This challenge was reflected in the models, with per ha feed demand increasing rapidly over this period (Figure 7) resulting in sharp reductions in APC levels (Figure 8). Altering the timing of stock sales (Morris and Kenyon, 2014) and adjusting ADGs (Cassells and Matthews, 1988) to better match pasture supply are mitigation strategies that may be practical in some circumstances. Sourcing autumn born dairy-origin calves is an alternative for this difficult period, however the potential to use autumn born cattle in an NGB system has not yet been investigated as winter feeding may then be an issue.

Maintaining suitable APC levels was also a challenge under NGB production. To overcome this, silage was harvested in spring, and fed back into the system during feed deficit periods. Although effective, this option was costly (Table 16), and relied on land being harvestable which may not always be the case. Managing APC levels with trade stock or forage crops are likely more efficient and profitable options. Future research with a whole farm system's approach looking at these strategies would be beneficial.

During review concerns were raised that the maximum APC constraint level of 3000 kgDM/ha used in this study was unrealistically high for class 4 land (B+LNZ classification). The implication of this was that it enabled modeled APC levels to become excessive in the feed budget models, particularly during late spring/early summer when PGR's peak. In reality, farming with an APC near 3000 kgDM/ha would result in pasture senescence and deterioration of feed quality (White and Hodgson, 1999), overall adversely affecting productivity. These effects are not captured in the feed budget models, as there is no interaction between APC and pasture quality. Without a full re-work of the models (which wasn't possible) it is difficult to estimate the direction of bias this choice of APC constraint created. However, it is likely to have implications for stocking rate and supplementary feeding requirements, which would have flow on affects to financial and environmental performance.

4.3 Financial performance of modeled farm system scenarios

Table 15 outlines the purchase cost/head, beef price/kg carcass weight at sale and price/head attained at slaughter for each scenario. Assumptions for the financial analysis can be found in Appendix F. All NGB scenarios generated more income than the bull scenarios, and NGB^{8} generated the most income overall (Table 14). This was driven by the higher number of cattle being sold in the NGB scenarios compared to the bull scenarios. Despite the limited throughput of cattle in the two bull scenarios, slaughtering at 18- or 24-months resulted in heavier carcass weights, and the combined impact meant revenues from Bull^{18} and Bull^{24} were 14 – 27% lower compared to NGB production (Table 14). Total expenses varied greatly (Table 14), with the major differences being in livestock purchases, and to a lesser extent variable interest on capital livestock purchases. Weaner purchase costs decreased as slaughter age increased and were 48 – 74% higher under NGB production compared to bull-beef production, as fewer cattle were purchased in the bull scenarios. This relationship was confounded by 100 kg weaner bulls being cheaper to procure compared to their steer counterparts (Table 15). All working expenses remained similar between scenarios, as they were calculated from total S.U.'s and the sheep:cattle ratio (Table 13).

Overall, NGB^{8} and NGB^{10} both generated negative GMs, while NGB^{12} was profitable, as weaner costs were \$355 - \$910/ha lower compared to NGB^{8} and NGB^{10}, respectively. (Table 14). In addition, seasonal beef price effects favoured NGB^{12}, with the beef price being \$0.22 – \$0.33/kg carcass weight higher than in the other NGB scenarios (Figure 6, Table 15). However, Bull^{18} produced the largest overall GM followed by Bull^{24} (Table 14). The bull-beef scenarios had lower relative weaner purchase costs compared to the NGB scenarios, as they grew straight dairy bred weaners, whereas the NGB scenarios grew more expensive dairy x beef breed weaners (Table 15). Therefore, even though the bull-beef scenarios generated less revenue than the NGB scenarios, their profitability was still superior to that of NGB production.

Irish modelling studies have shown it is possible to generate a GM of \$1,051/ha from a suckler beef system (Taylor *et al.*, 2018) or \$1,341/ha in an intensive mixed suckler beef and heifer/steer finishing system (Crosson *et al.*, 2006). These systems are not common in New Zealand, as overseas systems are heavily reliant on concentrate feeds, and subsequently exposed to risk around fluctuations in the cost of concentrate feeds (Murphy *et al.*, 2017a). Previously Ogle and Tither (2000) estimated a traditional New Zealand bull-beef enterprise would generate a GM of \$263/ha, while intensive enterprises supporting more cattle were capable of \$514/ha. The current study concurs, with Bull^{18} and Bull^{24} generating similar GMs to the aforementioned, and more recent (Dynes *et al.*, 2019) works. Under the current pricing structure NGB^{8} and NGB^{10} are unprofitable, while NGB^{12} is comparable with the Ogle and Tither (2000) low performing bull system. Sales timing had a significant effect on the

Table 14: Cattle enterprise revenues, expenses and gross margins per hectare (all values in $)

	Model scenario:				
	NGB[8]	NGB[10]	NGB[12]	Bull[18]	Bull[24]
Income					
Total Income	2679	2624	2577	2225	1951
Expenses					
Weaner purchases[b]	2376	1821	1466	763	629
Wages[c]	97	98	95	97	97
Animal Health[c]	55	56	54	55	56
Weed & Pest Control[c]	28	28	28	28	28
Shearing Expenses[c]	0	0	0	0	0
Fertiliser[c]	154	155	151	154	154
Lime[c]	11	11	11	11	11
Seeds[c]	8	8	8	8	8
Vehicle Expenses[c]	37	37	36	37	37
Fuel[c]	23	23	22	23	23
Electricity[c]	9	9	9	9	9
Feed & Grazing[c]	39	39	38	38	39
Irrigation Charges[c]	0	0	0	0	0
Cultivation & Sowing[c]	15	15	15	15	15
Cash Crop Expenses[c]	0	0	0	0	0
Repairs & Maintenance[c]	119	120	117	119	119
Cartage[c]	17	17	16	16	17
Administration Expenses[c]	28	28	28	28	28
Interest on capital stock value[d]	83	264	213	118	106
Total Expenses	3100	2728	2306	1519	1376
Net Gross Margin	-421	-104	271	706	575
Total Gross Margin	-67069	-16675	41713	111745	91585

[a] – Sourced from AgBrief (2016-18).

[b] – Sourced from AgriHQ (2016-18).

[c] – Working expenses sourced from B+LNZ (2018a).

[d] – Sourced from IRD (2018).

Table 15: Weaner purchase costs, beef price per kilogram of carcass weight and cattle sale prices attained at slaughter by model scenario (all values in $)

	Model scenario:				
	NGB⁸	**NGB¹⁰**	**NGB¹²**	**Bull¹⁸**	**Bull²⁴**
Weaner purchase cost ($/head)[a]	511	511	511	472	472
Beef price received at slaughter ($/kg)[b]	4.99	5.21	5.32	4.65	4.93
Finished bull/steer sale price ($/head)[c]	593	759	926	1420	1508

[a] – Average of three-years AgriHQ (2016-18) data.

[b] – Sourced AgBrief, (2016-18) three-year average of month schedule prices.

[c] – Beef price multiplied by carcass weight.

profitability of NGB, with returns being maximized in late winter when the 'prime' beef schedule price peaks (Figure 6). Slaughtering at 13 – 15 months of age under NGB production in seasons when feed is abundant, may enable greater profitability, as a function of high beef schedule prices combining with increased carcass weights.

When interpreting Table 14, readers should consider that neither a market nor value per kilogram of carcass weight have yet been determined for meat derived from NGB production systems. The 'prime' beef schedule used in this analysis represents the worst-case scenario, whereby NGB meat is not currently distinguished from the beef produced in traditional heifer and steer finishing systems. Research indicates the meat produced in NGB systems is of high quality (Pike *et al.*, 2019), and therefore may have the potential to attract a price premium. If a price premium was attained, this could greatly improve the financial competitiveness of NGB production relative to existing cattle production systems.

4.3.1 Whole farm gross margins (WFGM)

Table 16 presents WFGMs and provides a breakdown of enterprise specific GMs, along with whole farm expenses such as regrassing and silage making. The differences in sheep enterprise GMs resulted because working expenses were allocated from total S.U.s and the sheep:cattle ratio (Table 13), which varied by ±2% between scenarios. However, these differences were small, and had little bearing on WFGMs (Table 16). Cattle enterprise GMs are the same as the net values reported in Table 14. The area regrassed annually was the same across all scenarios, as such there was no variation in the cost of regrassing (Table 16). Silage making was a large expense in NGB^{12} and to a lesser extent NGB^{8}, and reduced the WFGM of these scenarios (Table 16). Overall, $Bull^{18}$ followed by $Bull^{24}$ generated the greatest WFGM (Table 16) and therefore were the most profitable scenarios. Under the current pricing structure, all NGB scenarios generated positive WFGMs, however in the cases of NGB^{8} and NGB^{10} this was due to the contributions of the sheep enterprise GM, while NGB^{12} was profitable in its own right (Table 16).

Table 16: Whole farm gross margin (by scenario) showing the contribution of each livestock enterprise along with whole farm expenses (all results in $)

	Model scenario:				
	NGB^{8}	**NGB^{10}**	**NGB^{12}**	**Bull^{18}**	**Bull^{24}**
Sheep enterprise GM	129138	129008	129796	129248	129132
Cattle enterprise GM	-67069	-16675	41713	111745	91585
Regrassing cost[a]	-39844	-39844	-39844	-39844	-39844
Silage making cost[b]	-6400	-1600	-24000	0	0
Total	15826	70889	107665	201149	180874

[a] – Sourced from Stevens *et al.* (2000).

[b] – Sourced from Askin and Askin (2016).

WFGMs are a more complete form of financial appraisal (compared to enterprise specific GMs), quantifying overall farm system profitability, which is vital in a commercial setting. Table 16 shows that although all farm systems were profitable, none of the NGB scenarios were financially competitive with bull-beef production under the current pricing structure. The low WFGM in NGB^{8} and NGB^{10} were attributable to negative cattle enterprise GMs, and although the cattle enterprise GM of NGB^{12} was positive, silage making was a large expense which reduced the WFGM to 54% or 60% of that generated under the two bull scenarios (Table 16). As mentioned earlier, managing APC levels with trade stock or forage crops may be more cost-effective strategies than simply cutting silage. However, these options have associated costs, and may not be practical in all circumstances, further research in to these options is required. Again, readers should consider that the price points used in the analysis for the NGB enterprises represent the worst-case situation, and a price premium (per kilogram of carcass weight) is possible given the meat's high quality attributes (Pike *et al.*, 2019).

4.3.2 NGB breakeven beef price relative to bull-beef production

Table 17 reports the price points required for each NGB scenario to breakeven with Bull^{18} and Bull^{24} respectively, along with the beef price required to cover costs. The NGB scenarios required a price premium of $0.67 - $2.08/kg carcass weight (11 – 29%) (depending on slaughter age) to be financially competitive with bull-beef production. As slaughter age increased, the price required to breakeven with the bull scenarios decreased (Table 17). NGB^{8} required the largest ($1.85 or $2.08/kg carcass weight) price premium, while NGB^{12}

required the smallest ($0.67 or $0.64/kg carcass weight price premium, Table 17). Similarly, the beef price required for the NGB scenarios to cover costs decreased as slaughter age increased, with NGB^{12} being profitable under the current pricing structure (Table 17).

Table 17: Beef price per kilogram of carcass weight required for each NGB scenario to breakeven with the $Bull^{18}$ ($4.65/kg carcass weight) and $Bull^{24}$ ($4.93/kg carcass weight) (difference ±% to current price) (all results in $)

	Model scenario:		
	NGB^{8}	**NGB^{10}**	**NGB^{12}**
Current price (used in model)[a] ($/kg)	4.99	5.21	5.32
Price to cover costs ($/kg)	5.77 (+14%)	5.42 (+4%)	4.76 (-12%)
Price to breakeven with $Bull^{18}$ ($/kg)	7.07 (+29%)	6.80 (+23%)	6.26 (+15%)
Price to breakeven with $Bull^{24}$ ($/kg)	6.84 (+27%)	6.55 (+20%)	5.99 (+11%)

[a] – Prime beef schedule price sourced from three-years of monthly AgBrief (2016-18) data.

Quantifying the price points ($/kg carcass weight) where NGB becomes financially competitive with bull-beef production, which is currently recognized as a high-performing livestock enterprise (Morris and Kenyon, 2014), was an important output of the current study. This information identifies the price required for farmers to consider implementing the system, and also provides a financial reference point to assist in developing markets for the product. Table 17 showed that although NGB^{12} was already profitable under the current pricing structure, to be financially competitive with other forms of beef production, and to be feasible to farmers, a price premium between $0.67 and $2.08/kg carcass weight (depending on slaughter age) was required.

Readers should be aware that the errors identified during review in the feed budget modeling process (Section 1.2) flow through to the financial analysis, and thus effect the accuracy of these results. It is difficult to speculate the direction of bias for these combined errors; however, it is possible that they could have a significant impact on the results. Therefore, further research putting more robust financial performance data around NGB production is crucial.

4.4 Environmental performance (nutrient losses and GHG emissions) of modeled farm system scenarios

Pressure is mounting on the agricultural sector to account for the environmental costs (in particular nutrient losses and GHG emissions) of production (Caradus, 2007), as these externalities have been identified as contributors to declining water quality (McDowell and Wilcock, 2008) and global warming (Basset-Mens *et al.*, 2009). Increasingly, farmers are factoring in the environment when making land use and farm system decisions. Given the lighter cattle and less time with cattle on farm, it was suggested that NGB may provide some solutions in regard to environmental sustainability. Prior to this study, the relative environmental footprint of NGB compared to traditional beef production had not been quantified in New Zealand.

Table 18 presents selected outputs from the OVERSEER nutrient budget model (see Appendix G for assumptions). Annual pasture yield and utilisation were similar between models, enabling fair comparisons. N losses varied between scenarios, with Bull^{18} producing the lowest N output and NGB^{10} the highest (Table 18). All NGB scenarios lost more N than the bull scenarios, with the exception of NGB^{8}, which lost 42 kg N/yr less than Bull^{24} (Table 18). Within the NGB scenarios, NGB^{10} had the highest N loss followed by NGB^{12}, suggesting no obvious interaction between slaughter age and N loss. Differences in P loss between all scenarios were negligible (Table 18). Differences in CH_4 emissions, the largest single gas contributing to GHG (Dynes *et al.*, 2019), were also negligible between scenarios, with Bull^{18} and Bull^{24} generating 2 – 5 kg/ha/yr more CH_4 than the NGB scenarios (Table 18). Differences in N_2O emissions were small, with the exception of NGB^{8} which generated less N_2O than all other scenarios (Table 18). NGB^{10} generated 3 – 7% less N_2O than both bull scenarios, whilst NGB^{12} yielded more N_2O than Bull^{24} and less than Bull^{18} (Table 18). Differences in CO_2 output were small. NGB^{10} produced the least CO_2, whilst NGB^{12} produced the most, with the other scenarios generating similar intermediary outputs (Table 18).

The OVERSEER nutrient budget model did not have a distinct stock class recognising cattle slaughtered within 1-year of age as prescribed under NGB production. As a result, there was limited scope to distinguish between NGB production and bull-beef production on an age basis within OVERSEER, which has implications for growth efficiency (Metcalfe and Monaghan, 2003). Therefore, it was unclear whether OVERSEER fully accounted for the differences in potential growth efficiency between steers slaughtered at less than 12-months, and bulls grown out to 18 – 24 months of age in its background energy calculations.

N losses and GHG emissions (the two primary research focuses in this field) reported in Table 18 were similar to the literature for sheep and beef farming in New Zealand (Horizons Regional Council, 2015, Smeaton *et al.*, 2011, Dynes *et al.*, 2019). N losses were very

Table 18: Selected output parameters from the OVERSEER nutrient budget model for the simulated farm system scenarios

	Model scenario:				
	NGB^{8}	**NGB^{10}**	**NGB^{12}**	**$Bull^{18}$**	**$Bull^{24}$**
Pasture:					
Yield (kgDM/ha/yr)	7645	7644	7646	7646	7644
Utilisation	73%	73%	73%	73%	73%
Nitrogen:					
Whole farm loss (kg N/yr)	4301	4604	4497	4146	4343
Loss per/ha (kg N/ha/yr)	10.1	10.8	10.6	9.8	10.2
Phosphorus:					
Whole farm loss (kg P/yr)	323	321	324	326	326
Loss per/ha (kg P/ha/yr)	0.76	0.76	0.76	0.77	0.77
Emissions[a]:					
Methane (kg/ha/yr)	2817	2817	2815	2820	2819
Nitrous oxide (kg/ha/yr)	1427	1649	1768	1770	1697
Carbon dioxide (kg/ha/yr)	136	131	142	138	138
Total GHG (kg/ha/yr)	4380	4597	4725	4728	4654

[a] – As CO_2 equivalents.

similar across all scenarios, and there was insufficient evidence to suggest NGB would generate less N than traditional bull-beef finishing. From the analysis, if steers were slaughtered at 10- or 12-months of age, N losses were likely to be higher compared to traditional bull-beef systems. In addition, differences in P losses were small. Although NGB production generated 0.6% - 1.5% less P than bull-beef production, these differences are unlikely to derive any practical advantage. In regard to emissions, there were no differences in CH_4 emissions between scenarios (Table 18). NGB^8 generated 13% - 19% less N_2O than the bull scenarios, so if N_2O became a limiting factor in the future, the 8-month slaughter variant of NGB may be of interest. Finally, CO_2 outputs were insufficiently dissimilar (between scenarios) to justify weighting this parameter as a factor when comparing the scenarios as a whole.

Overall differences in both nutrient losses and GHG emissions between the NGB and bull-beef scenarios were smaller than anticipated. One reason for this could be that all cattle modelled were male, whereas previous research has shown that dairy cattle (female) are the primary contributors to nutrient losses (Monaghan *et al.*, 2008) and GHG emissions (Knapp *et al.*, 2014). Therefore, the marginal differences between male cattle are small to begin with, so large differences in animal numbers or management practices are required to change environmental outputs. Interestingly, the greater use of silage in NGB^{12} didn't appear to have a discernible impact on environmental output.

Readers should remember there were some limitations around the environmental analysis in this study (section 4.3), and future work is required in this area. Relative pugging damage, which is expected to be lower under NGB production compared to bull-beef production could not be quantified in this study. In addition, it was unclear how well OVERSEER accounted for the differences in cattle growth efficiency between scenarios which has implication for nutrient losses and GHG emissions. Finally, readers should note that the feed budget modelling errors (Section 1.2) flow through to the environmental analysis, however it is very difficult to estimate the combined effect these errors had on the accuracy of the findings presented in Table 18. Overall, the OVERSEER analysis suggests that total cattle feed intake is more important than individual live weight, number of cattle, time of year, or supplement use in determining the nutrient losses and GHG emissions of male cattle. NGB production with slaughter occurring at 8-months of age generated less N_2O than traditional bull-beef finishing whilst maintaining a similar nutrient loss footprint, which could be helpful if GHG regulations are tightened in the future.

4.5 Variability analysis (genotype effects)

Results from the variability analysis indicate interactions between ADG (a proxy for genetic merit for growth), and physical and financial performance, while environmental performance is unaffected. All comparisons in this section, are made against the corresponding base NGB scenarios NGB^{8}, NGB^{10}, and NGB^{12} (Table 13, Table 14, Table 17, Table 18). As with the earlier sections, readers should be aware of the errors in the feed budget model (Section 1.2) as they flow through and affect the results presented in Tables 19 and 20.

Improved genetic merit for growth

Increasing ADG by 10% (above the experimental data, assumed due to improved genetic merit for growth), resulted in 17 kg, 22 kg, and 28 kg increases in slaughter weight (8 kg, 10 kg and 14 kg heavier carcass weights) for NGB^{8+}, NGB^{10+} and NGB^{12+} respectively (Table 19). The per head feed demand of the high genetic merit for growth steers was greater than that of the steers in the base scenarios, however the reduced number of cattle grown in the high genetic merit for growth scenarios, meant that overall feed supply and demand patterns remained similar to the base scenarios. The area harvested for silage decreased by 6% in NGB^{8+} as less silage was required, to remain under the maximum APC constraint in

November (Table 19). In NGB^{12+} 2% more silage was cut to provide the additional feed necessary to remain above the minimum APC constraint during late winter (Table 19). The number of steers purchased decreased by 8% in all scenarios in response to the greater per head feed demand of faster growing cattle, and stocking rates remained consistent with the base scenarios (Table 19). Carcass weight/ha and FCE remained similar to the base scenarios (Table 19). These findings indicate that the marginal per head increases in carcass weight/ha (associated with improved genetic merit for growth), are equal to the marginal reductions in carcass weight/ha associated with less cattle being grown.

Table 19: Summary of select physical, financial, and environmental outputs from the modelling exercise for the improved genetic merit for growth scenarios

	Model scenario		
	NGB^{8+}	**NGB^{10+}**	**NGB^{12+}**
Physical:			
ADG (kg/day)	0.96	0.94	0.96
Slaughter weight (kg)	269	325	376
Carcass weight (kg)	127	156	188
Silage area (ha)	15	4	61
Cattle purchased (head)	686	529	407
Cattle sold (head)	666	513	394
Stocking rate (S.U/ha)	11.3	11.4	11.1
Carcass production/ha (kg)[a]	531	500	482
Feed conversion efficiency[b]	7.6%	7.1%	7.0%
Financial:			
Gross margin ($/ha)	-271	35	392
Bull^{18} breakeven price ($/kg)[c]	6.82	6.54	6.02
Bull^{24} breakeven price ($/kg)[c]	6.58	6.28	5.75
Environmental:			
Nitrogen loss (kg/ha/yr)	10.1	10.8	10.6
Phosphorus loss (kg/ha/yr)	0.76	0.75	0.76
Total GHG emissions (kg/ha/yr)[d]	4379	4597	4726

[a] – Total carcass weight/ha of cattle sent for slaughter in the 12-month modeled period.

[b] – Total carcass weight (kg) sold/ total feed (kgDM) eaten.

[c] – Beef price required to breakeven with each bull-beef scenario.

[d] – As CO_2 equivalents.

All scenarios displayed improved profitability over the base scenarios. GMs increased by \$150/ha, \$139/ha, and \$121/ha for NGB^{8+}, NGB^{10+}, and NGB^{12+} respectively, however NGB^{8+} still failed to be profitable under the current price structure (Table 19). In addition, the beef price (per kg carcass weight) required to breakeven with Bull^{18} and Bull^{24}, decreased by in 4% in all scenarios (Table 19). Environmentally, increasing ADG as a proxy for improved genetic merit for growth had no impact on nutrient losses or GHG emissions, with all tested parameters remaining within ±0.1% of their respective base scenarios (Table 19).

Reduced genetic merit for growth

Decreasing ADG by 10% resulted in 14 kg, 19 kg, and 23 kg reductions in slaughter weight (7 kg, 9 kg, or 11 kg lighter carcass weights) for the NGB^{8-}, NGB^{10-}, and NGB^{12-} scenarios respectively (Table 20). The per head feed demand of the low genetic merit for growth steers was less than that of the steers in the base scenarios, however the higher number of cattle grown in the low genetic merit for growth scenarios, meant that overall feed supply and demand patterns remained similar to the base scenarios. Like the improved genetic merit for growth scenarios, the silage harvest area decreased by 6% in NGB^{8-} and increased by 2% in NGB^{12-}, to remain within APC constraint levels (Table 20). Silage requirements were consistent between the high and low genetic merit for growth scenarios, as differences on ADGs were offset by differences in cattle numbers, so overall feed demand, and seasonal feed demand patterns remained similar. Cattle purchases increased by 7% in all scenarios (Table 20), reflecting the lower per head feed demand of slower growing animals. Similar to the improved genetic merit for growth scenarios, carcass weight/ha, FCE and stocking rates remained similar to the base scenarios (Table 20). These findings suggest the marginal reductions in per head carcass weight production associated with reduced genetic merit for growth, are approximately equal to the increases in carcass weight/ha associated with growing more cattle.

As expected, profitability was reduced in all scenarios, with GMs being \$142/ha, \$133/ha, and \$163/ha lower in NGB^{8-}, NGB^{10-}, and NGB^{12-} respectively (Table 20). In addition, the beef price (per kg carcass weight) required to breakeven with the base scenarios increased by 3% in NGB^{8-} and NGB^{12-}, and 4% in NGB^{10-} (Table 20). Environmentally, reduced genetic merit for growth had minimal effects on nutrient losses and GHG emissions, with all outputs being within ±0.1% of the base scenarios (Table 20).

Variability analysis was conducted to determine the impact steer genetic merit for growth (proxied with ±10% changes in ADG) had on physical, financial, and environmental performance in the NGB scenarios. Improved genetic merit for growth resulted in higher

Table 20: Summary of select physical, financial, and environmental outputs from the modelling exercise for the reduced genetic merit for growth scenarios

	Model scenario		
	NGB[8-]	**NGB[10-]**	**NGB[12-]**
Physical:			
ADG (kg/day)	0.79	0.77	0.78
Slaughter weight (kg)	238	284	325
Carcass weight (kg)	112	137	163
Silage area (ha)	15	4	61
Cattle purchased (head)	797	614	473
Cattle sold (head)	773	595	459
Stocking rate (S.U/ha)	11.3	11.4	11.1
Carcass production/ha (kg)[a]	546	507	486
Feed conversion efficiency[b]	7.8%	7.2%	7.1%
Financial:			
Gross margin ($/ha)	-563	-237	158
Bull[18] breakeven price ($/kg)[c]	7.30	7.06	6.50
Bull[24] breakeven price ($/kg)[c]	7.07	6.81	6.23
Environmental:			
Nitrogen loss (kg/ha/yr)	10.1	10.8	10.6
Phosphorus loss (kg/ha/yr)	0.76	0.76	0.76
Total GHG emissions (kg/ha/yr)[d]	4381	4597	4718

[a] – Total carcass weight/ha of cattle sent for slaughter in the 12-month modeled period.

[b] – Total carcass weight sold/ total feed eaten.

[c] – Beef price required to breakeven with each bull-beef scenario.

[d] – As CO_2 equivalents.

slaughter and carcass weights, greater profitability, a lower beef price required to be financially competitive with bull-beef production and no change in environmental output. Conversely, reduced genetic merit for growth resulted in lighter slaughter and carcass weights, poorer profitability, a higher beef price required to be financially competitive with bull-beef production and no change in environmental output. The positive relationship between genetic merit for growth and profitability is likely attributable to live weight maintenance:weight gain ratios. Minimal variation in environmental outputs across all scenarios in the variation analysis suggests ADG has little bearing on nutrient losses or GHG emissions in the OVERSEER nutrient budget. Instead, management policies pertaining to the timing of sales and total feed intake are likely more important environmental considerations. Overall sourcing steers with improved genetic merit for growth increases profitability and decreases the beef price required to be financially competitive with existing forms of beef production, at no additional environmental cost.

Chapter 5. Conclusions

5.1 Conclusion

The New Zealand dairy cattle industries current use of surplus calves is potentially flawed, and could pose a threat to the sustainability of livestock farming in this country. As such, there is interest in identifying alternative ways to generate value from surplus dairy-origin calves. Growing these animals in a beef production system where slaughter occurs prior to one-year of age (in an NBG system) may overcome some of the current issues. The objective of the current study was to investigate this opportunity, by quantifying the growth and carcass traits of dairy-origin steers slaughtered at less than one-year of age, and determine the physical, financial, and environmental performance of the proposed enterprise relative to traditional bull-beef production in New Zealand. Ultimately, this study aimed to provide the information required to determine whether NGB production could be viable in New Zealand, and establish a base point for further research in this field.

When fed a predominately pastoral diet, Hereford x Friesian-Jersey steers can maintain ADGs in excess of 0.8 kg/day, and are capable of achieving final live weights of 251, 303 and 349 kg (118, 146 and 175 kg carcass weight) when slaughtered at 8-, 10- and 12-months of age respectively. At 8- and 10-months of age the steers achieved the same DO%, whilst 12-month slaughter resulted in a higher DO%. Beef producers should consider this effect when determining optimum slaughter policies.

Compared to $Bull^{18}$ and $Bull^{24}$, all NGB scenarios generated more carcass weight/ha and had a greater FCE. Despite the superior physical performance of NGB production, the comparatively lower financial margin per head based on current prices, meant that the proposed enterprises' financial performance (at all examined slaughter ages) was inferior to $Bull^{18}$ and $Bull^{24}$. This meant to be financially competitive with current bull-beef production systems, NGB production required a price premium of 11 - 29% per kilogram of carcass weight, with the size of the premium decreasing as slaughter age increased. Differences in nutrient losses and GHG emissions between the NGB and base bull-beef scenarios were small, with the exception of NGB^8 which produces 13 – 19% less N_2O than the bull scenarios. Proxying genotype effects with ADG showed that running cattle with superior genetic merit for growth increases physical and financial performance, without altering environmental output. Therefore, sourcing higher quality weaners represents an opportunity to increase the efficiency of NGB production, and decrease the beef price required to be financially competitive with other forms of beef production, at no additional environmental cost.

Overall the findings from the present study indicate that dairy-origin steers crossed with a beef sire are capable of growing well under typical beef finishing system conditions. Environmentally, NGB production is similar to bull-beef production, and therefore financial performance is the primary consideration for farmers looking at implementing the proposed enterprise. A price premium above the current ‘prime’ beef schedule price would be required for NGB production to be financially competitive. Recent research has shown that the meat derived from cattle grown in such systems is of high quality, and therefore could be rewarded with a price premium if suitable markets are located. This would necessitate the development of a new beef classification scheme and subsequent pricing structure, distinguishing cattle produced in yearling beef systems from the existing ‘prime’ and ‘manufacturing’ beef classifications. Furthermore, to become commercially viable changes would be required within meat processing plants to cope with the smaller size of carcasses produced in yearling systems.

5.2 Implications – Strengths and constraints of NGB

This section outlines the strengths and constraints of NGB production (summarized in Table 21), and highlights the potential implications this novel production system could have for New Zealand’s farming sector in the future. The live-animal experiment showed that Hereford x dairy-origin steers can be grown out to 251, 303 and 349 kg live weight (118, 146 and 175 kg carcass weight) when slaughtered at 8-, 10- and 12-months of age respectively on a predominantly pasture-based diet. Between 8- and 10-months of age no differences in DO% were observed, by 12-months of age DO% was greater indicating the ratio of carcass:non carcass growth changes around this age point (Domaradzki *et al.*, 2017). The results from the live-animal experiment are encouraging, and support earlier work suggesting dairy-origin cattle could be used to grow New Zealand’s beef exports (Schreurs *et al.*, 2014, Coleman *et al.*, 2016), albeit through a novel production system.

When modelled on a Class 4 farm alongside a typical self-replacing sheep enterprise, the NGB scenarios required more silage in order to remain within the pre-set APC constraint levels, but generated more carcass weight/ha and had a higher FCE compared to the bull-beef scenarios. Cattle enterprise feed supply and demand patterns varied considerably between scenarios, with NGB production having the most dynamic per ha feed demand patterns. NGB^8 and NGB^{10} had distinctive peaks in per ha cattle feed demand in summer due to the high numbers of cattle run in these scenarios. However, the cattle were also sold in early and late winter respectively, taking the pressure of pasture supply in the crucial and often challenging late winter pre-lambing period. Therefore, for farmers running breeding ewes, particularly high fecundity flocks with their associated high energy requirements (Rattray *et al.*, 2007, Kenyon *et al.*, 2011), NGB production provides a unique strategy to take the pressure off winter feed supply.

Financial analysis indicates under current ‘prime’ beef schedule prices, NGB production with 8- and 10-month slaughter makes a loss, while slaughtering at 12-months is profitable. However, none of the NGB scenarios were financially competitive with either of the current bull scenarios, with the beef price required to generate comparable returns ranging from $5.99 – $7.07/kg carcass weight, and having a negative relationship with slaughter age. Results from other research indicate the quality parameters and eating characteristics of meat derived from NGB carcasses are high, being more tender than meat derived from cattle processed at traditional ages (Pike *et al.*, 2019). Therefore, if ideal markets are found, the product may command a price premium.

In regard to environmental efficiency which is of increasing importance to farmers and consumers alike (Caradus, 2007), differences in nutrient losses and GHG emissions between NGB production and traditional bull-beef production were small, and unlikely to have practical significance. The only exception was NGB^8 which yielded 13 – 19% less N_2O than the bull scenarios, so may be of interest if this particular GHG becomes a limiting factor in the future. However, readers should consider the limitations of OVERSEER when interpreting the environmental findings from this study (see section 4.3).

Finally, variation in cattle genetic merit for growth (proxied with ±10% changes to ADG) showed that sourcing steers with favourable genetics for growth can increase financial returns across all slaughter ages. Furthermore, enhancing the genetic merit for growth of cattle used for NGB production decreased the beef price required to breakeven with the bull scenarios, without increasing environmental output. If the correct financial incentives can be developed or provided with 4 – 8 day old calf prices, dairy farmers may look to breed a proportion of their herd (not required as replacement milking stock) to a beef sire, thus providing a supply of higher genetic merit for growth dairy-origin cattle for finishing in NGB production systems. Theoretically this could increase the return dairy farmers attain from their surplus calves, whilst having negligible impact on their dairy enterprise, and simultaneously mitigating some of the social and ethical issues associated with the current fate of surplus dairy calves.

Table 21: Summary of the strengths and constraints of NGB production identified in the current study, and strategies for farmers to optimise the system

Strengths	**Strategies to maximise**
Capable of greater carcass weight production per/ha than traditional bull-beef finishing.	- Maximise feeding to increase ADGs. - Slaughter cattle while in their accelerated-growth period (less than 1-year of age). - Utilise forage crops to increase dietary ME, and provide feed in low pasture growth periods.
Feed conversion efficiency	- Grow cattle as fast as possible, and slaughter as soon as they reach their target age/weight to minimise maintenance feeding costs. - Slaughter cattle while in their accelerated-growth period (less than 1-year of age). - Utilise forage crops to increase dietary ME, and provide feed in low pasture growth periods.
Flexible sale timing	- Sales can be tailored to suit seasonal pasture growth patterns. In dry seasons cattle can be sold at 8-months of age, prior to winter to take the pressure off feed supply. Conversely, in good seasons sales can be made in late winter, thus fully utilising feed resources and maximising financial returns. Finally, in very wet seasons cattle can be sold in autumn to minimise pugging damage and safe guard future production.
Complementarity with other livestock enterprises	- Low feed demand from winter to early spring, means NGB fits well into systems that farms breeding ewes. The ability to take pressure of feed resources at this time is particularly valuable on farms running high fecundity ewes, where feed demand rapidly increases around lambing in late winter.
Low N_2O output	- If N_2O becomes a limiting factor in the future, NGB with slaughter occurring at 8-months could provide an environmentally compliant form of beef production.
High performance possible with good genetics	- Sourcing animals with high genetic merit for growth can boost physical and financial performance levels without altering environmental output.
Constraints	**Strategies to mitigate**
Dressing out %	- The DO% of NGB cattle increases between 8- and12- months of age. Farmers should consider this effect when determining sales policies, slaughter at older ages will maximise carcass yield.
Unique feed supply and demand pattern	- NGB systems unique feed supply and demand patterns necessitate careful management of APC levels. During winter there may be no NGB cattle on farm. Other options to control APC levels include: cutting silage; purchasing in trade stock; or altering ADGs of existing stock classes (i.e. breeding ewes).
Reliant on price premium to be financially competitive	- Profitability can be enhanced by sourcing quality weaners, increasing ADGs, slaughtering at times when beef prices are high and minimising supplement feed expenses.
Poor genetic merit for growth cattle compromise performance	- Poor genetic merit for growth cattle compromise the viability of NGB. Therefore farmers should only source weaners capable of the ADGs required to breakeven in this beef production system.

5.3 Limitations of the research

During the live-animal experiment, the Manawatu experienced a dry period over the summer of 2017/18, not typical of the region at this time. This necessitated meal supplementation and the use of forage crops to ensure a minimum ADG of 0.8 kg/day as per the experimental design. Therefore, the growth profile of steers over this period may differ slightly from an average year (which was what the modelling exercise aimed to simulate) given the unusually dry conditions. This was a limitation of the study, however as additional feed was supplied over this dry period to maintain growth, the impact it had on overall findings was likely small.

Investigating NGB production with simulation models, meant that findings from this study were relevant only to farm systems with physical features similar to the assumptions used in the modelling process. For example, farm systems operating on alternative land classes or with different livestock enterprises, may not be able to replicate the performance levels demonstrated in this study. Furthermore, by its nature, modelling has a degree of error associated with it, and therefore readers should remember results from the modelling exercise are estimates, not absolute values.

In the gross margin analysis B+LNZ class 4 farm working expense data was obtained, and apportioned based on total stocking units and the sheep:cattle ratio in each scenario model. This approach was accurate for most expense items, however, was problematic for animal health costs. The marginal increase in animal health costs associated with farming heavier animals is less than the marginal increase associated with farming more animals. This is because many health treatments use a standardized dose rate, and in the case of variable dose treatments the marginal change in treatment cost resulting from differential animal liveweights is small. Given the significant difference in cattle numbers between the NGB and bull beef scenarios (which isn't captured in total stocking units) it is likely animal health costs are understated in the NGB scenarios. Apportion animal health costs on a per/head basis could have better captured the different animal health expenditure requirements between the scenarios.

The OVERSEER nutrient budget model estimates total pasture production from stock numbers and animal performance levels, which are both user inputs. In this study OVERSEER's total pasture production estimates varied between scenarios (7.4 – 8.4 tDM/ha/yr and 73 – 74% utilisation). This variation may be explained by differences in OVERSEER's background energy calculations compared to the calculations used in the Microsoft EXCEL feed budgets. Total pasture production was used as a parameter to estimate N leaching and N_2O emissions in OVERSEER, therefore unadjusted differences in total pasture production could confound the aforementioned environmental outputs. To overcome this problem, stock numbers were adjusted in OVERSEER to give equal total pasture production levels (±1 kgDM/ha/yr) and utilisation estimates across all scenarios. Therefore, differences in cattle energy calculations between OVERSEER and the Microsoft EXCEL feed budgets were a limitation to the current study. In addition, the modelling approach this study took meant that it was not possible to quantify relative pugging damage, a parameter in which NGB production should excel. In the future, more accurate data could be obtained with a live-animal trial, utilising lysimeters (Malcolm *et al.*, 2016) to measure nutrient losses and respiration (Johnson *et al.*, 1994) and soil chambers (Husted, 1993) to measure GHG emissions.

Much of the recent literature comparing nutrient losses and GHG emissions between farm systems has utilised FARMAX Pro and OVERSEER concurrently (Smeaton *et al.*, 2011, Dynes *et al.*, 2019). This enables nutrient losses and emissions intensity (environmental output/kg product produced) to be quantified on a total product (kg/ha, drawn from FARMAX Pro) per kg of GHG emitted or nutrients lost per ha. In the current study Microsoft EXCEL feed budgets were used instead of FARMAX Pro, as this methodology enabled data collected in the live-animal experiment to be accurately inputted into the farm system models. A subsequent limitation of this approach was that emissions intensity could not be accurately compared between the current study and existing literature, as different modelling software was used. Future research on NGB production utilising FARMAX Pro and OVERSEER together could be valuable, as it would enable nutrient loss and emissions intensity to be quantified. This would allow additional comparisons to be made with existing literature and help better understand the potential of NGB production in New Zealand.

Examining the growth and carcass attributes of multiple breeds/genotypes of steers when slaughtered at 8-, 10- and 12-months of age, was outside the scope of this pilot study. Therefore, genotype effects were proxied with ADG based upon previous studies quantifying the growth of a range of breeds commonly used in the New Zealand dairy industry (Cole, 1975, Cundiff *et al.*, 1993, Barton *et al.*, 1994, Coleman *et al.*, 2016). Much of this work examined ADG in cattle older than those investigated in the current study, and therefore with potentially different growth efficiencies. This was a limitation of the current study. Future analysis utilising growth data sourced from a range of breeds being examined at less than one-year of age, would therefore be beneficial in better understanding the effect cattle breed has on NGB production. In addition, there may be an opportunity to grow cattle with a high

FCE in the proposed system. This would enable higher growth rates, or a greater number of cattle to be raised per unit of feed. Future research in this area would be beneficial.

Finally, the two important errors (Section 1.2) identified during review, represent significant limitations for this study. Because the errors were made in the initial stages of modelling they flow through the subsequent analysis and impact on the accuracy of many model outputs. Despite this being a major drawback, the dissertation still presents useful new information and discussion around the exciting concept of NGB production and provides a platform for future research in this field.

5.4 Future research

On Class 4 farms, when implemented alongside a self-replacing sheep enterprise, NGB production utilising Hereford x Friesian-Jersey steers slaughtered at 8 – 12 months of age, is physically and environmentally competitive with bull-beef production, but not financially competitive under the current pricing structure. Given that the majority of surplus dairy-origin calves are of HF x Jersey, HF or Jersey breed, future research should investigate the performance and profitability of these cattle genotypes, when farmed in a NGB production system. Furthermore, research into the viability of alternative cattle breeds and sex classes (heifers and bulls), when farmed in the proposed enterprise is warranted. It is possible that farming bulls may increase the efficiency of NGB through the higher ADGs associated with entire male cattle (Lund-Larsen *et al.*, 1977), without compromising carcass value as the young slaughter age means carcasses already have low fat levels (Pike *et al.*, 2019). The development of estimated breeding values for dairy origin weaners destined to be grown under NGB production could also be beneficial in the longer term. Finally, research determining the potential value of by-products i.e. offal and hides, derived from NGB production systems would be beneficial.

In this study the comparison against Friesian bull-beef production was chosen, as bull faming is recognised as one of the highest performing beef production systems in New Zealand (Morris and Kenyon, 2014), and therefore provides a realistic baseline for financial comparisons. Additional comparisons between NGB production and alternative agricultural enterprises such as dairy farming, breeding beef cattle, dairy grazing, and alongside a breeding sheep enterprise at a range of different sheep:cattle ratios would be beneficial in better understanding where the proposed enterprise may fit into the industry.

Finally, given the limitations of using OVERSEER to quantify the nutrient losses and GHG emissions of the proposed enterprise, a live-animal experiment comparing the environmental (nutrient and GHG) outputs and soil pugging damage of NGB production with traditional beef production systems, is justified. Such a study would more accurately quantify the potential differences between the enterprises and overcome a number of the limitations associated with using OVERSEER encountered in the current study.

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List of Appendices

Appendix A: Feed budget models for each scenario model

NGB[8] Feed budget

Model name: NGB 8 month												
Period Ending: June 30th	July	August	September	October	November	December	January	February	March	April	May	June
Days per period	31	31	30	31	30	31	31	28	31	30	31	30
Area in pasture	425	425	425	356	356	409	425	425	425	425	425	425
Closed for silage				16	16	16						
Regrassing				53	53							
Forage ME value	10.6	12.3	10.2	11.3	10.7	9.6	9.3	8	8.9	8.4	11	10.7
Net pasture growth rates (kg DM/ha/day)	9.8	15.6	21.5	33.2	35.8	28.6	20.8	15.0	16.9	13.7	15.0	10.4
Feed Demand (kg DM/ha/day)	8.4	8.2	9.9	12.4	24.5	29.1	28.5	38.3	33.7	24.4	13.0	8.8
Difference/day (kg DM/ha/day)	1.3	7.4	11.5	20.7	11.2	-0.5	-7.7	-23.3	-16.8	-10.8	1.9	1.6
Supplements (kg DM/ha/day; ME adjusted to pasture)												
Silage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.5	0.6	0.0	0.0
Total supplement (kg DM/ha/day)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.5	0.6	0.0	0.0
Net change in pasture cover (kg DM/ha/day)	1.3	7.4	11.5	20.7	11.2	-0.5	-7.7	-22.7	-16.3	-10.2	1.9	1.6
Initial average pasture cover (kg DM/ha)	1400	1440	1671	2018	2661	2997	2980	2740	2103	1598	1292	1352
Final average pasture cover (kg DM/ha)	1440	1671	2018	2661	2997	2980	2740	2103	1598	1292	1352	1400
Key Targets (end of period)	Min 1200					Max 3000			Opening APC	=	Closing APC	
Cattle feed demand	July	August	September	October	November	December	January	February	March	April	May	June
Weaner Steers	0	0	0	0	173	742	734	733	727	719	360	0
Intake (kgDM/hd/d)					7.0	7.1	8.3	11.9	11.1	7.5	6.5	
Total cattle feed demand (kg DM/ha/day)	0.0	0.0	0.0	0.0	3.4	12.9	14.3	20.6	18.9	12.8	5.5	0.0
Sheep feed demand	July	August	September	October	November	December	January	February	March	April	May	June
MA Ewes	1475	1471	1441	1412	1410	1210	1098	1490	1489	1484	1481	1478
Intake (kgDM/hd/d)	1.6	1.5	1.9	2.1	2.5	1.7	1.5	1.9	1.7	1.5	1.2	1.5
2 Tooth Ewes	405	401	397	397	396	396	396	395	395	394	394	394
Intake (kgDM/hd/d)	1.6	1.6	1.8	1.8	2.2	1.7	1.6	1.9	1.8	1.4	1.3	1.5
Hogget Ewes	421	417	413	408	408	408	407	407	406	406	406	405
Intake (kgDM/hd/d)	1.3	1.3	1.8	1.6	1.7	2.1	1.5	1.7	1.5	1.7	0.9	1.3
Lambs	0	0	0	0	2362	2596	2570	2544	2021	1235	435	421
Intake (kgDM/hd/d)					1.0	1.2	1.2	1.3	1.2	1.2	1.1	1.1
Rams	29	28	28	27	27	26	26	26	25	25	25	24
Intake (kgDM/hd/d)	1.5	1.3	1.6	1.4	1.5	1.7	1.8	2.1	1.9	1.2	0.9	1.5
Total sheep feed demand (kg DM/ha/day)	8.4	8.2	9.9	12.4	21.1	16.2	14.2	17.7	14.8	11.6	7.5	8.8
Total Feed Demand (kg DM/ha/day)	8.4	8.2	9.9	12.4	24.5	29.1	28.5	38.3	33.7	24.4	13.0	8.8

		July	August	September	October	November	December	January	February	March	April	May	June
Grass Silage		31	31	30	31	30	31	31	28	31	30	31	30
ME of pasture	Pulled from feed budget	10.6	12.3	10.2	11.3	10.7	9.6	9.3	8	8.9	8.4	10.8	10.7
Silage bales	kg DM fed per period								6933	6933	6933		
ME of supplement		10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Wastage		15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Supplement eaten as pasture equiv	kg DM/period (Past. equiv.)	0	0	0	0	0	0	0	7367	6622	7016	0	0

Weaner Steers	July	August	September	October	November	December	January	February	March	April	May	June
Days between weighing					3	33	27	27	29	34	23	
Start weight					100	103	130	156	188	222	239	
End weight					103	130	156	188	222	239	252	
Gain/loss/day					1.00	0.84	0.94	1.20	1.18	0.49	0.58	
Energy demands (MJ/day)												
Body maintenance					19.8	22.0	25.6	29.4	33.6	36.7	38.5	
Weight gain / loss					55.0	46.3	51.5	66.0	64.8	26.7	32.0	
MJ/animal/day					74.8	68.3	77.2	95.4	98.4	63.4	70.5	
kg DM/head/day					7.0	7.1	8.3	11.9	11.1	7.5	6.5	

MA Ewes	July	August	September	October	November	December	January	February	March	April	May	June
	31	31	30	31	30	31	31	28	31	30	31	30
Start weight	66	67	69	61	58	55	57	59	61	63	63	64
End weight	67	69	61	58	55	57	59	61	63	63	64	66
Gain/loss	0.05	0.06		-0.10	-0.10	0.05	0.06	0.07	0.06	0.02	0.03	0.05
Energy demands (MJ/day)												
Body maintenance	12.1	12.3	11.9	11.2	10.7	10.6	10.9	11.1	11.4	11.6	11.7	11.9
Weight gain / loss	2.7	3.1	0.0	-3.1	-3.0	2.7	3.5	3.9	3.5	0.9	1.8	2.8
Pregancy	2.2	3.5	1.6									1.0
Lactation			5.6	16.0	19.3	3.0						
MJ/animal/day	16.9	18.9	19.1	24.0	27.0	16.3	14.4	15.1	15.0	12.5	13.5	15.6
kg DM/head/day	1.6	1.5	1.9	2.1	2.5	1.7	1.5	1.9	1.7	1.5	1.2	1.5

2 Tooth Ewes	July	August	September	October	November	December	January	February	March	April	May	June
	31	31	30	31	30	31	31	28	31	30	31	30
Start weight	61	63	66	58	55	53	55	58	60	56	57	59
End weight	63	66	58	55	53	55	58	60	63	57	59	61
Gain/loss	0.08	0.08		-0.10	-0.06	0.07	0.07	0.08	0.08	0.03	0.05	0.07
Energy demands (MJ/day)												
Body maintenance	11.5	11.8	11.5	10.7	10.4	10.4	10.7	11.0	11.4	10.7	10.9	11.1
Weight gain / loss	4.4	4.7	0.0	-3.0	-1.9	4.0	4.1	4.5	4.4	1.4	2.7	3.7
Pregancy	1.5	2.8	1.4									0.8
Lactation			5.5	12.6	15.0	2.2						
MJ/animal/day	17.4	19.3	18.4	20.3	23.5	16.6	14.8	15.6	15.8	12.1	13.6	15.6
kg DM/head/day	1.6	1.6	1.8	1.8	2.2	1.7	1.6	1.9	1.8	1.4	1.3	1.5

Hogget Ewes	July	August	September	October	November	December	January	February	March	April	May	June
	31	31	30	31	30	31	31	28	31	30	31	30
Start weight	47	49	52	55	50	50	49	51	52	54	44	44
End weight	49	52	55	50	50	49	51	52	54	56	44	47
Gain/loss	0.06	0.09	0.11		-0.02	-0.02	0.06	0.06	0.06	0.07	0.01	0.08
Energy demands (MJ/day)												
Body maintenance	9.5	9.8	10.3	10.1	9.7	9.6	9.7	10.0	10.3	10.5	8.9	9.1
Weight gain / loss	3.4	5.0	5.9	0.0	-0.5	-0.7	3.3	3.5	3.3	3.7	0.4	4.6
Pregancy	0.4	1.1	2.4	1.2								
Lactation				7.0	9.0	11.0	0.9					
MJ/animal/day	13.3	15.9	18.5	18.3	18.2	19.9	13.9	13.5	13.5	14.2	9.3	13.7
kg DM/head/day	1.3	1.3	1.8	1.6	1.7	2.1	1.5	1.7	1.5	1.7	0.9	1.3

Lambs	July	August	September	October	November	December	January	February	March	April	May	June
	31	31	30	31	30	31	31	28	31	30	31	30
Start weight					28	31	34	37	39	41	42	45
End weight					31	34	37	39	41	42	45	47
Gain/loss					0.10	0.10	0.09	0.06	0.07	0.05	0.08	0.08
Energy demands (MJ/day)												
Body maintenance					5.7	6.1	6.5	6.9	7.1	7.4	7.6	7.9
Weight gain / loss					5.0	5.0	4.5	3.2	3.5	2.5	4.0	3.8
MJ/animal/day					10.7	11.1	11.0	10.1	10.6	9.9	11.6	11.7
kg DM/head/day					1.0	1.2	1.2	1.3	1.2	1.2	1.1	1.1

Rams	July	August	September	October	November	December	January	February	March	April	May	June
	31	31	30	31	30	31	31	28	31	30	31	30
Start weight	81	82	83	84	85	86	87	88	89	90	85	80
End weight	82	83	84	85	86	87	88	89	90	85	80	81
Gain/loss	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	-0.17	-0.16	0.03
Energy demands (MJ/day)												
Body maintenance	14.1	14.2	14.4	14.5	14.6	14.7	14.9	15.0	15.1	14.9	14.2	14.0
Weight gain / loss	1.8	1.8	1.8	1.8	1.8	1.8	1.8	2.0	1.8	-5.0	-4.8	1.8
MJ/animal/day	15.9	16.0	16.2	16.3	16.5	16.5	16.7	17.0	16.9	9.9	9.4	15.8
kg DM/head/day	1.5	1.3	1.6	1.4	1.5	1.7	1.8	2.1	1.9	1.2	0.9	1.5

NGB^{10} Feed budget

Model name: NGB 10 month												
Period Ending: June 30th	July	August	September	October	November	December	January	February	March	April	May	June
Days per period	31	31	30	31	30	31	31	28	31	30	31	30
Area in pasture	425	425	425	368	368	421	425	425	425	425	425	425
Closed for silage				4	4	4						
Regrassing				53	53							
Forage ME value	10.6	12.3	10.2	11.3	10.7	9.6	9.3	8	8.9	8.4	11	10.7
Net pasture growth rates (kg DM/ha/day)	9.8	15.6	21.5	33.2	35.8	28.6	20.8	15.0	16.9	13.7	15.0	10.4
Feed Demand (kg DM/ha/day)	16.3	8.2	9.9	12.0	22.7	25.4	25.0	33.5	29.7	21.0	18.1	16.1
Difference/day (kg DM/ha/day)	-6.5	7.4	11.5	21.1	13.1	3.2	-4.2	-18.5	-12.8	-7.4	-3.1	-5.7
Supplements (kg DM/ha/day; ME adjusted to pasture)												
Silage	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Total supplement (kg DM/ha/day)	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Net change in pasture cover (kg DM/ha/day)	-6.4	7.4	11.5	21.1	13.1	3.2	-4.2	-18.3	-12.8	-7.4	-3.1	-5.7
Initial average pasture cover (kg DM/ha)	1400	1202	1433	1779	2435	2827	2926	2796	2284	1888	1667	1570
Final average pasture cover (kg DM/ha)	1202	1433	1779	2435	2827	2926	2796	2284	1888	1667	1570	1400
Key Targets (end of period)	Min 1200					Max 3000			Opening APC	=	Closing APC	
Cattle feed demand	July	August	September	October	November	December	January	February	March	April	May	June
Weaner Steers	0	0	0	0	133	572	572	572	572	566	560	555
Intake (kgDM/hd/d)					6.1	7.1	8.0	11.7	11.1	7.0	8.0	5.6
R1 Steers	305	0	0	0	0	0	0	0	0	0	0	0
Intake (kgDM/hd/d)	10.9											
Total cattle feed demand (kg DM/ha/day)	7.8	0.0	0.0	0.0	2.2	9.6	10.8	15.8	14.9	9.4	10.6	7.2
Total sheep feed demand (kg DM/ha/day)	8.4	8.2	9.9	12.0	20.5	15.8	14.2	17.7	14.8	11.6	7.5	8.8
Total Feed Demand (kg DM/ha/day)	16.3	8.2	9.9	12.0	22.7	25.4	25.0	33.5	29.7	21.0	18.1	16.1

		July	August	September	October	November	December	January	February	March	April	May	June
Grass silage		31	31	30	31	30	31	31	28	31	30	31	30
ME of pasture	Pulled from feed budget	10.6	12.3	10.2	11.3	10.7	9.6	9.3	8	8.9	8.4	10.8	10.7
Silage bales	kg DM fed per period	2600							2600				
ME of supplement		10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Wastage		15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Supplement eaten as pasture equiv	kg DM/period (Past. equiv.)	2085	0	0	0	0	0	0	2763	0	0	0	0

Weaner Steers	July	August	September	October	November	December	January	February	March	April	May	June
Days between weighing					6	33	27	27	29	34	36	29
Start weight					100	105	132	156	188	222	236	267
End weight					105	132	156	188	222	236	267	276
Gain/loss/day					0.83	0.83	0.89	1.17	1.18	0.41	0.86	0.33
Energy demands (MJ/day)												
Body maintenance					20.0	22.3	25.8	29.4	33.6	36.5	39.2	41.5
Weight gain / loss					45.8	45.6	48.8	64.2	65.0	22.6	47.4	17.9
MJ/animal/day					65.8	67.9	74.6	93.7	98.6	59.1	86.6	59.4
kg DM/head/day					6.1	7.1	8.0	11.7	11.1	7.0	8.0	5.6
R1 Steers	July	August	September	October	November	December	January	February	March	April	May	June
Days between weighing	20											
Start weight	276											
End weight	303											
Gain/loss/day	1.32											
Energy demands (MJ/day)												
Body maintenance	43.5											
Weight gain / loss	72.4											
MJ/animal/day	116.0											
kg DM/head/day	10.9											

NGB[12] Feed budget

Model name: NGB 12 month												
Period Ending: June 30th	July	August	September	October	November	December	January	February	March	April	May	June
Days per period	31	31	30	31	30	31	31	28	31	30	31	30
Area in pasture	425	425	425	312	312	365	425	425	425	425	425	425
Closed for silage				60	60	60						
Regrassing				53	53							
Forage ME value	10.6	12.3	10.2	11.3	10.7	9.6	9.3	8	8.9	8.4	11	10.7
Net pasture growth rates (kg DM/ha/day)	9.8	15.6	21.5	33.2	35.8	28.6	20.8	15.0	16.9	13.7	15.0	10.4
Feed Demand (kg DM/ha/day)	17.6	18.5	10.8	14.2	26.0	27.6	22.4	29.1	25.9	19.6	15.5	14.1
Difference/day (kg DM/ha/day)	-7.8	-2.9	10.6	19.0	9.8	1.0	-1.6	-14.2	-9.0	-5.9	-0.5	-3.7
Supplements (kg DM/ha/day; ME adjusted to pasture)												
Silage	1.5	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total supplement (kg DM/ha/day)	1.5	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net change in pasture cover (kg DM/ha/day)	-6.3	-0.1	10.6	19.0	9.8	1.0	-1.6	-14.2	-9.0	-5.9	-0.5	-3.7
Initial average pasture cover (kg DM/ha)	1400	1204	1201	1519	2107	2400	2433	2383	1986	1706	1529	1512
Final average pasture cover (kg DM/ha)	1204	1201	1519	2107	2400	2433	2383	1986	1706	1529	1512	1400
Key Targets (end of period)	Min 1200					Max 3000			Opening APC	=	Closing APC	
Cattle feed demand	July	August	September	October	November	December	January	February	March	April	May	June
Weaner Steers	0	0	0	0	103	441	438	434	433	432	431	429
Intake (kgDM/hd/d)					5.6	7.7	7.9	11.2	10.9	7.8	7.9	5.3
R1 Steers	429	428	57	0	0	0	0	0	0	0	0	0
Intake (kgDM/hd/d)	9.1	10.3	7.0									
Total cattle feed demand (kg DM/ha/day)	9.1	10.3	0.9	0.0	1.9	9.4	8.2	11.4	11.1	7.9	8.0	5.3
Total sheep feed demand (kg DM/ha/day)	8.4	8.2	9.9	14.2	24.1	18.2	14.2	17.7	14.8	11.6	7.5	8.8
Total Feed Demand (kg DM/ha/day)	17.6	18.5	10.8	14.2	26.0	27.6	22.4	29.1	25.9	19.6	15.5	14.1

		July	August	September	October	November	December	January	February	March	April	May	June
Grass silage		31	31	30	31	30	31	31	28	31	30	31	30
ME of pasture	Pulled from feed budget	10.6	12.3	10.2	11.3	10.7	9.6	9.3	8	8.9	8.4	10.8	10.7
Silage bales	kg DM fed per period	24960	53040										
ME of supplement		10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Wastage		15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Supplement eaten as pasture equiv	kg DM/period (Past. equiv.)	20015	36654	0	0	0	0	0	0	0	0	0	0

Weaner Steers	July	August	September	October	November	December	January	February	March	April	May	June
Days between weighing					4	33	27	27	29	34	36	29
Start weight					100	103	134	158	187	221	239	269
End weight					103	134	158	187	221	239	269	276
Gain/loss/day					0.74	0.95	0.87	1.09	1.16	0.53	0.83	0.27
Energy demands (MJ/day)												
Body maintenance					19.8	22.3	26.0	29.5	33.5	36.6	39.4	41.6
Weight gain / loss					40.6	52.1	47.8	60.1	64.0	28.9	45.8	14.9
MJ/animal/day					60.4	74.4	73.8	89.6	97.4	65.5	85.2	56.5
kg DM/head/day					5.6	7.7	7.9	11.2	10.9	7.8	7.9	5.3

R1 Steers	July	August	September	October	November	December	January	February	March	April	May	June
Days between weighing	27	28	14									
Start weight	276	302	343									
End weight	302	343	348									
Gain/loss/day	0.96	1.44	0.39									
Energy demands (MJ/day)												
Body maintenance	43.5	47.2	49.7									
Weight gain / loss	52.6	79.2	21.4									
MJ/animal/day	96.1	126.3	71.1									
kg DM/head/day	9.1	10.3	7.0									

Bull[18] Feed budget

Model name: Bull beef 18 months												
Period Ending: June 30th	July	August	September	October	November	December	January	February	March	April	May	June
Days per period	31	31	30	31	30	31	31	28	31	30	31	30
Area in pasture	425	425	425	372	372	425	425	425	425	425	425	425
Closed for silage												
Regrassing				53	53							
Forage ME value	10.6	12.3	10.2	11.3	10.7	9.6	9.3	8	8.9	8.4	11	10.7
Net pasture growth rates (kg DM/ha/day)	9.8	15.6	21.5	33.2	35.8	28.6	20.8	15.0	16.9	13.7	15.0	10.4
Feed Demand (kg DM/ha/day)	13.7	13.5	16.8	19.8	30.3	27.6	22.7	25.2	20.8	18.6	13.5	14.5
Difference/day (kg DM/ha/day)	-3.9	2.1	4.7	13.3	5.5	1.0	-1.9	-10.2	-3.9	-4.9	1.5	-4.1
Supplements (kg DM/ha/day; ME adjusted to pasture)												
Silage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total supplement (kg DM/ha/day)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net change in pasture cover (kg DM/ha/day)	-3.9	2.1	4.7	13.3	5.5	1.0	-1.9	-10.2	-3.9	-4.9	1.5	-4.1
Initial average pasture cover (kg DM/ha)	1400	1278	1343	1483	1896	2060	2090	2032	1746	1624	1476	1522
Final average pasture cover (kg DM/ha)	1278	1343	1483	1896	2060	2090	2032	1746	1624	1476	1522	1400
Key Targets (end of period)	Min 1200					Max 3000			Opening APC	=	Closing APC	
Cattle feed demand	July	August	September	October	November	December	January	February	March	April	May	June
Weaner Steers	0	0	0	0	60	256	253	253	252	251	251	250
Intake (kgDM/hd/d)					5.8	7.6	8.6	10.0	10.2	11.7	10.2	9.6
R1 Steers	250	249	249	249	248	207	103	41	0	0	0	0
Intake (kgDM/hd/d)	8.9	9.1	11.7	11.9	13.7	15.3	13.6	15.5				
Total cattle feed demand (kg DM/ha/day)	5.2	5.4	6.9	8.0	10.1	12.0	8.5	7.5	6.0	6.9	6.0	5.6
Total sheep feed demand (kg DM/ha/day)	8.4	8.2	9.9	11.9	20.2	15.6	14.2	17.7	14.8	11.6	7.5	8.8
Total Feed Demand (kg DM/ha/day)	13.7	13.5	16.8	19.8	30.3	27.6	22.7	25.2	20.8	18.6	13.5	14.5

		July	August	September	October	November	December	January	February	March	April	May	June
Grass silage		31	31	30	31	30	31	31	28	31	30	31	30
ME of pasture	Pulled from feed budget	10.6	12.3	10.2	11.3	10.7	9.6	9.3	8	8.9	8.4	10.8	10.7
Silage bales	kg DM fed per period	0	0										
ME of supplement		10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Wastage		15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Supplement eaten as pasture equiv	kg DM/period (Past. equiv.)	0	0	0	0	0	0	0	0	0	0	0	0

Weaner Bulls	July	August	September	October	November	December	January	February	March	April	May	June
	31	31	30	31	30	31	31	28	31	30	31	30
Start weight					100	122	149	179	203	234	267	304
End weight					122	149	179	203	234	267	304	335
Gain/loss/day					0.74	0.88	0.94	0.88	1.01	1.08	1.21	1.01
Energy demands (MJ/day)												
Body maintenance					21.2	24.7	28.4	31.8	35.3	39.1	43.1	46.9
Weight gain / loss					40.8	48.2	51.9	48.2	55.6	59.3	66.7	55.6
MJ/animal/day					62.0	72.8	80.3	80.0	90.8	98.3	109.8	102.4
kg DM/head/day					5.8	7.6	8.6	10.0	10.2	11.7	10.2	9.6
R1 Bulls	July	August	September	October	November	December	January	February	March	April	May	June
	31	31	30	31	30	31	31	28	31	30	31	30
Start weight	335	360	393	428	469	514	558	558				
End weight	360	393	428	469	514	558	588	584				
Gain/loss/day	0.81	1.08	1.15	1.35	1.48	1.41	0.98	0.94				
Energy demands (MJ/day)												
Body maintenance	49.9	53.0	56.5	60.4	64.7	69.0	72.6	72.4				
Weight gain / loss	44.5	59.3	63.0	74.1	81.5	77.8	53.9	51.9				
MJ/animal/day	94.3	112.3	119.5	134.5	146.2	146.8	126.5	124.3				
kg DM/head/day	8.9	9.1	11.7	11.9	13.7	15.3	13.6	15.5				

NGB[24] Feed budget

Model name: Bull beef 24 months												
Period Ending: June 30th	July	August	September	October	November	December	January	February	March	April	May	June
Days per period	31	31	30	31	30	31	31	28	31	30	31	30
Area in pasture	425	425	425	372	372	425	425	425	425	425	425	425
Closed for silage												
Regrassing				53	53							
Forage ME value	10.6	12.3	10.2	11.3	10.7	9.6	9.3	8	8.9	8.4	11	10.7
Net pasture growth rates (kg DM/ha/day)	9.8	15.6	21.5	33.2	35.8	28.6	20.8	15.0	16.9	13.7	15.0	10.4
Feed Demand (kg DM/ha/day)	12.8	11.7	14.5	16.9	26.6	24.6	22.9	27.9	24.9	23.1	16.1	15.2
Difference/day (kg DM/ha/day)	-3.1	3.9	7.0	16.3	9.2	4.0	-2.1	-12.9	-8.0	-9.5	-1.2	-4.8
Supplements (kg DM/ha/day; ME adjusted to pasture)												
Silage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total supplement (kg DM/ha/day)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net change in pasture cover (kg DM/ha/day)	-3.1	3.9	7.0	16.3	9.2	4.0	-2.1	-12.9	-8.0	-9.5	-1.2	-4.8
Initial average pasture cover (kg DM/ha)	1400	1305	1425	1634	2140	2415	2540	2474	2113	1865	1580	1543
Final average pasture cover (kg DM/ha)	1305	1425	1634	2140	2415	2540	2474	2113	1865	1580	1543	1400
Key Targets (end of period)	Min 1200					Max 3000			Opening APC	=	Closing APC	
Cattle feed demand	July	August	September	October	November	December	January	February	March	April	May	June
Weaner Bulls	0	0	0	0	50	213	212	211	211	210	210	209
Intake (kgDM/hd/d)					4.8	6.2	7.0	8.1	8.2	9.3	8.1	7.6
R1 Bulls	209	209	209	208	208	208	207	207	207	206	172	103
Intake (kgDM/hd/d)	7.2	7.3	9.3	8.9	10.2	12.0	10.8	12.6	12.5	14.2	11.6	10.6
R2 Bulls	34	0	0	0	0	0	0	0	0	0	0	0
Intake (kgDM/hd/d)	10.5											
Total cattle feed demand (kg DM/ha/day)	4.4	3.6	4.6	5.0	6.3	8.9	8.7	10.1	10.1	11.5	8.7	6.3
Total sheep feed demand (kg DM/ha/day)	8.4	8.2	9.9	11.9	20.2	15.6	14.2	17.7	14.8	11.6	7.5	8.8
Total Feed Demand (kg DM/ha/day)	12.8	11.7	14.5	16.9	26.6	24.6	22.9	27.9	24.9	23.1	16.1	15.2

		July	August	September	October	November	December	January	February	March	April	May	June
Grass silage		31	31	30	31	30	31	31	28	31	30	31	30
ME of pasture	Pulled from feed budget	10.6	12.3	10.2	11.3	10.7	9.6	9.3	8	8.9	8.4	10.8	10.7
Silage bales	kg DM fed per period	0							0				
ME of supplement		10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Wastage		15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Supplement eaten as pasture equiv	kg DM/period (Past. equiv.)	0	0	0	0	0	0	0	0	0	0	0	0

Weaner Bulls	July	August	September	October	November	December	January	February	March	April	May	June
	31	31	30	31	30	31	31	28	31	30	31	30
Start weight					100	117	137	158	177	200	224	252
End weight					117	137	158	177	200	224	252	274
Gain/loss/day					0.55	0.65	0.70	0.65	0.75	0.80	0.90	0.75
Energy demands (MJ/day)												
Body maintenance					20.8	23.4	26.2	28.9	31.5	34.4	37.5	40.5
Weight gain / loss					30.3	35.8	38.5	35.8	41.3	44.0	49.5	41.3
MJ/animal/day					51.1	59.1	64.7	64.6	72.8	78.4	87.0	81.7
kg DM/head/day					4.8	6.2	7.0	8.1	8.2	9.3	8.1	7.6

R1 Bulls	July	August	September	October	November	December	January	February	March	April	May	June
	31	31	30	31	30	31	31	28	31	30	31	30
Start weight	274	293	318	343	371	401	434	456	476	502	531	562
End weight	293	318	343	371	401	434	456	476	502	531	562	584
Gain/loss/day	0.60	0.80	0.85	0.90	1.00	1.05	0.73	0.70	0.85	0.95	1.00	0.75
Energy demands (MJ/day)												
Body maintenance	42.8	45.3	48.0	50.9	54.0	57.2	60.1	62.2	64.5	67.2	70.0	72.6
Weight gain / loss	33.0	44.0	46.8	49.5	55.0	57.8	40.0	38.5	46.8	52.3	55.0	41.3
MJ/animal/day	75.8	89.3	94.8	100.4	109.0	115.0	100.1	100.7	111.2	119.4	125.0	113.8
kg DM/head/day	7.2	7.3	9.3	8.9	10.2	12.0	10.8	12.6	12.5	14.2	11.6	10.6

R2 Bulls	July	August	September	October	November	December	January	February	March	April	May	June
	31	31	30	31	30	31	31	28	31	30	31	30
Start weight	562											
End weight	584											
Gain/loss/day	0.70											
Energy demands (MJ/day)												
Body maintenance	72.6											
Weight gain / loss	38.5											
MJ/animal/day	111.1											
kg DM/head/day	10.5											

Appendix B: Stock reconciliations by scenario

SHEEP & BEEF CATTLE FARM STOCK RECONCILIATION				For the period ending		June 30th			
Model:	NGB 8 month			Effective Farm Area (ha)		425			
STOCK CLASS	OPENING STOCK	PURCH.	NATURAL INCREASE	SALES	DEATHS KILLERS MISSING	TRANSFERS OUT	TRANSFERS IN	CLOSING	DEATH RATE
SHEEP		Ewes	Hoggets						
	Lambing %	131%	60%						
Lambs			2704	2,094	189	421			7%
Hoggets	421				16	405	421	421	4%
Two tooths	405				12	394	405	405	3%
M.A. ewes	1,490			314	80		394	1,490	5%
Rams	30	5			5			30	17%
TOTAL	2,346	5	2,704	2,408	301	1,220	1,220	2,346	
	Check	5,055			5,055				
CATTLE									
Weaners		742		719	22				3%
TOTAL	0	742	0	719	22	0	0	0	
	Check	742			742				

Class	**SU**	**%**
Sheep	3,009	63%
Cattle	1,804	37%
Total	4,813	100%
Stocking rate:	Per ha =	11.3

SHEEP & BEEF CATTLE FARM STOCK RECONCILIATION				For the period ending		June 30th			
Model:	NGB 10 month			**Effective Farm Area (ha)**		425			
STOCK CLASS	OPENING	PURCH.	NATURAL	SALES	DEATHS	TRANSFERS	TRANSFERS	CLOSING	DEATH RATE
	STOCK		INCREASE		KILLERS	OUT	IN		
					MISSING				
SHEEP		Ewes	Hoggets						
	Lambing %	131%	60%						
Lambs			2704	2,094	189	421			7%
Hoggets	421				16	405	421	421	4%
Two tooths	405				12	394	405	405	3%
M.A. ewes	1,490			314	80		394	1,490	5%
Rams	30	5			5			30	17%
TOTAL	2,346	5	2,704	2,408	301	1,220	1,220	2,346	
	Check	5,055			5,055				
CATTLE									
Weaners		572			17	555			3%
R1 bulls	555			555			555	555	0%
TOTAL	555	572	0	555	17	555	555	555	
	Check	1,127			1,127				

Class	**SU**	**%**
Sheep	3,009	62%
Cattle	1,824	38%
Total	4,833	100%
Stocking rate:	Per ha =	11.4

SHEEP & BEEF CATTLE FARM STOCK RECONCILIATION				For the period ending		June 30th			
Model:	NGB 12 month			**Effective Farm Area (ha)**		425			
STOCK CLASS	OPENING STOCK	PURCH.	NATURAL INCREASE	SALES	DEATHS KILLERS MISSING	TRANSFERS OUT	TRANSFERS IN	CLOSING	DEATH RATE
SHEEP		Ewes	Hoggets						
	Lambing %	131%	60%						
Lambs			2704	2,094	189	421			7%
Hoggets	421				16	405	421	421	4%
Two tooths	405				12	394	405	405	3%
M.A. ewes	1,490			314	80		394	1,490	5%
Rams	30	5			5			30	17%
TOTAL	2,346	5	2,704	2,408	301	1,220	1,220	2,346	
	Check	5,055			5,055				
CATTLE									
Weaners		441			12	429			3%
R1 bulls	429			428	1		429	429	0%
TOTAL	429	441	0	428	13	429	429	429	
	Check	870			870				

Class	**SU**	**%**
Sheep	3,009	64%
Cattle	1,705	36%
Total	4,714	100%
Stocking rate:	Per ha =	11.1

SHEEP & BEEF CATTLE FARM STOCK RECONCILIATION				For the period ending		June 30th			
Model:	Bull beef 18 months			**Effective Farm Area (ha)**		425			
STOCK CLASS	OPENING STOCK	PURCH.	NATURAL INCREASE	SALES	DEATHS KILLERS MISSING	TRANSFERS OUT	TRANSFERS IN	CLOSING	DEATHS
SHEEP		Ewes	Hoggets						
	Lambing %	131%	60%						
Lambs			2704	2,094	189	421			7%
Hoggets	421				16	405	421	421	4%
Two tooths	405				12	394	405	405	3%
M.A. ewes	1,490			314	80		394	1,490	5%
Rams	30	5			5			30	17%
TOTAL	2,346	5	2,704	2,408	301	1,220	1,220	2,346	
	Check	5,055			5,055				
CATTLE									
Weaners		256			5	250			
R1 bulls	250			248	2		250	250	2%
TOTAL	250	256	0	248	8	250	250	250	1%
	Check	506			506				

Class	**SU**	**%**
Sheep	3,009	63%
Cattle	1,787	37%
Total	4,797	100%
Stocking rate:	Per ha =	11.3

SHEEP & BEEF CATTLE FARM STOCK RECONCILIATION				For the period ending		June 30th			
Model:	Bull beef 24			**Effective Farm Area (ha)**		425			
STOCK CLASS	OPENING	PURCH.	NATURAL	SALES	DEATHS	TRANSFERS	TRANSFERS	CLOSING	DEATH RATE
	STOCK		INCREASE		KILLERS	OUT	IN		
					MISSING				
SHEEP		Ewes	Hoggets						
	Lambing %	131%	60%						
Lambs			2704	2,094	189	421			7%
Hoggets	421				16	405	421	421	4%
Two tooths	405				12	394	405	405	3%
M.A. ewes	1,490			314	80		394	1,490	5%
Rams	30	5			5			30	17%
TOTAL	2,346	5	2,704	2,408	301	1,220	1,220	2,346	
	Check	5,055			5,055				
CATTLE									
Weaners		213			3	209			1.5%
R1 bulls	209			137	3	69	209	209	1.5%
R2 bulls	69			69			69	69	0.0%
TOTAL	278	213	0	206	6	278	278	278	
	Check	490			490				

Class	**SU**	**%**
Sheep	3,009	63%
Cattle	1,805	37%
Total	4,814	100%
Stocking rate:	Per ha =	11.3

Appendix C: Summary of livestock ADGs in the feed budget and OVERSEER models (by scenario)

		ADG (kg/head/day)											
Model	**Stock class**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
NGB[8]	Weaner steers					1.00	0.84	0.94	1.20	1.18	0.49	0.58	
NGB[10]	Weaner steers					0.83	0.83	0.89	1.17	1.18	0.41	0.86	0.33
	R1 steers	1.32											
NGB[12]	Weaner steers					0.74	0.95	0.87	1.09	1.16	0.53	0.83	0.27
	R1 steers	0.96	1.44	0.39									
Bull[18]	Weaner bulls					0.74	0.88	0.94	0.88	1.01	1.08	1.21	1.01
	R1 bulls	0.81	1.08	1.15	1.35	1.48	1.41	0.98	0.94				
Bull[24]	Weaner bulls					0.55	0.65	0.70	0.65	0.75	0.80	0.90	0.75
	R1 bulls	0.60	0.80	0.85	0.90	1.00	1.05	0.73	0.70	0.85	0.95	1.00	0.75
	R2 bulls	0.70											
All models	Mixed age ewes	0.05	0.06	0.00	-0.10	-0.10	0.05	0.06	0.07	0.06	0.02	0.03	0.05
	Two tooth ewes	0.08	0.08	0.00	-0.10	-0.06	0.07	0.07	0.08	0.08	0.03	0.05	0.07
	Ewe hogget's	0.06	0.09	0.11		-0.02	-0.02	0.06	0.06	0.06	0.07	0.01	0.08
	Lambs					0.1	0.1	0.09	0.06	0.07	0.05	0.08	0.08
	Rams	-0.10	-0.11	-0.13	0.00	0.12	0.12	0.04	-0.01	0.01	-0.02	0.07	0.00

Appendix D: Summary of livestock numbers in the feed budget and OVERSEER models (by scenario)

		Average monthly stock number											
Model	**Stock class**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
NGB^{8}	Weaner steers					173	742	734	733	727	719	360	0
NGB^{10}	Weaner steers					133	572	572	572	572	566	560	555
	R1 steers	305											
NGB^{12}	Weaner steers					103	441	438	434	433	432	431	429
	R1 steers	429	428	457									
Bull^{18}	Weaner bulls					60	256	253	253	252	251	251	250
	R1 bulls	250	249	249	249	248	207	103	41				
Bull^{24}	Weaner bulls					50	213	212	211	211	210	210	209
	R1 bulls	209	209	209	208	208	208	207	207	207	206	172	103
	R2 bulls	34											
All	Mixed age ewes	1475	1471	1441	1412	1410	1210	1098	1490	1489	1484	1481	1478
models	Two tooth ewes	405	401	397	397	396	396	396	395	395	394	394	394
	Ewe hogget's	421	417	413	408	408	408	407	407	406	406	406	405
	Lambs					2362	2596	2570	2544	2021	1235	435	421
	Rams	29	28	28	27	27	26	26	26	25	25	25	24

In the OVERSEER model, stock numbers were adjusted by: 109%, 95%, 97%, 78% and 73% in NGB^{8}, NGB^{10}, NGB^{12}, Bull^{18} and Bull^{24} respectively, to give equal (±1 kgDM/ha/yr) pasture yield estimates, enabling fair comparisons. Mean lamb weaning date was 3rd November. Selective culling (based on age, conformation and teeth wear) of mixed age ewes occurred between November 1st and December 31st, and replacement ewes were aged up on February 1st prior to mating.

Appendix E: Livestock stock conversion ratios used in the feed budget models

Model	Stock type	Stock class	Annual feed intake (kgDM/ha)	Number of stock (Annual average)	Stock unit conversion[a]
NGB[8]	**CATTLE**	Weaner steers	1118486	349.0	5.2
NGB[10]		Weaner steers	1027317	342	4.8
		R1 steers	103386	25	6.6
NGB[12]		Weaner steers	788188	262	4.9
		R1 steers	268641	76	5.7
Bull[18]		Weaner bulls	527862	152	5.6
		R1 bulls	580347	133	7.0
Bull[24]		Weaner bulls	353648	127	4.5
		R1 bulls	754268	196	6.2
		R2 bulls	11162	3	6.3
All models	**SHEEP**	Lambs	495380	1182	0.7
		Hogget ewes	227427	409	0.9
		Two tooths	243512	397	1.0
		M.A. ewes	884672	1412	1.0
		Rams	14725	26	0.9

[a] - Assumed one stock unit consumes 620 kgDM/year (Woodford and Nicol, 2004).

Appendix F: Financial analysis assumptions

B+LNZ Farm Survey - $ Per Stock Unit Analysis Class 4 N.I. Hill Country - Taranaki-Manawatu	
Working expenses	**$ Per SU**
Wages	8.58
Animal Health	4.90
Weed & Pest Control	2.49
Shearing Expenses	6.61
Fertiliser	13.61
Lime	0.95
Seeds	0.68
Vehicle Expenses	3.29
Fuel	2.02
Electricity	0.83
Feed & Grazing	3.41
Cultivation & Sowing	1.31
Repairs & Maintenance	10.53
Cartage	1.46
Administration Expenses	2.50
Total Working Expenses	63.17

Sourced from B+LNZ (2018a).

National average market values of specified livestock 2018		
Type of livestock	**Classes of livestock**	**Average market value** ($ per head)
Sheep	Ewe hogget's	123.00
	Two-tooth ewes	179.00
	Mixed-age ewes	160.00
	Rising five-year and older ewes	142.00
	Breeding rams	289.00
Cattle	Rising-one-year steers and bulls	922.00
	Rising-two-year steers and bulls	1283.00

Sourced from IRD, (2018).

Appendix G: OVERSEER soil features and climatic assumptions

Soil water content model assumptions

	0-30 cm	30-60 cm	> 60 cm	
Wilting point (15 bar)	14	15	10	mm per 10 cm
Field capacity	36	33	28	mm per 10 cm
Saturation	54	47	44	mm per 10 cm

Soil profile

Profile drainage class	Well

Lower profile

Depth to impeded drainage layer	None
Maximum rooting depth	None

Top soil horizon chemical and physical parameters

Anion storage capacity (ASC) or phosphate retention (PR)	19 %
Bulk density	1090 kg/m³
Clay	20 %
Sand	30 %

Sub soil [average from 10 to 30 cm]

Subsoil clay	22 %

Soil type used in model was Manawatu silt loam (S-map reference: Waim_45a.1).

Model farm climatic condition