Final report

Scoping the development of high value beef production from dairy bulls using forage-based systems.

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Abstract

Rearing male dairy calves is not a common practice in Australia but has been successfully adopted overseas in dairy and beef production systems using grain and protein concentrates. There is a shortage of information about cost effective forage feeding systems that can be used in Australia to achieve target growth rates for male dairy calves to become a high value beef product. The desktop study conducted a literature review and investigated the cost: benefit of a range of current and potential feeding systems. There was limited published information regarding the nutritional requirements of male dairy breed calves and a lack of data available on the potential growth rates and subsequent carcass characteristics from forage-based feeding systems. The economic analysis clearly identified that forage-based systems have the potential to improve the gross margin and return on investment of dairy beef production systems for a range of Australian beef markets. The cost of calf rearing was also identified as a key barrier for achieving a profit. The economic analysis of eight feeding systems across a range of beef markets has clearly identified the production and economic potential of low-cost high-quality forage systems and the future RD&E needs for growing out male dairy calves.

Executive summary

Background

Rearing male dairy calves is not a common practice in Australia but has been successfully adopted overseas in dairy and beef production systems using grain and protein concentrates. There is a shortage of information about cost effective forage feeding systems that can be used in Australia to achieve target growth rates for male dairy calves to become a high value beef product. Dairy and beef producers have an opportunity to capitalise on a resource that is currently not entering or is exiting too early along the beef supply chain. The outcomes of this desktop study will guide the future RD&E strategies for Meat and Livestock Australia (MLA) and Dairy Australia (DA) in collaboration with the Department of Agriculture and Fisheries (DAF) for rearing male dairy calves on low-cost high-quality forage-based feeding systems.

Objectives

Three objectives were undertaken within this desktop study:

1. A review of the literature on growth rates and nutritional requirements of male dairy calves (bulls and steers) post-weaning.

2. *A comprehensive desk-top modelling study analysing the cost: benefits of feeding dairy bull calves post-weaning to meet a range of potential beef markets in Australia, with the economic analysis based on a sensitivity analysis of the economic returns across a range of current and potential future feeding systems.*

3. Development of three key recommendations for the development of strategies for the dairy and beef industries to add economic value to male dairy calves.

Methodology

The desktop study included two components: a literature review and an economic analysis. The literature review focussed on the nutritional requirements of male dairy calves pre and post weaning and any published growth rate data across a range of feeding systems. The review was also expanded to identify the potential markets available for a dairy beef supply chain plus some of the key management strategies that will need to be considered as part of that supply chain development. The economic analysis identified the cost of production associated with growing male dairy calves across a range of feeding systems to meet the market specifications of five potential beef supply chains. A sensitivity analysis of growth rate versus market prices was used to identify the impact on gross margin and return on investment.

Results/key findings

The literature review identified a limitation in published information regarding the nutritional requirements of male dairy breed calves from birth to maturity, and there was a lack of data available on the potential growth rates and subsequent carcass characteristics from forage based feeding systems. There was sufficient information available regarding grower-finisher systems based on high concentrate feeding in feedlots.

The economic analysis clearly identified that forage-based systems have the potential to improve the gross margin and return on investment of dairy beef production systems for a range of Australian beef markets. The cost of calf rearing was also identified as a key barrier for achieving a profit.

Benefits to industry

The economic analysis of eight feeding systems across a range of beef markets has clearly identified the potential of low-cost high-quality forage systems for growing male dairy calves. These results will guide an RD&E strategy for the development of cost-effective dairy beef production systems in northern Australia, which will have flow on benefits in animal welfare and consumer perception for both the Australian dairy and beef industries.

Future research and recommendations

Future research and development into dairy beef production systems needs to focus on the following key areas:

- Nutritional requirements of male dairy breed calves pre and post weaning.
- Pre-weaning management strategies to reduce male calf rearing costs on dairy farms.
- Define the growth path of forage and concentrate based feeding systems and the impact of a compromised or accelerated growth path pre and post weaning.
- Develop and implement low-cost high-quality forage-based systems and define the growth rates, carcass characteristics and financial performance of each system.
- Effect of cross breeding on health and welfare, performance, and carcass characteristics, particularly with tropically adapted beef breeds.
- Define the environmental emissions from a range of dairy beef feeding systems.
- Long term analysis on the economic viability of dairy beef production systems.

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1. Background

The Australian dairy herd produces approximately 1 million calves per year with approximately half of those being female calves reared as replacement heifers. Though sexed semen technology is available in Australia, its adoption remains at about 10% of the total semen in the market, probably due to higher cost, lower conception rates and limited availability. Currently, approximately 400 000 male calves exit the value chain within 10 days of being born, either on farm or by abattoir. This creates concern for the consumer and general population in how young animals are managed and why alternatives such as being redirected into a productive and profitable red meat supply chain are not viable. Although male dairy calves can be considered a by-product of the milk industry with a low economic value, rearing them can be a profitable alternative. Rearing all male calves to 280 kg LW has the potential to increase beef calf stocking numbers by 26% and produce 56 000 tonnes of beef valued at over $162 million AUD. In Qld and northern NSW, where there are approximately 500 dairy farms that produce ~36 000 male calves per year, it would represent approximately 5 000 t of beef per year (valued over $20 million AUD). An opportunity exists to improve economic returns for both the dairy and beef industries nationally through the development of forage systems to achieve increased growth rates and margins for male dairy calves reared to meet a range of beef market requirements (including the high value MSA graded beef).

Rearing male dairy calves is not a common practice in Australia but has been successfully adopted overseas in dairy and beef production systems using grain and protein concentrates. There is a shortage of information about cost effective forage alternatives that can be used in Australia to achieve target growth rates for bull calves, either as castrated or entire males, to become a high value beef product.

Existing reports have identified the potential of entire bulls for high value markets (Fitzpatrick, 2014), Friesian steers in grain fed feedlot value chains (McAuliffe, 2017) and improved forages in beef systems (Bowen *et al*., 2015). Improved forage systems have the potential to improve productivity and gross margins on-farm. This activity will apply this approach to a scenario with *Bos taurus* type dairy (Holstein and Brown Swiss) bull calves with a very high genetic merit for growth. Fitzpatrick (2014) demonstrated that young entire beef males fed grain for 75 days achieved a higher gross value of approximately $52/head when compared with castrated beef males. There is potential to improve this with high genetic merit Holstein or Brown Swiss male animals. Entire male calves fed grain have also been reported to have higher growth rate compared with castrated males and have the potential to enter the MSA grading system at a younger age, therefore decreasing time to finishing and increasing the number of animals processed per year. The cost of grain, particularly during drought conditions, has a diminishing effect on margins. There is the potential to achieve high growth rates on high quality forage systems that will improve margins and turnoff rates using entire males or castrated males. Market opportunities for Friesian steers through feedlots have also been reported, but a consistent supply of male steers at target weight will be required to achieve market longevity.

Dairy and coastal-based beef producers in northern Australia, both of which are MLA levy payers, have an opportunity to develop and implement forage systems to grow out dairy bull calves to meet a range of Australian beef markets.

2. Objectives

This scoping study will define the potential of a dairy beef supply chain based on the development of forage-based production systems. The potential of this market will also be assessed using cost benefit analysis for rearing dairy bull calves post weaning for the Australian beef markets (domestic and overseas). The scoping study will provide (confidential) information for MLA, DAF and DA for identifying further R&D investment opportunities that will assess low-cost high-quality forage systems and their potential to achieve target growth rates and consumer acceptance.

The study will have three main outcomes:

1. Compile a review on growth rates and nutritional requirements of male dairy calves (bulls and steers) post-weaning to achieve target growth rates for Australian domestic and export beef markets.

2. Report on a desk-top modelling study (forage yield and growth rate responses to forages) including the economic analysis of the cost: benefits of feeding dairy bull calves post-weaning to meet a range of potential beef markets in Australia. The economic analysis will comprise of a sensitivity analysis of potential economic returns using system diet costs vs variable growth rates and their impact on system gross margins.

3. Provide recommendations for the development of strategies for the dairy and beef industries to add economic value to male dairy calves, with the aim of addressing issues on animal welfare, improving consumer perception and mitigating risks identified in Meat Industry Strategic Plan (MISP) 2020 for the beef and dairy sectors to remain sustainable, productive and profitable and continue to be supported by Australian consumers.

3. Methodology

3.1 Literature review

3.1.1 Introduction

Utilising male dairy calves is a facet of the dairy industry that is becoming increasingly important in relation to animal welfare and consumer concerns whilst potentially providing an alternative income source on Australian dairy farms with up to 500,000 male dairy calves born each year. Internationally, in the USA, dairy beef contributes up to 10% of the national beef herd and is responsible for one-third of the nation's prime grade beef (Hanson, 2020). Research in the area of male bobby calves has been conducted since the 1960s indicating that this has been highlighted as an area of interest for many decades, however there does not seem to be clear guidelines or solutions to this issue for the Australian industry. Given the genetic selection within the Holstein Friesian breed that has selected for consistency and high production in terms of milk yield and quality, the population within the breed has the potential to be homogenous in terms of carcass quality if management is optimised (Schaefer, 2005). This presents an opportunity for the dairy industry to create a marketable product and diversify across both dairy and beef industries.

The aim of this literature review is to compile information related to the growth rates and nutritional requirements of male dairy calves post-weaning to achieve target growth rates for the Australian domestic and export beef markets. The following key areas relevant to dairy beef production systems will be examined including current markets for dairy beef, the period from birth to weaning - focussing on calf rearing and rations, and the weaning to finishing period - nutrient requirements

for growth, diet and performance, management practices (castration and hormonal implants), genetics, sexed semen and carcass quality.

3.1.2 Markets

3.1.2.1 Australian beef industry

The Australian beef industry is currently valued at $11.4 billion per annum and Australia is the second largest exporter of beef products in the world, exporting to more than 100 countries. The products are exported as chilled and frozen beef consisting of both high-quality cuts and manufacturing grade products. In 2017 - 2018, Australia exported 1.1 million tonnes of beef valued at $8 billion with a similar quantity exported in 2018 - 2019 with the majority of the products destined for Japan, USA and South Korea (Sustainable Beef Industry, 2019).

African Swine Fever has had a major impact on the global meat market with an increase in Chinese import demand inflating prices across all proteins in 2019. This increase in demand has seen many exporting nations take advantage of the situation leaving many traditional markets with a supply deficit. The increased demand for red meat combined with a diminished herd arising from drought conditions has had a notable impact on the beef industry in terms of availability of high-quality products in Australia. In the MLA global snapshot for beef it was stated, "In many mature markets, growing consumer interest and awareness of provenance, sustainability, animal welfare, food safety and traceability provide messaging opportunities for Australian beef brands and underpin ambitious industry-wide programs for Australia to differentiate itself" (MLA, 2020). There is clear opportunity for Australia to expand its presence in the market and the dairy industry is primed to take advantage of this with the bull calves an excellent source of protein and an alternate source of income for dairy farmers. The dairy industry has excellent traceability, a trait that is highly valued in the international market.

The specifications for each of the Australian red meat markets are outlined in Figure 1. The domestic red meat market is the largest single market at 29% of the total market (Sustainable Beef Industry, 2019). Beef from dairy breeds is generally lean with palatability and tenderness, a quality highly regarded by the Australian red meat market, allowing dairy beef access to the domestic market. Within the domestic market there is often a requirement that cattle to be short fed in a feedlot for finishing for 60 – 70 days. This finishing method may be suitable for dairy breeds that have been backgrounded on a high-quality ration and require minimal finishing prior to processing. The desired qualities for the domestic butcher market are minimal fat cover (P8 fat depth 4-5 mm) and 0 - 2 teeth at processing, making dairy beef a very attractive product for this market. Dairy beef is also highly suitable for the restaurant market where there is a preference for lean, tender meat.

In regard to the chilled and frozen grain fed red meat export market dairy beef would meet the specifications for the majority of the grain fed markets if the desired fat cover (P8 fat depth 4-5 mm) and marbling is achieved. Dairy beef may struggle to meet the specifications for the grass-fed market as the required fat cover may not be achieved given the carcass weight restrictions, and combined with potentially lower growth rates these animals may not reach market specifications unless supplementation with a concentrate is utilised (Catrileo *et al.*, 2014; Utama *et al.*, 2018).

Backgrounding is a procedure that occurs prior to feedlot entry and allows the cattle to become adjusted to a penned arrangement, bunk feeding and feedlot rations and is generally the period between weaning to 200 kg liveweight (LW). Dairy breed animals will enter Australian feedlots at 200 kg LW post-backgrounding and will commence on a commercial feedlot ration. Often the animals are then be fed for up to 150-200 days on a high energy diet until slaughter at 450 – 500 kg LW. There is an opportunity for Australian dairy farmers or beef farmers looking to diversify to background dairy breed cattle for the feedlot market raising calves from birth and/or weaning to 200 kg LW on a high quality ration on farm and consign the cattle directly to a feedlot.
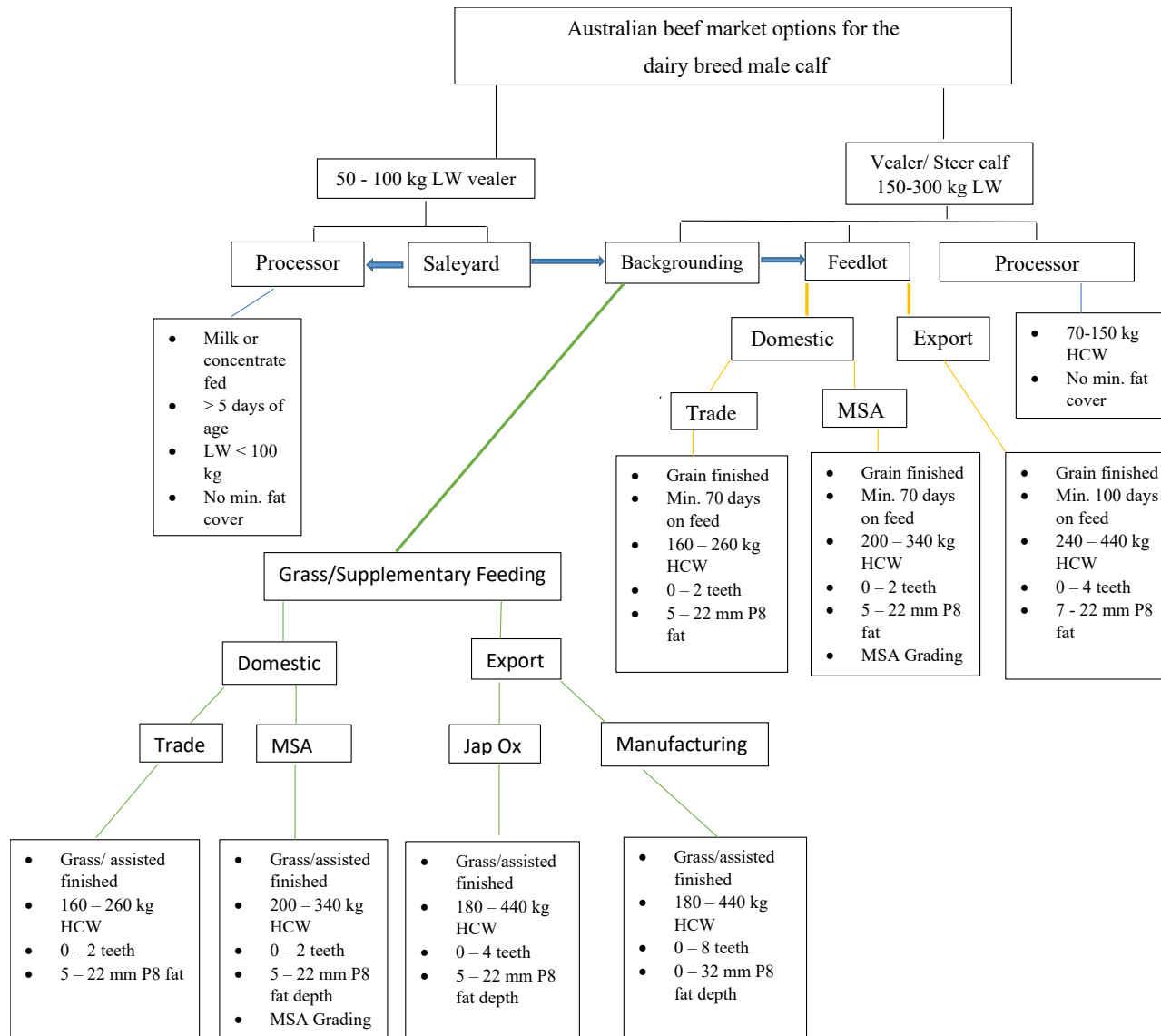
Figure 1. Australian beef markets and potential target markets for dairy beef production systems.

3.1.2.2   *Overseas beef industry*

When examining market options for dairy beef, the USA market as shown in Figure 2 is an established supply chain using male dairy calves and provides an indication of the possibilities that can be explored within the Australian markets.

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│processor│ │ fed veal)    │ │ raised veal) │    │ Exit 480 -540 │
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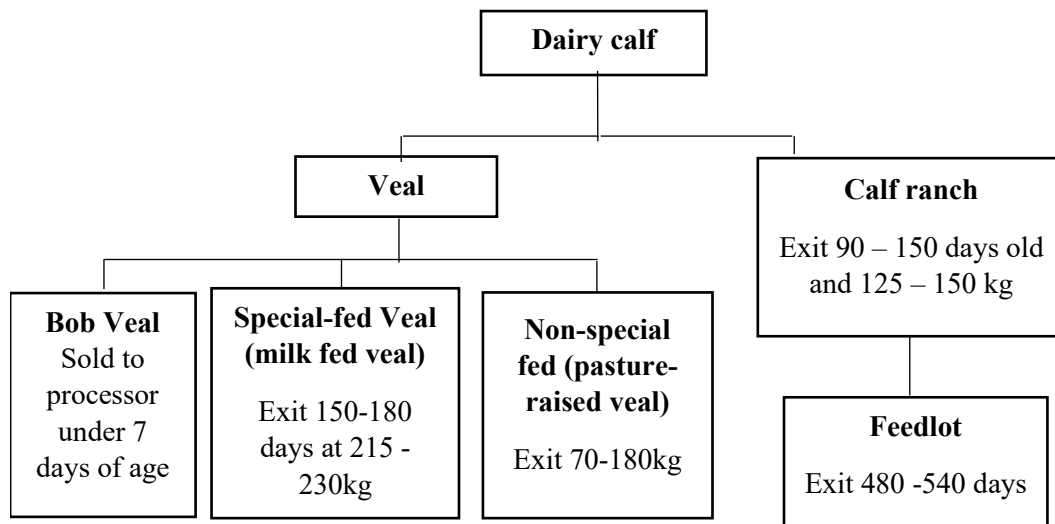
Figure 2. USA markets for dairy beef (Dairy Australia, 2018)

3.1.2.2.1   Veal

The USA veal market can be classified into three distinct markets; special-fed (milk fed veal), non-special fed (pasture raised) veal and bob veal.

Special-fed veal calves are fed a nutritionally balanced milk or soy-based diet. The iron levels are carefully monitored to achieve a standardised end-product and include housing the calves in wooden pens to prevent any iron consumption from metal pens rails. The restricted iron level allows the meat to maintain a light pink colour that is characteristic of veal. The majority of veal calves in the USA are special-fed calves. Non-special fed calves are generally fed a variety of diets which will include milk replacer, grain, and forages. Calves that are fed by this method are generally marketed at lower liveweights. Bob veal calves are calves that are too light in weight or unsuitable for rearing. This method lacks consistent regulation and monitoring. Calves often are transported long distances for processing and are slaughtered under seven days of age. The resultant product is of poor quality and contributes to 15% of all veal production (Dairy Australia, 2018).

3.1.2.2.2   Calf ranch or feedlot

Calves raised under this method will arrive at 'ranch' as young calves to be reared on milk for 60 - 70 days. The calves will be fed milk at a rate of 10 - 15% of LW with the range of total solids at 11 - 15% with feeding of solids above 16% deemed to non-profitable. The calves are castrated at 1 - 30 days of age by banding or physical cutting. The calves will then be weaned and fed on a backgrounding ration for another 60 - 70 days with rations consisting of pellets, grain, cotton trash, corn, and short stalk hay. The protein content of the rations will be within the range of 21 - 23%. The calves will then move to a feedlot with the average time for the animals to spend within a feedlot is approximately 360 days (340 – 380 days range) and marketed at an age of 15 - 18 months. The application of hormonal growth implants is regular practice with acetate and oestradiol as the most common implants used. Beta-agonist ractopamine is often fed within the last month of feeding to increase growth rate, feed efficiency and meat quality (ribeye area and yield). Some calves may be backgrounded on the dairy farm and bypass the ranch phase of the chain (Dairy Australia, 2018).

It is estimated that over half of the volume of beef that is consumed by USA citizens originates from dairy bred animals. Consumers tend to be ignorant of this fact. Dairy beef has traditionally been discriminated against by processors worldwide due to a lower carcass yield, poor muscling and dressing percentages compared with 'native' beef. Despite this, dairy beef has the capacity to achieve high quality grading due to increased intramuscular fat. Dairy carcasses also produce smaller ribeye area providing a smaller steak that is desired in some markets. Unfortunately, on a liveweight basis, dairy beef carcasses yield less than native beef on a hot carcass weight basis due to the naturally larger gastro-intestinal tract and organs of the dairy breeds. Generally, dairy beef carcasses meet the Prime or Choice, the higher quality grade, 70 - 75% of the time with the remaining carcasses meeting the Select grade, similar to the Australian supermarket grade (Dairy Australia, 2018).

3.1.2.2.3   Grading systems

In an attempt to increase the uniformity of beef from dairy origins, USA processors have begun to implement guidelines in relation to minimum and maximum carcass weights and grading specifications. The dairy specific grids are similar to the beef grids and also include a minimum longissimus muscle area or width requirement. The majority of calf-fed Holstein steers are placed on forward contract that stipulates the steers must be fed a diet containing a maximum of 10% roughage for a minimum of 10 months. Some processors have also implemented height restrictions to reduce the incidence of overly heavy and lengthy dairy breed carcasses (Lehmkuhler & Ramos, 2008).

Currently Australia lacks a specific grading system that targets the distinct carcass characteristics of the dairy beef animals. Research is currently in progress to revolutionise the grading system specifically for the dairy animals. This will change the way dairy beef is marketed in the domestic and international markets, making dairy beef a more consumer friendly and marketable product (Macdonald, 2019). Butt shape and fat cover are essential when grading beef products and penalties are applied when specifications are not reached. However, in a dairy breed carcass these parameters are often not met even though the beef is of a high quality with lack of butt shape common to all pure dairy breeds. A dairy specific grading system needs to take account for the lack of butt shape, minimal fat cover and lengthy and heavy carcasses that are often seen in a traditional dairy breed. The grading system needs to acknowledge that even though dairy beef does not meet native beef specifications, the meat is of outstanding quality and is highly appealing to the domestic and export red meat markets.

3.1.3   Preweaning nutritional requirements

The birth to weaning phase is the period from birth to 10 weeks of age. This can be a challenging phase for the young dairy calf with health concerns including digestive issues and viral and disease challenges frequently impacting performance. Housing arrangements and dietary adaption can predispose calves to health issues and is an ongoing concern for the dairy industry. This review is focussed on the weaning to finishing phase of the male dairy calf however, a summary of two pertinent issues surrounding calf rearing and its impact on the viability of the dairy beef system will be discussed.

3.1.3.1   *Feeding - milk*

Common industry practice involves removing calves from the dam within hours of birth and raising the calf on milk replacer or whole milk. This milk product will provide the calf with adequate nutrition for the first 8 – 10 weeks of life when combined with a concentrate or calf ration. Raising calves on milk replacer from birth to weaning can be an expensive and laborious task with twice daily feeding, health considerations and associated husbandry activities. To improve calf management and reduce costs, milk feeding can be altered to once daily. Initially calves will require twice a day feeding, but this can then be consolidated into one milk feed by 14 days of age (Kehoe *et*

al., 2007). Calves fed once daily in an experiment conducted by Willett et al (1969) found no significant differences in liveweight, heart girth and wither height compared with calves fed twice daily. The calves fed once daily did not await feeding when the twice daily fed calves were fed in the afternoon (Willett *et al.*, 1969). Calves fed once daily gained 0.118 kg less liveweight than twice daily fed calves at five weeks of age, however by seven weeks of age the once daily fed calves gained weight at a faster rate in experiments conducted by Ackerman *et al.* (1969).

An alternative to whole milk or milk replacer is suckling the calf on a foster cow with 1 - 3 calves/cow. It was determined by Everitt et al (1978) that calves produced under a suckling system were frequently heavier than those raised by an artificial rearing system, with suckling calves an average of 18.7 kg heavier at 12 weeks of age than artificially raised calves. Raising calves using a suckling system has other benefits including reduced mortality (Everitt *et al.*, 1978) and a reduction in costs in relation to milk replacer and related feeding equipment/infrastructure.

3.1.3.2   Feeding - rations

Calves will begin consuming small quantities of roughage or fibre from day 3 of life with feeds such as hay, grain and pellet mixes commonly fed (Dairy Australia, 2011). Fibre is an essential food source for young calves and can be attributed to improvements in rumen health. It has been claimed that unground diets with longer fibre length roughage can assist with rumen health by increasing rumen pH (Beharka *et al.*, 1998). The feeding of low energy fibrous feeds such as texturized coarse calf starters can inhibit calf performance (Hill *et al.*, 2008). Texturized calf starter diets may be consumed in larger quantities compared with pellet diets, which may increase rumination time and cause a resultant decrease in feed efficiency (Terré *et al.*, 2013).

Calves supplemented with forage from day 15 of age had higher feed intake when compared with calves supplemented with forage from day 3, arising from a more metabolically developed rumen in the older calves in a study conducted by Wu *et al.*(2018). The cellulolytic capacity of the young calf's rumen is limited in early life as the cellulolytic bacteria cannot proliferate in sufficient numbers to allow for significant fermentation in the initial 10 weeks of life. The rumen tissue weight and the proportion of this organ to the gastrointestinal tract was numerically greater in calves fed a calf starter with no supplementary forage compared with calves fed chopped oat hay. This suggests the feeding of a concentrate in early life can promote physiological development of the rumen and anatomical development of the omasum. The calves fed concentrate only had a higher incidence of diarrhoea and an elevated abundance of Clostridium in the rectum compared with the forage supplemented calves, questioning the overall rumen health and well-being of the concentrate only fed calves (Wu *et al.*,2018).

Feeding only calf starter meal will reduce rumen pH, decrease rumen motility, and may cause hyperkeratinisation and clumping of rumen papillae (Castells *et al.*, 2012). Feeding appropriate roughage in diets will stimulate the muscular layer of the rumen, promote rumination, enhance rumen wall integrity, and reduce behavioural issues (Castells *et al.*,2012). Castells *et al.* (2012) determined that feeding chopped grass hay with a 18% neutral detergent fibre (NDF) calf pellet improved the overall dry matter intake (DMI) and growth rates of the calves. Similarly, Thomas and Hinks (1982) concluded that the inclusion of 180 g of straw per kilogram of pelleted starter ration improved the overall performance of calves compared with calves fed pellets and straw separately. Terré *et al.*, (2013) claimed that calves fed a diet supplemented with forage had increased DMI and average daily gain (ADG), including increased crude protein (CP) and NDF intake compared with calves with no forage supplementation. Holstein heifer calves fed a higher energy diet (80% barley grain and 20% chopped alfalfa) (3.0 Mcal/kg) gained weight at a higher rate compared with calves fed a higher forage to grain ratio (ad-lib alfalfa hay and 1.8 kg grain/day) (2.7 Mcal/kg) with an ADG of 0.89 kg/day and 0.78 kg/day respectively (Gardener *et al.*, 1988).

End products that arise from the fermentation of the calf starter feeds within the rumen are largely butyrate and propionate. Butyrate is a volatile fatty acid (VFA) that stimulates significant growth of rumen mucosa papillae (Castells *et al.*, 2012). Combining a starter feed, forage, and milk within the calf diet will enable the calf to develop a healthy rumen that will enable the calf to be weaned earlier than the conventional 8 – 9 weeks of age. Calves can be weaned as early as 3 weeks of age, although there can be some difficulty in the calves accepting the dry feed (pellets) compared with calves of 5 weeks of age (Winter, 1978; Kehoe *et al.*, 2007). Kehoe *et al.* (2007) found that 3 week old calves ate less than 6 week old calves pre and post weaning (1.19 kg DM/day vs 2.43 kg DM/day), however Winter (1985) claimed there were no differences in ADG, and DMI in calves weaned at 3, 5 and 7 weeks of age. In the same experiment conducted by Kehoe *et al.* (2007), it was determined that there were no differences in rumen papillae length and width and growth measurements (liveweight, wither height, hip height) between calves weaned at 3, 4, 5 or 6 weeks of age.

Despite the lack of differences in performance and health, early weaning and once per day feeding of calves can require more attention and management, so this needs to be considered when making any management decisions. If costs can be reduced pre-weaning whilst maintaining animal health and welfare, this has the capacity to increase the viability of the overall system.

3.1.4   Post weaning management

The post weaning phase will usually occur from the age of 10 weeks until the targeted body condition, liveweight and/or market outcome is reached. Markets for dairy bull calves include backgrounding for feedlots or sale directly to a processor, servicing a range of market options. During this phase of growth there are many factors that can influence animal performance and profitability of the system. In order to understand the factors that impact this system the following areas will be reviewed; nutrient requirements for growth, diet and performance, management practices (castration and hormonal implants), genetics and sexed semen and carcass quality parameters.

3.1.4.1   Nutrient requirements for growth

There is a large quantity of information available in relation to nutrient requirements and feeding guidelines for growing beef cattle and dairy heifers and cows, however relevant information for dairy breed bulls and steers is limited. Guidelines for dairy heifers and beef cattle can be adapted for dairy breed bulls and steers with discretion. The applicability and outcomes of these guidelines may vary given the variance in response of dairy breed males in terms of biological differences and metabolic capacity.

Holstein Friesian cattle have a greater dietary energy requirement than beef breeds in general for maintenance, let alone for production. The energy requirement for liveweight gain will increase in line with increased liveweight and age/maturity resulting from the changes in the relative proportions of fat, protein, and water per unit of tissue gain. The energy required to deposit fat is almost double the requirement to deposit protein, therefore as the level of fat increases with age/maturity, more energy is required per unit of tissue gained. It has been determined that dairy breeds have at least 15% higher maintenance requirements compared with beef breeds due to the larger more metabolically active internal organs and fat deposits (omental and mesenteric fat) to allow for greater lactation requirements (NRC, 2000). The larger liver and digestive tract in a dairy breed animal are a major element in the elevated maintenance energy requirement of these animals (Schaefer, 2005).

When predicting growth rates and formulating diets, macro nutrients such as energy and protein, are considered as points of reference with macro minerals considered when targeting specific areas of nutrition.

3.1.4.1.1   Macro minerals

Macro minerals are essential for growth and development with deficiencies presenting as poor growth and appetite in the young calf. Calcium is essential for bone development and muscle function and phosphorus is essential for bone development and energy metabolism (Moran, 2005). Phosphorus plays a critical role in teeth and bone building, fat, carbohydrate, and protein metabolism and for efficient utilisation of feed products. The feeding of a phosphorus supplement to deficient cattle can increase feed intake by 10 – 60% (MLA, 2012). Magnesium, sodium, and potassium are essential electrolytes that should be included in a calf diet to minimise digestive issues, including scouring. Deficiencies in the major minerals mentioned are rare in calves artificially raised on milk replacer, however deficiencies can arise when calves are weaned onto diets deficient in these minerals causing a restriction in growth rates. For a 200 kg dairy breed calf to grow at a rate of 1 kg/day, the daily mineral requirements are 24 g calcium, 13 g phosphorus and 6 g magnesium. If levels of the minerals are restricted, growth rates will be notably comprised (Moran, 2005).

3.1.4.1.2   Macro nutrients - Metabolisable energy and protein

The nutrient requirements of cattle change as they increase in age, liveweight, body condition and target weight gain. Table 1 specifies the daily nutritional requirements of weaned dairy breed calves at 100 kg LW at varying levels of gain. Maintenance requirements for a weaned calf at 100 kg LW (0 g/day gain) is 1.25 kg DMI, 15.2 MJ metabolisable energy (ME) and 90 g CP. Whereas, at 100 kg LW and 900 g/day gain the DMI increases to 2.84 kg, ME increases to 34.4 MJ and CP to 430 g, over double the maintenance requirements (NRC, 2001).

Table 1. Daily nutritional requirements (dry matter intake (DMI, kg), metabolisable energy (ME, MJ) and crude protein (CP, g)) of weaned dairy breed calves (NRC, 2001).

Liveweight (kg)	Gain (g/day)	DMI (kg/day)	ME (MJ/day)	CP (g/day)
	0	1.25	15.2	90
	600	2.22	27.0	316
100	700	2.42	29.4	354
	800	2.63	31.9	392
	900	2.84	34.4	430

Specific nutrient requirements for weaned dairy breed males are not available therefore nutrient requirements of heifers will be discussed. Table 2 below provides an indication of the ME, CP and DMI values required to grow at a rate of 1 kg/day. Feed intake will also increase in line with liveweight and it is expected that dairy breed males will consume 2.5 – 3 % of liveweight. With regard to heifer nutrient requirements, ME requirements increase and CP decreases as liveweight increases; protein is required for frame growth and development and energy is required for milk production. This can also be applied to dairy breed males as frame development is required at lower liveweights and younger ages and fat and muscle deposition is required as the animal increases in liveweight and approaches finishing. A finishing diet high in ME will contribute to liveweight gain and improved body condition and fat cover. Energetic efficiency is inversely related to the energy utilised for protein synthesis. Protein synthesis requires up to 0.19 MJ of ME/g of protein synthesised, whereas fat synthesis only requires 0.04 MJ of ME/g of fat, making the ME more efficient for fat synthesis (Comerford *et al.*, 1992).

Table 2. Daily nutritional requirements (metabolisable energy (ME, MJ), and crude protein (CP, %) of heifers %) of heifers at a liveweight range 100 – 600 kg with an average daily gain (ADG) rate of 1.0 kg/day (Dairy Australia, 2013).

Liveweight (kg)	ADG (kg/day)	Maintenance ME (MJ ME/day)	Growth ME (MJ ME/day)	Total ME (MJ/day)	CP (%)
100	1.0	17	20	37	17
150	1.0	24	23	47	17
200	1.0	29	27	56	17
250	1.0	35	30	65	15
300	1.0	40	33	73	15
350	1.0	45	36	81	14
400	1.0	49	40	89	14
450	1.0	54	42	96	14
500	1.0	58	45	103	14
550	1.0	62	45	108	14
600	1.0	67	45	112	14

Nutritional requirements for large frame beef breed steers are presented in Table 3 as a comparison for the information presented on dairy breed heifers. From the information presented in Table 3, as liveweight and daily gain increase the requirements for DMI, protein and energy increase. It also needs to be noted that at a lower liveweight (227 kg), the requirement for protein is higher and will increase in line with increases in daily gain and the higher DMI of the larger 454 kg steer. The point to note is that the nutrient requirements outlined in Table 2 are for dairy breed heifers, where additional protein required for frame development is essential. Therefore, rearing male dairy calves with heifers and according to heifer guidelines may be having a negative impact of the performance and profitability of the male calves if used for beef markets. Also, a pertinent question is do male dairy calves have a similar nutritional requirement to large frame beef breeds or has their genetic selection over time resulted in an animal with intrinsically higher nutrient requirements for maintenance and production?

Table 3. Daily nutritional requirements (dry matter intake (DMI, kg), protein (kg, %), metabolisable energy (ME, MJ/kg), net energy for maintenance (NEm, MJ/kg), net energy for gain (NEg, MJ/kg),and protein (CP, kg, %) of large frame beef breed steers (Perry, 1995).

Liveweight (kg)	Daily gain (kg)	DMI (kg)	Protein (kg)	Dietary protein (%)	Dietary ME (MJ/kg)	Dietary NE_g (MJ/kg)	Dietary NE_m (MJ/kg)
227	0.908	6.3	0.713	11.4	9.6	5.9	3.5
227	1.589	6.2	0.908	14.7	11.7	7.9	5.2
454	0.908	10.5	0.898	8.6	9.6	5.9	3.5
454	1.589	10.4	1.016	9.8	11.7	7.9	5.2

Diet can be manipulated to enable fat deposition and limit frame growth in dairy breed cattle. Diets high in energy (ME > 12.0 MJ/kg; NEg > 6.3MJ/kg) have the capacity to enable fat deposition. By managing diet from an early age, intramuscular fat deposition (marbling) and rapid and efficient growth can be enabled, although energy will still be partitioned to subcutaneous fat deposition. Carcass leanness can be increased by restricting energy intake through methods such limit feeding; however, this can reduce the rate of gain, increase the time taken to reach market weight and decrease marbling scores. There is evidence to suggest that glucose provides 50 – 75% of the acetyl units for *in vitro* lipogenesis in the subcutaneous fat depots. It may then be presumed that increasing blood glucose may increase intramuscular fat deposition without impacting subcutaneous fat deposition (Schoonmaker *et al.*, 2004).

3.1.4.2   *Feeding management*

There are numerous methods of feeding cattle with rations formulated to achieve desired growth rates and growth phases. In the USA, the feeding of Holstein steers is a common practice with feedlots stocking many of these animals, especially during drought conditions when the availability of beef stock can become scarce. At Wildorado, approximately 40km west of Amarillo on the Texas Panhandle, this feedlot is home to ~ 25,000 Holsteins in its 50,000 head facility. The Holsteins are fed three times daily on a ration of cotton seed, steam flaked corn, and a mixture of wet and dry distillers grain with a micro-mixing machine used to add specific nutritional and performance additives to the ration. Over the final 21 days of the feeding program a high-performance growth enhancer is used. This helps to finish off the carcass to give a high-quality carcass. Mr Deyhle of Wildorado claims that the Holstein steers are slower growing, bigger animals and they are feeding to overcome the frame of the animal, aiming to produce a 635kg LW at finishing (Phelps, 2013).

Holstein calves will typically enter the feedlot at weights as low as 115 kg LW and will generally be fed for a period of greater than 300 days (Torrentera *et al.*, 2017). Kang *et al.* (2005) fed Holstein steers for 540 days from an age of 7 – 24 months with the steers commencing at a liveweight of 196.9 ± 25.2 kg and finishing at 770.0 ± 54.3 kg with a carcass weight of 461. 1 ± 475 kg and 6.9 ± 3.6 mm of back fat.

According to an article in Dairy Herd Management on calf fed Holsteins in the US, dairy breed calves have the capacity to consume high energy diets from an early age and are not required to go through a grower phase and develop a frame, unlike beef breeds. Feeding a high energy diet allows dairy breed animals to develop muscle and fat despite the rapid frame growth that is typical of these animals. Dairy steers can be fed a high energy diet from a liveweight of 100 kg with 62 – 65 Mcal NEg /cwt.DM (259 – 272 MJ) is the ideal energy content for a finishing ration, finishing at a LW of 600 – 700 kg (Hanson, 2020).

The intensive feeding of energy dense diets typical of finishing rations that are generally high in starch and low in forage can increase the risk of digestive upsets and impact overall performance. This can be enhanced in Holsteins due to their genetically enhanced gut capacity, which can lead to wider variation in voluntary feed intake and metabolic issues including bloat, acidosis and liver abscesses and should be considered when formulating diets for dairy breed cattle. Many finishing diets are corn based and high in readily fermentable non-structural carbohydrates (64 – 66% DM). By decreasing the level of non-structural carbohydrates, the risk of digestive upsets can be minimised. If the level of forage in the diet is increased and starch is decreased in both growing and finishing diets, energy intake may be reduced, limiting performance and growth. Diets need to be formulated to allow for adequate energy levels for growth and sufficient forage and fibre to minimise digestive upsets (Ramos-Aviña *et al.*, 2018).

Feeding systems that are utilised to grow and finish dairy breed cattle can be generalised to two common systems, a growing – finishing system with varying levels of forage and concentrate, and a forage system.

3.1.4.2.1   Growing-finishing systems

The feeding period can be divided into two phases; growing and finishing, with rations altered to cater for different nutritional requirements or specifications within each phase. Di Constanzo (2005) reported that within a two-phase growing and finishing system, the forage proportion of the growing diet needs to be less than 55% to allow for viable performance. Holstein steers that were fed a high forage diet (> 55% DM) during the growing period were not able to recover performance with higher DMI/kg gain ($P < 0.05$) in the finishing period.

Increasing the proportion of alfalfa hay in growing-finishing diets decreased efficiency (feed:gain and ADG) and carcass quality (marbling, fat depth and quality grade). Cattle fed a diet with 75% alfalfa hay content in growing and finishing had an ADG of 0.91 kg/day and feed:gain of 7.83 kg DM/kg gain, whereas cattle fed 75% alfalfa hay in growing and 9% in finishing had an ADG of 1.21 kg/day and feed:gain of 6.43 kg DM/kg gain (Miller *et al.*, 1986).

Kang *et al.*, (2005) partitioned the feeding period for Holstein steers into 3 distinct phases with a diet specific to each phase with an average DMI across the 540-day feeding period of 12.73 kg/day (with 26% roughage content). Diets were fed according to age rather than condition which may impact the efficiency of the diet depending on the individual growth rates within the cohort. The grower ration contained the highest fat and protein content, followed by the fattener and finisher rations. The steers finished well under this feeding regime with a dressing percentage of 60.8%, back fat thickness of 6.9 mm and rib eye area of 88.8 cm2. Table 4 below shows the chemical composition of each diet.

Table 4. Chemical composition (dry matter, %, crude protein, %, crude fat, %, crude fibre, %, ash, %) and total digestible nutrient (TDN) value of experimental diets fed to Holstein steers (Kang *et al.*, 2005).

Feed name	Dry matter %	Crude protein %	Crude fat %	Crude fibre %	Ash %	TDN
Concentrates						
Grower (7-12 months of age)	87.7	14.5	3.50	6.30	6.60	71.0
Fattener (13-18 months of age)	86.6	12.2	3.20	6.60	5.70	72.3
Finisher (19-24 months of age)	86.7	11.2	2.80	5.80	5.10	74.0
Roughage						
Rice straw	88.0	4.50	2.20	28.30	15.10	37.50

Altering the dietary net energy level and reducing roughage in the diet as days on feed progressed did not affect the performance of Holstein steers with clear consistency in the performance outcomes in terms of intake and carcass aspects between the dietary treatments ($P > 0.05$) (Table 5) (Lehmkuhler & Ramos, 2008). The low backfat thickness exhibited by the animals on both dietary treatments may be attributed to low net energy levels across all feeding phases. Justification for lack of difference between the diets may be related to compensatory gain of the HIGH treatment in the finishing period with a higher ADG (1.41 vs 1.38 kg/day) when finished on a common low roughage finishing diet. This has been seen in similar studies conducted by Schoonmaker *et al.* (2004), Comerford *et al.* (1992) and Bond *et al.* (1972).

When Holstein steers were fed one of two diets, a high energy diet continuously for 160 days (HEN) or a phase feeding schedule with decreasing roughage and increasing energy levels (PHASE) with both dietary treatments subjected to the same finishing diet (day 161 to slaughter), there were differences in performance and carcass attributes (Table 6). The HEN steers presented better ADG in the growing period ($P < 0.001$) with the PHASE steers exhibiting evidence of compensatory gains in the finishing period. The higher DMI of the PHASE steers in the finishing phase supports the elevated ADG of this treatment, however, gain efficiency (GE) in this period was equal for both treatments ($P = 0.79$). There were slight improvements in the carcass attributes of the HEN steers compared with the PHASE steers with higher hot carcass weights (HCW) (362 vs 340 kg; $P = 0.02$) and backfat thickness (0.69 vs 0.59 cm; $P = 0.01$). The PHASE steers were on feed for 269 days, whereas the HEN steers were fed for 260 days ($P = 0.02$) making the HEN steers the most efficient overall (Lehmkuhler & Ramos, 2008).

Table 5. Dietary specifications and ingredients and performance of Holstein steers fed one of two diets (high roughage HIGH; low roughage LOW) for phase 1 and 2 (phase 1 day 0 to 90, phase 2 day 91 to 173) and a common finishing diet from day 174 to slaughter on day 250 (Lehmkuhler & Ramos, 2008).

Item	Phase 1		Phase 2		
	HIGH	LOW	HIGH	LOW	FINISHING
Whole HM corn, % DM	19.5	36.5	49.3	64.3	78.7
Alfalfa haylage, % DM	40.0	-	10.0	-	-
Corn silage, % DM	30.0	50.0	30.0	25.0	12
DM, %	56.0	56.0	60.0	10.7	75
CP, %	17.4	14.3	11.5	12.9	13.4
NE_g, Mcal/kg	0.96	1.28	1.26	1.35	1.31
Roughage level, %	55.0	25.0	25.0	12.5	6
					LOW — HIGH
ADG, kg/day	1.15	1.23	1.16	1.16	1.41 — 1.38
DMI, kg/day	5.74	5.67	7.07	6.78	8.97 — 8.68
Initial liveweight, kg	170.0	164.0	-	-	-
Final liveweight, kg	371.0	373.0	-	-	-
HCW, kg	208.1	211.49	-	-	-
Dressing percentage, %	56.1	56.7	-	-	-
Backfat thickness, cm	0.42	0.47	-	-	-

Table 6 Dietary specifications and ingredients and performance of Holstein steers fed one of two diets (high energy diet continuously (day 0-160) HEN; phase feeding PHASE) in phase 1 (day 0-76) and phase 2 (day 77-160), both treatments were fed the same diet in Finish period (day 161 to harvest) (Lehmkuhler & Ramos, 2008).

Item	Phase 1		Phase 2		Finish		P value
	PHASE	HEN	PHASE	HEN	PHASE	HEN	
High Moisture corn (% DM)	20.6	60.3	43.6	60.3	64.6		-
Roasted soybeans (% DM)	12.0	12.0	9.0	12.0	8.0		-
Corn silage (% DM)	60.0	20.0	40.0	20.0	20.0		-
DM (%)	50.5	65.0	54.0	63.5	64.5		-
CP (% DM)	14.3	14.8	13.6	14.8	13.6		-
NDF (% DM)	30.6	24.3	25.3	20.3	19.0		-
NEg (Mcal/kg)	1.23	1.45	1.33	1.45	1.44		-
Roughage level (% DM)	30.0	10.0	20.0	10.0	10.0		-
ADG, kg/day *	1.26	**1.65**	1.47	**1.64**	**1.86**	1.73	< 0.001
GE, kg LW/kg DMI *†	0.20	**0.23**	0.18	0.17	0.15	0.15	< 0.001
DMI, % LW *	2.8	**3.0**	2.5	2.5	**2.5**	2.2	< 0.001
Initial liveweight, kg	174	179	-	-	-	-	-
Final liveweight, kg	594	614	-	-	-	-	-
Hot carcass weight, kg *	340	**362**	-	-	-	-	0.02
Dressing percentage, %	57.4	58.9	-	-	-	-	-
Backfat thickness, cm *	0.59	**0.69**	-	-	-	-	0.01
Days on feed, days	269	**260**	-	-	-	-	0.02

* denotes significant differences between diets with the significantly higher or most efficient value indicated in **bold** lettering; P value is indicated in the table

†Gain efficiency (GE) = kilograms of liveweight gain per kilogram of dry matter intake (DMI)

Schaefer (2005) determined that solely feeding high energy diets fed over an extended period can cause Holsteins to become excessively fat. When Holstein steers were raised from 4 months of age and 140 kg LW to 18 months of age and 635 kg LW they had 0.9 cm ribeye fat thickness. The same steers were then fed to 24 months of age and 773 kg LW with a subcutaneous fat thickness of 1.5 cm. It is believed that the feeding of a high grain diet alters the partitioning of surplus dietary energy between subcutaneous and intermuscular adipose depots (Schaefer, 2005).

In a study conducted by Schoonmaker *et al.* (2004) HGP treated Holstein steers were fed one of three diets with the concentrate diet consisting of 70% high moisture corn with orchard grass haylage and the forage diet consisting of soy hulls and orchard grass haylage. The three dietary treatments utilised were:

1. *Ad libitum concentrate (ALC)* – ad libitum concentrate for 334 days (CP 15.81%, NE_g 6.07 MJ/kg)
2. *Limit fed concentrate (LFC)* – limit fed concentrate for 55 days to achieve gain of 0.8kg/day (CP 16.22%, NE_g 6.07 MJ/kg), followed by 98 days limit fed to achieve a gain of 1.2 kg/day (CP 15.81%, NE_g 6.07 MJ/kg)
3. *Ad libitum forage (ALF)* – 60 % haylage diet, ad libitum forage for 55 days (CP 14.49%, NE_g 3.10 MJ/kg), 25 % haylage diet ad libitum for 98 day (CP 15.11%, NE_g 3.56 MJ/kg)

On day 153 all steers were transitioned to a common high concentrate finishing diet (CP 15.81%, NE_g 6.07 MJ/kg) of high moisture corn, corn silage and soybean meal.

All steers commenced the study at a similar liveweight (ALC 139.3 kg, ALF 138.1 kg, LFC 138.0 kg) (P = 0.97). At day 153, ALC steers were significantly heavier at 350.2 kg (P < 0.01) compared with ALF 284.2 kg and LFC 291.8 kg steers. ALC steers presented the highest ADG from day 0 to 153 at 1.39 kg/day (P < 0.01) compared with ALF 0.96 kg/day and LFC 1.02 kg/day, however from day 153 to slaughter the ALC steers presented the lowest ADG 1.41 kg/day compared with ALF 1.68 kg/day and LFC 1.69 kg/day (P < 0.01). During finishing when all treatments were fed a common concentrate diet, ALF and LFC steers gained 19.9% faster (P < 0.01) than ALC achieved in the growing phase (day 0 – 153). Gain:feed of LFC steers (246 g/kg) were 10.3 and 39% more efficient (P < 0.05) in the growing phase than ALC (223 g/kg) and ALF (177 g/kg), respectively. Schoonmaker *et al.* (2004) labelled this response as an inverse relationship in growth that develops in realignment of previously limit fed steers compared with steers that have not had their growth restricted at any point, similar to compensatory gain.

Table 7 shows the carcass quality data for all treatments at the completion of the feeding period (334 days) and indicates clear differences between treatments for many parameters. ALC steers presented the greatest fat thickness and longissimus muscle area at day 153, whereas LFC steers presented the highest fat thickness, dressing percentage and yield grade at slaughter. This supports the inverse relationship of limit fed cattle indicating that the finishing diet favoured fat deposition in previously restricted fed animals. The ALF steers were at a clear disadvantage at day 153 in terms of fat coverage (P < 0.10) however they were similar to ALC and LFC steers for most parameters at slaughter. The ALF steers had a numerically higher intramuscular fat % at day 153 indicating that by feeding a forage diet and potentially delaying physiological maturity this can allow the cattle to accumulate more intramuscular fat before slaughter (Schoonmaker *et al.*, 2004).

The increased fat thickness for ALC steers in the growing phase can be attributed to a greater (P < 0.05) mean adipocyte diameter in the subcutaneous fat depot compared with the subcutaneous fat depot of ALF and LFC steers. There was no difference in the mean subcutaneous adipocyte diameter (*P* > 0.10) between ALF and LFC at the completion of the growing phase. A numerical decrease in the mean subcutaneous adipocyte diameter from the end of the growing phase to the end of the finishing phase for ALC steers indicates that hyperplasia (new population of adipocytes), rather than hypertrophy (increase in adipocyte diameter), may be making a larger contribution to fat deposition in these animals. Overall, it can be concluded from this study that when cattle are fed the same diet in the finishing phase any differences that occurred during the growing phase are diminished or non-evident at slaughter (Schoonmaker *et al.*, 2004).

Table 7. Effect of source of energy and rate of gain on carcass characteristics of Holstein steers slaughtered at the end of the finishing phase (334 days) (Schoonmaker et al., 2004)

Item	Treatment[b]				
	ALC	ALF	LFC	SE	P value
Number of animals	16	18	15	-	-
Hot carcass weight, kg	352.7	344.0	356.2	6.2	0.33
Dressing percentage, %	58.3[y]	59.0[yz]	59.6[z]	0.4	0.10
Fat thickness, cm					
Day 0[d]	0.13	0.13	0.13	0.03	0.33
Day 153[d]	0.30[w]	0.15[x]	0.20[x]	0.03	0.05
Slaughter[e]	0.91[yz]	0.79[y]	1.07[z]	0.10	0.10
Longissimus muscle area, cm^2					
Day 0[d]	23.9	25.8	24.5	1.3	0.47
Day 153[d]	46.5[w]	38.1[x]	40.6[x]	1.3	0.05
Slaughter[e]	76.8	78.1	74.2	1.9	0.38
Kidney, pelvic and heart fat, %	2.3	2.1	2.2	0.1	0.61
Yield grade	3.0[wz]	2.7[w]	3.3[x]	0.1	0.05
Intramuscular fat, %					
Day 0	2.7	2.4	2.7	0.2	0.48
Day 153	3.6	4.2	4.0	0.4	0.47
Marbling score[ce]	336.0	313.0	362.0	19.9	0.21
Longissimus muscle composition, %[d]					
Fat	3.4[y]	3.2[y]	4.2[z]	0.3	0.10
Moisture	73.9	74.1	73.4	0.3	0.17
Intramuscular adipocyte mean diameter, μm – growing day 145	87.0	67.9	22.9	4.6	0.57
Intramuscular adipocyte mean diameter, μm – finishing day 334	130.5	124.9	122.4	9.4	0.82
Subcutaneous adipocyte mean diameter, μm – growing day 145	121.4[w]	92.9[x]	100.7[x]	6.0	0.05
Subcutaneous adipocyte mean diameter, μm – finishing day 334	117.1	102.0	111.9	5.4	0.16

[b] ALC – ad libitum concentrate for 334 days, CP 15.81 %, NE_g 1.45; LFC – limit fed concentrate for 55 days (CP 16.22 %, NE_g 1.45), 1.2 kg/day for 98 days (CP 15.81 %, NE_g 1.45); ALF – 60 % haylage diet, ad libitum forage for 55 days (CP 14.49 %, NE_g 0.74) , 25 % haylage diet ad libitum for 98 day (CP 15.11 %, NE_g 0.85)

[c] Practically devoid = 100 -199, slight = 200 – 299

[d] Measured via ultrasound

[e] Measured at slaughter

[w,x] Within a row, means without a common superscript differ (P < 0.01)

[y,z] Within a row, means without a common superscript differ (P < 0.05)

From the data presented on the growing – finishing systems it can be concluded that diets high in energy that are predominantly corn or corn silage based will allow dairy breed cattle to grow at an acceptable rate and finish to a high standard. Limit feeding during the growing phase does have some impact on growth as to be expected, however as long as acceptable muscle and fat deposition occurs within this period, the cattle will engage in compensatory gain in finishing if provided with adequate nutrition. A high forage diet can negatively impact finishing in terms of efficiency and liveweight gain and carcass quality at slaughter (fat coverage and marbling). If placed on a high energy finishing diet, compensatory gain will occur but will not completely counteract the lack of growth achieved in the growing period.

3.1.4.2.2 Forage system

The profitability of a feeding system can be related to the forage:concentrate ratio in the diet. A higher concentrate diet will increase input costs due to the high cost of purchased concentrates relative to homegrown forage. Generally, a forage-based diet will be less expensive and sourced on-farm, reducing freight and storage costs. A diet that is based on a forage or grazing system is also less vulnerable to market volatility with less requirement to pay market prices for feed products (Ashfield *et al.*, 2014).

According to Winks *et al.* (1979) from information presented by Von La Chevallerie (1969), Friesians should not be marketed off grazing but should be yard fed prior to slaughter with 200 – 220 kg carcasses failing to meet eye muscle area fat coverage of 7 – 9 mm. It has been suggested by Utama *et al.* (2018) that there is low production efficiency by finishing dairy breed animals on pasture as growth performance is limited and not closely controlled, however there is evidence to indicate that high quality pastures can drive animal performance.

In a study conducted by Catrileo *et al.* (2014) fourteen-month-old Holstein Friesian bulls were fed one of two diets. A forage diet (FD) of mixed ryegrass and clover with additional pasture silage of ryegrass and clover, access to kale and concentrate at 1% of their liveweight (average LW 338.6 ± 20 kg); concentrate diet (CD) with *ad libitum* access to the FD pasture silage and a daily amount of concentrate at 2% of liveweight (average LW 341.3 ± 17 kg). The concentrate was the same for both dietary treatments and consisted of 65% triticale, 33% lupins, 1% mineral salt and 1% sodium bicarbonate with 14% protein and 10.88 MJ ME kg^{-1} to achieve weight gains over 1 kg/day. Performance was similar ($P > 0.05$) between both treatments with a daily weight gain of 1.44 kg for FD and 1.56 kg for CD. The CD bulls reached a final LW of 549 kg at day 147, whereas the FD bulls reached a LW of 552 kg at day 170, taking an extra 23 days to reach the target weight. There were no significant differences ($P > 0.05$) between the diets for dressing percentage, rib eye fat and fat cover. The CD bulls presented higher kidney fat (4.44 vs 2.61 kg.animal^{-1}) ($P < 0.05$) which may be attributed to the concentrate diet that can cause higher levels of lipoenzyme activity. The CD bulls also presented a higher pH 24-hours post-mortem (5.72 vs 5.46) ($P < 0.05$) which could be associated with the concentrate diet allowing for higher levels of muscle glycogen at slaughter. The percentage of intramuscular fat was higher for the CD bulls (1.94 vs 0.90%) ($P < 0.05$), although the level of intramuscular fat present is generally low in bulls due to the presence of testosterone associated with the increased capacity for muscle growth in bulls. There was a slightly higher incidence of dark cutting in CD bulls (39.90 vs 35.93) ($P < 0.05$) occurring as there was an increase in activity at slaughter due to unfamiliar surroundings. It has also been suggested that pasture fed animals have a higher incidence of dark cutting due to increased activity and higher levels of muscle myoglobin, however this was not seen in the current study.

Beef can be a viable source of *n*-3 fatty acids with the FD bulls exhibiting higher levels of 18:3 n-3 and all n-3 fatty acids ($P < 0.05$). Human diets with high n-6:n-3 ratios are seen as risk factors for certain cancers and coronary heart diseases with a value of 4.0 or less advised to be healthy. The beef from the FD bulls was below 4.0 (2.64) with the CD bulls presenting a value of 4.54 ($P < 0.05$).

In a study conducted by Comerford *et al.* (1992) Holstein steers were fed a forage source of either corn silage or alfalfa haylage. There were slight differences in the performance between the diets with the corn silage treatment steers on feed for less days (277.4 ± 6.5 vs 295.9 ± 6.7 days) ($P < 0.05$) and presenting a higher overall ADG (1.11 ± 0.03 vs 1.0 ± 0.03 kg/day) ($P < 0.05$). At processing, the corn silage treatment presented a higher dressing percentage (60.2 vs 58.5%) ($P < 0.05$) and higher kidney, pelvic, heart fat (2.70 vs 2.35%) ($P < 0.05$) with no significant differences in other parameters (fat thickness, marbling, longissimus muscle area, yield grade).

High quality forages have the ability to provide adequate nutrition and performance. Fodder beet, for example, is a high-quality feed that has the potential to provide for high quality feed in seasons when pasture supply is limited. It is a high yielding crop with high stocking rates of 20 - 30 cattle/ha for a period of 100 - 150 days. Fodder beet is high in ME (12 MJ/kg DM) and is highly palatable. Yearling steers (>280 kg LW) gained 1 kg/day LW for 40 days when consuming 5.6 kg fodder beet and 1 kg grass silage. The yearlings presented a comparatively high rumen pH, low rumen ammonia and high microbial protein production (Gibbs *et al.*, 2015). Consumption of the fodder beet was increased gradually with peak intake reaching 8.5 - 9.0 kg DM/day, a ratio of 85 - 90% fodder beet to pasture (Gibbs *et al.*, 2015).

Leucaena is an example of a productive forage and is a highly palatable grazing forage legume that has the capacity to produce large quantities of high-quality forage. Yields will vary depending on climate, rainfall, altitude, density and cutting frequency, but is productive in suitable conditions. Leucaena prefers humid to sub-humid climates and can tolerate up to seven months dry period, it does not tolerate flooding or water logging. Leucaena is highly tolerant of regular cutting or grazing once established. This forage species can enable excellent growth rates with rates of over 1 kg/day reported however, with growth rates of 0.700 to 0.850 kg/hd/day more common in beef cattle (Bowen *et al.*, 2011). Bowen & Chudleigh (2019) reported annual weight gains of 255 kg when *Bos taurus* steers grazed on Leucaena and buffel grass.

Forage systems have the capacity to enable adequate growth rates provided energy levels are sufficient and do not allow the cattle to develop the large frame that is typical of the Holstein breed. The capacity for finishing dairy breed cattle on a forage only system has limitations in terms of fat coverage but can be used for backgrounding prior to finishing on a high quality, high energy diet.

3.1.4.3   Growth rates and performance

3.1.4.3.1   Efficiency and performance

The tight genetic pool within the dairy industry that has selected for high milk production has resulted in a relatively narrow genetic base compared to the beef industry. This has enabled more consistent and predictable intake performance of dairy breed cattle raised for beef (Grant *et al.*, 1993). Feeding dairy breeds for beef can be slightly more challenging than beef breeds as Holsteins tend to develop a frame rather than gain muscle and this can negatively impact performance and the overall quality of the final product. Paul Cameron of Mesquite Cattle Co in Brawley, California stated 'the beauty in feeding Holsteins is the breed's tight genetic pool, which leads to better consistency in feedlot performance and end-product characteristics' (Peck, 2005). Daily gains of 1 – 1.3 kg are expected for dairy breeds on a high-quality finishing diet (Grant *et al.*, 1993). Holstein steers have the capacity to grow faster than beef steers at equivalent weights and have the capacity to double their liveweight in the first 90 – 100 days in the feedlot (Ramos-Aviña *et al.*, 2018).

Brown *et al.* (2016) estimated that an Angus and a Friesian steer both beginning at 40 kg LW and growing at rate of 0.7 kg/day to a slaughter weight of 600 kg at 27 months would require a total ME requirement of 30.76 GJ and 35.49 GJ respectively. If grazing pasture with an average ME of 10.5 MJ/kg DM, the Friesian steers would require an extra 450 kg of pasture to meet their higher maintenance requirement, giving rise to an additional cost of $67.50 over the life of the steer at a cost of $0.15/kg DM.

Compensatory growth can arise when dairy breed animals have limited growth rates in the early stages of life. Cattle fed low energy diets during the growing period are known to compensate during the finishing period with increases in DMI and ADG (DiCostanzo, 2005). Everitt *et al.* (1980) determined that calves with lower growth rates presented a greater degree of compensation compared with calves raised on farms with a high growth rate. Holstein steers fed from seven months to 24 months of age (540 days) gained 574 kg across the period with an average daily gain of 1.061 ± 0.08 kg/day and a feed:gain of 8.83 kg for concentrate and 3.17 kg for rice straw. The feeding period was divided into three distinct periods with a diet specific to each period; growing period (7 - 12 months of age), fattening period (13 – 18 months of age) and finishing period (19 – 24 months of age). The greatest ADG was seen in the fattening period with 1.280 ± 0.10 kg/day. The steers consumed 9.37 kg/day of concentrates and 3.36 kg/day of rice straw on average across the feeding period, with 1.91 % and 0.68%, respectively for DMI expressed as a percentage of liveweight (Kang *et al.*, 2005).

In an experiment conducted by Winks *et al.* (1979) Friesian steers produced better gains (0.52 kg/day) across an 18 month period from September 1970 to May 1972 compared with Brahman (0.43 kg/day) and Shorthorn steers (0.42 kg/day) (P < 0.05) when grazing green panic (*Panicum maximum* var. *trichoglume*) and glycine (*Glycine wightii* cv. Tinaroo). At slaughter, the Brahman steers (52. 0%) produced a heavier carcass than both the Shorthorn (48.2%) and Friesian steers (49.6%) arising from a higher dressing percentage (P < 0.05). The Friesian steers exhibited the numerically lowest fat trim percentage at 6.3%, with Shorthorn at 7.3% and Brahman at 6.3%. It was concluded from this study that Friesian steers are more efficient and capable of higher growth rates than beef breeds, producing leaner carcasses. The beef breeds tended to have a higher fat deposition, whereas the Friesian steers were capable of producing higher gains (Winks *et al.*, 1979).

Consistency within the dairy breeds genetic pool can allow for predictable intakes and uniformity in carcass aspects. Dairy breed cattle have the ability to grow rapidly and undertake compensatory gain on a high energy finishing diet when previously fed on limited energy growing diets. Holstein steers have the capacity to grow faster than beef steers at equivalent weights and have the capacity to double their liveweight in the first 90 – 100 days in the feedlot making them highly productive when fed on a high quality ration.

3.1.4.3.2   Carcass attributes

The dressing percentage of dairy breeds will typically be lower when compared with carcasses from beef breeds. This occurs as dairy breed carcasses contain a higher proportion of non-carcass tissue including gut and liver tissues and non-carcass fat (mesenteric and omental fat) that need to be removed at slaughter prior to the recording of carcass weight (Brown *et al.*, 2016). Dairy carcasses also contain a large proportion of bone due to their large frame size, which has the potential to reduce the amount of saleable meat (Brown *et al.*, 2016). It has also been determined that Holstein steers generally have poor muscularity and a low muscle:bone ratio when compared with beef steers (Schaefer, 2005). When comparing dairy breeds with beef breeds, it was determined by Brown *et al.* (2016) that there was little difference in the overall yield of saleable high value cuts (cube roll, striploin, tenderloin) when expressed as a percentage of the total carcass at similar maturity and liveweights.

The hide as a proportion of body weight is less in dairy breeds which provides these animals with a dressing percentage advantage with the hides also viewed as more valuable than beef hides as they are generally thinner, larger and undamaged by branding (Schaefer, 2005). There are some concerns for blemishes and damage to the muscle and hide of artificially raised dairy calves. This is due to the higher morbidity that occurs during the rearing of the calves and the resultant injectable medications. It has been claimed that this accounts for 14% of injection site lesions on the inside round of dairy breed steers (Schafer, 2005).

Carcass quality is often estimated by the size of the eye muscle area. Holstein carcasses will often have a smaller eye muscle area compared with beef breeds, however it has been stated that this area is smaller due to the increased length of this muscle (*longissimus thoracis*) in Holsteins (Brown *et al.*, 2016). The ribeye of Holstein beef is elongated when compared with the 12 - 13th rib longissimus cross section from a beef breed carcass (Schaefer, 2005). Winks *et al.* (1979) raised Friesian, Brahman and Shorthorn steers on pasture (green panic and glycine) and found that the Friesians presented the smallest eye muscle area at 51.6 cm^2, compared with 56.6 cm^2 for Brahman steers (P < 0.05) but was similar to the Shorthorn steers at 51.8 cm^2 (P > 0.05). The Friesians steers presented a significantly longer carcass at 113.3 cm compared with 107.2 cm for Brahman and 106.5 cm for the Shorthorn steers (P < 0.05) (Winks *et al.*, 1979).

Consumers view meat quality in terms of appearance (presentation at sale, cut size, leanness and fat colour and fat distribution (marbling)) and palatability (tenderness, texture, aroma, juiciness, and flavour) (Brown *et al.*, 2006). There has been a significant quantity of research conducted examining the meat quality and consumer acceptance of dairy beef with varying outcomes. The quality of the rib eye steaks from Hereford, Friesian and Hereford x Friesian steers raised together and slaughtered at the same age and weight and maturity level (finish level) were compared by Muir *et al.* (2000). There were no differences in meat colour, however the Friesian steers presented yellower fat. When slaughtered at the same age, there were no breed differences in shear force measures but when slaughtered at the same maturity level the Friesian steers had a higher shear force measurement, indicating a reduction in meat tenderness. The difference in shear force measurements may have arisen as the Friesian steers were 6 – 8 months older than the other breeds showing that it may take longer for purebred Friesian steers to reach the desired finish level when compared with Hereford and Hereford x Friesian steers (Muir *et al.*, 2000).

Schaefer *et al.* (1986) finished Holstein and Charolais crossbred steers to 500 kg LW on a high corn grain:corn silage diet. The Select and Choice longissimus steaks from the Holstein steers were compared with Choice crossbred steer steaks. It was determined that there was no difference between the breeds for juiciness, tenderness, flavour, overall acceptability or the Warner-Bratzler shear force test.

Achieving desired fat cover on dairy breeds can be a challenge and in general, dairy breed carcasses have less subcutaneous fat compared with beef breeds. This reduces the need for trimming but can reduce the overall carcass weight at slaughter and affect carcass grading (Brown *et al.* 2016). Marbling is desirable characteristic for many markets including export and domestic markets and a highly marbled carcass is a specific attribute for long fed export quality beef, often related to tenderness and juiciness. It has been determined by many researchers that Holstein beef is comparable with or higher than native beef breeds in marbling levels (Brown *et al.*, 2016; Rust & Abney, 2020; Schaefer, 2005; Muir *et al.*, 2000). In a study conducted by Muir *et al.* (2000) Friesian steers presented a value of 19.8% for marbling in terms of chemical fat percentage with Herefords achieving a value of 18.6% and Hereford x Friesian 22.2%. When Holstein steers were fed corn silage they presented higher dressing percentage, fat thickness, marbling and overall yield grade compared with steers fed alfalfa haylage indicating diet and forage source will influence fat coverage and grading (Comerford *et al.*, 1992). Protein source was also shown to influence marbling with fish meal (55.5) improving marbling compared with soybean meal (51.0) in Holstein steers (Comerford *et al.*, 1992).

Dairy breeds such as Holstein have a characteristically large, lengthy frame with a high proportion of bone and low levels of subcutaneous fat. These characteristics can reduce dressing percentage and meat yield but lessen the need for trimming at processing. The lengthy frame of these animals will give rise to a longer longissimus muscle and a resultant reduction in eye muscle area; however, this has no impact on meat quality. The ability to marble can be inconsistent in dairy breeds however, it has been determined that Holstein beef is equivalent to or higher than native beef breeds in

marbling levels. Overall, dairy beef is comparable to native beef in terms of consumer acceptance, juiciness, tenderness, flavour, and palatability.

3.1.4.4   Management

3.1.4.4.1   Hormonal growth implants

The application of hormonal growth implants to enhance gain, efficiency, carcass weights and longissimus muscle area (LMA) has been claimed to be an essential management tool for Holstein steers (Torrentera et al., 2017). In an experiment conducted by Torrentera et al. (2017) Holstein calves were implanted at one of three weights; 267 kg LW, 291 kg LW, 321 kg LW and all calves were reimplanted on day 112 of the trial. When compared with the non-implanted control calves, implanted calves had improved ADG, gain efficiency and net energy. Improvements seen in net energy in implanted animals may be a reflection of the non-nutritional action of implants on the composition of gain, the enhancement of net protein retention and leaner tissue growth (Reinhardt, 2007). Overall, Torrentera et al. (2017) determined that the numerically optimal LW in terms of growth performance response for steers was 291 kg LW for first implant. It was also determined that hip height accounted for 77% of the variation in LW, emphasising the importance of assessing frame characteristics when measuring performance responses. The study also discovered that implanting increased carcass weight by 8.8% ($P < 0.01$), increased LMA by 9.2% ($P < 0.01$) and decreased kidney, pelvic and heart fat by 14% ($P = 0.08$) when compared with non-implanted steers. Liveweight at first implant had no effect ($P > 0.10$) on carcass traits including dressing percentage, fat thickness and yield and quality grade (Torrentera et al., 2017).

Anabolic steroids have been shown to increase the growth rate in Holstein steers but there has been some apprehension in relation to the impact of the implants on carcass quality and meat tenderness and palatability (Schaefer, 2005b). An intense implant regime of trenbolone acetate, oestradiol benzoate and progesterone will result in an increase in growth rate, carcass weight, longissimus muscle area and skeletal maturity in Holstein steers. This regime also resulted in more carcasses grading Choice but did not affect panel tenderness ratings or shear force values (Apple et al., 1991).

When repeat implants of trenbolone acetate and oestradiol at days 0, 112 and 224 were used in Holstein steers there was increases in skeletal maturity and an elevated Warner-Bratzler shear force value with 2 of the 31 samples presenting shear force values greater than 5 kg (consumer acceptability threshold is 4.5 kg) indicating that hormonal implants negatively affected carcass quality in the current study (Scheffler et al., 2003).

Hormonal growth implants can enhance gain, efficiency and overall carcass weight however, there is some consumer apprehension in relation to hormone treated meat and there are often discounts applied to treated beef at Australian slaughterhouses of up to 10 c/kg carcass weight to reflect this. This is not specifically associated to carcass quality concerns but more so to consumer perceptions of artificial hormones in food products.

3.1.4.4.2   Castrated vs entire males

Entire Holstein bulls can present some challenges in terms of aggression towards humans and other cattle. Holsteins in general have an inquisitive and destructive nature which is exacerbated in an entire male. The majority of the literature and research related to dairy breeds is based on castrated males (steers) indicating that it is common practice to castrate all males. Bulls can have advantages over steers when examining liveweight and carcass gains, they can also have higher feed conversion rates, gaining up to 2.23 kg/day in the finishing period (Ashfield et al., 2014). It was determined by Keane (2003) that bulls presented improvements in confirmation and greater dressing percentage when slaughtered at similar carcass weights. The quality of meat from bulls was generally deemed to be similar to steers with regards to tenderness and acceptability. Unfortunately, the carcass price for bulls within the red meat industry can be diminished compared with steers, however the improved

overall performance of the bulls may counteract this (Ashfield *et al.*, 2014). There is also the risk of bruising and carcass damage in group housed bulls as dominance hierarchy is established and challenged within the pen, which can increase the risk of decreases in grading and discounts applied at slaughter for bruised and damaged carcasses.

Chládek & Ingr (2003) quoted information from Papstein & Grosse (1986) in relation to the performance of German black and white bulls castrated at 2, 7 and 12 months. It was determined that steers castrated at 2 months of age had a higher proportion of kidney fat compared with the steers castrated at a later age suggesting that early castration positively influences performance and finishing.

Overall, it can be concluded that castration in dairy breed males raised for the red meat market is commonplace and recommended practice to prevent issues with aggression towards other animals and humans and for the production of high quality, undamaged beef.

3.1.4.4.3   Genetics

Genetic selection within the dairy industry for high milk production may be an advantage when related to beef production as bulls that present high milk production attributes will often also possess a good capacity to produce beef (Calo *et al.*, 1973). Genetic uniformity within the dairy industry is also an advantage when attempting to produce high quality carcasses from purebred calves.

Another viable option for the dairy industry is breeding a beef cross calf. An article in Stock and Land in July 2016 explores the emergence of dairy beef cross calves, Wagyu cross Holstein. The articles outline a procedure where calves are contract reared, grown out on pasture to 350 to 400 kg LW and then finished for 400 days in a feedlot. The animals are then slaughtered at 750 kg LW and exported to 12 countries under the Sher Wagyu and Sher Black brands (Goodwin, 2016).

According to Huuskonen *et al.* (2013) crossbreeding between dairy cows and beef breed bulls has improved carcass production compared to pure dairy breeds. When comparing the growth of purebred Holstein heifers with beef breed cross heifers, the purebred Holstein heifers were the lowest-performing with the lowest carcass weight, carcass daily gain and confirmation score and were the oldest at slaughter ($P < 0.01$). The top performing crossbred animal was the Holstein x Charolais heifer with the highest carcass weight, carcass daily gain and was the youngest at slaughter ($P < 0.01$) (Huuskonen *et al.*, 2013).

When examining the growth from birth to 12 weeks of age of pure Friesian calves compared with various Friesian cross beef breed calves there were only slight differences in the growth rates between the breeds. Generally, the pure bred Friesian calves performed well and gained at a comparative rate to the beef cross calves with the daily weight gain from birth to 12 weeks of age for Friesian calves attaining 0.61 kg/day compared with 0.57 kg/day for Hereford x Friesian calves and 0.62 kg/day for Simmental x Friesian calves (Everitt *et al.*, 1978). From 12 weeks of age to slaughter (15 – 22 months of age) the purebred Friesian steers performed at an average daily gain rate of 0.59 kg/day, followed by the South Devon x Friesian steers (0.58 kg/day) and the Blond d'Aquitaine x Friesian steers (0.58 kg/day) (Everitt *et al.*, 1980). At slaughter the Friesian steers presented eye muscle fat depth from 1.8 - 2.6 mm with the Hereford x Friesian steers presenting a fat depth of 4.6 mm (Everitt *et al.*, 1980). When comparing carcass weights, the purebred Friesian steers exhibited dressing percentages as low as 48.2% with the Charolais x Friesian steers dressing at 50.2% with a 12 kg heavier carcass, allowing them to present overall improved performance compared with the purebred Friesian steers (Everitt *et al.*, 1980).

Crossbreeding dairy with beef can produce a productive animal taking advantage of the large frame and growth rate of dairy breeds combined with the ability to gain muscle and fat coverage in beef breeds. Beef from crossbred cattle produces a more marketable product with higher yields and increased fat coverage.

3.1.4.4.4 Sexed semen

The use of sexed semen in both dairy and beef production allows predetermination of calf sex with 90 % reliability (Holden & Butler, 2018). The adoption of sexed semen for artificial insemination in dairy cattle has generally been limited by cost, low conception rates and sexing inaccuracies. The precision of sexing has improved vastly with accuracy rates now as high as 90% (McCullock *et al.*, 2013). Sexed semen can be used to produce replacement heifers with genetically superior animals selected to be inseminated. This program can be used in combination with a cross breeding program with beef semen to assist with revenue generation from non-replacement calves (McCullock *et al.*, 2013).

The economic benefits of sexed semen to the dairy industry include:

- Higher prices could be obtained for female dairy calves compared with male calves
- The added value of crossbred calves that are not bred as replacements
- Optimised herd turnover rates
- Reduced dystocia
- Increased rate of genetic progress
- An increased supply of heifer calves may be beneficial as it will provide the producer with a higher capacity to cull poor performing heifers and avoid future losses from poor performing cows
- Improved biosecurity if open herds can be closed (De Vries *et al.*, 2008)

Extra costs that may be incurred as a result of sexed semen include:

- Higher semen prices
- Higher costs for pregnancy diagnosis and ovulation synchronisation due to reduced fertility (De Vries *et al.*, 2008)

The implementation of sexed semen within a dairy herd may limit the number of dairy bull calves born, however, there may be an increase in dairy x beef calves conceived as producers diversify their herd (Ashfield *et al.*, 2014). There is some evidence to suggest that cows producing daughters may have a lower milk yield compared with cows producing sons due to the positive association between birth weight and milk production making bull calves a viable option to improve yields (De Vries *et al.*, 2008).

3.1.5 Conclusions and recommendations

Despite the significant utilisation of dairy breed males for red meat internationally, there seems to be a lack of uptake of this system within the Australian industry. The Australian dairy industry is in an excellent position to utilise male dairy breed calves with up to 500,000 calves entering the system annually. There is the capacity to manipulate all phases from birth through to finishing to improve the profitability and viability of this system.

From the literature reviewed it can be concluded that there are many feeding systems utilised to raise the calves from weaning through to finishing; however, clear guidelines for nutrition and feeding systems are lacking and requires further investigation. The most common growing – finishing diet for male dairy breeds are diets that are high in energy that are predominantly corn or corn silage based, which allow the cattle to grow at an acceptable rate and finish to a high standard. Limit feeding and/or a high forage diet during the growing phase does have an impact on growth, however provided acceptable muscle and fat deposition occurs within this period, the cattle will engage in compensatory gain when finished on a high quality, high energy diet. A high forage diet can negatively impact finishing in terms of efficiency and liveweight gain and carcass quality at slaughter (fat coverage and marbling) and may not produce a carcass that meets the specifications for some markets.

Contrary to the viewpoint held by many within the beef industry, beef from dairy breed animals is high quality and comparable to native beef breed products. The traceability and tight genetic pool of dairy breeds makes dairy beef an attractive option for international markets with food safety and biosecurity a persistent societal concern. Dairy breeds such as Holstein have a characteristically large, lengthy frame with a high proportion of bone and low levels of subcutaneous fat. These characteristics can reduce dressing percentage and meat yield but lessen the need for trimming at processing. Dairy beef is comparable to native beef in terms of consumer acceptance, juiciness, tenderness, flavour, and palatability. The refinement of the MSA grading system to accommodate dairy beef will assist with the marketing of Australian dairy beef for both the domestic and export markets and increase consumer acceptance of this high-quality product.

Crossbreeding dairy with beef breeds can produce a productive animal taking advantage of the large frame and growth rate of dairy breeds combined with the ability to gain muscle and fat coverage in beef breeds. Beef from crossbred cattle produces a decidedly marketable product with high yields and adequate fat coverage and is a viable option that can be pursued within the Australian industry.

The Australian dairy industry and the red meat industry in general can benefit from utilising dairy beef providing an alternate protein source, a solution to an ongoing issue, a reliable source of income for Australian dairy farmers whilst improving welfare, public perception of dairying and diversifying the industry.

3.2   Desk-top study

The desk-top modelling study utilised existing forage quality data together with modelled forage intakes (QuikIntake v6 NRDR mod spreadsheet, McLennan and Poppi 2019) to estimate the cost of production across a range of potential growth rates and forage-based feeding systems. An economic analysis of the cost of production and return on investment of feeding dairy bull calves post-weaning was conducted across eight feeding systems to meet a range of potential beef markets (Figure 1) in Australia. The economic analysis included a sensitivity analysis of potential economic returns using system diet costs vs variable growth rates and their impact on system gross margins and return on investment.

3.2.1   Forage quality and yield

Forage quality data was collated from the FeedPlu$ feed analysis database (Queensland Department of Agriculture and Fisheries 2016) where available or from values within published literature. Forage yield data was compiled from the literature and historical data achieved within the C4Milk project reports (Barber, 2017; Callow, 2014; Callow *et al.,* 2013). Quality parameter values provided in Table 8 are mean values for each forage type.

Table 8. Annual forage yield (t DM/ha) and quality (dry matter (DM), crude protein (CP), neutral detergent fibre, starch and metabolizable energy) of the forages used within the desk-top study to assess a range of forage systems. The quality parameter means includes data from raingrown and irrigated forages where applicable.

Forage	Source	Forage System #	Annual Yield (t DM/ha)	$n^\dagger$	DM (%)	CP (% DM)	NDF (% DM)	Starch (% DM)	ME (MJ/Kg DM)
Rhodes Grass [R/I]	QDAF (2016)	1 & 6	12 - 15	44	27.99	15.52	63.96	1.24	8.48
Barley Hay [R/I]	QDAF (2016)	2	7 - 10	7	87.35	8.70	59.76	1.65	8.55
Kikuyu [I]	QDAF (2016)	4	12 - 15	69	19.66	22.24	51.28	2.18	10.07
Annual Ryegrass [I]	QDAF (2016)	4	10 - 15	220	17.04	22.00	45.51	1.60	9.85
Forage Sorghum [R/I]	QDAF (2016)	5	9 - 15	56	23.57	16.74	55.93	2.93	9.67
Oats pasture [R/I]	QDAF (2016)	5	6 - 10	108	17.84	23.74	44.38	1.78	10.28
Leucaena	Bowen & Chudleigh (2018)	6	1 - 15	NA	29.90	23.30	40.90	-	11.00
White sorghum headlage [I]	Barber (2017)	7	5 - 6	6	50.40	12.00	27.40	51.00	11.50
Lablab silage [R/I]	QDAF (2016)	7	5 - 8	8	43.71	15.94	48.12	5.70	8.68
Fodderbeet [I]	Barber (2017)	8	25 - 30	3	9.70	27.10	21.65	50.30	10.35
Lucerne pasture [I]	QDAF (2016)	8	12 - 15	39	24.65	26.33	32.94	4.30	10.58

$\dagger$ n = number of samples used from Feed Plu$ 4 feed analysis database to calculate the mean of each quality parameter.
R/I – raingrown and irrigated forages analysis included in the quality parameter means.
I - irrigated forages analysis included in the quality parameter means.

3.2.2   Forage feeding system attributes and assumptions

A range of high-quality forage systems were considered based on their potential forage quality and annual dry matter yield. Two feeding systems were used as a current benchmark of existing feeding strategies and included a tropical pasture with supplement system and a grain and hay feeding system. These systems are currently used within dairy production systems of northern Australia for heifers and bull calves post weaning, however the proportion of farms that rear bull calves is low due to low economic returns under the existing feeding strategies. A total mixed ration (TMR) system was also included as there are a few TMR dairy farms in Queensland and NNSW that rear bull calves using the milker ration to save on labour and time. The remaining five feeding systems are based on high-quality forages and contain two forage sources to allow for annual forage production to occur. The attributes and assumptions used in each of the eight feeding systems is outlined below:

3.2.2.1   *Tropical grass (Rhodes grass) pasture with supplement system (RGSS1)*

A low input system which is typically used for dairy heifers and bull calves in northern Australia and included as a benchmark to compare with high quality forage systems 4 to 8. Input data (ME and supplement intake) used to estimate forage intake in QuikIntake and feed costs used in the sensitivity analysis to calculate diet costs are listed in Table 12. Nutrient composition of the dry lick supplement is listed in Table 9. The recommended intake level of the dry lick supplement for weaner and yearling cattle is 200 to 600 grams/head.d^{-1}, with 400 grams used in this system to calculate pasture intake within the QuikIntake model. The dry lick supplement was input into the spreadsheet as a supplement.

Table 9. Nutrient and ingredient composition of the Feed Pro Australia ProPhos Weaner boost mix used as a dry lick supplement in the QuikIntake simulations.

Nutrient/ingredient	Concentration (% DM)
Nutrient	
Total Protein	35
Crude Protein	20.5
Phosphorus	1.0
Calcium	1.5
Sulphur	0.75
Ingredient	Inclusion Rate (%)
Protein meal	50.0%
Urea	4.0%
Salt	4.0%
Vit-min package (kg/tonne)	3.0
Rumensin (ppm)	300

3.2.2.2   Grain and cereal hay system (GCHS2)

A high input system which is typically used for dairy bull calves in northern Australia and included as a benchmark to compare with high quality forage systems 4 to 8. Input data (ME and concentrate intake) used to estimate forage intake in QuikIntake and feed costs used in the sensitivity analysis to calculate diet costs are listed in Table 12. The concentrate used in this system is a grain-based meal fed in a self-feeder bin, with concentrate intake increasing by 1 kg for every 0.25 kg increase in growth rate. Concentrate intake in the sensitivity analysis ranged from 3.0 kg DM/head.d^{-1} at a growth rate of 0.5 kg/head.d^{-1}, up to 8 kg DM/head.d^{-1} at a growth rate of 1.75 kg/head.d^{-1}. The concentrate mix was input into the spreadsheet as a supplement. Barley hay was used as the forage source and hay DM intake was estimated in QuikIntake as pasture intake using the barley hay ME concentration. Nutrient and ingredient composition of the concentrate mix is listed in Table 10.

Table 10. Ingredient and nutrient composition of the grain-based concentrate mix used as a supplement in the QuikIntake simulations.

Ingredient	Inclusion rate, %
Barley, rolled	48.13
Sorghum, rolled	20.00
Soybean hull pellets	18.00
Soyabean meal 46 %	3.50
Vegetable oil, mixed	2.00
Molasses	2.00
Limestone	1.50
Sodium bicarbonate	1.25
Salt	0.35
Urea	0.625
Sulphur	0.021
Rumensin 100	0.02
Bentonite granular	2.50
ANP Beef premix	0.10
Nutrient composition	
Dry matter, %	89.53
Crude protein, %	11.87
Neutral detergent fibre, %	21.86
Starch, %	38.15
Metabolisable energy, MJ/kg	11.56
Calcium, %	0.70
Phosphorus, %	0.26

3.2.2.3 Total mixed ration (TMRS3)

A high input mixed ration system which is typically used by total mixed ration (TMR) farms for dairy bull calves in northern Australia and included as a benchmark to compare with high quality forage systems 4 to 8. Dairy farms that use this system typically use the milker TMR to feed bull calves post-weaning. Input data (ME) used to estimate forage intake in QuikIntake and feed costs used in the sensitivity analysis to calculate diet costs are listed in Table 12. The TMR metabolizable energy concentration was used to estimate forage intake, with no supplement added as the diet is mixed and therefore not fed separately. Nutrient and ingredient composition of the TMR is listed in Table 11, with the reference TMR being the Herd 2 Milker diet from the Gatton Research Dairy on the 29 April 2020.

Table 11. Ingredient and nutrient composition of the grain-based concentrate mix used as a supplement in the QuikIntake simulations.

Ingredient	Inclusion rate, %
Grain sorghum silage	31.13
Soybean hull pellets	23.24
Corn silage	18.90
Canola Meal	12.89
Wheat Grain (disc-milled)	9.09
Lucerne Hay	2.30
Limestone	0.81
Sodium bicarbonate	0.51
Salt	0.40
Magnesium Oxide	0.30
Dicalcium phosphate	0.25
Trace mineral premix	0.13
Nutrient composition	
Dry matter, %	54.4
Crude protein, %	14.5
Neutral detergent fibre, %	41.1
Starch, %	23.1
Metabolisable energy, MJ/kg	10.07

3.2.2.4 Kikuyu and Ryegrass pasture system (KRS4)

A high-quality irrigated pasture-based system which is typically used for dairy cows in northern Australia. ME values used to estimate forage intake in QuikIntake and feed costs used in the sensitivity analysis to calculate diet costs are listed in Table 12. It was assumed that kikuyu and annual ryegrass would contribute equally to intake over the 12-month period, with 6 months of each pasture type and hence a 50:50 contribution to the annual ME mean. Average ME's for each forage

type were also calculated (Table 8) from a range of samples within Feed Plu$ 4 (DAF, 2016) that were collected throughout the year for each pasture type, therefore the variability in pasture quality across the year will be accounted for in the ME mean value.

3.2.2.5   Forage Sorghum and Oats pasture system (FSOS5)

A high-quality irrigated or raingrown pasture-based system which is typically used for dairy cows in northern Australia. ME values used to estimate forage intake in QuikIntake and feed costs used in the sensitivity analysis to calculate diet costs are listed in Table 12. It was assumed that forage sorghum and oats would contribute equally to intake over the 12-month period, with 6 months of each pasture type and hence a 50:50 contribution to the annual ME mean. Average ME's for each forage type were also calculated (Table 8) from a range of samples within Feed Plu$ 4 (DAF, 2016) that were collected throughout the growing period for each pasture type, therefore the variability in pasture quality across the year will be accounted for in the mean ME value across both forage types.

3.2.2.6   Tropical legume (Leucaena) and grass pasture system (LRGS6)

A high-quality irrigated or raingrown grass-legume pasture-based system which is typically used for growing beef cattle in northern Australia. ME values used to estimate forage intake in QuikIntake and feed costs used in the sensitivity analysis to calculate diet costs are listed in Table 12. It was assumed that Leucaena and Rhodes grass would contribute equally to intake over the 12-month period, with 6 months of each pasture type and hence a 50:50 contribution to the annual ME mean. Average ME's for Rhodes grass were also calculated (Table 8) from a range of samples within Feed Plu$ 4 (DAF, 2016) that were collected throughout the year for each pasture type, therefore the variability in pasture quality across the year will be accounted for in the mean ME value across both forage types.

3.2.2.7   Conserved forage (white sorghum headlage & lablab silage) system (WSLS7)

A high-quality irrigated or raingrown grass-legume cropping-based system which has been investigated as part of the C4Milk project (Barber, 2017) for use with dairy cows and heifers in northern Australia. ME values used to estimate forage intake in QuikIntake and feed costs used in the sensitivity analysis to calculate diet costs are listed in Table 12. White sorghum headlage was allocated at a flat rate of 3 kg DM/d across all target growth rates and was input into the spreadsheet as a supplement. Average ME's for Lablab silage were also calculated (Table 8) from a range of samples within Feed Plu$ 4 (DAF, 2016) that were collected throughout the year.

3.2.2.8   Fodderbeet and legume (Lucerne) pasture system (FBLS8)

A high-quality irrigated crop-legume pasture-based system which has been investigated as part of the C4Milk project (Barber, 2017) for use with dairy cows and heifers in northern Australia. Fodderbeet is extensively used in New Zealand for wintering dairy cows or beef cattle growing systems. ME values used to estimate forage intake in QuikIntake and feed costs used in the sensitivity analysis to calculate diet costs are listed in Table 12. Fodderbeet was allocated at a flat rate of 3 kg DM/d across all target growth rates and was input into the spreadsheet as a supplement. Average ME's for Lucerne pasture were also calculated (Table 8) from a range of samples within Feed Plu$ 4 (DAF, 2016) that were collected throughout the year, therefore the variability in pasture quality across the year will be accounted for in the mean ME value.

Table 12. Forage system input data (metabolizable energy (ME) and dry matter intake (DM)) used for QuikIntake simulations and feed costs used for the calculation of diet costs within the desk-top study.

Feed	Forage System #	ME (MJ/KG DM)	DMI (kg DM)	Cost ($/kg DM)
Dry lick supplement†	1	8.00	0.4	0.75
Rhodes grass pasture*	1 & 6	8.70	-	0.10
Grain-based concentrate mix	2	11.56	3 to 8	0.32
Barley hay	2	8.55	-	0.25
Total Mixed Ration	3	10.07	-	0.33
Kikuyu pasture	4	10.07	-	0.09
Annual ryegrass pasture	4	9.85	-	0.14
Forage sorghum pasture	5	9.67	-	0.09
Oats pasture	5	10.28	-	0.09
Leucaena	6	11.00	-	0.03
White sorghum headlage	7	11.50	-	0.15
Lablab silage	7	8.68	-	0.20
Fodderbeet	8	10.35	-	0.07
Lucerne pasture	8	10.58	-	0.11

† Feed Pro Australia - Pro Phos Weaner Boost supplement and estimated dry matter intake (DMI) based on recommended rates for the dry lick supplement. * Raingrown and irrigated values used in the mean.

3.2.3   Intake estimation

Dry matter intake was estimated using the QuikIntake spreadsheet (McLennan and Poppi, 2019). Diet dry matter digestibility (DMD), current liveweight and growth rate were input into the model to generate an estimate of pasture and total DM intake across the 8 forage systems. The range in growth rates used in the simulations was 0.15 to 1.75 kg/d (Table 13) and was dependant on the potential of the forage system to achieve the target growth rates.

Table 13. Target growth rates used for each forage system within the QuikIntake simulations.

Forage System	Growth rate (kg/day)							
	0.15	0.25	0.5	0.75	1.0	1.25	1.5	1.75
RGSS1	×	×	×	×				
GCHS2			×	×	×	×	×	×
TMRS3			×	×	×	×	×	
KRS4			×	×	×	×	×	
FSOS5			×	×	×	×	×	
LRGS6			×	×	×	×	×	
WSLS7			×	×	×	×	×	
FBLS8			×	×	×	×	×	

3.2.3.1   Dry matter digestibility (DMD)

The dry matter digestibility of individual forages was unknown for this forage dataset, however data was available on the ME content of each forage (Table 12) and therefore ME of the forage system could be calculated where two forages were used within a forage system based on their proportion

(Table 14). DMD was estimated and changed in the spreadsheet until the correct forage or forage system M/D (ME content) was achieved. Actual M/D was input for supplements (Table 12).

Table 14. Forage M/D and DMD used for each forage system within the QuikIntake simulations.

Forage System	Forage M/D (MJ/kg DM)	Forage DMD (%)
RGSS1	8.48	56.9
GCHS2	8.55	57.3
TMRS3	10.07	65.7
KRS4	9.96	65.1
FSOS5	10.29	66.9
LRGS6	9.74	63.9
WSLS7	8.68	58.0
FBLS8	10.58	68.5

3.2.3.2   Liveweight – current

Current liveweight used in the QuikIntake simulations was based on the mid-point between 150 kg and the target liveweight requirement for each market based on the carcass weight. A 50% dressing percentage was assumed to calculate target liveweight for each market. For example, if 225 kg is the target carcass weight, then 450 kg was used as the target liveweight. The midpoint was selected as this will represent the average intake across the growing period from 150 kg to the target market liveweight, assuming a linear intake response equation is used for the prediction of intake based on liveweight. Target carcass and liveweights for each of the 5 grass-fed beef markets are outlined in Figure 3 in section 3.2.5 below. It was assumed that the starting liveweight for each forage system was 150kg at 4 months of age based on the calf rearing costs in section 3.2.4.1 below.

3.2.3.3   QuikIntake simulations

The DMD and current liveweight were input into the spreadsheet for each forage system, then a range of simulations based on growth rate (Table 13) were run. Pasture and supplement (kg DM/day), total DM (expressed as kg DM/day and % liveweight) and ME (MJ/day) intake were recorded and input into the sensitivity analysis spreadsheet for each forage system and market option. An example QuikIntake simulation is presented in Picture 1.

Picture 1. QuikIntake simulation of forage system 1 (RGSS1) at a growth rate of 0.5kg/day and current liveweight of 300kg for the MSA and Trade cattle markets.

3.2.4   Forage and diet cost

3.2.4.1   Calf rearing costs – birth to 150 kgs

Calf rearing costs were calculated using the Heifer Cost Model v3.51 (Dairy Australia, 2016) to calculate rearing costs from birth to 150kg at four months of age. Three separate scenarios were costed as follows:

1. Calf rearing using waste milk – waste milk was costed at 25 cents per litre (cpl) ($2.08/kg DM) to cover feed costs fed to milkers and fed at 5.5 litres/calf per day for 10 weeks until weaning. Waste milk includes colostrum milk from fresh cows up to 5 days in milk and high somatic cell count milk.
2. Calf rearing using milk powder – milk powder costed at 47 cpl ($4.00/kg DM) fed at 5.5 litres/calf per day for 10 weeks until weaning.
3. Calf rearing using vat milk – saleable whole milk from the vat at 70 cpl ($5.83/kg DM) fed at 5.5 litres/calf per day for 10 weeks until weaning.

Costings from birth (42 kg) to 150 kg include feed (Table 15), animal health and management, labour and capital depreciation, but does not include interest and fuel and electricity. Birth to weaning (80 kg) was defined as a 10-week period followed by an 8-week period of growth to achieve 150 kg of liveweight by 18 weeks (4 months) of age.

Table 15. Feed ingredients list, amount and cost used for estimating the feed costs across the pre (milk replacer) and post weaning period up to 150kg liveweight.

Feed	Birth to weaning (10 weeks)	Weaning to 150kg (7 weeks)	Cost ($/kg DM)
Milk replacer (L/day)	5.5	-	4.00
Calf starter mix (kg DM/day)	0.4	2.7	0.60
Oaten hay (kg DM/day)	0.54	0.9	0.25

3.2.4.2   Forage costs – 150 kgs to target market liveweight

Individual forage costs were estimated using the C4Milk feed cost calculators (DAF, 2017) and the indicative yields listed for each forage in Table 8. Forage costs include irrigation, fertiliser, land preparation, insecticide, and labour costs where applicable and at commercial rates. Perennial forages such as kikuyu are costed across the productive lifetime of the pasture (Picture 2), with grazed pastures also including a utilisation factor as part of the costing process to take wastage into account. Forage costs were input into the sensitivity analysis to calculate diet costs.

Irrigated perennial kikuyu, grazed in SE Qld

Assumptions							Kikuyu
Machinery costs include Fuel, oil, repairs and maintenance							Irrigated
Life of the crop (years)	10						Grazed
Irrigation costs	$100		/ML				

Establishment		Machinery		Inputs			Total
	Month	$/ha	Units/ha	Unit	$/unit	$/ha	$/ha
Offset discs	Mar	22.93				0.00	22.93
Spray - Roundup	Mar	5.05	3.0	L	8.80	26.40	31.45
Power harrows	Mar	33.76				0.00	33.76
Seed with a spreader	Mar	5.02	5.0	kg	44.00	220.00	225.02
Roller	Mar	7.32				0.00	7.32
Fertiliser, CK88 using spreader	May	5.02	200.0	kg	0.68	136.00	141.02
Fertiliser, Greentop K using spreader	May	5.02	150.0	kg	0.69	103.50	108.52
Fertiliser, Urea using spreader	Jun	5.02	100.0	kg	0.65	65.00	70.02
Fertiliser, Urea using spreader	Jul	5.02	100.0	kg	0.65	65.00	70.02
Fertiliser, Urea using spreader	Aug	5.02	100.0	kg	0.65	65.00	70.02
Fertiliser, Greentop K using spreader	Sept	5.02	150.0	kg	0.69	103.50	108.52
						0.00	0.00
Irrigation	Various		3.0	ML	100.00	300.00	300.00
Total establishment cost							**1,188.60**
Establishment cost averaged over the life of the crop							118.86

Annual maintenance		Machinery		Inputs			Total
	Month	$/ha	Units/ha	Unit	$/unit	$/ha	$/ha
Fertiliser, CK88 using spreader	Oct	5.02	200.0	kg	0.68	136.00	141.02
Fertiliser, Urea using spreader	Nov	5.02	100.0	kg	0.65	65.00	70.02
Fertiliser, Urea using spreader	Dec	5.02	100.0	kg	0.65	65.00	70.02
Fertiliser, Greentop K using spreader	Jan	5.02	150.0	kg	0.69	103.50	108.52
Fertiliser, Urea using spreader	Feb	5.02	100.0	kg	0.65	65.00	70.02
Fertiliser, Urea using spreader	Mar	5.02	150.0	kg	0.65	97.50	102.52
						0.00	0.00
Irrigation	Various		4.0	ML	100.00	400.00	400.00
Total annual maintenance cost							**962.12**
Total annual cost (maintenance and establishment)							**1,080.98**

Feed production and utilisation							
Feed produced (kgDM/ha)							17,000
Feed utilisation (kgDM/ha)			Utilisation %	70%			**11,900**
Cost of feed ($/kgDM)							**$0.09**

Picture 2. C4Milk feed cost calculator for irrigated kikuyu pasture.

3.2.4.3   Diet cost (per day and the whole growing period)

Daily diet cost is calculated in the sensitivity analysis from the QuikIntake estimates for each feed type and their individual cost, either calculated from the C4Milk feed costs calculator or the commercial value of the feed. Total diet cost is then calculated by multiplying daily feed cost by the number of days to achieve the target liveweight, which is calculated by dividing the target liveweight minus start weight (150 kg) then dividing by the growth rate. For example, with a target liveweight of 450 kg for the MSA market, a growth rate of 1kg/day and a daily feed cost of $1.03, total feed costs for the growing period is calculated as (Picture 3):

- 450kg Liveweight – 150kg start weight = 300kg
- 300kg of growth ÷ 1.0kg/day = 300 days
- 300 days x $1.03 feed cost/day = **$309 total feed cost** during the forage system growing period.

Target Market:	MSA Steer				
Target Liveweight:	450 kg				
Feeding System 4:	Kikuyu (6mths) / Ryegrass (6mths) pasture (DMD 65.5)				
Data Input:					
Predicted growth rates (300 kg LWT)					
Growth rate (kg/day)	0.50	0.75	1.00	1.25	1.50
Age at 300 kgs (yrs - Quikintake)	1.20	0.90	0.70	0.70	0.60
DMI Pasture (kg DM/day)	6.51	7.74	8.95	10.17	11.41
DMI (kg DM/day; Quik Intake Predicted)	6.51	7.74	8.95	10.17	11.41
DMI (% LW)	2.17	2.58	2.98	3.39	3.80
Total ME (MJ/day)	64.90	77.10	89.20	101.30	113.70
DMI - Forage NDF 1%LWt (% LW)	1.05	1.25	1.44	1.64	1.84
Months required: 150 to 450 kg	19.7	13.2	9.9	7.9	6.6
Age at Sale (years):	2.0	1.4	1.2	1.0	0.9
Estimated costs					
Kikuyu Pasture cost ($/kg DM)	0.09	0.09	0.09	0.09	0.09
Ryegrass Pasture cost ($/kg DM)	0.14	0.14	0.14	0.14	0.14
Total diet cost ($/day)	0.75	0.89	1.03	1.17	1.31
Diet cost from 150kg to 450 kg ($)	449	356	309	281	262
Costs from birth to 4mo (150 kg) ($)	510	510	510	510	510
Other cost from 150kg to 450 kg ($)	50	50	50	50	50
Total cost from birth to 450 kg ($)	$1,009	$916	$869	$841	$822

Picture 3. Calculation of diet costs, calf rearing costs and other management costs of the KRGS4 forage system for the MSA steer target market. Example provided in the text outlined in red.

3.2.4.4   Cost of production

The total cost from birth to target market liveweight (Picture 3) includes the following costs:

1. Calf rearing costs from birth to 150 kg liveweight – includes feed, animal health and management, labour, and capital depreciation costs.
2. Diet costs from 150 kg to target market liveweight – includes forage and supplement costs.
3. Other costs from 150 kg to target market liveweight – includes animal health and management costs and is varied depending on target market liveweight. A value of $50 was

included for the MSA and Trade steer markets; $75 for the Jap Ox and Manufacturing steer markets to account for the increased time to slaughter; and $25 for the Vealer market to account for the reduced time to slaughter.

No fixed cost associated with land to manage these animals was factored into the total cost of production due to the variability in scenarios. Individual situation can be factored into the gross margin and return on investment values presented in this report. Cost of production was used to calculate gross margin ($/head) and return on investment (%) across a range of market prices.

3.2.5 Target markets and prices

The target markets used in the sensitivity analysis of the desk-top study are outlined in Figure 3 and highlighted in red and include their market specifications. The grass-fed markets were the primary target for the high-quality forage systems, with the traditional vealer market for dairy calves also investigated. Table 16 outlines the market prices used in the sensitivity analysis, which includes a 3-year (November 2017 to November 2020) average, 3-year highest and lowest prices. Additional median prices between the 3-year average and lowest prices, and the 3-year average and highest prices were also included in the sensitivity analysis to analyse the effect of market price across 5 price points.
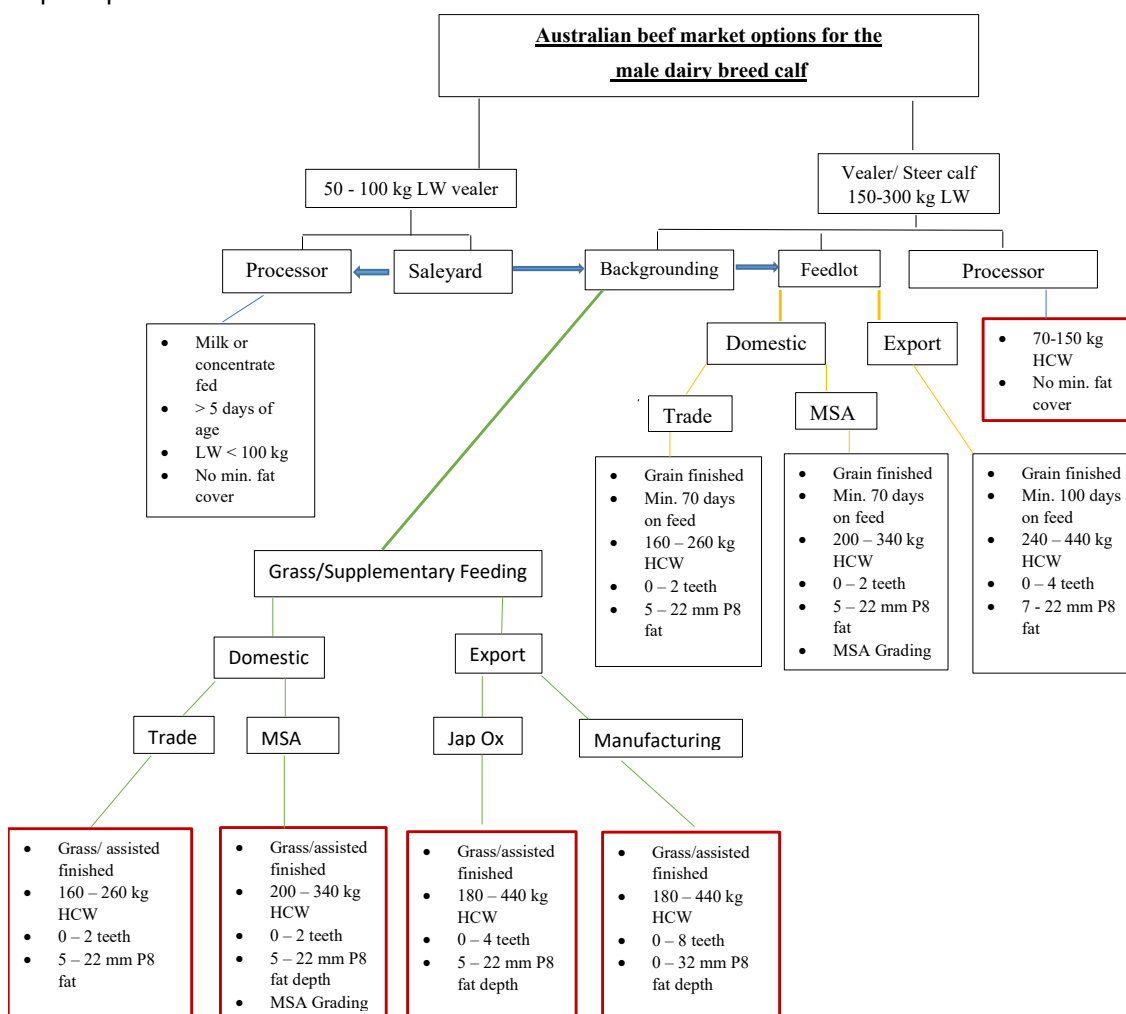
Figure 3. Australian beef markets and target markets for high quality forage dairy beef production systems (red boxes).

Table 16. Grass-fed steer and vealer market hot carcass weight (HCW) prices (average, lowest and highest) used in the sensitivity analysis (SA). Prices are sourced from the MLA website over a 3-year period for Queensland from November 2017 to November 2020 unless stated otherwise.

Market	SA Target HCW (kg)	MLA Category	MLA HCW Range (kg)	Dentition	Muscle Score	Fat Depth (mm)	Market prices ($/kg HCW)		
							Low	Average	High
MSA	225	MSA Yearling Steers	220-240	0-2 (YG)	A-C	5-22	4.74	5.50	6.72
Trade	225	Yearling steers	220-240	0-2 (YG)	A-C	5-22	4.55	5.32	6.61
Jap Ox	300	Grown Steers	300-400	0-4 (YP)	A-C	5-22	4.67	5.46	6.69
Manufacturing	300	Grown Steers	300-400	0-8 (S)	A-C	5-22	4.55	5.35	6.58
Vealer†	150	Dairy	130-150	-	-	-	4.00	5.50	7.00

† Prices sourced from NCMC Foods at Casino, NSW from November 2018 to November 2020.

3.2.6   Sensitivity Analysis

The sensitivity analysis was conducted for the following attributes:

3.2.6.1   Gross margin

The gross margin sensitivity analysis compared carcass price versus growth rate to identify the minimum growth rate target and price required to achieve a positive gross margin (Picture 4).

Carcass Price vs Growth Rate Sensitivity Analysis					
	Growth rate (kg/day)				
Carcass Price ($/kg)	0.50	0.75	1.00	1.25	1.50
$4.74	$57	$150	$198	$226	$244
$5.12	$143	$236	$284	$312	$330
$5.50	$229	$322	$370	$398	$416
$6.07	$357	$450	$497	$526	$544
$6.64	$485	$578	$625	$653	$672

Picture 4. Gross margin ($/head) sensitivity analysis of carcass price ($/kg HCW) versus growth rate (kg/day) of the KRGS4 forage system for the MSA steer target market.

3.2.6.2   Return on investment (ROI)

The return on investment sensitivity analysis compared carcass price versus growth rate to identify the minimum growth rate target and price required to achieve a positive ROI and an ROI greater than 10% (Picture 5). The sensitivity analysis table is colour coded to easily identify a loss (red shaded), a ROI between 0 and 10% (yellow shaded) and an ROI greater than 10% (green shaded).

Carcass Price vs Growth Rate Sensitivity Analysis - Return On Investment (ROI, %)							
	Growth rate (kg/day)						
Carcass Price ($/kg)	0.50	0.75	1.00	1.25	1.50	1.75	
$4.74	-37%	-26%	-19%	-13%	-9%	-6%	ROI
$5.12	-31%	-20%	-12%	-6%	-2%	1%	Loss
$5.50	-26%	-14%	-5%	1%	5%	9%	0-10%
$6.07	-19%	-5%	4%	12%	16%	20%	>10%
$6.64	-11%	4%	14%	22%	27%	31%	

Picture 5. Return on investment (%) sensitivity analysis of carcass price ($/kg HCW) versus growth rate (kg/day) of the GCHS2 high input system for the MSA steer target market.

3.2.6.3   Supplement and concentrate costs

The supplement and concentrate costs sensitivity analysis compared carcass price versus supplement costs at the target growth rate to identify the effect of carcass price and supplement cost on gross margin (Picture 6). Supplement cost was altered 20% below and above the cost used in the diet costs.

Carcass Price vs Supplement Cost Sensitivity Analysis at Target Growth Rate			
Growth rate	0.25 kg/day		
	Supplement cost ($/kg DM)		
Carcass Price ($/kg)	$0.60	$0.75	$0.90
$4.74	-$514	-$586	-$658
$5.12	-$428	-$500	-$572
$5.50	-$342	-$414	-$486
$6.07	-$214	-$286	-$358
$6.72	-$68	-$140	-$212

Picture 6. Gross margin ($/head) sensitivity analysis of carcass price ($/kg HCW) versus supplement costs at a target growth rate (0.25 kg/day) of the RGSS1 low input system for the MSA steer target market.

3.2.6.4   Calf rearing costs

The calf rearing costs sensitivity analysis compared carcass price versus calf rearing costs at the target growth rate to identify the effect of carcass price and calf rearing costs on ROI (Picture 7). The sensitivity analysis table is colour coded to easily identify a loss (red shaded), a ROI between 0 and 10% (yellow shaded) and an ROI greater than 10% (green shaded). Calf rearing costs were calculated using waste milk ($410), milk replacer ($510) and whole saleable milk ($600) according to the methods outlined in section 3.2.4.1.

Carcass Price vs Calf Rearing Cost (4mo) Cost Sensitivity Analysis at Target Growth Rate				
Growth rate	0.50 kg/day			
	Rearing Costs Birth to 4 months ($/hd)			
	Waste Milk	Replacer	Vat Milk (70 cpl)	
Carcass Price ($/kg)	$410.00	$510.00	$600.00	
$4.74	-4%	-12%	-19%	**ROI**
$5.12	4%	-5%	-12%	Loss
$5.50	11%	2%	-5%	0-10%
$6.11	22%	14%	6%	>10%
$6.72	33%	25%	18%	

Picture 7. Return on investment (%) sensitivity analysis of carcass price ($/kg HCW) versus calf rearing costs at a target growth rate (1.0 kg/day) of the WSLS7 cropping-based forage system for the MSA steer target market.

4. Results

4.1 Desk-top Study

4.1.1 Forage DM intake for each system

Forage DM intake differences between feeding system and target market are compared across a range of growth rates in Table 17. Forage intake increased with growth rate, except for GCHS2 where the grain concentrate intake was increased linearly with growth rate. Where the supplement was held constant (RGSS1, WSLS7 and FBLS8), pasture intake increased with increasing growth rate, however at a lower value compared to forage only systems. Figure 4 highlights the differences in pasture intake across forage feeding systems and the higher pasture intake required to meet the ME requirements of increased growth rates.
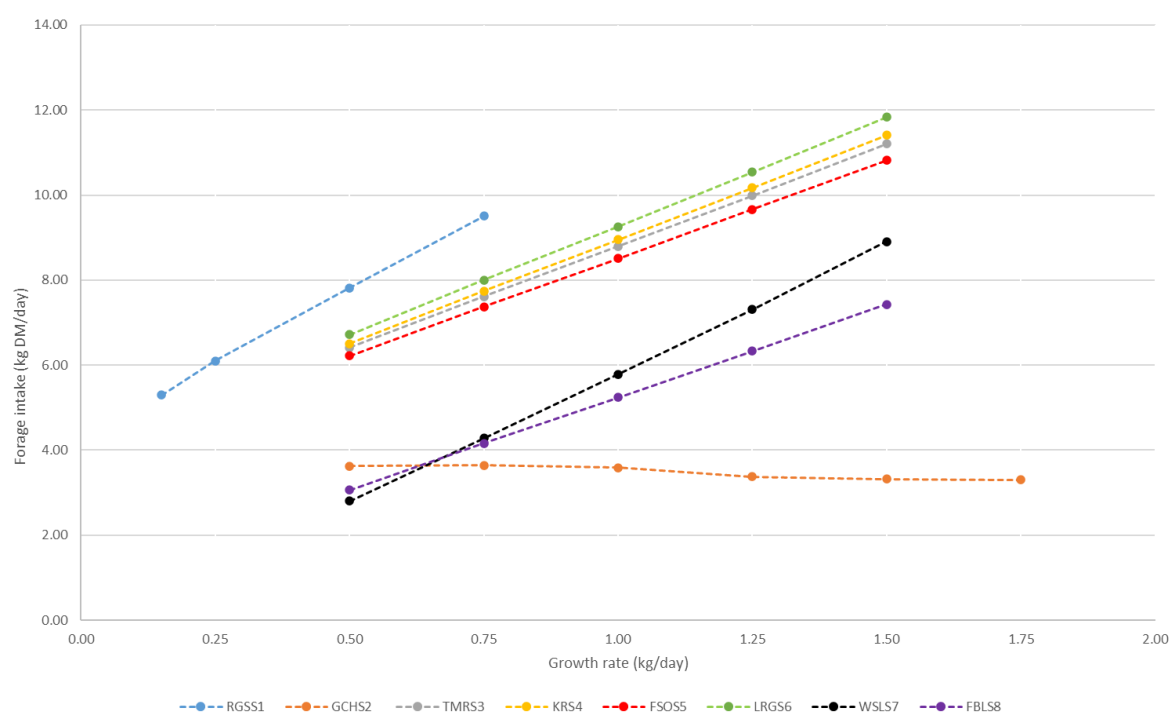
Figure 4. Estimated pasture intake for 8 feeding systems across a range of growth rates from 0.15 to 1.75 kg/head.d^{-1} for the MSA and Trade steer sensitivity analysis.

For example, RGSS1 has a higher pasture intake at lower growth rates due to a lower forage M/D and low rate of supplement fed. The forage only systems (KRS4, FSOS5 and LRGS6) all had similar estimated DM intakes to the TMR3 system, which suggests high quality forage systems can achieve moderate to high ME intakes but at a reduced diet cost (Table 19) compared to TMR systems. The WSLS7 and FBLS8 had similar forage intakes at low target growth rates then diverged as intake increased. This was due to the flat rate feeding of the white sorghum headlage and the lower quality lablab silage compared to lucerne pasture, hence as the growth rate increased, the intake of lower quality forages also needs to increase at a greater rate to meet the ME requirements as the proportion of high ME supplement is reduced. There will be a physical limit to increased intake as fibre concentration and digestibility will reduce rumen passage rates and therefore reduce DM intake. When expressing total DM intake as a percentage of liveweight (Table 18), it is evident that

there will be a limit to the potential growth rate achieved in these feeding systems, with animals of this liveweight unlikely to consume in excess of 3% of their body weight. This however will be influenced by diet structure and forage fibre characteristics, with some feed types like Fodderbeet and Lucerne likely to perform differently in field trials compared to a desk top study based on their quality parameters. Forage intake differences have been seen when the same forages have been presented in different formats, for example grazed versus cut, chopped, and fed on a feedpad. GCHS2 forage intake was relatively constant across all growth rates due to increasing concentrate intake which met the increased ME requirements of increasing growth rate.

Table 17. Forage dry matter (DM) intake (kg DM/head.d^{-1}) within each of the eight forage feeding systems for the five target markets.

System	Growth Rate (kg/day)							
	0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
MSA and Trade steer @ 300 kg liveweight								
RGSS1	5.30	6.10	7.82	9.51	-	-	-	-
GCHS2	-	-	3.63	3.64	3.59	3.38	3.32	3.30
TMRS3	-	-	6.41	7.61	8.80	9.99	11.21	-
KRS4	-	-	6.51	7.74	8.95	10.17	11.41	-
FSOS5	-	-	6.22	7.37	8.51	9.66	10.82	-
LRGS6	-	-	6.72	8.00	9.26	10.54	11.83	-
WSLS7	-	-	2.80	4.28	5.79	7.31	8.91	-
FBLS8	-	-	3.06	4.16	5.24	6.33	7.43	-
JapOx and Manufacturing steer @ 375 kg liveweight								
RGSS1	6.16	7.17	9.22	11.15	-	-	-	-
GCHS2	-	-	5.00	5.28	5.42	5.39	5.51	5.62
TMRS3	-	-	7.51	8.89	10.20	11.52	12.85	-
KRS4	-	-	7.63	9.03	10.38	11.72	13.08	-
FSOS5	-	-	7.29	8.61	9.87	11.13	12.41	-
LRGS6	-	-	7.87	9.34	10.74	12.14	13.56	-
WSLS7	-	-	4.16	5.90	7.56	9.28	11.01	-
FBLS8	-	-	4.09	5.34	6.54	7.74	8.95	-
Vealer steer @ 225 kg liveweight								
RGSS1	4.29	4.87	6.24	7.62	-	-	-	-
GCHS2	-	-	2.05	1.74	1.44	0.97	0.67	-
TMRS3	-	-	5.17	6.15	7.16	8.20	9.25	-
KRS4	-	-	5.25	6.26	7.29	8.34	9.42	-
FSOS5	-	-	5.02	5.96	6.93	7.92	8.93	-
LRGS6	-	-	5.42	6.46	7.54	8.64	9.77	-
WSLS7	-	-	1.25	2.44	3.70	5.03	6.41	-
FBLS8	-	-	1.91	2.81	3.73	4.67	5.63	

Table 18. Total dry matter (DM) intake (% Liveweight) within each of the eight forage feeding systems for the five target markets. Values highlighted in blue is the target growth rate based on achieving an intake level between 2.5 and 3.0 % of liveweight, except for the GCHS2 system where higher intakes are achievable due to increased proportion of grain in the diet.

System	Growth Rate (kg/day)							
	0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
MSA and Trade steer @ 300 kg liveweight								
RGSS1	1.89	2.16	2.73	3.30	-	-	-	-
GCHS2	-	-	2.20	2.53	2.85	3.14	3.45	3.77
TMRS3	-	-	2.14	2.54	2.93	3.33	3.74	-
KRS4	-	-	2.17	2.58	2.98	3.39	3.80	-
FSOS5	-	-	2.07	2.46	2.84	3.22	3.61	-
LRGS6	-	-	2.24	2.67	3.09	3.51	3.94	-
WSLS7	-	-	2.10	2.59	3.10	3.60	4.14	-
FBLS8	-	-	2.02	2.39	2.75	3.11	3.48	-
JapOx and Manufacturing steer @ 375 kg liveweight								
RGSS1	1.74	2.01	2.56	3.08	-	-	-	-
GCHS2	-	-	2.13	2.46	2.76	3.05	3.34	3.64
TMRS3	-	-	2.00	2.37	2.72	3.07	3.43	-
KRS4	-	-	2.03	2.41	2.77	3.13	3.49	-
FSOS5	-	-	1.94	2.30	2.63	2.97	3.31	-
LRGS6	-	-	2.10	2.49	2.86	3.24	3.62	-
WSLS7	-	-	2.04	2.51	2.95	3.41	3.87	-
FBLS8	-	-	1.89	2.23	2.55	2.87	3.19	-
Vealer steer @ 225 kg liveweight								
RGSS1	2.07	2.33	2.94	3.56	-	-	-	-
GCHS2	-	-	2.23	2.78	2.84	3.11	3.42	-
TMRS3	-	-	2.30	2.74	3.18	3.64	4.11	-
KRS4	-	-	2.33	2.78	3.24	3.71	4.19	-
FSOS5	-	-	2.23	2.65	3.08	3.52	3.97	-
LRGS6	-	-	2.41	2.87	3.35	3.84	4.34	-
WSLS7	-	-	2.11	2.64	3.20	3.79	4.40	-
FBLS8	-	-	2.18	2.58	2.99	3.41	3.84	-

4.1.2   Diet costs for each system

Diet cost differences between feeding system and target market are compared across a range of growth rates in Table 19. Diet cost also increased with increasing growth rate as expected due to increased DM intake. Diet cost was higher where grain-based concentrates were used in the feeding system (RGSS1, GCHS2, TMRS3 and WSLS7), relative to the forage only based systems (Figure 5). The relative difference in diet cost between feeding systems was seen across all growth rate levels (Table 19). For a specific feeding system, increased growth rate will result in a reduced feed cost during the growing period and therefore improve the gross margin of the system. Therefore, for higher cost systems, it is imperative that the maximum potential growth rate is achieved. Alternatively, if forage-based feeding systems can achieve high growth rates due to increased ME intake through forage quality rather than concentrates, then there is the ability to achieve higher margins even at lower market prices and provides more margin for error within a system.
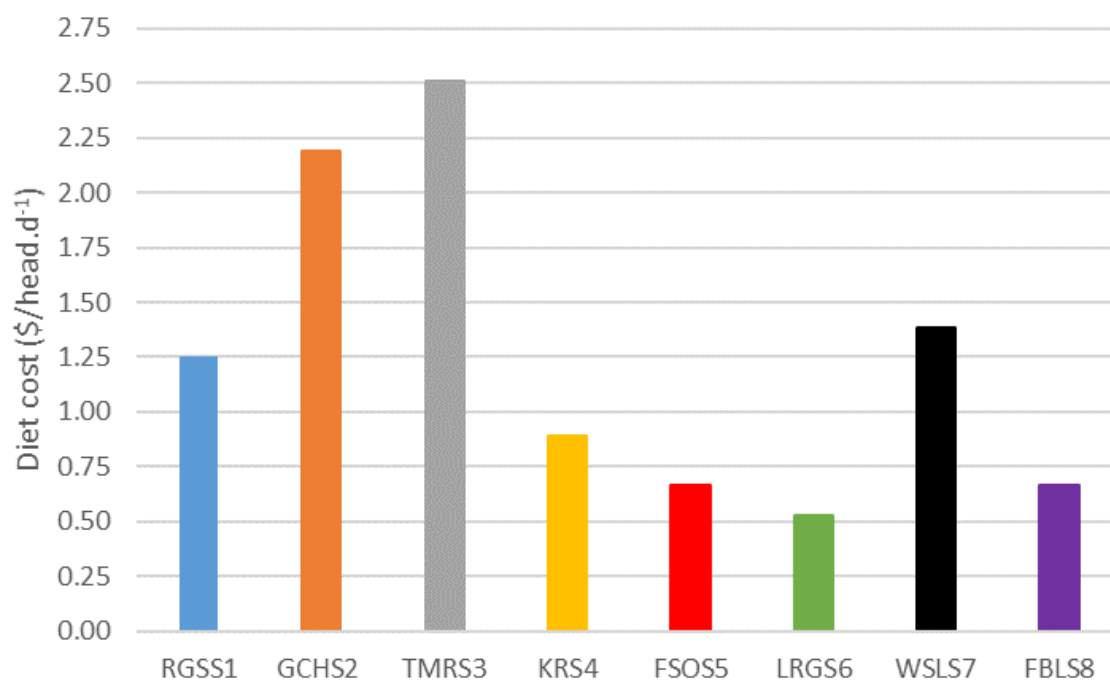
Figure 5. Diet cost comparison across the 8 feeding systems for the MSA and Trade steer market at 0.75 kg/head.d^{-1} growth rate.

Table 19. Diet cost ($/head.d^{-1}) within each of the eight forage feeding systems for the five target markets.

	Growth Rate (kg/day)							
System	0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
MSA and Trade steer @ 300 kg liveweight								
RGSS1	$0.83	$0.91	$1.08	$1.25	-	-	-	-
GCHS2	-	-	$1.87	$2.19	$2.50	$2.77	$3.07	$3.39
TMRS3	-	-	$2.12	$2.51	$2.90	$3.30	$3.70	-
KRS4	-	-	$0.75	$0.89	$1.03	$1.17	$1.31	-
FSOS5	-	-	$0.56	$0.66	$0.77	$0.87	$0.97	-
LRGS6	-	-	$0.44	$0.52	$0.61	$0.69	$0.77	-
WSLS7	-	-	$1.09	$1.38	$1.68	$1.99	$2.31	-
FBLS8	-	-	$0.55	$0.67	$0.79	$0.91	$1.03	-
JapOx and Manufacturing steer @ 375 kg liveweight								
RGSS1	$0.92	$1.02	$1.22	$1.42	-	-	-	-
GCHS2	-	-	$2.21	$2.60	$2.96	$3.27	$3.62	$3.97
TMRS3	-	-	$2.48	$2.93	$3.37	$3.80	$4.24	-
KRS4	-	-	$0.88	$1.04	$1.19	$1.35	$1.50	-
FSOS5	-	-	$0.66	$0.77	$0.89	$1.00	$1.12	-
LRGS6	-	-	$0.52	$0.61	$0.70	$0.80	$0.89	-
WSLS7	-	-	$1.36	$1.71	$2.04	$2.38	$2.73	-
FBLS8	-	-	$0.66	$0.80	$0.93	$1.06	$1.19	-
Vealer steer @ 225 kg liveweight								
RGSS1	$0.73	$0.79	$0.92	$1.06	-	-	-	-
GCHS2	-	-	$1.47	$1.72	$1.96	$2.16	$2.41	-
TMRS3	-	-	$1.71	$2.03	$2.36	$2.71	$3.05	-
KRS4	-	-	$0.60	$0.72	$0.84	$0.96	$1.08	-
FSOS5	-	-	$0.45	$0.54	$0.62	$0.71	$0.80	-
LRGS6	-	-	$0.36	$0.42	$0.49	$0.57	$0.64	-
WSLS7	-	-	$0.78	$1.01	$1.27	$1.53	$1.81	-
FBLS8	-	-	$0.42	$0.52	$0.62	$0.72	$0.83	-

4.1.3   Sensitivity analysis – MSA trade steer market

The results provided in this section will focus on the MSA steer market only, with the sensitivity analysis tables for all other markets provided in Appendix 1 to 4. The sensitivity analysis compared the Queensland 3-year low, average, and high carcass price versus growth rate and calf rearing costs for all systems, plus the comparison with supplement costs for the RGSS1 and GCHS2 systems only.

4.1.3.1   Carcass price versus growth rate gross margin

The gross margin of the 8 feeding systems in Table 20 highlights that there is an increased probability of achieving a profit when forage only systems are used to grow out dairy steers. For systems where a supplement or concentrate was fed (RGSS1, GCHS2, TMR3 and WSLS7), there is a higher likelihood of achieving a loss, particularly when growth rate and carcass prices are low, with growth rate having more influence than carcass price. The comparison between feeding systems at a

growth rate of 0.75 kg/day in Figure 6 also supports a reduced or negative return in systems that utilise a purchased supplement to increase ME intake. Given the high quality forages used in this sensitivity analysis have a relatively high M/D and can be grown under irrigation and fed at a significantly lower cost than purchased supplements, this offers an opportunity for the development of high quality forage systems to grow out dairy male calves for the Australian beef markets. Also the forage M/D used in the QuikIntake simulations for the sensitivity analysis were an average value from a number of feeds in the Feed Plu$ feed analysis database, therefore the values used are relatively conservative and therefore it would be possible to achieve a higher forage M/D and subsequent growth rate for these high quality forage-based feeding systems.

Similar trends in gross margin were seen in the other markets for trade (Appendix 8.1), JapOx (Appendix 8.2), manufacturing (Appendix 8.3) and vealer (Appendix 8.4) steers, however the likelihood of a negative return was greater when carcass prices were lower.
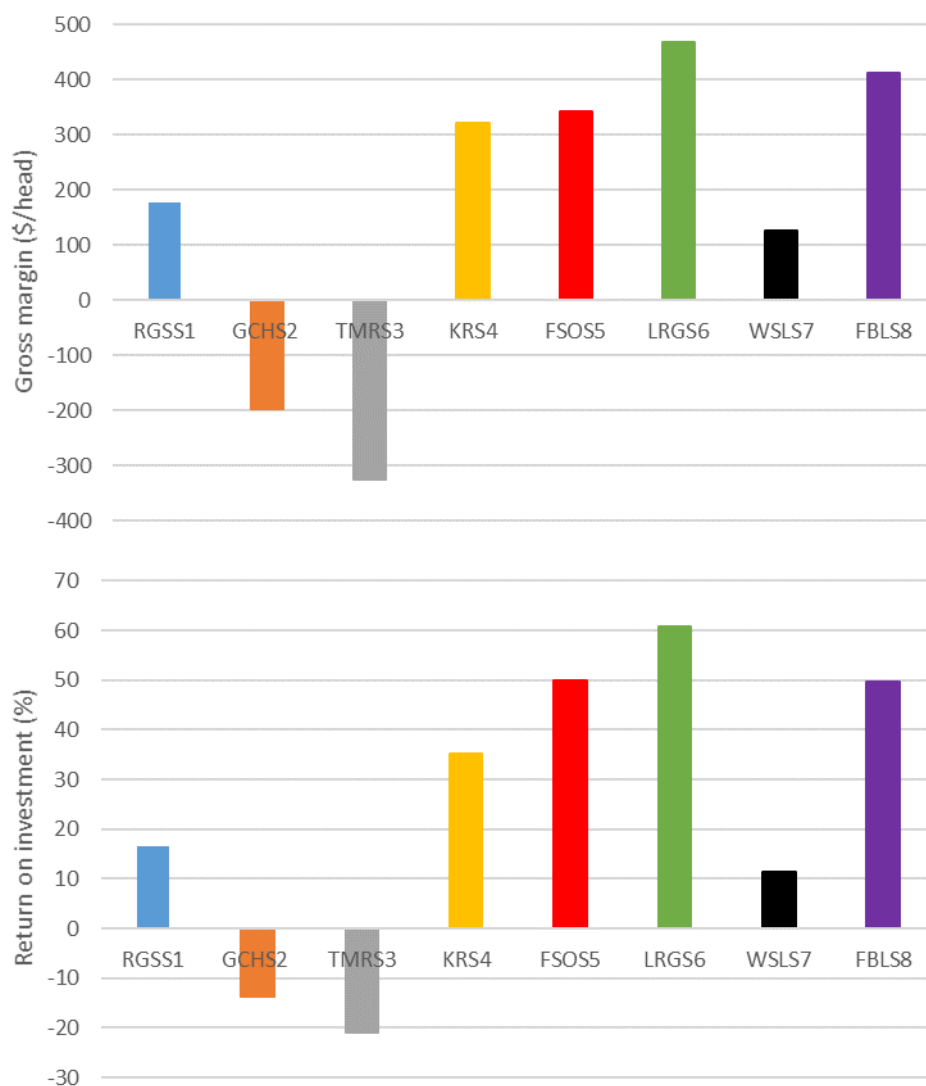
Figure 6. Gross margin (top) and return on investment (bottom) comparison across the 8 feeding systems for the MSA steer market at 0.75 kg/head.d-1 growth rate using the Queensland 3-year average carcass price ($5.50 /kg HCW).

Table 20. Gross margin sensitivity analysis comparing carcass price ($/kg HCW) and growth rate (kg/day) within each of the eight forage feeding systems for the MSA steer market. Values shaded in green represent a profit and values shaded in red represent a loss.

System	Carcass price ($/kg HCW)	Growth Rate (kg/day)							
		0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
RGSS1	4.74	-$1,154	-$586	-$143	$5	-	-	-	-
	5.12	-$1,068	-$500	-$57	$91	-	-	-	-
	5.50	-$982	-$414	$29	$177	-	-	-	-
	6.07	-$845	-$277	$166	$314	-	-	-	-
	6.72	-$708	-$140	$303	$451	-	-	-	-
GCHS2	4.74	-	-	-$614	-$370	-$243	-$157	-$108	-$74
	5.12	-	-	-$528	-$284	-$157	-$71	-$22	$12
	5.50	-	-	-$442	-$198	-$71	$15	$64	$98
	6.11	-	-	-$305	-$61	$66	$152	$201	$235
	6.72	-	-	-$169	$76	$203	$288	$338	$372
TMRS3	4.74	-	-	-$763	-$498	-$365	-$285	-$233	-
	5.12	-	-	-$677	-$412	-$279	-$199	-$147	-
	5.50	-	-	-$591	-$326	-$193	-$113	-$61	-
	6.11	-	-	-$454	-$189	-$56	$24	$75	-
	6.72	-	-	-$317	-$53	$81	$161	$212	-
KRS4	4.74	-	-	$57	$150	$198	$226	$244	-
	5.12	-	-	$143	$236	$284	$312	$330	-
	5.50	-	-	$229	$322	$370	$398	$416	-
	6.11	-	-	$366	$459	$506	$535	$553	-
	6.72	-	-	$503	$596	$643	$671	$690	-
FSOS5	4.74	-	-	$171	$241	$277	$298	$312	-
	5.12	-	-	$257	$327	$363	$384	$398	-
	5.50	-	-	$343	$413	$449	$470	$484	-
	6.11	-	-	$479	$550	$585	$607	$620	-
	6.72	-	-	$616	$687	$722	$743	$757	-
LRGS6	4.74	-	-	$242	$297	$325	$341	$352	-
	5.12	-	-	$328	$383	$410	$427	$437	-
	5.50	-	-	$414	$469	$496	$513	$523	-
	6.11	-	-	$551	$606	$633	$650	$660	-
	6.72	-	-	$688	$742	$770	$786	$797	-
WSLS7	4.74	-	-	-$145	-$46	$2	$30	$45	-
	5.12	-	-	-$59	$40	$88	$116	$131	-
	5.50	-	-	$27	$126	$174	$202	$217	-
	6.11	-	-	$164	$263	$310	$338	$354	-
	6.72	-	-	$301	$400	$447	$475	$491	-
FBLS8	4.74	-	-	$179	$239	$271	$289	$301	-
	5.12	-	-	$264	$325	$357	$375	$387	-
	5.50	-	-	$350	$411	$442	$461	$473	-
	6.11	-	-	$487	$548	$579	$598	$610	-
	6.72	-	-	$624	$685	$716	$734	$747	-

4.1.3.2 Carcass price versus growth rate return on investment

The return on investment (ROI) values in Table 21 show a similar result to the gross margin sensitivity analysis, where the forage-based feeding systems had a positive ROI at all levels of growth rate and carcass prices. The lowest ROI at 6% was seen in the KRS4 system at the lowest growth rate and carcass price. A ROI of greater than 100% was seen in the LRGS6 system when a growth rate of 1.0 kg/day was used in conjunction with the high carcass prices that are currently being seen in the MSA steer markets. The ROI comparison in Figure 6 also highlights that reduced or negative returns are likely when purchased supplements are used to grow our dairy male calves when compared to the forage-based systems. To define the optimum growth rate and carcass price is difficult to achieve with two variables, so Table 21 can be used to define the optimum growth rate and carcass price for each feeding system to achieve the desired return on investment. Additional analysis was conducted on the weekly MSA carcass prices over a 3-year period (24 November 2017 to 20 November 2020) to determine the likelihood of achieving a 10% ROI (Figure 7) if a growth rate of 0.75 kg/day was achieved across all feeding systems. Most of the feeding systems used in the sensitivity analysis are capable of achieving this growth rate with the exception of RGSS1, which will be highly dependent on forage quality across the year and particularly during the dry season in northern Australia. Therefore, a conservative growth rate of 0.25 kg/day was used for the RGSS1 feeding system.
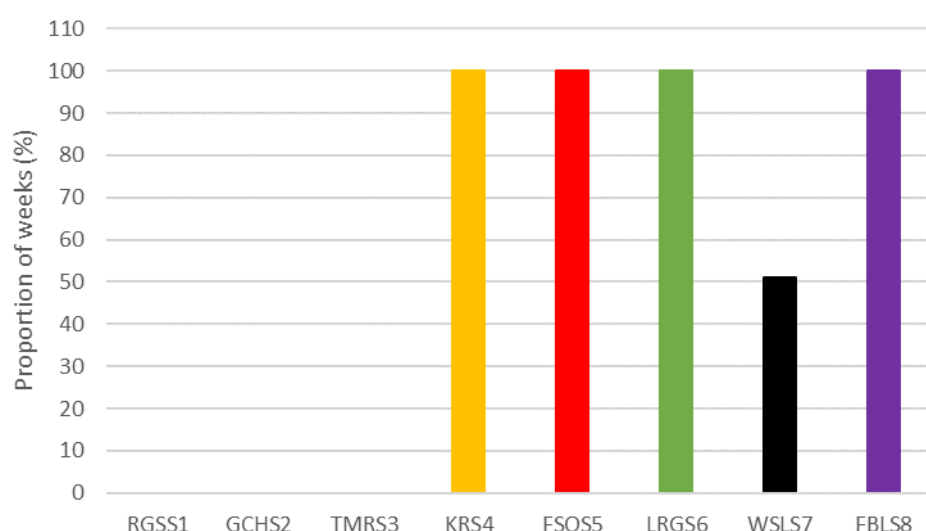
Figure 7. Likelihood of achieving a 10% return on investment across the 8 feeding systems for the MSA steer market at 0.75 kg/head.d^{-1} growth rate using the Queensland MSA weekly carcass prices from 24 November 2017 to 20 November 2020. A growth rate of 0.25 kg/head.d^{-1} was used for the RGSS1 feeding system.

At a conservative growth rate for all feeding systems, the RGSS1, GCHS2 and TMR3 feeding systems did not return a 10% ROI for any week over the past 3 years using the MSA steer prices for Queensland. The WSLS7 system achieved a 10% ROI 51% of the time and the remaining forage-based systems achieved a 10% ROI every week over the past 3 years with a $1.98 range ($4.74 to $6.72) in carcass price over that period, further highlighting the potential of high quality forage based feeding systems to achieve improved returns from growing out dairy male calves. Additional tables with gross margin and ROI values for the trade, JapOx, manufacturing and vealer markets are documented in Appendix 8.1 to 8.4, with similar trends seen in those markets at lower prices.

Table 21. Return on investment (ROI) sensitivity analysis comparing carcass price ($/kg HCW) and growth rate (kg/day) within each of the eight forage feeding systems for the MSA steer market. Values shaded in green represent a ROI >10%, values shaded in gold represent a ROI between 0 and 10% and values shaded in red represent a ROI <0%.

System	Carcass price ($/kg HCW)	Growth Rate (kg/day)							
		0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
RGSS1	4.74	-52%	-35%	-12%	0%	-	-	-	-
	5.12	-48%	-30%	-5%	9%	-	-	-	-
	5.50	-44%	-25%	2%	17%	-	-	-	-
	6.07	-38%	-17%	14%	30%	-	-	-	-
	6.72	-32%	-8%	25%	42%	-	-	-	-
GCHS2	4.74	-	-	-37%	-26%	-19%	-13%	-9%	-6%
	5.12	-	-	-31%	-20%	-12%	-6%	-2%	1%
	5.50	-	-	-26%	-14%	-5%	1%	5%	9%
	6.11	-	-	-18%	-4%	5%	12%	17%	21%
	6.72	-	-	-10%	5%	15%	24%	29%	33%
TMRS3	4.74	-	-	-42%	-32%	-25%	-21%	-18%	-
	5.12	-	-	-37%	-26%	-19%	-15%	-11%	-
	5.50	-	-	-32%	-21%	-13%	-8%	-5%	-
	6.11	-	-	-25%	-12%	-4%	2%	6%	-
	6.72	-	-	-17%	-3%	6%	12%	16%	-
KRS4	4.74	-	-	6%	16%	23%	27%	30%	-
	5.12	-	-	14%	26%	33%	37%	40%	-
	5.50	-	-	23%	35%	43%	47%	51%	-
	6.11	-	-	36%	50%	58%	64%	67%	-
	6.72	-	-	50%	65%	74%	80%	84%	-
FSOS5	4.74	-	-	19%	29%	35%	39%	41%	-
	5.12	-	-	29%	40%	46%	50%	53%	-
	5.50	-	-	38%	50%	57%	61%	64%	-
	6.11	-	-	54%	67%	74%	79%	82%	-
	6.72	-	-	69%	83%	91%	97%	100%	-
LRGS6	4.74	-	-	29%	39%	44%	47%	49%	-
	5.12	-	-	40%	50%	55%	59%	61%	-
	5.50	-	-	50%	61%	67%	71%	73%	-
	6.11	-	-	67%	79%	85%	90%	92%	-
	6.72	-	-	83%	96%	104%	108%	111%	-
WSLS7	4.74	-	-	-12%	-4%	0%	3%	4%	-
	5.12	-	-	-5%	4%	8%	11%	13%	-
	5.50	-	-	2%	11%	16%	19%	21%	-
	6.11	-	-	14%	24%	29%	33%	35%	-
	6.72	-	-	25%	36%	42%	46%	48%	-
FBLS8	4.74	-	-	20%	29%	34%	37%	39%	-
	5.12	-	-	30%	39%	45%	48%	51%	-
	5.50	-	-	39%	50%	56%	59%	62%	-
	6.11	-	-	55%	66%	73%	77%	80%	-
	6.72	-	-	70%	83%	90%	94%	98%	-

4.1.3.3   Carcass price versus supplement cost gross margin

Gross margins increased with a reduction in supplement cost and an increase in carcass prices as expected (Table 22). The point at which a supplement or concentrate becomes uneconomical is difficult to determine as it will also be strongly influenced by growth rate. Carcass prices are externally controlled so it will therefore be important to understand the two things that can be controlled, target growth rate and the upper limit for supplement cost. Therefore, feeding supplements adds an increased risk of reduced margins or a loss as the margin for error will be greater if carcass prices are low at turnoff time.

Table 22. Gross margin sensitivity analysis for the MSA steer market comparing carcass price ($/kg HCW) and supplement cost ($/kg DM) for the 2 feeding systems where supplements are fed separately from the forage (RGSS1 and GCHH2). Values shaded in green represent a profit and values shaded in red represent a loss.

System	Carcass price ($/kg HCW)	Supplement cost ($/kg DM)		
Target growth rate - 0.50 kg/day		0.60	0.75	0.90
RGSS1	4.74	-$107	-$143	-$179
	5.12	-$21	-$57	-$93
	5.50	$65	$29	-$7
	6.07	$202	$166	$130
	6.72	$339	$303	$267
Target growth rate - 1.25 kg/day		0.26	0.32	0.38
GCHS2	4.74	-$65	-$157	-$249
	5.12	$21	-$71	-$163
	5.50	$107	$15	-$77
	6.11	$244	$152	$59
	6.72	$381	$288	$196

4.1.3.4   Carcass price versus calf rearing cost return on investment

Return on investment decreased as the cost of rearing calves to four months of age increased (Table 23). Feeding systems with any purchased supplement had a reduced ROI even at the lower calf rearing costs, particularly when carcass prices were also low. Whilst the high quality forage feeding systems had an ROI greater than 10% with high calf rearing costs and low carcass prices, the relative difference between the low ($410) and high ($600) calf rearing costs at the lowest carcass prices ($4.74) resulted in a 54% reduction in ROI when averaged across the forage only feeding systems. At the highest carcass price, the average reduction in ROI was 24% for the forage only systems when calf rearing costs increased by $190/head. Calf rearing costs to some degree are a fixed cost within the growing phase of dairy male calves, and the proportion of the fixed cost will have a big effect on profitability of the growing system. Hence there is further potential to improve returns on farm through the development of lower cost calf rearing options which may include early weaning strategies. Alternatively, growing dairy male steers out to a greater liveweight may also be an option to water down the fixed costs of rearing these calves.

Similar trends were seen for the other markets but will lower carcass prices, except for the vealer market which was also affected by time to reach market weight and therefore an inability to water down the fixed cost of calf rearing.

Table 23. Return on investment (ROI) sensitivity analysis comparing carcass price ($/kg HCW) and calf rearing costs ($/head) within each of the eight forage feeding systems for the MSA steer market. Values shaded in green represent a ROI >10%, values shaded in gold represent a ROI between 0 and 10% and values shaded in red represent a ROI <0%.

System	Carcass price ($/kg HCW)	Calf rearing costs birth to 4 months ($/head)		
		410.00	510.00	600.00
RGSS1	4.74	-4%	-12%	-19%
	5.12	4%	-5%	-12%
	5.50	11%	2%	-5%
	6.07	22%	14%	6%
	6.72	33%	25%	18%
GCHS2	4.74	-5%	-13%	-20%
	5.12	2%	-6%	-13%
	5.50	9%	1%	-6%
	6.11	21%	12%	5%
	6.72	32%	24%	16%
TMRS3	4.74	-18%	-25%	-32%
	5.12	-12%	-19%	-26%
	5.50	-6%	-13%	-20%
	6.11	3%	-4%	-10%
	6.72	13%	6%	-1%
KRS4	4.74	34%	23%	12%
	5.12	44%	33%	22%
	5.50	54%	43%	32%
	6.11	70%	58%	48%
	6.72	86%	74%	64%
FSOS5	4.74	48%	35%	24%
	5.12	59%	46%	35%
	5.50	69%	57%	45%
	6.11	87%	74%	63%
	6.72	104%	91%	80%
LRGS6	4.74	52%	39%	27%
	5.12	63%	50%	38%
	5.50	74%	61%	49%
	6.11	92%	79%	67%
	6.72	109%	96%	85%
WSLS7	4.74	5%	-4%	-12%
	5.12	13%	4%	-4%
	5.50	20%	11%	3%
	6.11	33%	24%	16%
	6.72	45%	36%	28%
FBLS8	4.74	47%	34%	23%
	5.12	57%	45%	33%
	5.50	68%	56%	44%
	6.11	85%	73%	61%
	6.72	103%	90%	79%

5. Key findings

5.1 Literature review

The literature review on the nutritional requirements and potential growth rates of male dairy calves identified the following key findings:

1. There are two key pathways for the development of male dairy calf growing systems – grass fed, or grain fed with 6 Australian markets available.
2. There are management options available such as early weaning and foster rearing to reduce calf rearing costs without compromising growth rates long term.
3. There is limited published data on the nutrient requirements of male dairy breed calves.
4. Dairy breeds have at least a 15% higher maintenance requirement than beef breeds primarily due to a larger organ mass.
5. Protein requirements for dairy heifers is greater than large-framed beef breeds, but there is no information for male dairy breeds.
6. Dairy breeds have the ability to consume higher energy diets at an early age, therefore reducing the need for a grower phase as muscle and fat develops in line with skeletal growth.
   Growth rates in grower and finishing feedlot systems between 1.15 and 1.85 kg/day have been reported in the literature.
7. Differences in diet during the growing phase can be diminished during the finishing phase on the same diet in Holstein steers.
8. Growth rates on forage-based diets between 1.0 and 1.44 kg/day have been reported in the literature however the data is limited.
9. Pasture based diets have a positive impact on fatty acid composition of meat making them more favourable for human health.
10. Dairy breeds tend to have a lower carcass dressing percentage due to a larger organ mass and proportion of bone compared to beef breeds.
11. Dairy breeds tend to have a smaller eye muscle area due to an increased eye muscle length.
12. Dairy breeds tend to have a lower level of subcutaneous fat cover but increased marbling, both of which can be manipulated with nutritional management.
13. Dairy breeds, particularly Holstein and Brown Swiss, lend themselves to crossbreeding with beef breeds, resulting in improved carcass characteristics, although most of the information presented in the literature focusses on crosses with *Bos taurus* or temperate breeds.

5.2 Sensitivity analysis

The sensitivity analysis identified several key findings that support the potential of developing a dairy beef supply chain based on high quality forage-based production systems, and include:

1. The forages investigated in this study potentially have M/D values if managed correctly, with the ability to improve ME intake equivalent to grain based supplements.
2. DM intake of the high-quality forages is likely to be high due to the high M/D values.
3. High forage intake resulted in high potential growth rates due to ME intake of the high-quality forages.

4. Diet cost was significantly lower for the high-quality forage systems compared to the supplement-based benchmark systems.

5. The use of forage based homegrown energy sources such as white sorghum headlage have a lower diet cost than the supplement based and TMR systems with a similar growth rate, so profitability was higher.

6. Gross margin was primarily affected by diet cost and potential growth rate, which in turn affected time to turn off and total cost of production.

7. Systems that utilised a purchased supplement or concentrate had a higher likelihood of a negative gross margin at any growth rate and at lower carcass prices.

8. High quality forage systems had a positive gross margin and ROI irrespective of growth rate and carcass price for all markets except as a vealer steer.

9. The high-quality forage systems with the most potential to return a profit under most market situations at any growth rate were:
    - Leucaena and Rhodes grass pasture systems
    - Fodderbeet and lucerne pasture system
    - Forage sorghum and oats pasture system
    - Kikuyu and annual ryegrass pasture system

10. Supplement cost had a minor impact on gross margin as profitability was already low in these systems due to higher diet costs relative to the forage-based systems.

11. Calf rearing costs have a big impact on system profitability acting as a fixed cost and had a further negative influence on margins in systems with a high diet cost and cost of production. Increased growth rate and time to turnoff is required to reduce their effect on profit.

12. The most profitable market option in any feeding system is the MSA steer market due to higher carcass prices, however specific carcass parameters need to be met to achieve grading in this system.

13. The trade and JapOx steer markets are also an opportunity if carcass parameters are unlikely to be met under the MSA system.

14. The vealer market has limited opportunities for profit even with potentially higher carcass prices due to the limited time to minimise the effect of calf rearing costs.

6. Conclusion and recommendations

6.1 Conclusion

The Australian red meat industry is currently experiencing a shortage in supply of beef animals to meet domestic and export demands; hence market prices have risen. With the shortage of beef animals across Australia, there is an opportunity to fill part of that demand through the development of cost-effective production systems for male dairy calves. Retaining and growing out male dairy calves will also reduce welfare issues on dairy farms, provided these production systems have long term viability and are resilient to fluctuations in carcass and feed prices. Hence, the development of low-cost high-quality forage systems has the potential to deliver positive outcomes for both the Australian dairy and beef industries.

There is limited information in the literature on the nutritional requirements of male dairy breed calves, both pre and post weaning. There is also limited information in the literature on the growth rate response of male dairy breed bulls and steers to forage based diets and systems, particularly using tropical adapted or C4 forages. Collation of quality data for a range of forages (temperate and tropical) identified several forages that were high in ME and crude protein content relative to typical forages used in the beef industry of northern Australia. These forages are grown under raingrown and irrigated systems, with irrigated forages tending to have a higher yield and quality compared to raingrown forages. A range of forages were selected for the sensitivity analysis that were high in ME content and that could be grown or fed all year round in combination with another forage type. Intake and growth rate predictions were comparable to the supplement and concentrate based benchmark systems used in the study, with the diet cost and cost of production for forage-based systems being significantly lower.

The sensitivity analysis clearly identified that the inclusion of purchased supplements or concentrates significantly decreased gross margin and return on investment. The high quality forage based systems, with the exception of the white sorghum lablab silage (WSLS) system, all have a positive gross margin and return on investment across all growth rates and all but one of the market prices. The vealer market performed poorly due to a reduced time for turn off and high calf rearing costs. Calf rearing costs had a negative impact at low market prices, particularly for the benchmark systems that utilised supplements or concentrates to drive ME intake. Supplement or concentrate prices had minimal impact on the systems that already had low or a negative profit margin.

The results of this desk-top study highlight several opportunities for the dairy and beef industries in Australia to develop low-cost high-quality forage systems that are resilient to market price fluctuations. The benefit to both industries will be a reduction in welfare issues associated with bobby calf euthanasia, an increase in profitability of both dairy and beef businesses and an increase in the supply of a high quality and high value beef for the Australian domestic and export market, with flow on financial and social benefits to agriculture service industries along the supply chain of both industries.

6.2 Recommendations

The following recommendations are based on the key findings of this report and in the context of developing a sustainable and resilient dairy beef supply chain. The key recommendations are:

1. Develop a communications plan in partnership with Dairy Australia for the dairy and beef industry to communicate the outcomes of this study and the potential market opportunities for male dairy calves in Australia.

2. Develop a cross industry (dairy and beef) research, development and adoption project, with a focus on early adoption on both dairy and beef farms in northern Australia and nationally to address the following knowledge gaps specific to high genetic merit male dairy breed animals:
   - Nutritional requirements (maintenance and production) from birth to slaughter weight across a range of market target weights.
   - Pre-weaning management strategies to reduce male calf rearing costs on dairy farms.
   - Develop and implement low-cost high-quality forage-based systems and define the growth rates, carcass characteristics and financial performance of each system.
   - Define the growth path on forage and concentrate based feeding systems and the impact of a compromised or accelerated growth path pre and post weaning.
   - Response to protein supplementation on high quality forage systems.
   - Effect of cross breeding on health and welfare, performance, and carcass characteristics, particularly with tropically adapted beef breeds.
   - Define the environmental emissions from a range of dairy beef feeding systems.
   - Long term analysis on the economic viability of dairy beef production systems.

3. Meat and Livestock Australia and Dairy Australia develop a joint long-term strategic plan to develop a profitable and resilient supply chain for male dairy calves that also addresses welfare, social and environmental issues.

7. References

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8. Appendix

8.1 Trade steer sensitivity analysis

Table 24. Gross margin sensitivity analysis comparing carcass price ($/kg HCW) and growth rate (kg/day) within each of the eight forage feeding systems for the Trade steer market. Values shaded in green represent a profit and values shaded in red represent a loss.

System	Carcass price ($/kg HCW)	Growth Rate (kg/day)							
		0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
RGSS1	4.55	-$1,196	-$628	-$185	-$38	-	-	-	-
	4.94	-$1,109	-$541	-$98	$49	-	-	-	-
	5.32	-$1,022	-$454	-$12	$136	-	-	-	-
	5.97	-$878	-$310	$133	$281	-	-	-	-
	6.61	-$733	-$165	$278	$426	-	-	-	-
GCHS2	4.55	-	-	-$657	-$412	-$286	-$200	-$150	-$117
	4.94	-	-	-$570	-$325	-$199	-$113	-$63	-$30
	5.32	-	-	-$483	-$238	-$112	-$26	$24	$57
	5.97	-	-	-$338	-$94	$33	$119	$168	$202
	6.61	-	-	-$193	$51	$178	$264	$313	$347
TMRS3	4.55	-	-	-$805	-$541	-$407	-$327	-$276	-
	4.94	-	-	-$718	-$454	-$320	-$240	-$189	-
	5.32	-	-	-$632	-$367	-$234	-$154	-$102	-
	5.97	-	-	-$487	-$222	-$89	-$9	$43	-
	6.61	-	-	-$342	-$77	$56	$136	$187	-
KRS4	4.55	-	-	$15	$108	$155	$183	$201	-
	4.94	-	-	$102	$195	$242	$270	$288	-
	5.32	-	-	$188	$282	$329	$357	$375	-
	5.97	-	-	$333	$426	$474	$502	$520	-
	6.61	-	-	$478	$571	$618	$647	$665	-
FSOS5	4.55	-	-	$128	$198	$234	$255	$269	-
	4.94	-	-	$215	$285	$321	$342	$356	-
	5.32	-	-	$302	$372	$408	$429	$443	-
	5.97	-	-	$447	$517	$553	$574	$588	-
	6.61	-	-	$591	$662	$697	$719	$732	-
LRGS6	4.55	-	-	$200	$254	$282	$298	$309	-
	4.94	-	-	$287	$341	$369	$385	$396	-
	5.32	-	-	$374	$428	$456	$472	$483	-
	5.97	-	-	$518	$573	$601	$617	$627	-
	6.61	-	-	$663	$718	$745	$762	$772	-
WSLS7	4.55	-	-	-$187	-$89	-$41	-$13	$2	-
	4.94	-	-	-$100	-$2	$46	$74	$89	-
	5.32	-	-	-$13	$85	$133	$161	$176	-
	5.97	-	-	$131	$230	$278	$306	$321	-
	6.61	-	-	$276	$375	$422	$450	$466	-
FBLS8	4.55	-	-	$136	$197	$228	$246	$258	-
	4.94	-	-	$223	$284	$315	$333	$345	-
	5.32	-	-	$310	$371	$402	$420	$432	-
	5.97	-	-	$455	$515	$547	$565	$577	-
	6.61	-	-	$599	$660	$691	$710	$722	-

Table 25. Return on investment (ROI) sensitivity analysis comparing carcass price ($/kg HCW) and growth rate (kg/day) within each of the eight forage feeding systems for the Trade steer market. Values shaded in green represent a ROI >10%, values shaded in gold represent a ROI between 0 and 10% and values shaded in red represent a ROI <0%.

System	Carcass price ($/kg HCW)	Growth Rate (kg/day)							
		0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
RGSS1	4.55	-54%	-38%	-15%	-4%	-	-	-	-
	4.94	-50%	-33%	-8%	5%	-	-	-	-
	5.32	-46%	-28%	-1%	13%	-	-	-	-
	5.97	-40%	-19%	11%	26%	-	-	-	-
	6.61	-33%	-10%	23%	40%	-	-	-	-
GCHS2	4.55	-	-	-39%	-29%	-22%	-16%	-13%	-10%
	4.94	-	-	-34%	-23%	-15%	-9%	-5%	-3%
	5.32	-	-	-29%	-17%	-9%	-2%	2%	5%
	5.97	-	-	-20%	-7%	3%	10%	14%	18%
	6.61	-	-	-11%	4%	14%	22%	27%	30%
TMRS3	4.55	-	-	-44%	-35%	-28%	-24%	-21%	-
	4.94	-	-	-39%	-29%	-22%	-18%	-15%	-
	5.32	-	-	-35%	-23%	-16%	-11%	-8%	-
	5.97	-	-	-27%	-14%	-6%	-1%	3%	-
	6.61	-	-	-19%	-5%	4%	10%	14%	-
KRS4	4.55	-	-	1%	12%	18%	22%	24%	-
	4.94	-	-	10%	21%	28%	32%	35%	-
	5.32	-	-	19%	31%	38%	42%	46%	-
	5.97	-	-	33%	47%	55%	60%	63%	-
	6.61	-	-	47%	62%	71%	77%	81%	-
FSOS5	4.55	-	-	14%	24%	30%	33%	36%	-
	4.94	-	-	24%	35%	41%	45%	47%	-
	5.32	-	-	34%	45%	52%	56%	59%	-
	5.97	-	-	50%	63%	70%	75%	78%	-
	6.61	-	-	66%	80%	88%	93%	97%	-
LRGS6	4.55	-	-	24%	33%	38%	41%	43%	-
	4.94	-	-	35%	44%	50%	53%	55%	-
	5.32	-	-	45%	56%	61%	65%	68%	-
	5.97	-	-	63%	74%	81%	85%	88%	-
	6.61	-	-	80%	93%	100%	105%	108%	-
WSLS7	4.55	-	-	-15%	-8%	-4%	-1%	0%	-
	4.94	-	-	-8%	0%	4%	7%	9%	-
	5.32	-	-	-1%	8%	12%	16%	17%	-
	5.97	-	-	11%	21%	26%	29%	31%	-
	6.61	-	-	23%	34%	40%	43%	46%	-
FBLS8	4.55	-	-	15%	24%	29%	32%	34%	-
	4.94	-	-	25%	34%	40%	43%	45%	-
	5.32	-	-	35%	45%	50%	54%	56%	-
	5.97	-	-	51%	62%	69%	73%	75%	-
	6.61	-	-	67%	80%	87%	91%	94%	-

8.2 JapOx steer sensitivity analysis

Table 26. Gross margin sensitivity analysis comparing carcass price ($/kg HCW) and growth rate (kg/day) within each of the eight forage feeding systems for the JapOx steer market. Values shaded in green represent a profit and values shaded in red represent a loss.

System	Carcass price ($/kg HCW)	Growth Rate (kg/day)							
		0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
RGSS1	4.67	-$1,932	-$1,015	-$284	-$33	-	-	-	-
	5.07	-$1,813	-$896	-$165	$86	-	-	-	-
	5.46	-$1,694	-$777	-$46	$205	-	-	-	-
	6.08	-$1,510	-$593	$138	$389	-	-	-	-
	6.69	-$1,326	-$409	$322	$573	-	-	-	-
GCHS2	4.67	-	-	-$1,173	-$744	-$514	-$360	-$269	-$204
	5.07	-	-	-$1,054	-$625	-$395	-$242	-$150	-$85
	5.46	-	-	-$935	-$506	-$276	-$123	-$32	$34
	6.08	-	-	-$751	-$322	-$92	$62	$153	$218
	6.69	-	-	-$567	-$138	$92	$246	$337	$402
TMRS3	4.67	-	-	-$1,414	-$944	-$699	-$553	-$456	-
	5.07	-	-	-$1,296	-$825	-$580	-$434	-$337	-
	5.46	-	-	-$1,177	-$707	-$461	-$315	-$219	-
	6.08	-	-	-$993	-$522	-$277	-$131	-$34	-
	6.69	-	-	-$808	-$338	-$93	$53	$150	-
KRS4	4.67	-	-	$26	$193	$279	$331	$365	-
	5.07	-	-	$145	$312	$398	$450	$484	-
	5.46	-	-	$264	$431	$516	$568	$602	-
	6.08	-	-	$448	$615	$701	$753	$787	-
	6.69	-	-	$632	$799	$885	$937	$971	-
FSOS5	4.67	-	-	$226	$351	$416	$455	$481	-
	5.07	-	-	$344	$470	$535	$574	$600	-
	5.46	-	-	$463	$589	$654	$693	$719	-
	6.08	-	-	$647	$773	$838	$877	$903	-
	6.69	-	-	$832	$957	$1,022	$1,061	$1,087	-
LRGS6	4.67	-	-	$352	$449	$499	$530	$550	-
	5.07	-	-	$471	$568	$618	$649	$668	-
	5.46	-	-	$590	$687	$737	$767	$787	-
	6.08	-	-	$774	$871	$921	$952	$971	-
	6.69	-	-	$958	$1,055	$1,105	$1,136	$1,156	-
WSLS7	4.67	-	-	-$405	-$207	-$101	-$41	-$2	-
	5.07	-	-	-$287	-$88	$18	$78	$117	-
	5.46	-	-	-$168	$31	$137	$196	$236	-
	6.08	-	-	$17	$215	$321	$381	$420	-
	6.69	-	-	$201	$399	$505	$565	$604	-
FBLS8	4.67	-	-	$222	$338	$398	$434	$458	-
	5.07	-	-	$341	$456	$517	$553	$576	-
	5.46	-	-	$460	$575	$635	$671	$695	-
	6.08	-	-	$644	$759	$820	$856	$879	-
	6.69	-	-	$828	$944	$1,004	$1,040	$1,064	-

Table 27. Return on investment (ROI) sensitivity analysis comparing carcass price ($/kg HCW) and growth rate (kg/day) within each of the eight forage feeding systems for the JapOx steer market. Values shaded in green represent a ROI >10%, values shaded in gold represent a ROI between 0 and 10% and values shaded in red represent a ROI <0%.

System	Carcass price ($/kg HCW)	Growth Rate (kg/day)							
		0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
RGSS1	4.67	-58%	-42%	-17%	-2%	-	-	-	-
	5.07	-54%	-37%	-10%	6%	-	-	-	-
	5.46	-51%	-32%	-3%	14%	-	-	-	-
	6.08	-45%	-25%	8%	27%	-	-	-	-
	6.69	-40%	-17%	19%	40%	-	-	-	-
GCHS2	4.67	-	-	-46%	-35%	-27%	-20%	-16%	-13%
	5.07	-	-	-41%	-29%	-21%	-14%	-9%	-5%
	5.46	-	-	-36%	-24%	-14%	-7%	-2%	2%
	6.08	-	-	-29%	-15%	-5%	3%	9%	14%
	6.69	-	-	-22%	-6%	5%	14%	20%	25%
TMRS3	4.67	-	-	-50%	-40%	-33%	-28%	-25%	-
	5.07	-	-	-46%	-35%	-28%	-22%	-18%	-
	5.46	-	-	-42%	-30%	-22%	-16%	-12%	-
	6.08	-	-	-35%	-22%	-13%	-7%	-2%	-
	6.69	-	-	-29%	-14%	-4%	3%	8%	-
KRS4	4.67	-	-	2%	16%	25%	31%	35%	-
	5.07	-	-	11%	26%	35%	42%	47%	-
	5.46	-	-	19%	36%	46%	53%	58%	-
	6.08	-	-	33%	51%	62%	70%	76%	-
	6.69	-	-	46%	66%	79%	88%	94%	-
FSOS5	4.67	-	-	19%	33%	42%	48%	52%	-
	5.07	-	-	29%	45%	54%	61%	65%	-
	5.46	-	-	39%	56%	66%	73%	78%	-
	6.08	-	-	55%	74%	85%	93%	98%	-
	6.69	-	-	71%	91%	104%	112%	118%	-
LRGS6	4.67	-	-	34%	47%	55%	61%	65%	-
	5.07	-	-	45%	60%	69%	74%	78%	-
	5.46	-	-	56%	72%	82%	88%	92%	-
	6.08	-	-	74%	91%	102%	109%	114%	-
	6.69	-	-	91%	111%	123%	130%	136%	-
WSLS7	4.67	-	-	-22%	-13%	-7%	-3%	0%	-
	5.07	-	-	-16%	-5%	1%	5%	8%	-
	5.46	-	-	-9%	2%	9%	14%	17%	-
	6.08	-	-	1%	13%	21%	26%	30%	-
	6.69	-	-	11%	25%	34%	39%	43%	-
FBLS8	4.67	-	-	19%	32%	40%	45%	49%	-
	5.07	-	-	29%	43%	51%	57%	61%	-
	5.46	-	-	39%	54%	63%	69%	74%	-
	6.08	-	-	55%	71%	82%	88%	93%	-
	6.69	-	-	70%	89%	100%	108%	113%	-

8.3 Manufacturing steer sensitivity analysis

Table 28. Gross margin sensitivity analysis comparing carcass price ($/kg HCW) and growth rate (kg/day) within each of the eight forage feeding systems for the Manufacturing steer market. Values shaded in green represent a profit and values shaded in red represent a loss.

System	Carcass price ($/kg HCW)	Growth Rate (kg/day)							
		0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
RGSS1	4.55	-$1,968	-$1,051	-$320	-$69	-	-	-	-
	4.95	-$1,848	-$931	-$200	$51	-	-	-	-
	5.35	-$1,729	-$811	-$80	$170	-	-	-	-
	5.96	-$1,544	-$626	$104	$355	-	-	-	-
	6.58	-$1,359	-$442	$289	$540	-	-	-	-
GCHS2	4.55	-	-	-$1,209	-$780	-$550	-$396	-$305	-$240
	4.95	-	-	-$1,089	-$660	-$430	-$277	-$186	-$120
	5.35	-	-	-$970	-$541	-$310	-$157	-$66	-$0
	5.96	-	-	-$785	-$356	-$126	$28	$119	$185
	6.58	-	-	-$600	-$171	$59	$213	$304	$369
TMRS3	4.55	-	-	-$1,450	-$980	-$735	-$589	-$492	-
	4.95	-	-	-$1,331	-$861	-$615	-$469	-$372	-
	5.35	-	-	-$1,211	-$741	-$495	-$349	-$253	-
	5.96	-	-	-$1,026	-$556	-$311	-$164	-$68	-
	6.58	-	-	-$841	-$371	-$126	$20	$117	-
KRS4	4.55	-	-	-$10	$157	$243	$295	$329	-
	4.95	-	-	$110	$277	$363	$414	$448	-
	5.35	-	-	$230	$396	$482	$534	$568	-
	5.96	-	-	$414	$581	$667	$719	$753	-
	6.58	-	-	$599	$766	$852	$904	$938	-
FSOS5	4.55	-	-	$190	$315	$380	$419	$445	-
	4.95	-	-	$309	$435	$500	$539	$565	-
	5.35	-	-	$429	$554	$620	$659	$684	-
	5.96	-	-	$614	$739	$804	$844	$869	-
	6.58	-	-	$799	$924	$989	$1,028	$1,054	-
LRGS6	4.55	-	-	$316	$413	$463	$494	$514	-
	4.95	-	-	$436	$533	$583	$613	$633	-
	5.35	-	-	$555	$652	$703	$733	$753	-
	5.96	-	-	$740	$837	$888	$918	$938	-
	6.58	-	-	$925	$1,022	$1,072	$1,103	$1,123	-
WSLS7	4.55	-	-	-$441	-$243	-$137	-$77	-$38	-
	4.95	-	-	-$322	-$123	-$17	$43	$82	-
	5.35	-	-	-$202	-$4	$103	$162	$201	-
	5.96	-	-	-$17	$181	$288	$347	$386	-
	6.58	-	-	$168	$366	$472	$532	$571	-
FBLS8	4.55	-	-	$186	$302	$362	$398	$422	-
	4.95	-	-	$306	$421	$481	$518	$541	-
	5.35	-	-	$425	$541	$601	$637	$661	-
	5.96	-	-	$610	$726	$786	$822	$846	-
	6.58	-	-	$795	$911	$971	$1,007	$1,031	-

Table 29. Return on investment (ROI) sensitivity analysis comparing carcass price ($/kg HCW) and growth rate (kg/day) within each of the eight forage feeding systems for the Manufacturing steer market. Values shaded in green represent a ROI >10%, values shaded in gold represent a ROI between 0 and 10% and values shaded in red represent a ROI <0%.

System	Carcass price ($/kg HCW)	Growth Rate (kg/day)							
		0.15	0.25	0.50	0.75	1.00	1.25	1.50	1.75
RGSS1	4.55	-59%	-43%	-19%	-5%	-	-	-	-
	4.95	-55%	-39%	-12%	4%	-	-	-	-
	5.35	-52%	-34%	-5%	12%	-	-	-	-
	5.96	-46%	-26%	6%	25%	-	-	-	-
	6.58	-41%	-18%	17%	38%	-	-	-	-
GCHS2	4.55	-	-	-47%	-36%	-29%	-23%	-18%	-15%
	4.95	-	-	-42%	-31%	-22%	-16%	-11%	-7%
	5.35	-	-	-38%	-25%	-16%	-9%	-4%	0%
	5.96	-	-	-30%	-17%	-7%	2%	7%	12%
	6.58	-	-	-23%	-8%	3%	12%	18%	23%
TMRS3	4.55	-	-	-52%	-42%	-35%	-30%	-27%	-
	4.95	-	-	-47%	-37%	-29%	-24%	-20%	-
	5.35	-	-	-43%	-32%	-24%	-18%	-14%	-
	5.96	-	-	-36%	-24%	-15%	-8%	-4%	-
	6.58	-	-	-30%	-16%	-6%	1%	6%	-
KRS4	4.55	-	-	-1%	13%	22%	28%	32%	-
	4.95	-	-	8%	23%	32%	39%	43%	-
	5.35	-	-	17%	33%	43%	50%	55%	-
	5.96	-	-	30%	48%	59%	67%	73%	-
	6.58	-	-	44%	63%	76%	84%	90%	-
FSOS5	4.55	-	-	16%	30%	39%	44%	48%	-
	4.95	-	-	26%	41%	51%	57%	61%	-
	5.35	-	-	36%	53%	63%	70%	74%	-
	5.96	-	-	52%	70%	82%	89%	94%	-
	6.58	-	-	68%	88%	100%	109%	115%	-
LRGS6	4.55	-	-	30%	43%	51%	57%	60%	-
	4.95	-	-	42%	56%	65%	70%	74%	-
	5.35	-	-	53%	69%	78%	84%	88%	-
	5.96	-	-	71%	88%	98%	105%	110%	-
	6.58	-	-	88%	107%	119%	127%	132%	-
WSLS7	4.55	-	-	-24%	-15%	-9%	-5%	-3%	-
	4.95	-	-	-18%	-8%	-1%	3%	6%	-
	5.35	-	-	-11%	0%	7%	11%	14%	-
	5.96	-	-	-1%	11%	19%	24%	28%	-
	6.58	-	-	9%	23%	31%	37%	41%	-
FBLS8	4.55	-	-	16%	28%	36%	41%	45%	-
	4.95	-	-	26%	40%	48%	54%	57%	-
	5.35	-	-	36%	51%	60%	66%	70%	-
	5.96	-	-	52%	68%	78%	85%	90%	-
	6.58	-	-	67%	86%	97%	104%	109%	-

8.4 Vealer steer sensitivity analysis

Table 30. Gross margin sensitivity analysis comparing carcass price ($/kg HCW) and growth rate (kg/day) within each of the eight forage feeding systems for the Vealer steer market. Values shaded in green represent a profit and values shaded in red represent a loss.

System	Carcass price ($/kg HCW)	Growth Rate (kg/day)						
		0.15	0.25	0.50	0.75	1.00	1.25	1.50
RGSS1	4.00	-$2,122	-$1,352	-$767	-$572	-	-	-
	4.75	-$2,010	-$1,239	-$654	-$460	-	-	-
	5.50	-$1,897	-$1,127	-$542	-$347	-	-	-
	6.25	-$1,785	-$1,014	-$429	-$235	-	-	-
	7.00	-$1,672	-$902	-$317	-$122	-	-	-
GCHS2	4.00	-	-	-$1,260	-$964	-$817	-$714	-$657
	4.75	-	-	-$1,148	-$852	-$705	-$601	-$545
	5.50	-	-	-$1,035	-$739	-$592	-$489	-$432
	6.25	-	-	-$923	-$627	-$480	-$376	-$320
	7.00	-	-	-$810	-$514	-$367	-$264	-$207
TMRS3	4.00	-	-	-$1,470	-$1,153	-$998	-$909	-$851
	4.75	-	-	-$1,358	-$1,040	-$886	-$797	-$738
	5.50	-	-	-$1,245	-$928	-$773	-$684	-$626
	6.25	-	-	-$1,133	-$815	-$661	-$572	-$513
	7.00	-	-	-$1,020	-$703	-$548	-$459	-$401
KRS4	4.00	-	-	-$478	-$367	-$312	-$280	-$260
	4.75	-	-	-$366	-$254	-$200	-$168	-$147
	5.50	-	-	-$253	-$142	-$87	-$55	-$35
	6.25	-	-	-$141	-$29	$25	$57	$78
	7.00	-	-	-$28	$83	$138	$170	$190
FSOS5	4.00	-	-	-$342	-$257	-$216	-$192	-$176
	4.75	-	-	-$229	-$144	-$103	-$79	-$64
	5.50	-	-	-$117	-$32	$9	$33	$49
	6.25	-	-	-$4	$81	$122	$146	$161
	7.00	-	-	$108	$193	$234	$258	$274
LRGS6	4.00	-	-	-$255	-$189	-$157	-$139	-$127
	4.75	-	-	-$142	-$76	-$45	-$26	-$14
	5.50	-	-	-$30	$36	$68	$86	$98
	6.25	-	-	$83	$149	$180	$199	$211
	7.00	-	-	$195	$261	$293	$311	$323
WSLS7	4.00	-	-	-$633	-$543	-$504	-$486	-$477
	4.75	-	-	-$520	-$430	-$392	-$374	-$365
	5.50	-	-	-$408	-$318	-$279	-$261	-$252
	6.25	-	-	-$295	-$205	-$167	-$149	-$140
	7.00	-	-	-$183	-$93	-$54	-$36	-$27
FBLS8	4.00	-	-	-$313	-$246	-$214	-$196	-$184
	4.75	-	-	-$201	-$134	-$102	-$83	-$71
	5.50	-	-	-$88	-$21	$11	$29	$41
	6.25	-	-	$24	$91	$123	$142	$154
	7.00	-	-	$137	$204	$236	$254	$266

Table 31. Return on investment (ROI) sensitivity analysis comparing carcass price ($/kg HCW) and growth rate (kg/day) within each of the eight forage feeding systems for the Vealer steer market. Values shaded in green represent a ROI >10%, values shaded in gold represent a ROI between 0 and 10% and values shaded in red represent a ROI <0%.

System	Carcass price ($/kg HCW)	Growth Rate (kg/day)						
		0.15	0.25	0.50	0.75	1.00	1.25	1.50
RGSS1	4.00	-78%	-69%	-56%	-49%	-	-	-
	4.75	-74%	-63%	-48%	-39%	-	-	-
	5.50	-70%	-58%	-40%	-30%	-	-	-
	6.25	-66%	-52%	-31%	-20%	-	-	-
	7.00	-61%	-46%	-23%	-10%	-	-	-
GCHS2	4.00	-	-	-68%	-62%	-58%	-54%	-52%
	4.75	-	-	-62%	-54%	-50%	-46%	-43%
	5.50	-	-	-56%	-47%	-42%	-37%	-34%
	6.25	-	-	-50%	-40%	-34%	-29%	-25%
	7.00	-	-	-44%	-33%	-26%	-20%	-16%
TMRS3	4.00	-	-	-71%	-66%	-62%	-60%	-59%
	4.75	-	-	-66%	-59%	-55%	-53%	-51%
	5.50	-	-	-60%	-53%	-48%	-45%	-43%
	6.25	-	-	-55%	-47%	-41%	-38%	-35%
	7.00	-	-	-49%	-40%	-34%	-30%	-28%
KRS4	4.00	-	-	-44%	-38%	-34%	-32%	-30%
	4.75	-	-	-34%	-26%	-22%	-19%	-17%
	5.50	-	-	-23%	-15%	-10%	-6%	-4%
	6.25	-	-	-13%	-3%	3%	7%	9%
	7.00	-	-	-3%	9%	15%	19%	22%
FSOS5	4.00	-	-	-36%	-30%	-26%	-24%	-23%
	4.75	-	-	-24%	-17%	-13%	-10%	-8%
	5.50	-	-	-12%	-4%	1%	4%	6%
	6.25	-	-	0%	9%	15%	18%	21%
	7.00	-	-	12%	23%	29%	33%	35%
LRGS6	4.00	-	-	-30%	-24%	-21%	-19%	-17%
	4.75	-	-	-17%	-10%	-6%	-4%	-2%
	5.50	-	-	-3%	5%	9%	12%	13%
	6.25	-	-	10%	19%	24%	27%	29%
	7.00	-	-	23%	33%	39%	42%	44%
WSLS7	4.00	-	-	-51%	-47%	-46%	-45%	-44%
	4.75	-	-	-42%	-38%	-35%	-34%	-34%
	5.50	-	-	-33%	-28%	-25%	-24%	-23%
	6.25	-	-	-24%	-18%	-15%	-14%	-13%
	7.00	-	-	-15%	-8%	-5%	-3%	-3%
FBLS8	4.00	-	-	-34%	-29%	-26%	-25%	-23%
	4.75	-	-	-22%	-16%	-12%	-10%	-9%
	5.50	-	-	-10%	-3%	1%	4%	5%
	6.25	-	-	3%	11%	15%	18%	20%
	7.00	-	-	15%	24%	29%	32%	34%