Future dairy farm systems: a bio-economic analysis

A thesis presented in partial fulfilment of the requirements for the degree of

Masters of AgriCommerce

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Abstract

The dairy industry is an important component of New Zealand economy particularly in terms of foreign exchange earnings, local communities and employment, contributing around 3.5% of NZ's total GDP annually. The future of the dairy industry can be influenced by consumer trends, the volatility of production, input and output prices, the environmental footprint, stricter trade regulations and animal welfare. In a previous study, a series of likely future scenarios had been developed conceptually through a rigorous analysis that involved farmers, researchers, industry participants and a multitude of stakeholders. However, the likely impact of these scenarios at a farm level has not yet been quantified. In an attempt to quantify the implications of these scenarios, this study developed a bio-economic analytical framework. This framework has been empirically applied on a case study dairy farm using FARMAX® whole-farm system software. Future scenarios simulated are "Consumer is King", "Governments Dictate", and "Regulation Rules". Determining the on-farm adjustments and then modelling the impact of these on the case study farm enabled in-depth analysis to occur. The feasibility of each and the economic implications of the changes differed between scenarios. For two of the scenarios, if they eventuate, further on-farm adjustments will be required.

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Dedicated to Beltran, Sara & Clara.

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Abbreviation	**Meaning**
AMS	Automatic Milking System
ATR	Asset Turnover Ratio
BW	Breeding Worth
CK	Consumer is King
DM	Dry Matter
FTE	Full-Time Equivalent
GD	Government Dictates
GPS	Global Positioning System
MA	Mix Aged
MS	Milk Solids
N	Nitrogen
NZ	New Zealand
OAD	Once A Day
OP	Operating Profit
PKE	Palm Kernel Expeller
ROA	Return On Assets
RR	Regulation Rules
R&M	Repair and Maintenance
SR	Stocking Rate
WMP	Whole Milk Powder

Chapter 1: Introduction

1.1 Context and Rationale

1.1.1 The New Zealand Primary Industry post deregulation

In the mid-1980s, the near bankruptcy of the New Zealand (NZ) economy from excessive external debt led to immediate reforms and the introduction of deregulation, resulting in the removal of farm subsidies (Moot *et al.*, 2010). By 1987, total government assistance to agriculture in New Zealand fell from 32 to 3 per cent of the value of the output (**Figure 1-1**), and controls on foreign exchange, wages, prices and imports were removed (Frengley & Engelbrecht, 1998). As Beux Garcia (2013) observed, this situation created conditions for restructuring the agricultural sector and for changing farming practices towards higher efficiency. Without subsidies, farmers started facing lower and more fluctuating market prices, while still bearing high domestic costs and high inflation (Martin *et al.*, 2005). Declining profitability, falling land values and high annual interest rates –up to 20%– reinforced the need for sound financial and risk management (Martin *et al.*, 2005), forcing farmers to become internationally more competitive. Inefficient and poor performing farmers found themselves fully exposed to market competition, being the ones with highest debt/asset ratio and cash flow losses forced to sell their farms due to financial pressures (**Figure 1-1**).

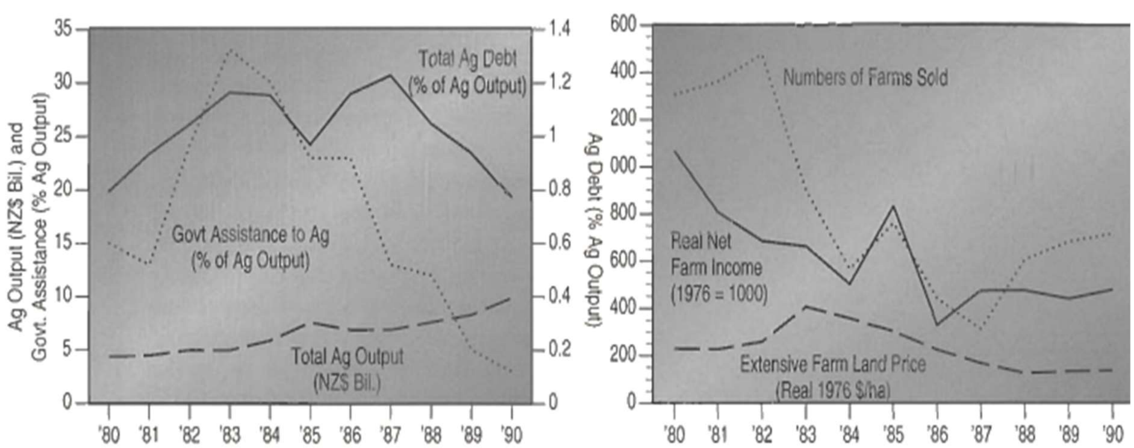


Figure 1-1: Immediate pre and post deregulation: Agricultural Indicators (left) & Sheep & beef farm income & land sales (right) (Frengley & Engelbrecht, 1998)

On the other hand, top farmers who were previously inhibited by the government intervention were now rewarded by the free market for their management excellence, improving their self-reliance and self-esteem. According to Frengley & Engelbrecht (1998), those farmers who had their management system under continuous review, spent wisely, were more conscious of flexibility, proactive rather than reactive, and monitor their work via sound recording, were the ones that stood out after the deregulation.

Broadly, as the profitability of different industries changed, there was considerable enterprise substitution. Reliance on income from sheep products fell, being displaced mainly by the expansion of dairying, cash cropping and forestry (Frengley & Engelbrecht, 1998).

1.1.2 The growth of the Dairy Industry

As Tuñon (2005) observed, the cut in subsidies done by the New Zealand government made farmers compete more successfully in the international milk commodity market, as the country was able to produce at a low cost compared to its global competitors. Figures show how since the deregulation the dairy industry has been a significant contributor to New Zealand success, representing more than 40% of the primary industries' exports and 25% of the country's total exports (Shadbolt & Apparao, 2016). Only in the 2014-15 year, the dairy industry earned $13.2 billion from its exports, contributing with around 3.5% of NZ's total GDP annually (IFCN, 2016).

Furthermore, the dairy industry makes a significant contribution to the support of rural communities: 48,240 people in total are employed by the industry of whom 12,900 people worked in processing and the other 35,340 worked on-farm, managing the 5 million dairy cows that graze throughout the country (DairyNZ, 2016). The industry not only provides financial returns, food and employment for New Zealanders, it also produces almost 3% of all the milk in the world (IFCN, 2016).

On the whole, as Shadbolt *et al.* (2015) highlighted, New Zealand has relied heavily on the dairy industry to maintain economic growth rates, buffer the economy from declines on other key agribusiness sectors –such as Red Meat, Wool, Forestry, Wine and Horticulture– and to protect the economy from the impact of Global Financial Crises.

1.1.3 Characteristics of the dairy industry in New Zealand

Since the beginning, New Zealand dairying has always been principally an export-oriented activity. Almost 95% of the milk produced in the country is exported overseas and New Zealand milk comprises 40% of the milk exported worldwide, being the world's largest exporter of dairy products and the 8th largest milk producer worldwide (IFCN, 2016). As most of this production is sold at international market prices, milk prices follow closely the prices of commodities on the world market. Around 200 different products are exported to a variety of countries (DairyNZ, 2017a).

New Zealand's clean, green and environmentally friendly image in countries that have been shaken by food safety scares, contributed also to the dairy industry success as many products have been repositioned into high-value markets (Shadbolt & Martin, 2005). In addition, the distance between New Zealand and its main export markets, combined with an environment suitable for pastoral production and a favourable context in terms of global supply and demand changes, had been favouring New Zealand dairy industry's success.

According to Shadbolt *et al.* (2015), the success of the dairy industry can not only be linked to New Zealand's natural competitive capability –based on highly efficient pasture and processing systems– but also on the contribution of effective primary processors and marketers. Moreover, farm systems had evolved rapidly in New Zealand as a consequence of a combination of improved animal genetics, precision farming, irrigation, changing pasture and feed systems and better farm management, leading to a global recognition of being low-cost producers of high quality milk (IFCN, 2016).

1.1.3.1 Actual issues surrounding the dairy activity

Globally, dairy farmers are being faced with complex, dynamic and interrelated changes in the production context, related to –among other things– climate change, increasing food demand, scarcity of natural resources, volatile input and output prices, rising energy costs and administrative regulations (Martin *et al.*, 2013).

In New Zealand, the rapid growth in milk production has had some unintended consequences: the environmental impact of higher stocking rates –especially on free draining soils and under irrigation, or in high rainfall areas–, is now being closely monitored and controlled (Shadbolt & Apparao, 2016). Moreover, the inherent volatility of the dairy industry has always been an issue for New Zealand, whose limited domestic market –less than 5% of New Zealand milk is consumed within the country– with a relatively small and extremely competitive traded market, is subject to quite significant shifts in supply and demand volumes and prices.

On the social aspect, people are becoming less accepting of the negative impacts of farming, not recognizing the important economic and social contribution that agriculture has to the nation (Clark *et al.*, 2007). In recent times, this has led to a disconnection between urban New Zealand and the rural community. Whereas in the past almost all New Zealanders had some contact with farming, the number of people with no involvement has been growing, creating a social gap between 'townies' and farmers. As a result, more attention has been put on highlighting agriculture's interaction with surroundings, such as the environment, production methods and food safety.

In terms of compliance, external entities like the government and social media have been putting pressure on the agricultural industry to change production focus from quantity to quality and sustainability (Sørensen *et al.*, 2010). As a consequence, farmers find that they are having to modify some of their practices, keeping better records of animal treatments as well as informing the wider public about both new and old technologies (Martin *et al.*, 2005). Along with this, the less political influence had reduced farmer's freedom to operate within some property rights. The power of social media has been growing, giving farming –and especially dairying– a hard time. Organizations such as SAFE (Save Animals from Exploitation) are actively acting to communicate and inform –through media campaigns as shown in **Figure 1-2**– what they believe standard practices of the dairy industry are attempting against animal welfare.

Figure 1-2: Example of a campaign ad done by SAFE organization about the dairy industry in Auckland City (source: www.safe.org.nz)

To mitigate this, industry organisations have been actively working in pushing back on negative reporting of dairy farming. DairyNZ, the industry organisation that represents all New Zealand dairy farmers, is working on a public perception programme to drive positive commentary in the media and to create opportunities for direct conversations with the public. The focus is to share positive stories and encourage farmers to share their stories about dairy, what is actually happening on-farm to protect waterways, and how farmers care for their animals through their management practices (DairyNZ, 2017a).

1.1.4 The future of the industry

Uncertainty is a fact of life in New Zealand dairying (Shadbolt & Apparao, 2016). It is also a fact that future farms will differ from those of today, as they will be forced to adapt to more strict and demanding regulations related with the make-up of the milk, mainly associated with the environment and animal husbandry. However, it is uncertain what these future farm systems will look like at a farm level. For that reason, significant investments are being made both on and off-farm based on a view of the future.

The Centre of Excellence in Farm Business Management (CEFBM) –a joint venture between Massey and Lincoln Universities in New Zealand–, began a project to research Dairy Farm Systems for the Future. The purpose was to explore how to identify and design farm systems best suited to the changing environment and farmer circumstances. In this project, Shadbolt *et al.* (2015) emphasized on the importance of looking beyond the common view of the future to understand what are the underlying issues that are shaping the future of the dairy industry, as this will be critically important not only for the prosperity of the industry but also for New Zealanders in general, taking into account the significant contribution the industry represents to the economy of the country. The project initiated with the design of the future scenarios, which demanded a rigorous analysis in which farmers, researchers, industry participants and a multitude of stakeholders were involved. A set of "plausible scenarios about the future (10-20 years)" was articulated, contemplating a diverse range of factors and uncertainties that are set to shape volume, value, cost, complexity and volatility in the future of the dairy industry. They were developed to support decision makers in exploring how the farm systems might have to change to stay competitive under different scenarios.

In this thesis, the aim will be put in searching for resources able to bring those future scenarios to a farm level, to evaluate how they can potentially perform under the circumstances described. To do this, a research in what simulation tools are available and how successful these tools have been in representing scenarios must be undertaken.

1.1.5 How can modelling help

New Zealand dairy farmers' have been continuously adapting –with more or less success– their farming systems to the changing world, but the pace, scale and even the direction of such changes are hardly predictable (Thompson & Scoones, 2009). Thus, designing alternative dairy farm systems that could potentially flourish in this modern world is a complex and diverse task that needs practical, commercial and scientific data to be sourced and put together (Bicknell *et al.*, 2015). Moreover, quantifying the outcomes of adopting farm systems influenced by plausible future facts represents also a big challenge, as risk management is also involved.

Modelling is a tool which can play an important role in the development of these future scenarios. As field and farm experiments require a large number of resources –and may still not provide sufficient information in space and time to identify appropriate and effective practices–, farm systems modelling has become a valuable tool for farmers requiring to make a decisions for short-term situations, as various scenarios can be tested at a considerable speed (Jones *et al.*, 2017).

Furthermore, as on-farm experimentation is an expensive type of research to conduct, testing ahead of applying on-farm research is vital to minimise time and cost. For example, as Hart *et al.* (1998) argued, computer simulation and optimization have the potential to improve dairy farming practices without the need of doing an enormous amount of physical tests.

In practice, the develop of farm-specific models have been helping farmers to plan their activities in response to changing circumstances, enabling them to explore the various trade-offs inherent in any decision making process (O'Grady & O'Hare, 2017) and providing them with the means to adapt their system rapidly and effectively if needed. The ability of a model to simulate interactions between cows, pasture, crops and management in a farm system contribute to answering questions that would take time and work in real life. Equally important, information collected from simulations help farmers exploring today the options that could work for the future (DairyNZ, 2017c).

1.2 Problem Statement

New Zealand dairy farmers have operated in a deregulated environment for more than 30 years. During this time, consumers and markets have become more demanding, representing a challenge for farmers that have to meet their requirements while managing their costs, utilising their resources in a sustainable way that preserves the environment, and do all this while achieving long-term profitability and growth (Shadbolt & Martin, 2005).

The future of the Dairy industry is underpinned by growth drivers but there is a history of volatility and many uncertainties that may have significant implications for NZ's dairy farm systems, including climatic extremes, variable milk and input prices, legislative constraints, environmental and animal welfare concerns, etc. Given the importance of the dairy industry for New Zealand, all participants need to work together to prepare the field for what the future holds.

After the rigorous analysis made by Shadbolt *et al.* (2015) to come up with the four future plausible scenarios, further investigation is required to determine the potential impact that these scenarios could have at a farm level, as this could be useful to support farmers and decision makers in exploring how farm systems might have to change to stay competitive. Consequently, an additional stage is required to analyse how a current dairy farm system would look like at a farm level if the future scenarios described end up occurring.

Nowadays, modelling had become an important tool for describing and analysing an existing farm and planning for changes to it. The ability of a model to simulate interactions between variables –such as cows, pasture, crops and management– in a farm system contribute to answering questions that would take time and work in real life (Bywater & Cacho, 1994). Information collected from simulations help to explore today the options that could work for the future, providing the means to adapt farm systems rapidly and effectively if needed. Moreover, this opportunity of easy explore managerial changes can effectively be translated into an increase in farm profits (DairyNZ, 2017c).

Therefore, using a single case study farm as a baseline system, this research will aim to simulate what a current farm system could look like under the changes described on the future scenarios in order to analyse how this new system design could potentially perform at a farm level.

1.3 Research Question

What are the farm level implications of the likely future scenarios?

1.4 Research Objectives

1. Develop a bio-economic analytical framework for systems design
2. Determine the on-farm adjustments required for each future scenario
3. Quantify the economic implications of these farm system changes for each future scenario

1.5 Thesis Outline

The purpose of the study has been set out in this chapter. The rest of the thesis is structured in the following order:

Chapter 2 reviews the relevant literature, which will introduce the concepts that will then work as the background for the modelling approach. It will start with systems theory, followed by a review on farming systems, which will cover literature on pasture-based farm systems in New Zealand and its characteristics. Secondly, the metrics used in pasture-based systems will be outlined and reviewed, with the purpose of finding those that could be used for the physical and financial assessment planned for this study. Finally, farm system design and modelling literature will be presented and reviewed. This will include existing commonly used modelling platforms in NZ, with their description, benefits and how they have been used and how successful they have been, deriving subsequently on their limitations.

Chapter 3 starts presenting a summary of the future scenarios. It will then discuss the implications that the occurrence of the facts mentioned on the scenarios could bring to farmers. After that, the challenge of simulating the characteristics of the future scenarios on a farm level using the available modelling tools (discussed previously) will be set. This will led to examine the importance of setting boundaries and how this was done for this research in particular. Lastly, this chapter reviews current and future technologies and innovations in farming that could help overcome some of the challenges and issues delimited inside the boundaries of this study.

Chapter 4 presents the method used, commencing with the research strategy followed to answer the research question set for this study. The description of the case study farm that will work as the base farm system for this research is then given. Afterwards, the chapter explains how data was collected and analysed, and how it was used to calibrate the models. Finally, the proposed farm systems are introduced.

Chapter 5 outline the results of the modelling.

Chapter 6 discusses the results. Comparisons on how the proposed farm systems behaved led to the final conclusions of this study, outlined in Chapter 7.

Chapter 2: Literature review

The aim of this chapter is to review relevant literature to provide the concepts needed to support the choices made for the design of the new farming systems able to cope with the challenges stated in the future scenarios.

2.1 Systems theory

It has become clear that the problems and challenges we face nowadays are highly interlinked, multidisciplinary and complex (Hieronymi, 2013). An understanding of systems theory is a much-needed competence to deal better with this increasingly complex world, as it allows to comprehend how different elements interact and how an adjustment to one of them may alter overall performance in more ways than first thought.

2.1.1 What is a system

The concept of a system is one of the most widely used concepts in science (Hieronymi, 2013). Broadly, Johnson *et al.* (1964) defined a system as "an organized or complex hole; an assemblage or combination of things or parts forming a complex or unitary whole" (p. 367). Bywater & Kelly (2005) contribute to this definition by describing a system as a set or group of components –things, people or ideas– that interact to perform a function. Alone, these components are reduced to small, single parts to be assumed individually. Coming together and combining what is known about these parts, they can be seen and understood as a part of a whole thing. Therefore, as Bywater & Kelly (2005) observed, when adding new components to a system or when changing an existing part of it, a new dynamic is created which is likely to alter overall system performance. In conclusion, in a system, everything is or can be connected to everything else.

2.1.2 Key elements contained on a system

Bywater & Kelly (2005) determined that 9 key features must be included in a system:

Firstly, systems are delimitated by *boundaries* (1), which are determined as means for defining a system. For example, the physical land area of a dairy farm could be used as a boundary for a system analysis. Elements contained within these boundaries have strong relationships with each other but limited to non-existent relationships with elements outside the boundaries (Bywater & Kelly, 2005; Hammond, 2015). In with this idea of a 'boundary', Johnson *et al.*

(1964) argue that a system provides a framework for visualizing internal but also external environmental factors as an integrated whole.

Systems also have a hierarchical *structure* (2), meaning that a system is made up by sub-systems, each of which is also part of a higher level system. A number of systems are contained on an individual farm system and are used to manage land, labour and capital (Bywater & Kelly, 2005).

Any element outside the system's boundaries is part of the *environment* (3) and should be considered for the purpose of analysis (Bywater & Kelly, 2005).

A system has a *purpose or a reason* (4) to be defined. A farm system is often created to assist with the understanding and comprehension of the farm whole entity, in order to make improvements (Bywater & Kelly, 2005).

All systems involve the transformation of some type of input into an output (5). For example, turning animal feed and supporting resources into marketable consumer products (Bywater & Kelly, 2005; Hammond, 2015).

For a better understanding of how systems work, it is important to analyse the meaning of holistic thinking (6). The concept of holism considers the assembly of the components of a system as a whole rather than the sum of its parts. This view also accepts that everything is or can be connected to everything else. Thinking holistically not only allows to understand other perspectives but also to learn how to gain that understanding (Bywater & Kelly, 2005; Hammond, 2015). As Johnson *et al.* (1964) pointed out, it is important to recognize the integrated nature of specific systems, including the fact that has both inputs and outputs, which can be seen as a self-contained unit.

Components or elements and the relationship between them (7) are important for the comprehension of how systems are organised and how they could be modelled (Bywater & Shadbolt, 2005; Hammond, 2015). Hieronymi (2013) remarked how interactions among components can have a major influence on responses of systems; hence it is not sufficient to draw conclusions about an overall system by studying components in isolation.

Communication and control (8) involve the transfer of information, energy or materials between system elements (communication) and the subsequent feedback used in the measurement of the purpose of the system (control) (Bywater & Kelly, 2005; Hammond, 2015).

A system has emergent properties (9) which are outputs that can only be discovered by assembling the system components, only discovered by looking at the whole system (Bywater & Kelly, 2005; Hammond, 2015).

2.1.3 Whole-farm system

In order to make better decisions about how to manage financial, physical and human resources, farmers must have an understanding of the farm they manage as a whole entity, without breaking it down and reducing into components. In other words, the concept of 'wholeness' involves looking at 'the big picture' and not just things in isolation.

Shadbolt & Martin (2005) pointed out how 'the whole' normally involves –at the minimum– people (including owners and anyone with the power of alter or veto a decision, i.e. advisers, suppliers, customers and clients), resources (land) and money (cash on hand, potential for borrowing and potential earnings generated from the resources). Understanding how these parts relate to each other and combining what is known about them is important for comprehending 'the whole'.

As further suggested by Shadbolt & Martin (2005), the successful outcome of a whole-farm management will finally be the achievement of the goal and objectives of its owners.

2.1.4 Thinking holistically

Understanding how things work in a system as a whole creates a new way of thinking that can be then applied everywhere else, which is relevant considering farm managers nowadays not only have to manage their resources for their satisfaction, but also for the satisfaction of their bankers, customers, neighbours, communities and society as a whole. As Bywater & Kelly (2005) observed, dealing with all this context brings challenges to farmers, who are increasingly confronted with views, concepts, principles, methods and perspectives which may differ from their own, creating confusion and the danger of not seeing the forest for the trees.

The principle of holism suggests that it is good and useful to look at the world as if it were made up of complex wholes called systems, which will not perform if any of the components or connections are absent. Hence, holism is about understanding the complexity and the effects of activities and interactions within the hole being managed, as well as the impacts of the factors that are outside the defined system (Shadbolt & Martin, 2005).

All in all, by thinking holistically farmers not only are able to understand other perspectives, but also to learn how to gain that understanding, and therefore to strengthen their farming business.

2.1.5 Systems approach

A system approach is the act of applying system concepts, features or ideas to analyse an entity or a whole, in order to deal with problems and improve the selected system (Hammond, 2015). As described by Wilson & Morren (1990), the aim of a system approach is to understand 1) the interaction amongst the parts or sub-systems, 2) the emergent properties, 3) the transformations that occur amongst the components of a system, 4) control processes, 5) communication between the linked components, 6) the purpose and performance measures of a system, 7) the environment and its constraints, 8) inputs and resources (or outputs), and 9) details of management, ownership, or dominance.

Over the years, a number of approaches have been developed to use systems thinking and improve the capacity to manage and improve systems. According to Wilson & Morren (1990), these approaches can be applied to any subject, including agriculture.

The two types of systems approach commonly defined in farm systems literature are hard-systems and soft-systems.

- **Hard-system approach**

When working to seek a unique or optimal solution, hard-system approaches such as systems engineering and operations research are more appropriate to use, as they deal with problems that are characterised by being well-defined, structured and quantifiable (Bywater & Kelly, 2005). As Hammond (2015) observed, this approach has evolved with technology, often applying quantitative models and simulations of a system in the search of satisfying the known desirable objective.

Wilson & Morren (1990) explained how a hard-system approach works (**Figure 2-1**). It all starts with the recognition and quantitative definition of 'the problem' or objective. The analyst will then organise the project and define the purpose. Once this is done, a system will be designed, which will be relevant to the purpose and objective. Following, a system model can be formulated using data and assumptions of the system components. Itself, this model represents a simplification of the real-world system that will assess the designed system and relative efficiency of alternative technologies, strategies or policies related to the system purpose and problem.

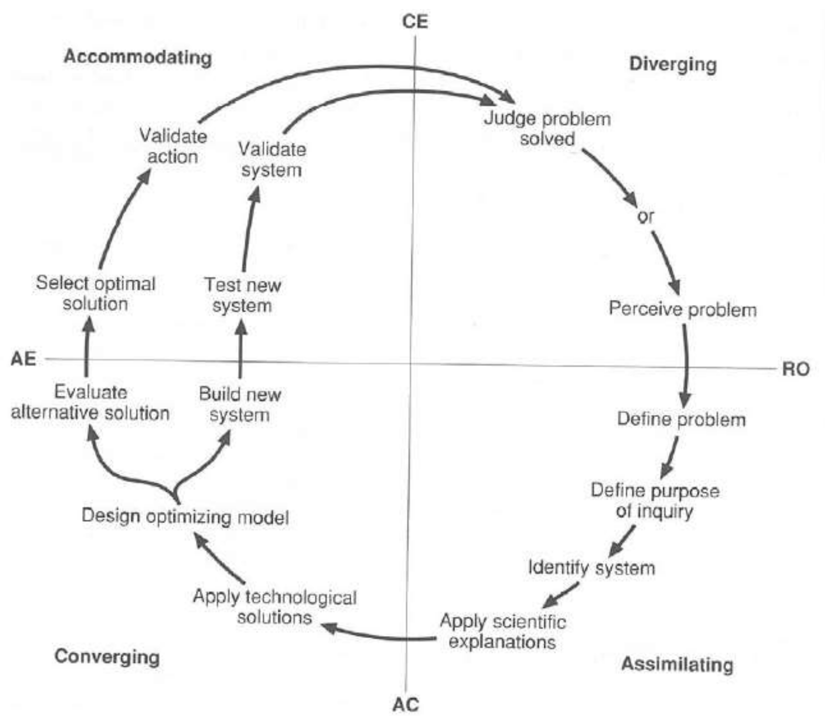


Figure 2-1: The process of a hard-system approach (Wilson & Morren, 1990)

- **<u>Soft-system approach</u>**

There are social elements which are not easy to be captured by hard-systems. Often, people differ in their points of view on a problem, or well certain problematic situations are ill-defined and 'messy'. Soft-systems analysis was developed to deal with these problems within a system, where human perceptions, behaviour or actions are the dominating factors. According to Bicknell *et al.* (2015), this approach is suitable when goals, objectives and the interpretation of events are difficult to be defined.

Bywater & Kelly (2005) additionally considered that what soft-systems finally seek is to improve a problematic situation rather than to find the 'best' solution. These authors observed how soft-systems are more flexible compared to hard-systems, and how the process of resolving a problem may be more valuable than the solution. For example, when dealing with on-farm staff problems, gaining an understanding of their feelings concerning a farming issue may be more useful than fixing the problem itself, as this contributes to learning to value rather than criticise others' strengths, which finally helps to have a stronger team.

The most well-known way of approaching the problems that soft-systems features and to tackle ill-structured problems was developed by Checkland (1988) through the Soft-system Methodology (SSM) depicted in **Figure 2-2**. This methodology is a "learning system" that begins specifying the problem situation and expressing its nature. Relevant human activity systems are then identified, modelled and the compared to real-world situations, in order to create actions to improve the problem situation. It is a "learning process" because the people involved in the SSM get an understanding of the problem situation without necessarily solving the problem (Hammond, 2015). As Checkland (1988) remarked, the participants and their willingness to contribute to the understanding of the problem situation are the key elements of the SSM.

Figure 2-2: An outline of the process involved in soft-system methodology (SSM) (Checkland, 1988)

2.2 Farming systems

In this section, relevant literature on farming systems will be reviewed. The aim is to cover the concepts that will be involved in the changes needed for the design of the new farm systems for each future scenario, to back up the decisions made.

2.2.1 What is a farming system?

According to Jones *et al.* (1997), farming systems can be defined as arrangements of land, crops, livestock, labour and other capital goods, put together for the primary objective of producing plant and animal products for consumption. This definition is supported by Bywater & Shadbolt (2005), which further explained that the essential purpose of a farm system is to provide food to meet human's needs, adding that this goal must be accompanied with the earning of sufficient profit to ensure business viability without compromising the sustainability of the resources used for production.

Further, Woodward *et al.* (2008) pointed out that another important aspect of a farming system is its potential of touching many individual farms, farm families, communities, businesses and stakeholders, all of whom may have an interest in improving the physical, biological, economic and social outcomes of farming.

2.2.2 Pasture-based dairy systems in New Zealand

As discussed by Homes & Roche (2007), a distinguishing aspect of milk production in the dairy industry of New Zealand is the fact that most farming operations use pastoral farming systems. Unlike many other countries, New Zealand's agriculture is dominated by pastoral farming systems (Shadbolt & Martin, 2005), where cows are mostly free ranged and not housed (**Figure 2-3**). The temperate maritime climate of the country combined with fertile soils and high rainfall (usually evenly distributed throughout the year), has allowed the development of farming systems almost exclusively based on the grazing of perennial pastures (White *et al.*, 2010). As distinguished by Pembleton *et al.* (2015), for New Zealand dairy farms in particular, perennial ryegrass (*Lolium perenne*) is the primary source of home-grown feed as its high utilization is a key factor in the low cost of production, and hence, in the ability of dairy farm systems to maintain international competitiveness. This dominant species is commonly mixed with white clover (*Trifolium repens*), mainly due to their high nutritional value, quick establishment, high productivity, and well understood grazing management requirements (Fulkerson & Donaghy, 2001).

For a dairy farm system to be entirely pastoral, the farmer must rely heavily on matching pasture growth with feed demand. Garcia & Fulkerson (2005) observed that at least 50% of the metabolizable energy (ME) requirement should be grazed from the pasture or home-grown forages for a dairy farm system to be considered pasture-based. If pasture growth or stored pasture *in situ* is insufficient, pastoral farms have the option of supplementary feeds (defined as any feed supplied to cows that are an addition to grazed pastures) either made or grown on-farm or bought-in to fill feed deficits to maintain the desired level of production (Holmes *et al.*, 2003).

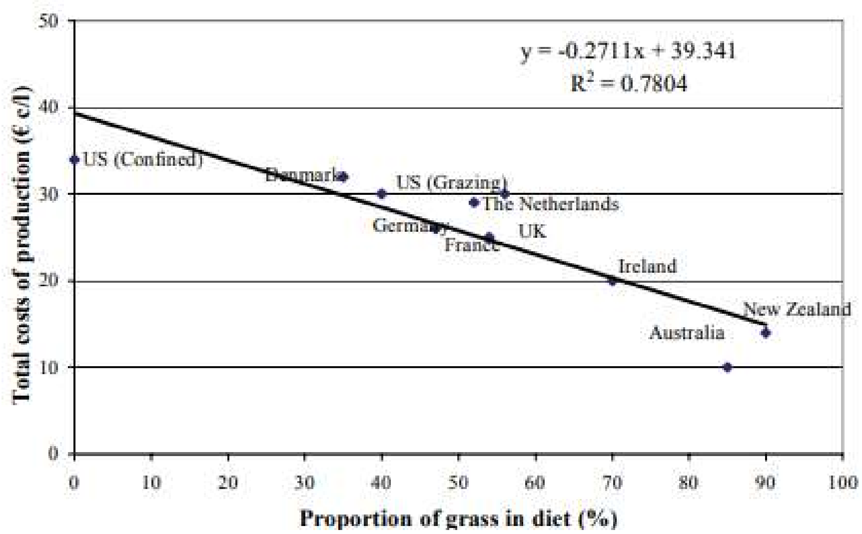


Figure 2-3: Relationship between total costs of production and the proportion of grazed pasture in cows ration (Dillon *et al.*, 2005)

Other management interventions suggested by Bryant *et al.* (2010) to implement if pasture targets will not be achieved (apart from feeding supplements) are nitrogen applications, culling animals or reducing to once-a-day milking.

In terms of how production systems are grouped, Hedley *et al.* (2006) classified them based on the timing, purpose and amount of imported feed use, both purchased as supplements and grazing off for dry cows. They progress from 'low input' of system one to the 'high input' of system five. Feed brought onto the milking platform to supplement the pasture accounts as imported feed for the system, as well as the feed provided as grazing or supplement for cows removed from the milking platform. As Shadbolt (2012) showed in the research conducted to examine the financial performance of the five systems, the choice of the system a farmer makes ends up being based purely on personal preference and attitude to different sources of risk, as it makes no difference –on average– to returns.

2.2.2.1 Seasonality

Milk production from pasture in New Zealand is seasonal. Pasture growth is dependent on climatic conditions and has a distinct seasonality curve: more abundant and reliable in Spring (September to November), lowest in Winter (June to November), and least predictable in the Summer (September to November). As a result, cows are managed to minimize the requirements for fresh pasture during winter, through the provision of conserved forages (with or without housing) during the winter months, or are moved to an alternative property for feeding before calving (Ramsbottom *et al.*, 2015). Therefore, since milk production in NZ is driven by available pasture and forage crops, it follows a distinct seasonal pattern with the shape of the milk production curve being a reflection of pasture seasonality (**Figure 2-4**).

As a consequence, as argued by Beux Garcia (2013) seasonality affects not only milk volume, but also milk quality –composition, fat, protein, and lactose content– as well as the herd's reproductive performance. Additionally, seasonality makes supply fluctuation a common feature of the industry, providing challenges for the processors: the final product class is affected as well as the monthly milk prices and the milk processing ability (Holmes *et al.*, 2003). In response, significant investments have been made to efficiently make long-life products from milk at peak, such as powders (whole & skim), cheeses, whey products and fats (butter and Anhydrous milk fat) (Shadbolt & Apparao, 2016).

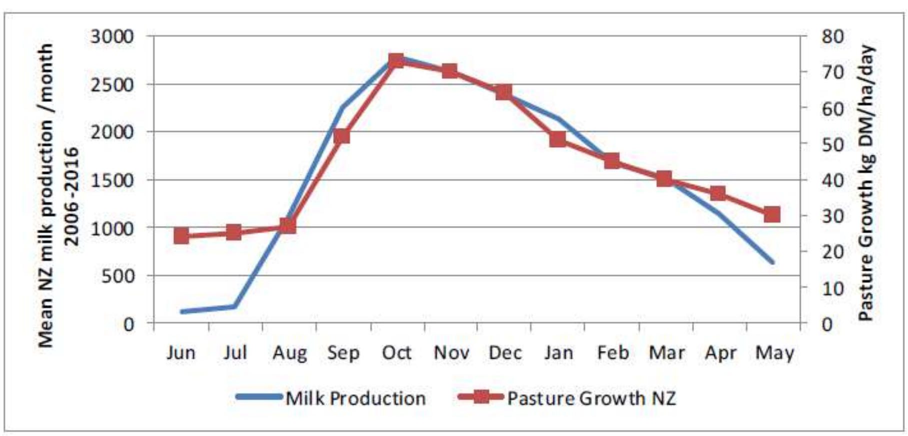


Figure 2-4: Typical pasture growth curve in New Zealand and Mean milk production per month
Source: DairyNZ (Ruakura -16.4 DM/ha/year): DCANZ 2006-2016 (www.dcanz.com)

Another challenge that arises for the processing industries is associated with the scheduling and utilization of the plant infrastructure, as the handling of milk during peak season requires a suitable processing capacity while plants are often idle during autumn and winter months (Holmes, 2003). In addition, the excess capacity created, adds substantial processing costs to the system, which are finally paid by all, farmers and processors (Beux Garcia, 2013). As a result of this, the number of milk processors has declined dramatically. There are only a few processors remaining, with Fonterra Co-operative Group Ltd (Fonterra) processing approximately 95 per cent of the milk (Shadbolt & Martin, 2005).

In order to deal with the issue of seasonality, several strategies have been designed directed to improve the non-seasonal yield of milk. These can be defined by the time and pattern of calving chosen, two key elements in the construction of any pastoral dairy farming system.

2.2.2.2 Calving Systems

According to García & Holmes (1999), seasonal systems are defined by the SR, planned start of calving date, and calving pattern. These authors also explained that a dairy cow can conceive, calve and lactate successfully at any time of the year as long as enough energy can be provided when required.

Traditionally in New Zealand –as well as in other temperate countries–, the physiological demand of the cows is synchronized with the period of maximum availability of quality pasture supply, which is normally spring (Garcia & Holmes, 2000). However, when it comes to choosing calving systems, each farmer has different seasonal plans, as no calving time is optimal in all environments. Some of the factors influencing farmers decisions are mainly cash-flow, dairy and beef markets, regional climate, herd size and labour (Fonterra, 2017).

1) Spring-calving

The usual milking season in New Zealand starts in August (with cows calving) and ends in May (with cows being dried off). Usually, concentrated spring-calving patterns are used with the aim of matching the herd's feed demand with the pasture growth and to fully feed all cows on pasture at peak milk yield (Clark *et al.*, 2007). Keown *et al.* (1986) observed how typical spring lactation curves show a peak –which occurs between 4 and 8 weeks after calving–, followed by a steady decline in milk yield until the cow is dried-off, or the lactation is naturally terminated. Once dried off in late summer–early autumn, most dairy cows are taken to other farms over winter, as either their body condition or the pasture availability in the farm is less than optimum, or both (Holmes *et al.*, 1987).

Nevertheless, whereas traditional concentrated spring calving pattern ensures efficient use of grazed pasture, it also creates an uneven flow of milk to processing plants in New Zealand, making their plant capacity less efficient than other countries where milk is produced year round (Clark *et al.*, 2007).

2) Autumn-calving & Split-calving

A small portion of farmers continues milking some of their herd during the winter months of June and July. The low levels of milk produced during these months (termed “winter milk”) primarily supply the domestic dairy market with fresh dairy product and the export of shorter shelf-life products such as UHT milk (Shadbolt & Apparao, 2016). In general, autumn calving systems –or the combination of spring and autumn systems– are found in areas were pasture growth is slower in summer than winter.

In order to produce winter milk, a proportion of the herd must calve in autumn, which is less than optimum in terms of the herd’s body condition score and the pasture availability of the farm throughout the year, which do not match with the cow’s feed requirements (Garcia & Holmes, 2005). Consequently, autumn calving requires more supplementary feed –such as crop, hay and silage dry matter– to match the increased energy requirements for maintenance and lactation in winter. Therefore as Hodgson & Chestnut (1999) observed, alternative systems are more suitable if affordable supplements can be fed at any time of the year.

To compensate for these higher production costs incurred in producing milk under difficult conditions, farmers get paid a premium as an incentive for their effort (Garcia & Holmes, 2000). Also, there are records of better-grown young stock (and a better market price), as well as less pasture damage from having no dry cows in winter. Altogether, winter milking benefits farmers to have a more steady and less volatile cash flow (DairyExporter, 2017b).

In a study made Garcia & Holmes (2000), lactation curves of autumn-calved cows (At) showed lower yields at peak of lactation compared with spring-calved (Sp) (shaded in red in **Figure 2-5**), but higher yields in mid and late lactation (shaded in green).

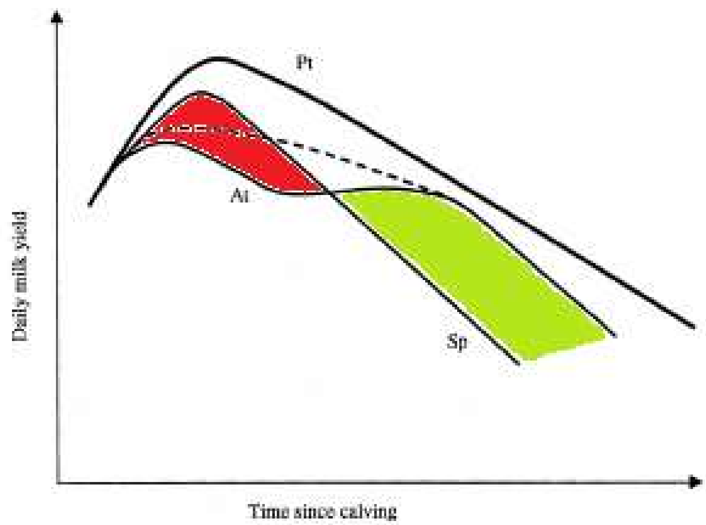


Figure 2-5: Hypothetical explanation of the differences between lactation curves of cows calving in the autumn (At), or spring (Sp) in pasture-based systems, in which both groups of cows are prevented from achieving the potential yield (Pt) (Garcia & Holmes, 2000).

In their study, Garcia & Holmes (2000) found out that similar quantities of milk could be harvested with fewer cows, as they produce greater yields compared with spring-calved cows (as well as making also cow's lactation last longer). They also suggest that the installed industry facilities could be utilised more fully by processing more milk during winter, benefiting the country's milk supply. Additionally, García *et al.* (1998) analyzed the effect of calving season on milk production and end up concluding that economic results are diverse and are mainly a function of the premium payment received for the milk harvested in winter and the prices paid for supplements.

In terms of labour, the management of two herds can be more intensive and with no clear break when allowing for two sets of breeding, calving and weaning new-borns. However, in some situations, this may be an advantage as it eases the labour of the whole herd calving at once, spreading the workload over a longer period (Fonterra, 2017).

2.2.2.3 Stocking Rate

Also known as stocking density, the stocking rate (SR) refers to the number of livestock supported per hectare or unit of area. Even though 'cows/ha' is recognised to be a weak ratio for its lack of accuracy, it is used for its simplicity.

The SR a farm can support is limited by the availability of pasture and the intensity of the use of supplements (Penno *et al.*, 1999), meaning the potential for pasture production depends mainly on the quality of the land. Often potential of the land is challenged by the available supplement cropped or purchased.

Physical resource constraints, such as soil type, could affect pasture production if increasing SR. Also, a farm may be able to carry more cows per hectare, if smaller breed such as Jersey is chosen, in which case a financial disadvantage per head may be offset by higher stock numbers per hectare.

Increasing SR has been shown to improve pasture utilization and quality in farmlet system studies (Fariña *et al.*, 2011). It was found that at higher SR, more pasture is consumed per ha, and thus, less pasture is wasted, with also an associated increase in nutritive value (Homes & Roche, 2007).

In terms of the environmental effect that modifying SR on a pasture-based dairy production system brings, a study made by Roche *et al.* (2016) showed that NO3-N leached per ha tend to decline with increasing SR. These authors identified that higher SR was associated with fewer days in milk per cow, resulting in a reduction in estimated urine N excretion per cow (the main source of N leaching) during the climatically sensitive period for NO3-N leaching (i.e., late summer to winter).

2.2.2.4 Once-a-day milking

As observed by Stelwagen *et al.* (2013) dairy farming systems are becoming more diverse regarding farm management practices and the purposes of farming. Even though twice-a-day (TAD) milking is predominantly used in pasture-based dairy farming in New Zealand, accounting 59% of farmers using it all season (Eastwood *et al.*, 2018), once-a-day milking is becoming a more common alternative among farmers (Chobtang *et al.*, 2017). According to Edwards (2018), the number of full-season OAD farms has been increasing since the early 2000s, accounting for approximately 5% of the total dairy farms in New Zealand in the 2015/16 season (DairyNZ, 2016). 22% were using tactical within-season OAD and 7% were using a 16-hour milking interval (Eastwood *et al.*, 2018).

Reasons for milking dairy cows once-a-day are diverse (Bewsell *et al.*, 2008). According to Armstrong & Ho (2009), they could be strategic (long-term), i.e. opting for OAD full lactation, or tactical (short-term), to respond to adverse seasonal conditions within a lactation (i.e. low pasture availability and high supplementary feed prices).

Labour wise, OAD milking reduces labour inputs, expanding the pool of available labour and improving the utilization of labour resources (e.g. more time can be used for pasture management or heat detection) (Edwards, 2018).

Aditionally, Armstrong & Ho (2009) remarked how OAD milking could allow relatively cheap/less productive land to be used for dairying, as it enables greater distances to be walked between milking.

From an environmental point of view, OAD milking can also have an important role in the future. In a study undertaken by Chobtang *et al.* (2017) using a Life Cycle Assessment approach to analyse the environmental impacts of OAD relative to TAD farming systems, results obtained showed a lower impact on the OAD case study farm compared with the average environmental profile of both low and high intensity TAD dairy farms in the Waikato. However, as the authors observed, this was partly due to the relatively low amount of brought-in farm inputs, and therefore they suggested further studies should be undertaken to substantiate the conclusions of the study.

Further literature on OAD milking will be covered in the description of the case study farm.

2.2.2.5 Nitrate Leaching on dairying

Interest in pasture-based dairy production systems has been rejuvenated because of the potential for reduced production costs and perceived animal welfare advantages (Ramsbottom *et al.*, 2015). However, as Roche *et al.* (2016) observed, N-use efficiency has traditionally been low in grazing systems. Dairy pastures frequently contain a higher concentration of N than dairy cows require, and most of the excess is excreted in urine and deposited on the soil, as ruminants are inefficient users of N and excrete 70-90% of their ingested dietary-N (Di *et al.*, 2016). Urinary N (UN) is concentrated in a small area and is more than plants can use (soil mineral N is higher than the plant N uptake), therefore much of it is prone to leaching into the groundwater.

According to Di *et al.* (2016), UN excreted by dairy cattle is one of the New Zealand dairy industry's more significant environmental polluters because nitrate derived from UN contributes to ground and surface water contamination, causing an environmental threat. Moreover, as pasture-based dairy systems have intensified in time in NZ, the use of inputs of water (through irrigation) and N fertiliser has increased, causing a rise in leaching losses of N mainly as a consequence of the over-application of N from fertiliser and effluent. As a consequence of this, nitrogen-sensitive or nitrogen-vulnerable zones have become commonplace where animal population density near waterways has led to an increase in water NO3-N concentrations (Oenema *et al.*, 2011). According to Roche *et al.* (2016), regulations around nitrogen-sensitive zones were designed to ensure that no more than a defined amount of N is leached per hectare.

Estimated N leaching rates from dairy farms nationwide ranged from around 12-200 kg N/ha/year, depending on soil type, amount of fertiliser applied, source and quantity of supplementary feed, SR, and irrigation use (Foote *et al.*, 2015). OVERSEER estimated an average N leaching on dairy land of 28 kg N/ha/year, while in NZ average from agricultural land (including dairy land) was 8 kg N/ha/year (Ledgard *et al.*, 2000). These authors further observed how the on-farm reduction of nutrients may be cheaper than removing nutrients once they reach wider ecosystems.

Therefore, expansion and further intensification of dairy farming, while economically attractive, is being restricted due to environmental constraints (Pembleton *et al.*, 2015).

2.2.2.6 Brought-in Feed

Intensification requires feed to be brought into the farm system with the purpose of grazing cows off the milking area and/or extending lactation periods and increasing SR (Foote *et al.*, 2015). A particularly important feed supplement is palm kernel expeller (PKE), a product left after oil extraction from the palm seeds of oil palm. According to the Index Mundi (2012), NZ is the largest global importer of PKE, importing 30% of the total global trade in 2012. The problem observed by Foote *et al.* (2015) is that the production of palm oil generates environmental impacts outside NZ, including deforestation, biodiversity loss, and GHG emissions.

A Life Cycle Assessment (LCA) done by Ledgard *et al.* (2016) to evaluate resource use and environmental emissions of dairy production systems in Waikato, showed an increase in emission per kg milk for the high intensification level compared to the low intensification level of 5-32% (**Figure 2-6**).

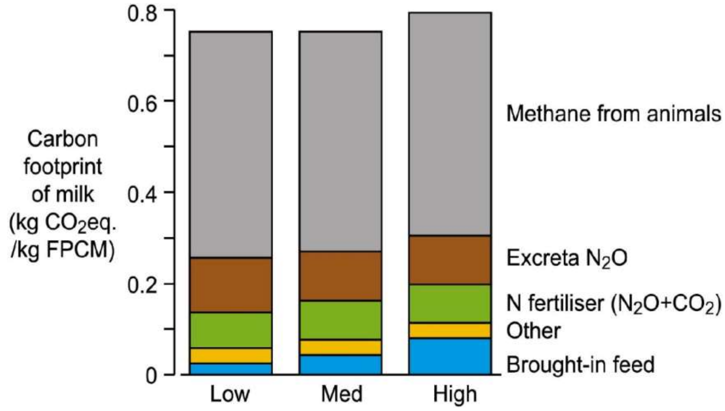


Figure 2-6: Carbon footprint of milk and contributing factors from Waikato farms that had low, medium or high levels of intensification based on the level of brought in feed (Ledgard *et al.*, 2016).

Figure 2-7 shows the volumes of PKE imports into New Zealand since 2007-08. Volumes increased to 1.89 million tonnes in 2013-14 and have remained at this elevated level since. The volumes of PKE imports in 2016-17 (1.91 million tonnes) were more than double those in 2007-08. The majority of the PKE was imported from Indonesia and Malaysia in 2016-17. In a study done by Ledgard *et al.* (2016), PKE was found out to be the main feed providing the highest carbon footprint comparing with waste fruit and vegetables.

Figure 2-7: PKE imports in the last 10 seasons

2.2.2.7 Milk price

As in New Zealand over 95 per cent of the milk is exported, the price farmers receive is strongly influenced by the milk world price, which is characterized by its uncertainty (Shadbolt & Apparao, 2016).

Figure 2-8: World Milk Commodity Prices ($US per tonne) (DairyNZ, 2017b)

The main dairy product exported, the whole milk powder (WMP), had been highly volatile in the past decade (**Figure 2-8**), representing a major challenge to dairy farm viability and resilience and pushing the dairy sector towards higher cost-efficiency (Demeter *et al.*, 2009).

2.3 Metrics used in pasture-based systems

In the pursuit of improving farm performance, farmers require an effective management and measurement of both physical and financial resources. As Beux Garcia (2013) distinguished, the selection of the best measure of performance will depend on each particular farm and its goals, and will reflect in some essential way the purpose of the business.

The set of critical indicators –which are rarely new to the organization– were defined by Parmenter (2010) as ‘key performance indicators’ (KPIs), and will focus on the aspects that will contribute to the current and future success of the organization. Hansen *et al.* (2005) further pointed out how these KPIs can be used to recognize differences in economic efficiency between farms, e.i. as a benchmarking tool.

2.3.1 Physical KPIs

Often expressed as ratios, physical performance indicators provide a more holistic view of a business by showing how certain resources have been allocated. As Rawlings (1999) indicated, they are valuable for tracking performance over time as well as for identifying strengths and areas for improvement.

2.3.1.1 Production

Production measures such as grazing area, pasture supply, use of supplements, calving percentage or SR, are often set as targets which are then monitored closely to ensure goals are met in the short-term. They must be included in any basic set of physical KPIs, with other measures such as dairy area (usually expressed in hectares), herd size, labour input, production (litres, kg MS) and production ratios (any previous measure on a per cow, area or labour unit basis).

Nevertheless, while physical indicators are extensively used and provide relevant feedback to farm managers, Rawlings (1999) emphasised how they are unable to present a complete picture of the business health. This author further stated that this is achieved only when they are combined with financial measures.

2.3.2 Financial KPIs

A financial KPI is often a ratio of an output to an input. Even though most industries have very specific KPIs, financial indicators such as Return On Assets (ROA), Gross Margins and Debt Ratios are used generically (Bogetoft & Otto, 2011).

2.3.2.1 Liquidity

As defined by Shadbolt & Gardner (2002), liquidity means having sufficient cash available to meet commitments (payments to the government and providers of capital) as they arise. These authors further observed how liquidity was and continues to be vital for all businesses, at the same time that –for several reasons– lack of liquidity is the most common cause of business failure. In support of this, Barry & Ellinger (2012) remarked how bankruptcy occurs when a business is unable to pay its short-term commitments without liquidating fixed assets.

Shadbolt & Gardner (2002) also distinguished that even though liquidity is, as mentioned previously, 'the available cash', it is more accurate to say liquidity is the available working capital. To land on the working capital, current assets of the business –which includes positive bank balances, accounts receivable and short-term investments– should be deducted by current liabilities –includes negative bank balances, accounts payable and any short-term debt (Shadbolt & Martin, 2005).

The liquidity indicators most commonly used in farming are:

- **Working Capital (WK)**

WK is another way to evaluate the farm's liquidity as it shows the ability of a business to meet its financial commitments. Change in WK gives a very accurate picture of what is happening to cash in the business but, as it does not take in consideration movements in inventories, the value of unpaid family labour, or changes in physical resources, it ends up failing in showing the true picture of the farming business profit (Shadbolt & Martin, 2005). A positive WK value is desired, but not too high as it may indicate that there are many lazy assets that are being held.

- **Current Ratio**

Shows the ability of the current farm assets, if liquidated, to cover current liabilities. The higher the ratio, the greater the liquidity. It is also an important indicator of short-term financial viability (Shoemaker *et al.*, 2008).

- **Disposable Income**

Is considered to be an important KPI, representing the cash available to meet capital purchases, debt repayments, drawings and extraordinary expenses (Beux Garcia, 2013).

2.3.2.2 Wealth

Indicates how successful strategic investments decisions have been combined with the operation efficiency of the business (DairyNZ, 2017d). To increase wealth, earnings must be retained for investments, as well as existing investments should improve in value (Shadbolt & Martin, 2005).

Equity is a measure of wealth, as it shows the capacity of a business to withstand adversity and to cope with risk (Shadbolt & Martin, 2005). Wealth creation may be represented by a positive change in equity, which can occur as a result of an appreciation in value or the retention of increased earnings. Conversely, the depreciation in the value of assets or negative returns will result in a negative change in wealth (Shadbolt & Gardner, 2002).

2.3.2.3 Profitability

Profit is the most commonly accepted measure of business performance and it is comprised of the sum of the returns from the farming and the property business of a farm investment (Shadbolt & Martin, 2005). As these authors further explained, while the farming business delivers a cash result, the property business does not, as it reflects the value of the assets. Historically, the property business returns have been more volatile than those from the farming business.

As pointed out by Beux Garcia (2013), profitability may be the closest to an efficiency measure of all the financial indicators, as it captures both inputs and outputs. In New Zealand, some of the most important KPIs for dairy farming systems are Operating Profit (OP) per hectare, Farm Working Expenses (FWE) per kgMS, ROA and Return On Equity (ROE) (DairyBase, 2015). The downside of the ROA and ROE ratios is their reliance on asset valuation, therefore a sound representation of the assets valuation is needed to ensure that meaningful interpretation is gained from these measures (Rawlings, 1999).

The profitability indicators most commonly used in farming are:

- **<u>Operating Profit (OP)</u>**

Also known as earnings before interest and tax, OP is calculated as gross income minus variable costs and overhead costs. Gross income refers to the quantity of output multiplied by output price, plus gains (or minus losses) from changes in stock and feed inventories and other sources of income related to the farm business (i.e. dividends on milk company shares).

Variable costs are those that contribute directly to output and change in proportion to the amount of output produced (i.e. feed, she, permanent labour and management, and R&M costs). Overhead costs were defined by Ho *et al.* (2013) as those that do not vary as the level of production changes, for example, depreciation and administration costs.

As Martin & Shadbolt (2005) additionally distinguished, OP is a measure of business profitability, independent of ownership or funding. It is also a measure of the efficiency of all the capital managed in the business for a year –excluding the interest paid– and a measure of business performance, as it takes in account internal and external factors.

Expressed on a per hectare basis, OP is particularly useful for comparing the profitability between farms (DairyNZ, 2017b).

- **Asset Turnover Ratio (ATR)**

ATR measures the efficiency by which all farm assets generate revenue. As Shoemaker *et al.* (2008) suggested, the higher the value of the ratio, the more efficiently assets generate revenue. These authors also claimed that farms that rent their facilities –or that rent some or all of their land to grow crops– should have a higher ATR. Conversely, farms with greater investment in land and/or facilities usually have a lower ATR.

- **Return On Assets (ROA)**

This measure is based on OP from both dairy and non-dairy farming operations, plus the change in the value of capital assets, excluding any leased capital. It is calculated by dividing OP by the value of the total assets managed. The higher the ROA, the more profitable the farming operation. In NZ, for the past decade the total return on assets has ranged between -6.6 per cent and 16.5 per cent, driven by changes in the value of land and buildings, dairy company share values, livestock values and profits (DairyNZ, 2017b).

Additionally, Shoemaker *et al.* (2008) highlighted how ROA can be a useful metric for determining what the assets invested in a business had earned. Moreover, ROA also embodies the opportunity cost of having the assets invested in a business as opposed to investing in another business or other investment opportunity that might generate a higher or lower return.

- **Return on Equity (ROE)**

Measures the return achieved by the owner's invested capital and is specific to a farm business (Rawlings, 1999), including capital changes after interest is paid. In other words, it is the interest rate earned on the farm's net worth (Olson, 2011). According to Shadbolt & Martin (2005), ROE is based on OP and considers not only business ownership but also financing. The ROE will be higher than the total ROA when the latter is greater than the cost of debt and vice versa. The ROE ratio can be used to compare returns from other potential investments (DairyNZ, 2017b).

2.3.2.4 Solvency

Solvency provides an indication of the ability of the business, at a point in time, to meet all debt obligations following the sale of all assets (Shoemaker *et al.*, 2008). Therefore, a business is solvent if assets exceed liabilities and insolvent if vice versa (Beux Garcia, 2013). It is illegal for a business to trade if it is insolvent. In addition, as explained by Kay *et al.* (2012), it also measures the liabilities of an operation relative to the amount of the owner's equity invested in the business.

- **Debt: Asset Ratio**

The most common solvency indicator used is the Debt: Asset ratio, which comes from dividing the Total Farm Liabilities with the Total Farm Assets. The Debt: Asset ratio increases as the business incurs greater levels of debt and decreases as debt is paid off. A business with little debt has a Debt: Asset ratio close to zero (Shoemaker *et al.*, 2008).

D/A ratio	Financial position of business
< 40%	Strong
40 to 70%	Possibly stressed
> 70%	Very stressed

Table 2-1: Classification according to levels of debt per assets (retrieved from https://www.extension.umn.edu/agriculture/dairy/business-tools-and-budgeting/docs/15-measures-of-dairy-farm-competitiveness.pdf)

This ratio can also be called Leverage Ratio because it can 'lever up' return on equity. Higher ratios are common in new and expanding businesses, but are acceptable for limited periods of time when plans and projections indicate that the profitable business will quickly generate funds to pay down debt and bring the ratio below the competitive level (Shoemaker *et al.*, 2008).

2.3.3 Benchmarks

According to Martin *et al.* (2005) benchmarks are metrics that may be used as operating statistics to identify performance gaps and the competitive position of a particular business. Additionally, as stated by Bogetoft & Otto (2011), benchmarks can also be used for decision making, coordination, control and motivation. Necessary physical and financial performance benchmarks for pasture-based farming systems include ratios per cow, per unit of milk sold, and per unit of land area (Benson, 2008).

In this thesis, the 2016-17 DairyNZ Economic Survey has been used to compare the case study farm physical and financial performance respect other similar dairy farms indicators. This survey summarises a sample of dairy farm data from the DairyBase® database, which is a platform available to all levy paying New Zealand dairy farmers. Participation in DairyBase® is voluntary and at the present contains farms with above average milk production performance. The purpose of DairyBase® is to improve the financial understanding and performance of dairy farmers using a benchmarking approach and is designed to link the production and financial performance of farms. DairyBase® contains financial data from annual farm accounts, as well as physical data supplied by the farmer and estimated current market values of fixed assets.

2.4 Farm system design & Modelling

This chapter will review the literature on farm systems design and modelling. Firstly, an overview on farm systems design will be accompanied with relevant definitions and classifications, to further acknowledge the role of modelling in farm systems simulations and its benefits. Finally, a review on existing models commonly used in New Zealand and how they have been applied in practice will be presented, followed by a discussion on the limitations they exhibit and the challenges to be addressed in the future.

2.4.1 Farm system design

As Martin *et al.* (2013) very broadly defined, farm system design is the process of devising a new system, component or process that meets stakeholders' requirements. These stakeholders traditionally have been identified as the farm owner or manager (Bicknell *et al.*, 2015).

Farm system design can search for innovations that are either exploitative, which are those that are incremental in nature and designed to improve existing farming systems, or exploratory, which are associated with a more radical change (Martin *et al.*, 2013). As an example of an exploitative innovation, Woodward *et al.* (1995) used a computer model to evaluate a range of rotational grazing schedules to improve the economic performance of an existing pasture-based farming system. Conversely, Bos *et al.* (2009) designed a novel sustainable farming system for a dairy, meaning a radical in-depth modification was made, and thus, an exploratory innovation was applied. Compared with exploitative innovations, the design and implementation of exploratory innovations come together with changes in the goals and values of the farmer (Bicknell *et al.*, 2015).

2.4.2 Definition of a model

By definition, Bywater & Kelly (2005) described a model as "a *simplification of reality*, an abstraction, which is formulated for a specific purpose based on assumptions and data" (p.73). Martin *et al.* (2013) also referred to models as abstract representations of a real-world situation, i.e. the problematic operand or part of it, and possibly of the solution space. Woodward *et al.* (2008) further advocated this view, claiming that a model is a virtual world where simulations of various aspects of problematic situations take place.

At the same time, Kenny (2017) pointed out how models allow for the simulation of the full cause and effect sequences and feedbacks of a complex situation, without the actual altering of reality. These authors also presented arguments to emphasize the importance of models in allowing simplification, considering farming systems are complex and dynamic systems whose products and impacts are difficult to measure let alone predict or control.

2.4.3 What are the models used for?

Over the years, modelling had become an important tool for describing and analysing an existing business –i.e. a farm– and planning for changes to it (Bywater & Kelly, 2005). The need to answer 'what if' questions related to on-farm everyday decision making from farmers has led to the development of these decision support systems models, in order to provide them with assistance in making informed decisions in their farming enterprises (Bryant *et al.*, 2010). Vogeler *et al.* (2017) additionally highlighted the importance of farm system models in evaluating the performance of farming systems, as well as understanding management strategies on on-farm production, profitability and emissions. This statement coincides with Bicknell *et al.* (2015), who observed that the most important objective for farm system models involves improving biological or economic performance and/or mitigating environmental impact.

In terms of research, farm simulation models made a major contribution in guiding experimental research: from the identification of critical gaps in knowledge or data to the interpretation of experimental results and the development of improved systems of production (Bywater & Cacho, 1994). In line with this, Sempore *et al.* (2015), confirmed in their study how whole-farm models facilitate discussion between researchers and farmers around the conception of innovative production systems, regardless of their type, and how they also helped ex-ante assessments of a range of alternatives, facilitating the acquisition of new knowledge by those participating in the approach.

Further, other authors highlighted how farm simulation models are used as a direct extension and management tools, to increase the knowledge and understanding about a certain alternative system (Bright *et al.*, 2001; Shalloo *et al.*, 2004).

However, despite the benefits that simulation models can provide, their efficacy for everyday farm management has proven to be somehow limited (Sempore *et al.*, 2015). Reasons behind this include complexity, lack of time and a concern that there will be no increase in profit relative to the effort spent.

2.4.4 Types of models

There are several different aspects of modelling. For instance, there are hard and soft systems, models that deal with specific sectors and areas, and within them, models that focus on different aspects of the system being modelled.

In terms of the mathematical models used in farming systems, there are two general techniques: optimization or simulation.

- **<u>Optimisation models</u>**

Generally developed for a specific situation –and therefore less suited to study the consequences of a wide range of management strategies–, optimization models seek to optimize some criterion or set of criteria subject to a set of constraints (Shalloo *et al.*, 2004). In practice, these models allow to identify profitable system configurations efficiently and to get the best possible solution, without the need for manual trial-and-error and field-test experiments (Doole *et al.*, 2013). In support of this, King *et al.* (1993) observed the importance that optimization models can have in assisting the decision-making objectives of farm managers, such as minimizing the cost of animal weight gain, enhancing weed control, or boosting farm profits. Regarding Martin *et al.* (2013) classification described previously, optimization approaches are oriented towards the development of exploitative rather than exploratory innovations.

Due to these reasons outlined, optimization techniques are nowadays attracting the interests of entrepreneurs, as well as researchers (Bicknell *et al.*, 2015).

- **<u>Simulation models</u>**

Simulation models were developed with the purpose of accurately describe the evolution of systems. However, simulation models are questioned because, as no field experiments are involved, their credibility is in doubt (McCall, 1993). Aditionally, Doole & Pannell (2008) remarked that although simulation models can incorporate much greater complexity than nonlinear-programming models, it is more difficult within them to efficiently identify these superior solutions in a consistent and coherent way. Woodward *et al.* (2008) also recognized the importance that simulation modelling methodology appears to have in farming innovation but also acknowledged that existing simulation models appear to have a limited impact on improving farm systems. Thus, because of its limitations, these authors suggested that some challenges must be addressed, which are: involving the right people to ensure compatibility between user needs and processes, determining what system to model to remain relevant to stakeholder's needs, representing in models what farm managers might logically do, and making sound comparisons between alternative farm management policies.

In contrast with the previous views, Shalloo *et al.* (2004) distinguish the importance of simulation models in providing the opportunity to explore difficult relationships that cannot be explored in any other way. Supporting this, Martin *et al.* (2013) additionally emphasize on the fact that, because in simulation models the conceptualization of the design problem is central to the farming system design process, the subsequent exploration of the solution is left to human creativity.

- **Levels of models**

Broadly, *Deterministic* models assume input values such as price or yield are fixed, while *stochastic* allows the variables chosen to change (Martin & Shadbolt, 2005).

As argued by Bywater & Kelly (2005), while analytical models traditionally have been deterministic in design –allowing one set of assumptions to be tested at a time–, the progress of computer hardware and software had made possible to develop stochastic models that also simulate the variability that exists in agricultural systems. Woodward *et al.* (2008) emphasized on the importance of this progress, as models without including uncertainty (i.e., deterministic models) may convey in a misleading sense of certainty about the future and may be in fact less relevant in a decision making context.

According to Beux Garcia (2013), in choosing where to use deterministic or stochastic methods, the key question to have in mind is whether the analysis requires flexibility in the mean structure or precision in the noise separation.

2.4.5 Existing models of dairy farm systems & their applications

As McCown (2002) observed, the use of agricultural decision support models by farm managers is still minimal. O'Grady & O'Hare (2017) also found out how sporadic models are used in individual farms, despite the significant research effort that has been expended in the development of agricultural models. According to McCown (2002), reasons for the lack of interest include overly complex models that are not easy to use, lack of involvement of users in the design of models, lack of demonstration of their value to the business and lack of training.

Still, there is a range of models that are being used nowadays, either alone or combined with others, depending on the type of research. The models discussed above have been chosen due to their perceived relevance to New Zealand and dairy farming, or a particular component of a dairy farm system.

- **FARMAX®**

FARMAX® is an evidence-based system software for planning and controlling how to effectively convert pasture into profit (Bryant *et al.*, 2010). This unique method of planning enables to calculate the implications and changes in revenue when different variables are introduced across the farming systems. Developed by AgResearch in the late ’80s, it was first commercially launched in 1993 to help sheep and beef farmers make informed decisions on how to improve their businesses (AgResearch, 2013). As pointed out by Bryant *et al.* (2010), the development of FARMAX® has largely focused on the prediction and representation of feed supply, animal performance, realistic farm management and economics, and to simplify and facilitate the use and generation of informative reports.

FARMAX® software is today used by many consultants and farmers in the sheep and beef as well as in the dairy industry. Since its introduction to the dairy industry, FARMAX® has been used by industry, researchers, consultants and farmers to model thousands of different farm scenarios (AgResearch, 2013). It is a useful software to model various options for development and compare the expected profitability with an existing system.

a. Description of the model

Bryant *et al.* (2010) defined FARMAX® as “a whole-farm decision support model that uses monthly estimates of pasture growth, farm and herd information to determine the production and economic outcomes of managerial decisions” (p.14). As its heart is a computerised model, FARMAX® allows to set up a model of a farm, where a wide range of 'what if' scenarios can be considered before deciding on the right way forward.

FARMAX® covers most of the input and output costs of the farming business and summarises it all in one place. Fariña *et al.* (2013) identified that the model uses pasture growth, forage crop yields, supplementary feed intake and the herd's calving pattern, and genetic merit information to determine the physical and economic performance of a system, allowing the user to evaluate possible outcomes of different management decisions for the farm business.

For farmers, the use of this modelling tool offers the opportunity to set clear plans and goals for their business, allowing them to plan objectives they aim to achieve for the year. Also, as the model allows to model different scenarios across the farming system, farmers can assess options for their farm and make decisions with a greater level of confidence. This opportunity of easy explore managerial changes, can effectively be translated into an increase in farm profits.

In the case of farm consultants, FARMAX® provides a tool that can be used to undertake quite complex analyses very quickly, enabling them to offer advice based on a robust and proven model that uses a system custom built for New Zealand.

b. How FARMAX® works

Dooley *et al.* (2012) distinguished how Farmax can be used at three different levels of a farm operation: strategic, tactical and operational. For example, FARMAX® can model responses to tactical decisions in a dairy farm, such as whether to increase or decrease supplement usage, to dry off cows, or to apply nitrogen. It can also be used on a day to day operational level, having the ability to input actual results that can then be compared to what was planned. On the strategic level, FARMAX® is a very powerful tool as it enables the users to improve their level of accuracy of planning over time and base future plans on actual results rather than continued guesses.

The following example of FARMAX® use was provided by Bryant *et al.* (2010): if on a farm the pasture cover is below the minimum cover to meet the desired level of animal performance, the model's user can specifically choose to reduce pasture intake with an accompanied reduction in animal performance, increase supplementary feed intake, maintain the same individual animal performance and increase pasture cover by adding nitrogen, or sell animals. Alternatively, users can manually alter each of these factors or change calving dates, milking frequency or drying-off dates to create a feasible system.

c. Benefits

Some of the key benefits of using Farmax include the possibility of increasing the understanding of a farm system (for both the farmer and consultant). It also provides an independent and neutral perspective on a current situation. As additionally pointed out by Dooley *et al.* (2012), FARMAX® can be used as an extension tool (i.e. in discussion groups, it can be used to demonstrate the merits of pursuing different management options), and it also enables scenario testing of farm system prior to actual changes being made, therefore it reduces the guesswork. Moreover, through a user interface of the software, the user can visualize the availability and use of pasture, forage crops and supplements in time and space, making it possible to readily observe the effect of changes in these variables on milk production and body condition (Fariña *et al.*, 2013).

d. The model's applications

Stevens & Knowles (2011), used FARMAX® for their study to determine on-farm decisions about pastures, as they aimed to identify which pastures need to be renewed and whether the profitability will be increased when renewing these pastures. A case study approach was used and the results showed that complex models such as FARMAX® provide more realistic estimates of the value of pasture renewal. In the case of Brazendale *et al.* (2011), they also used FARMAX® to study the behaviour of pastures: a simulation was made to study the effects of the persistence of new pastures on whole-farm profitability for Waikato, Taranaki, Canterbury and Southland dairy farms, considering the new pastures following an old pasture without cropping.

Bourdot *et al.* (2012) did a trial at Golden Bay to analyse the effect of giant buttercup infestation on a case study dairy farm's physical and financial performance. To do this, FARMAX® was used for constructing the optimised base model. However, as the model does not explicitly include the effect of giant buttercup on pasture supply, the model's pasture utilization parameter was reduced according to the seasonal ground cover pattern for giant buttercup. This study finally arrived at the conclusion that giant buttercup has a significant impact upon the profitability of affected dairy farms, given its propensity to develop herbicide-resistant populations and the potential for it to become more widespread, needing closer attention.

Another trial that used FARMAX® was carried out by Bryant *et al.* (2010), who wanted to determine if it was possible to achieve 1750 kgMS/cow per ha using forages grown within the milking area of a case study farm in Hamilton. To do this, managerial changes were represented in the model, such as earlier calving dates, use of a chicory crop, and additional intakes of pasture in summer. The model predicted increases in performance of 50-190 kg MS/ha, which was at least 81 kg MS/ha shorter than the target level of production.

- **<u>The Integrated Dairy Enterprise Analysis Model (IDEA)</u>**

a. Description of the model

IDEA is a whole farm model that focuses on biophysical conditions on a farm. Its framework is a deterministic, steady-state optimization model developed to provide a detailed insight into optimal management on pasture-based dairy farms (Doole *et al.*, 2013). Bicknell *et al.* (2015) highlighted how the model provides a rich description of New Zealand pasture-based dairy farms as it includes emissions, grazing mass, pasture growth, digestibility, rotation length, intake regulation, pasture utilization and stocking rates.

b. How IDEA works

The model is solved utilising a nonlinear programming in the General Algebraic Modelling System (GAMS) using the CONOPT3 solver (Brooke *et al.*, 1992). This algorithm is used, for example, to identify the solution that maximises operating profit on a determine farm-system given a series of defined constraints. As the central concept of the model is to balance energy supply with energy demand, the supply of energy needs to be calculated (from grazed pasture and supplements provided) as well as the energy demand, which will depend on individual cow attributes and herd structure.

c. Benefits

Doole *et al.* (2012) observed how IDEA is the first optimization model of grazing system to consider, both independently and together: 1) post-grazing residual mass as a decision variable of the producer, 2) pasture growth and digestibility that differ with residual pasture mass and rotation length, 3) pasture utilization that varies by stocking rate, 4) inclusion of nonlinear functions describing substitution rates, and 5) different levels of intake regulation.

In addition, as a nonlinear programming model, IDEA is a valuable technique for farm-systems modelling as it allows the development of models containing a rich description of key economic and biophysical processes (Doole *et al.*, 2013). Doole & Romera (2015) also remarked how IDEA also has substantial scope to incorporate strong nonlinearities, integrating diverse data without recourse to statistical estimation involving all systems equations, and allowing the efficient identification of solutions that maximise a given objective. Furthermore, IDEA remains the most comprehensive and robust method to assess greenhouse gases (GHG) mitigation strategies on-farm (Doole, 2014b).

d. The model's applications

Model developers Doole *et al.* (2013) have used the model to suggest that pasture-based grazing systems have the potential to decrease the cost of milk production while improving conditions for animal welfare.

Romera *et al.* (2017) also employed the model but to explore the role of mixed swards on New Zealand dairy farms, with the purpose of improving economic and environmental outcomes. In their study, the IDEA model provided insight into the implications of diverse swards for production on farm profit and N leaching. Broadly, they discovered that diverse swards may provide a cost-effective mitigation option for reducing N losses from NZ dairy farms.

In another study undertaken by Doole (2014a) to analyze how to improve the profitability of Waikato dairy farms, with the help of the IDEA model it was found that maximising milk volume of a case study farm reduces operating profit by 12-23% due to higher production costs. Another conclusion of the study was that even though imported concentrate is valuable to augment production in mid-lactation, it is best to avoid feeding cows to their potential given the high cost of supplement.

- **OVERSEER®**

a. Description of the model

The Overseer® Nutrient Budgeting model (Overseer) is a New Zealand based agricultural management tool that, using a budgeting approach, assists examination of the nutrient use, nutrient cycling and nutrient losses to the environment within a farm system (MPI *et al.*, 2015). It was created as a response to the environmental consequences of dairying, which include pollution of surface and groundwater, destruction of wetland and native lowland forest for farm development, indirect damage to freshwater and estuarine habitat, soil erosion, soil contamination and damage to soil structure, and discharge of GHG (Bicknell *et al.*, 2015).

b. How Overseer works

Overseer requires farm productivity and farm inputs to be entered by the user across a defined boundary (the boundary of the farm or blocks within the farm), which are usually known for existing farms or can be estimated for hypothetical farms using farm system models such as FARMAX® (Bryant *et al.*, 2010). Inputs and outputs are presented in an annual nutrient budget based on long-term annual averages.

c. Benefits

Validation showed how this model provides a reasonably accurate description of nitrogen leaching loads arising from New Zealand farming systems (Thomas *et al.*, 2005; Wheeler *et al.*, 2010).

d. The model's applications

Overseer has been widely used for calculating nutrient losses from rural land enterprises in New Zealand (Dymond *et al.*, 2013; Matthew *et al.*, 2010; Parfitt *et al.*, 2012).

Beukes *et al.* (2010) for example, conducted a research on improving production efficiency as a strategy to mitigate GHG emissions on pastoral dairy farms in New Zealand. For the study, Overseer was used to exploring the environmental impacts of a series of changes to the farm system, such as reducing replacement rates and improving pasture management and cow efficiency.

e. Limitations of the model

A limitation of the model is that it does not take into account transformations, attenuation or dilution once nutrients leave the boundary of the farm, leading to potential errors in the estimations (Wheeler *et al.*, 2010). Consequently, Overseer cannot tell anything about the water quality in groundwater and/or surface water (Wheeler *et al.*, 2010).

- **<u>e-Dairy</u>**

Designed for New Zealand pasture-based dairy farm systems, this stochastic and dynamic simulation model was built on the e-Cow model to explore the effects and interactions between genetic merit, supplementation, SR, and the impacts on biophysical and economic aspects of the farm (Baudracco *et al.*, 2013). The model behaves stochastically and can be used for grazing dairy systems with differing calving patterns, to evaluate the trade-offs between profit and the associated risk.

The e-Dairy model was proven by the authors to simulate the annual performance of dairy cows with acceptable levels of accuracy for both ryegrass- and lucerne-based dairy systems. However, one of the weaknesses found by Bicknell *et al.* (2015), is that the model appears to focus on individual cows and their interaction at a farm level rather than providing a holistic 'systems' view of the farm.

Nevertheless, as the model has the ability to simulate individual cows and to account for genetic differences between cows, Bicknell *et al.* (2015) claimed that the model could be useful for future farm systems that call for specific genetic traits and therefore it may be appropriate to incorporate into a future modelling framework.

- **<u>Using multiple models</u>**

Many of the models described previously can be linked together through the use of a modelling framework (Bicknell *et al.*, 2015). Moreover, according to Kenny (2017), combining modelling types is not only possible but sometimes preferable.

For instance, considering the actual growing public concern on environmental protection, dairy farmers apart from pursuing better productivity and profitability are also increasingly encouraged to run their businesses in a manner that constrains nitrogen (N) leaching and reduces GHG emissions. Certainly, these requirements indicate the need to develop a model with multiple output indicators. One way to do it is by combining the use of two or more models. A variety of authors used such approach, as many models described earlier can be linked together through the use of a modelling framework.

Muller (2017) for example, demonstrated how dairy farm systems can meet potential nutrient regulations through the use of FARMAX® and Overseer models together. The author recognized the importance of combining these models to ensure a farm's feed supply and demand is balanced.

In addition, FARMAX® and Overseer have also been widely used to create abatement cost curves for pastoral farm systems in New Zealand (Kaye-Blake *et al.*, 2014; Vibart *et al.*, 2015). Using these models together, Smeaton *et al.* (2011) tested associations between farm productivity, profit, N leaching and GHG emissions across sheep/beef and dairy farms, Results of the study suggested that systems that are both profitable and have modest emission output should be possible.

After analysing crop and livestock models, Jones *et al.* (2017) concluded that different platforms for combining models and data for specific purposes are necessary.

2.4.6 Limitations of models

Although current farm systems models have important features to help farm management to reduce risk, increase resilience, and better long-term well-being, research suggest that they have many limitations and therefore need to be improved (Jones *et al.*, 2017). The common limitations found by these authors were: the scarcity of data for developing, evaluating, and applying farming system models, and the inadequate knowledge systems that effectively communicate model results to society.

Another limitation found out by Le Gal *et al.* (2010) is how the use of models is frequently limited to the world of research scientists, without the adequate involvement of farm advisors, who are generally restricted to provide researchers with the information to parameterize certain elements of a model.

Bicknell *et al.* (2015) also highlighted how there are still two broad areas where whole-farm models appear to be lacking: in the social and economic areas, and in factors that influence farmer decisions and actions. However, despite these limitations, the authors acknowledged that there is an increasing demand for applying farming systems models beyond point/field scales to support planning and decision-making.

Looking further, as Jones *et al.* (2017) observed, major advances are needed to achieve the next generation of data, models, and knowledge systems to address more complex future issues, as the current state of farming system models is only sufficient for some contemporary applications. In addition, Kenny (2017) suggested that future models should go beyond a sole examination of economic aspects to also include considerations of social capital, such as norms and values.

Therefore, the challenge for this research –where futuristic farm systems will be simulated on an actual farm system– is to find the most suitable whole-farm model to design the future scenarios. After the review done on available modelling tools commonly used in New Zealand, it was identified that FARMAX® could potentially facilitate the design of these futuristic scenarios at a farm level, as the model is capable of representing the main components of seasonal dairy systems in an interactive and dynamic way. The model is a mathematical, dynamic, stochastic (although some inputs behave deterministically), and mechanistic model that allows the user to interact and make decisions while running the simulation and therefore, it could help to evaluate *ex-ante* the impacts of the new technologies needed to be simulated at a farm level.

Chapter 3: Future Scenarios

The purpose of this chapter is to, first, present an overview of the future scenarios. Second, the picture of what would happen if these scenarios occur will be depicted, along with the challenge of modelling such complex futures with the available tools. After that, some literature on system boundaries will be covered to explain how the boundaries for this study have been set. Lastly, this chapter contains a review of current and new technologies and innovation in farming practices that could potentially be useful to address some of the issues that have been described inside the boundaries.

3.1 Overview

Using a scenario analysis approach, the CEFBM developed three possible, plausible futures that dairying might operate under plus a base scenario developed from commonly used assumptions of the future. Broadly, in the three scenarios Shadbolt *et al.* (2017) point to vastly different futures where there is a need for improved technology and capability build throughout the value chain, as well as a commitment from farmers, processors, marketers, funders, government, NGOs and society to be agile to provide solutions. They also provide a framework for thinking in a world where disorder is seen as the one evitable future, and to avoid thinking either the past will continue or there is a certain direction. The rationale for this was a belief that too many farm systems were being developed around the "common view", with a strong on-farm focus, paying little attention to emerging global trends (Shadbolt & Apparao, 2016). The three future scenarios arrived at were: 'Consumer is the King' (CK), in which a wide range of dairy products are produced in direct response to consumer demand (a consumer-driven scenario), 'Regulation Rules' (RR), in which regulatory requirements of dairy farm businesses are considerably greater (a highly-regulated scenario), and 'Governments Dictate' (GD), in which dairy products are produced for a world where political chaos exists, markets are shrinking and trade is dictated by governments scenarios (a highly-intervened and chaotic scenario) (Dooley *et al.*, 2018).

It is relevant to acknowledge that while the scenarios developed were in some aspects extreme, soft signals already present suggest the future might have aspects of all three. These scenarios are reported in Shadbolt *et al.* (2017) and a summary is shown in **Table 3-1**.

Table 3-1: A summary of the main characteristics of each future scenario

	<u>Scenario 1:</u> **Consumer is the King**	<u>Scenario 2:</u> **Governments Dictate**	<u>Scenario 3:</u> **Regulation Rules**
The World	Significant economic growth, driven especially by emerging nations of Asia and Africa. Total global demand for dairy is robust. Supply of dairy has not been able to keep up with demands in many regions. Agrifoods market more complex and fragmented. Milk price of certain classes of milk is quite volatile.	Sustained deceleration in economic growth, regional conflicts and un-favourable weather events resulted in a higher proportion of people living in poverty. Huge price volatility. Global demand for dairy highly constrained. Imports highly controlled.	Global demand for dairy products is robust, but regulatory requirements constrain supply globally. Middle-class population worldwide continue to grow. Urban-rural divide intensifies globally. There would be risks with the escalating demands to use technology at a micro level.
New Zealand	Numerous market options for NZ dairy, as world trade is expected to increase. Increase in the number and type of farms as dairying is found to be quite lucrative.	Protectionist policies and political chaos make major export markets extremely difficult to access. Processing/manufacture of fresh dairy products limited mainly to serving domestic consumption. Majority of milk produced in NZ processed into milk powder.	Natural pasture-based farming systems provide NZ with an advantage most global competitors do not have. High standards and lack of corruption in NZ. Industry activities and communications are contributing in closing the gap in the urban-rural divide.
Consumers	More engaged in the world of food, as they are better informed. Looking for tailored products and demanding a connection between the products they buy with the farm they came from. Major interest on milk produced from cows raised on pasture, as research studies highlight significant health benefits.	Increases in the cost of living reduced disposable income. People eat out less frequently. Price sensitive: interested in getting maximum nutrition at a minimum price. Not concerned about the naturalness of food.	Better informed and more aware of environmental, social, animal welfare and food safety issues. Decreasing tolerance to farming and industry practices that have negative environmental, social and animal welfare impacts.
Farm systems	Higher costs of farm inputs and animal feed. Moved up in value chain producing high-value products. Defined by the specific value chain the farmer aims to operate in.	Reduced reliance on imported supplements (became costly). Focus on producing at the lowest cost. Fewer but larger farms. Increasing costs resulted in very low returns for farmers. Drop in land prices and capital value for dairy farms.	Some farms opting for mixed pasture/herd home systems to meet environmental, animal welfare and 'natural' standards. Restrictions on stocking rates and feed sources. Ban on the slaughter of Bobby Calves. Ban on antibiotics.

	Scenario 1: Consumer is the King	Scenario 2: Governments Dictate	Scenario 3: Regulation Rules
Supply Chain	Force to innovate and evolve at all levels as products now need to be highly tailored.	Retailers have considerable power, offering both traditional and online options to consumers. Focus on efficiency across the supply chain. Maximizing logistics and minimizing wastage is critical.	Under pressure to meet social demands such as environment, animal welfare and labour relations. All players expected to exhibit strong corporate social responsibility, service-orientation and transparency. Intense monitoring and regular audits throughout the supply chain.
Regulations/ Compliance	More auditing and certification schemes have come into effect. Bio-diversity, water quality, soil health, energy efficiency, animal welfare, working conditions, social responsibility and waste management are continuously under the spotlight.		Tighter and more stringent food safety & milk quality compliance. Focus on eliminating negative environmental externalities. Technological advances in measuring & monitoring empowered the regulators.
Human Resources	Improvements in technology will require a new type of work-force and people with advanced qualifications and soft skills. Farmers too are better educated, technology savvy, business focused and more professional than ever before.	Due to low wages and difficult working conditions, the industry struggles to attract and retain talent. Heavy reliance on immigrant labour which is constrained by restrictions imposed on travel.	Working hours are limited to 37.5 hours a week. The staff has more diverse skills and are rewarded accordingly, resulting in a positive view of farming as a career. Jobs are becoming highly automated, increasing accuracy and reducing human error.
Technology/ Innovation	Better connectivity, smarter products, automated mobile-robotic milking systems and the use of precision agriculture tools to a large extent reduced considerably the pressure and stress on the workforce, also improving the efficiency of operations. Milk is being used in innovative ways to create new products and formulations. Dis-assembly and re-assembly of milk.	Automated milking systems to solve labour related challenges. Solar and biogas technologies to reduce dependence on external sources of energy. Cloning and gene-manipulation used by NZ competitors, eroding NZ's competitive advantage.	On-farm technologies enable high per cow production while meeting animal welfare and environmental expectations. Precision agriculture help to improve animal health measures and reduce culling levels. Newer technologies make measurement more accurate. Some dairy products can now be disassembled and assembled. Technologies that track product from pasture to plate.
Communication/ Social Media	Right activists campaigns against housed dairy farming. An unhappy customer can tell hundreds of their friends and their friends "friends" about their unsatisfactory experience through Facebook or Twitter.		Constant pressure from consumer rights activists. 24-hour real-time webcam surveillance on farms. Strong support networks among farming communities. Promotion of farming best practice activities through social media.

3.2 Implications if the scenarios occur

As described in the future scenarios, dairy farms will face huge challenges as the world is becoming every time more complex, mainly due to factors such as the growing population and its demands for more food, water, and energy, the limited arable land for expanding food production, and the increasing pressures on natural resources –all of this compounded by the climate change. This context of increasing demand will require farmers to adapt their farm systems to maximize production while minimizing the environmental impact on resources. A problem that arises with this is the fact that nowadays greater milk production is a synonym of intensification, which increases social concerns over sustainability, as intensification is commonly associated with resource exploitation. Moreover, in the case of New Zealand, intensification required to harvest more milk will potentially increase the cost of milk production, as costs associated with pastures and supplements are the single biggest operating costs (excluding debt servicing) (Shadbolt & Martin, 2005). Equally, this will also attempt with the low-cost competitive advantage that local farmers have in the international markets and New Zealand's fame of being efficient in the use of grazed pastures (Clark *et al.*, 2007).

Further, as reported on the future scenarios, the community environment will become more challenging as people these days are more rigorous and demanding regarding the impacts of the farm operations not only on the environment but also on animal husbandry. In a study carried out by Cardoso *et al.* (2016) to assess the views of people not affiliated with the dairy industry on what they perceived to be the ideal dairy farms, the authors found out that some of the most common concerns are related to cow treatment, cow access to pasture and open space, and the use of antibiotics and its impact on dairy products. Therefore, dairy farms in general –and especially those located closest to cities– will have to operate taking care of the scrutiny that surrounds them, as the power of social media could affect their *modus operandi* severely.

In summary, the evolution of world agriculture and the nature of the challenges it faces –in terms of production as well as ecological impacts– will require an increase in efforts regarding farming system design, as farm systems will be asked to be environmentally friendly while economically viable.

3.3 How can these scenarios be modelled?

The future scenarios developed need to be modelled, as farmers are urged to prepare themselves to respond to the new challenges, with soft signals already occurring. Yet, as reviewed on the literature of farm systems design, within existing models there are significant limitations associated with the social components of the models, as they cannot address questions faced by society that transcend agriculture. Moreover, as Bicknell *et al.* (2015) observed, where economic components are included, often they do not go beyond farmer profit-maximization/cost-minimization. Therefore, farming systems models need to be challenged to move beyond just including economic and sustainability issues.

Some of the relevant questions that could work as a guide in the design of the farm systems required for the future were asked by Jones *et al.* (2017) and range from 1) how to better manage systems for higher and more efficient production, 2) what changes are needed in a farming system for higher profitability without harming the environment, 3) what policies are needed to help farming systems evolve to meet societal goals, and 4) what systems are needed to adapt to the continual changes that agriculture faces, including climate change, changes in demand for farming products, volatile energy prices, labour shortage, and limitations of land, water, and other natural resources.

Built on this, the challenge for this thesis will be to design dairy farm systems at a farm level able to interpret the changes described conceptually in the future scenarios. However, as the literature review on existing modelling tools revealed, the models available cannot simulate all of the external factors affecting the farmers.

Therefore, the boundaries of this study will be set to provide a picture of how further the use of existing modelling tools can reach and to explore what will be needed to simulate the information that cannot be captured by the existing models.

3.4 Boundaries

This section will firstly distinguish the relevance of setting boundaries by reviewing some relevant literature. Finally, the boundaries of this thesis will be delimited.

3.4.1 System boundaries

The importance of setting the boundaries was discussed in the past by Bywater & Kelly (2005). They argued that the elements of a system contained within a boundary have a strong functional relationship with each other, whereas they have a limited, weak or no relationship with the elements or grouping of elements outside the boundary. Woodward *et al.* (2008) distinguished some of these external factors beyond immediate managerial control that are capable of influencing farming systems outcomes. They enlightened that they are not only physical, biological, economic and social factors, but also include other externalities such as farm location, farm resource conditions in the past, and farm future environment.

Figure 3-1: Current internal and external needs or wants, conflicts and problems faced by a farm manager. The clouds symbolise existing conflicts or problems, whereas the arrows represent the needs/wants (Sørensen *et al.*, 2010)

As illustrated in **Figure 3-1**, Sørensen *et al.* (2010) found out that in a system boundaries can be described in terms of users, where users are entities interfacing with the system. These authors presented this model to help paint a picture of the externalities farmers have to deal nowadays. Even though this model is not specific to New Zealand farming, some external interactions with the "Farm Manager" are common to New Zealand, for example, government, researchers, neighbours, etc.

Using the model done by Wolfert *et al.* (2008), Allen & Wolfert (2011) made an adaptation to it with the aim of showing how the information flows between the external and internal farm system in New Zealand. Eight different "stakeholder" organisations are part of the model shown in **Figure 3-2**, also including (in addition to the previous model) data suppliers, consultancy, supporting technology, accountancy, processors and input suppliers. As these authors argued, each of these groups may interact with a farm by providing information to or demanding/requiring information from the farm, either for compliance and/or decision making.

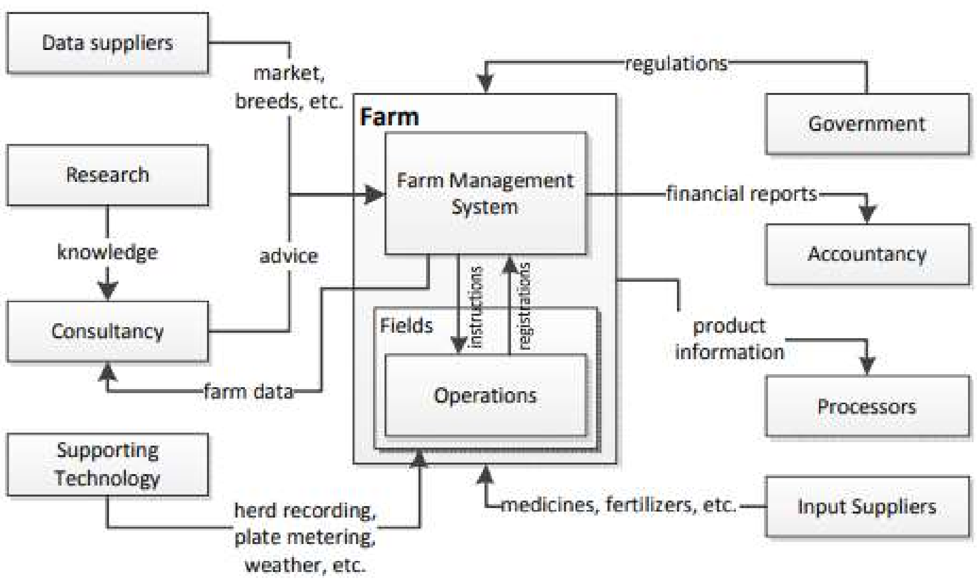


Figure 3-2: Simplified representation of some information flows within and around the farm cited by Allen & Wolfert (2011) adapted from Wolfert *et al.* (2008)

Hammond (2015) went a step further from the presented models of Sørensen *et al.* (2010) and Allen & Wolfert (2011) and arrived at the model presented in **Figure 3-3.** In this model, the author aimed to portray a closer representation of the external environment that New

Zealand farm managers must consider both for compliance and be used in decision making, therefore it also incorporated PR/media and corporate administration.

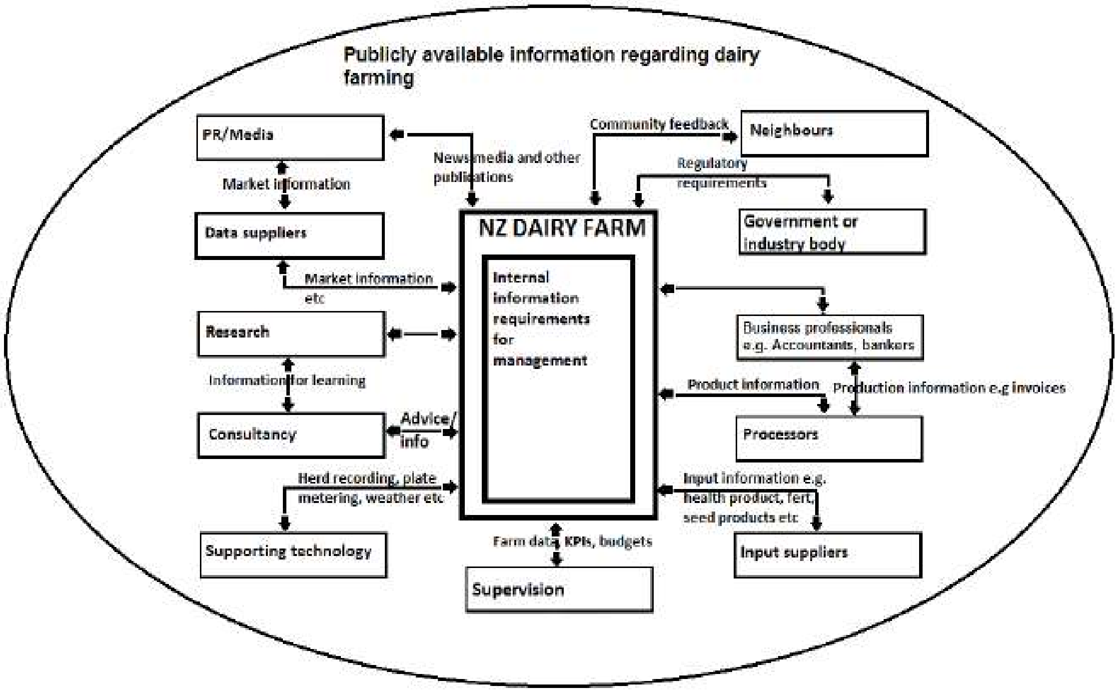


Figure 3-3: Information flows to, from and around the farm (Hammond, 2015)

3.4.2 Setting the boundaries for this study

Since most of New Zealand's dairy products are exported and the dairy industry is the largest contributor to the total value of New Zealand's agricultural exports, a global perspective was taken for the design of future scenarios, which included some broad and complex challenges that in the practice are difficult to be controlled by the farm manager.

As one of the objectives of this research is to bring the future scenarios to a farm level where a modelling approach can be applied, a first step will be taken to reduce the amplitude and diversity of the characteristics described in the scenarios. This will be done by grouping some of the issues and challenges shared between the three scenarios inside "areas of conflict". The four areas of conflict will be: 1) market dynamics, 2) climate change, 3) labour constraints, and 4) environmental social and animal welfare concerns. These areas will act as the limits for the next step of this study, in which a series of possible internal solutions will be presented and reviewed. These potential solutions involve applying a diversity of new technologies and innovations, which are pointed out to have a critical role in the future.

3.5 Potential ways of addressing the future issues

Worldwide, dairy farm management has historically been based on the experiential learning and intuitive decision-making of farmers (Jago *et al.*, 2013). It is documented how dairy farmers are making important management decisions in a non-programmed manner, relying mainly on intuition and experience (Groenendaal & Galligan, 2005).

Data-driven decision-making is a necessity in today's dairy farm systems. According to Schewe & Stuart (2014), the adoption of technology in agriculture can considerably reorganize production and relationships amongst humans, animals, and the environment. Nevertheless, although new technologies are promising, implementing them on a large scale in the dairy sector is a problem because of their high costs. Also, as Demeter *et al.* (2009) pointed out since increasing food prices are likely to lead to higher profitability in the future, farmers may find themselves with a lack of incentive to adopt new innovations.

In New Zealand, the commercial imperative of low-cost grazed pasture systems has driven dairy farmers to remain relatively low-tech compared to their competitors (Kamphuis *et al.*, 2015). Moreover, some farmers resist technology adoption as they see a potential consequence of future 'de-skilling' of staff in animal handling and decision making, along with other fears such as power failure or internet disruption (Eastwood, Klerkx, Ayre, & Dela Rue, 2017). Also, according to Bewley & Russell (2010), new farming technologies require support structures to facilitate learning and reduction of uncertainty in the implementation and adaptation process. Other reasons for dairy farmers not to invest in new technologies include the perception that current commercially available technologies are unproven, unreliable, and have an uncertain return on investment (Kamphuis *et al.*, 2015).

3.5.1 Overview of current technologies

As it is a fact that maintaining current agricultural practices will have negative effects on global food production, the reconciliation of sustainability with productivity, economic factors, and environmental impact is the challenge to be addressed (Liu *et al.*, 2015). Technology is called to play a vital role in the pursuit of this reconciliation, as it has the ability to increase food production while minimizing pressure on the environment, offering great potential for improving efficiency, effectiveness and productivity. Moreover, the use of new technologies presents an opportunity to improve farm productivity and address future on-farm challenges not only related to the environment, but also to animal care, and social-ethical issues (Gargiulo *et al.*, 2018).

The introduction of 'smart farming' –also referred to as digital farming, digital agriculture and precision agriculture– has arisen as an opportunity to manage land, stock and staff more effectively. Furthermore, scientists and policymakers are looking to smart farming as a technological solution to address societal concerns around farming, including food traceability, animal welfare and the environmental impact of different farming practices (Eastwood, Klerkx, Ayre, & Rue, 2017).

In this line, O'Grady & O'Hare (2017) argued the importance that smart farming will have in delivering meaningful information in near real-time, enabling farms to become more efficient, productive, and profitable. Moreover, new technologies will offer farmers the ability to monitor their farms with an unprecedented level of detail.

An example of a current innovation applied in farming are the automatic cup removers (ACRs), a very well-known and accepted technology that helps improve milking consistency, increase labour efficiency, reduce the incidence of over-milking and maintain teat condition and milk quality (Jago *et al.*, 2013). Also, as acknowledged by Edwards *et al.* (2014), sorting gates, calf feeders, post-milking disinfection and milk plant wash systems are nowadays also offering the possibility of either reduce pressure on the staff or improve labour efficiency, especially in larger herds. In an online survey conducted by Lyons *et al.* (2016) to find out the top 5 currently installed milking-related technologies in New Zealand, the first were electronic identification (37%), automatic in-parlour feeding (33%), ACRs (29%), automatic teat spraying (27%), and automatic sorting gates (15%).

In terms of data capturing technologies, the C-Dax Pasture Meter® is an automated technology currently being used to measure pasture covers, which works by simply using a quad bike or ATV with mounted pasture height readers which are capable of mapping. This tool has been adopted by possibly ten per cent of New Zealand dairy farmers and is used for example to monitor the grass growth rate, pre and post-grazing residuals in order to make grazing management decisions such as allocating supplement input where there are deficits (Eastwood & Yule, 2015). Additionally, there are other precision technologies that rely on data capture and are currently used to monitor parameters at an individual cow level, including technologies such as automatic oestrus detection systems, inline milk meters, electronic cow identification systems and herd management software (Gargiulo *et al.*, 2018).

Other technologies such as virtual fencing (Umstatter, 2011), low power wireless networks, robotic milking and electronic identification of individual animals, were identified as smart dairying innovations with an important role on future NZ dairy farms (Eastwood, Klerkx, Ayre, & Dela Rue, 2017), as it has been observed that they could have economic, environmental and animal health benefits (Jensen *et al.*, 2012; Schlageter Tello *et al.*, 2015).

3.5.2 Description of each area of conflict and potential solutions

Following, each of the conflict areas which reunite some of the issues and challenges discussed in the future scenarios will be described. After that, a series of probable solutions which involve the use of new technologies that could potentially help to overcome the challenges at a farm level will be reviewed. These suggestions will then be the basis for the proposed farm-systems changes applied to the case study farm of this research.

1) <u>Market dynamics</u>

a. Introduction

The dairy sector around the world is facing changes in consumer demand, mostly fuelled by the increasing population and purchasing power in developing countries. China has an ever-increasing thirst for milk, with a predicted 3.2-fold increase in demand by 2050 (Bai *et al.*, 2018). Currently, China is the leading milk importer, importing 12 Tg fresh milk equivalent in 2013, which was 123-times larger than that in 1961, and equal to 25% of the domestic consumption in 2013 (FAO, 2016). In addition to China, the traditional lower milk consumption countries of South and East Asia and sub-Saharan Africa are experiencing significant increases in milk consumption due to population growth and a higher level of incomes. As Shadbolt *et al.* (2017) observed, consumers are consuming more fresh and organic products, which reflects a desire for purchasing 'health'. A study on the value on NZ's 'clean green' image found surveyed international consumers would purchase 54% fewer dairy products if NZ's environment was perceived as degraded (Ministry for the Environment, 2011).

This provides an opportunity for New Zealand, whose international recognised pasture-based farming systems can be adapted to provide milk all-year round.

b. The problem

As New Zealand dairy farm systems are mostly seasonal, there is not a big supply of winter milk to be exported to the world. The reason why most farmers worked on a seasonal basis was explained previously, but in summary, is the fact that extra feed is needed to add to the system as the pasture growth rate curve do not follow the feed demand of autumn dairy herds.

Additionally, as observed by Clark *et al.* (2007) there is an urgent need to reduce the capital and operating costs associated with the use of imported feeds, as it is increasing the financial risk of farmers. The inclusion of purchased supplementary feeds to increase milk production per cow (through greater dry matter intake) and per hectare (through increased stocking rate) is often proposed as a strategy to increase profitability as a consequence of land becoming a more limited resource for pasture-based dairy farming (Ramsbottom *et al.*, 2015)**.** Yet, the purchased feed is the greatest operating expense on dairy farms (**Figure 3-4**), so reliance on bought-in supplements implies exposure to the vagaries of international commodity prices.

In recent years, the increase in the volatility of market prices –both inputs and outputs– has led to a further debate around which dairy system is the more suitable to cope in such conditions. Shadbolt (2012) for example, indicated that when a farm moves from a low-input system to a high-input system, mitigates one source of risk but ends up creating another.

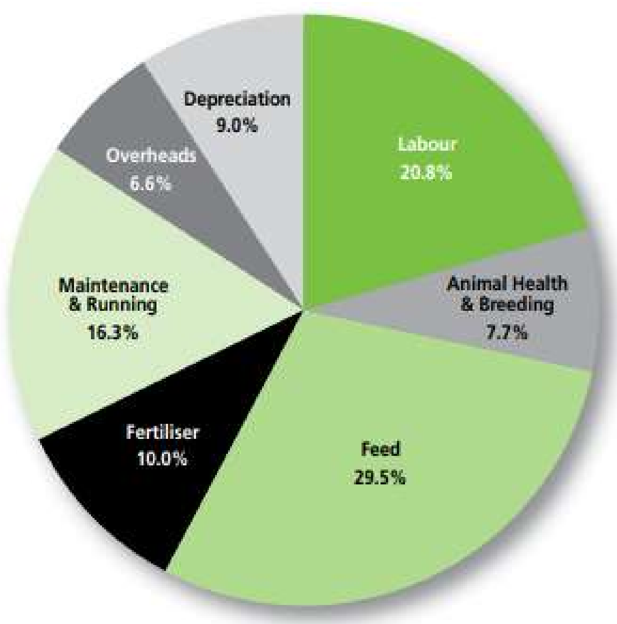


Figure 3-4: Dairy Operating Expenditure for 2016-17 (DairyNZ, 2017b)

c. Potential Solution

In order to produce fresher and more customized milk and derived products with improved shelf life, dairy farmers and the processing industry could consider the following practices:

✓ **<u>Winter milking/all-year-round milking</u>**

Seasonality restricts the types of products that can be produced, especially those requiring year-round supply. It also leads to poor capacity utilization of the processing industry, adding to the operating costs of the processor. Some "winter milk" is nowadays normally required to be produced out of season for the fluid market and for the manufacture of specific all-year-round products. To supply fresh liquid milk, producers are compensated with a premium milk payment for the extra costs involved. Dillon *et al.* (2008) claimed that this practice has a huge potential in relation to the value that can be added to milk, as well as the better plant utilisation.

✓ **<u>Improve Logistics/Packaging</u>**

Taking in consideration that the demand for fresh and nutritious foods with improved shelf life is growing in developed countries (Devlieghere *et al.*, 2004), improving overall quality and freshness of milk by reducing the length of the dairy chain could be an important practice in the future. New methods for storing and transporting milk must be considered. For example, Demeter *et al.* (2009) suggested that in the future tankers may no longer carry just one milk type, but instead can collect different milk types from one or more farms separately yet simultaneously.

✓ **<u>Improve Genetics/Breeding</u>**

Research has suggested selective breeding could be useful for farmers to meet specific consumer or industrial demands, by taking advantage of the genetic variation underlying the differences among cows. Dillon *et al.* (2008) commented that the genetic make-up of a dairy herd will be critical to the profitability of any dairy enterprise in the future.

Further, in terms of genetics and breeding, Clark *et al.* (2007) observed that Jersey cattle appear to be more tolerant to OAD milking compared to Friesian cattle, with less of a reduction in milk yield. However, Friesian cattle partition more feed to live-weight change than Jersey cattle (Clark *et al.*, 2006).

✓ **Premium grass-fed milk**

The success of the farming industry in NZ is tied to the country's environmentally-conscious image as well as to the ability to produce a high quality product at low costs. The clean, green and environmentally friendly image of New Zealand, added to the fact that cows graze outdoors for most of the year, contributed to a more 'natural' and 'welfare-friendly' perception of production from consumers around the world. As can be seen in **Figure 3-5**, in the last 5 years the amount of pasture in the cows' diet has been increasing, showing a positive trend.

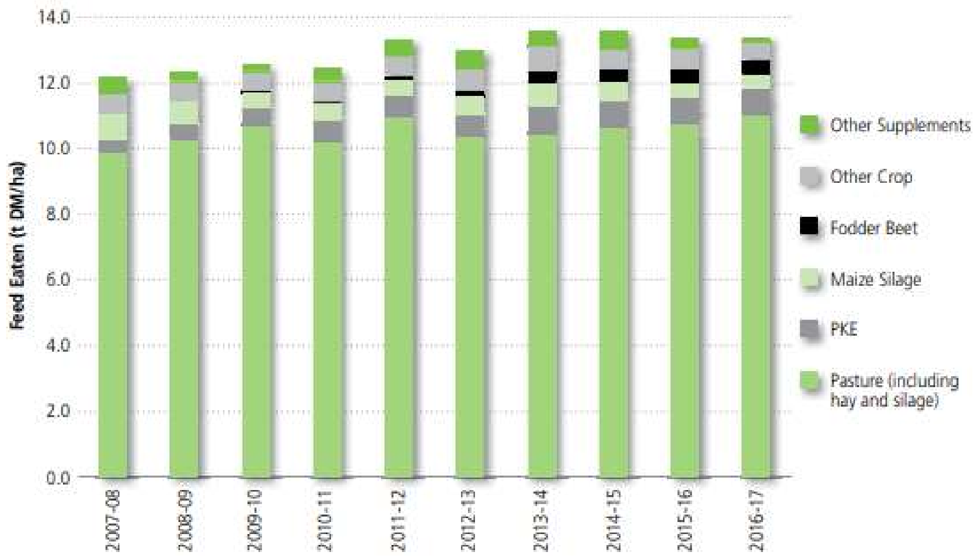


Figure 3-5: Trends in the Main Components of Feed Eaten by dairy cows in New Zealand (DairyNZ, 2017b)

In terms of nutrition, Lock & Bauman (2004) suggested that improving the nutritional quality of milk and dairy products could contribute to a more favourable human diet, given that milk and derived products are important sources of nutrients in human diets. Supporting this, many studies have reported that pasture-based systems of milk production have a distinct advantage over high input systems, with grazing systems associated with greater global sustainability, increased product quality, improved animal welfare, and increased labour efficiency (Dillon *et al.*, 2005; Macdonald *et al.*, 2008; O'Brien *et al.*, 2012; Peyraud *et al.*, 2010).

2) <u>Climate change</u>

a. Introduction

In pastoral farming, climate uncertainty has a big impact on production. As claimed by Homes & Roche (2007) a distinguishing aspect of milk production in the dairy industry of New Zealand compared with its competitors is the fact that most farming operations use pasture-based farming systems. The type of pasture used to feed the cows depends mostly on the environmental conditions and the ability of the pasture to adapt and produce enough amount of forage. For all but the irrigated farmers, this ability is determined by rainfall: excess or deficient water supply restricts the growth of New Zealand pasture. Adequate Rainfall –and temperatures– dictates whether pasture grows or not through the critical summer months. Moreover, as suggested by Shadbolt & Apparao (2016) reliance on rainfall provides the additional complication of the seasonality of production, with processors running plants at varying levels of capacity throughout the season.

b. The problem

The frequency of extreme weather conditions has been calling the attention of farmers, who need to be ready to adapt their farm-systems to the growing impact that climate change brings. Severe droughts can result in a substantial decrease in the availability of irrigation water and supplementary feed, and a subsequent increase in the price of these inputs (Armstrong & Ho, 2009).

Irrigation could help to increase the input of water and nutrients into the system when draughts occur, allowing for productivity gains. As acknowledged by Hedley & Pinxterhuis (2017), major advances have been made in the New Zealand irrigation industry over the last 30 years, which has seen irrigation efficiency improves by 50%, providing an estimate of $2.7 billion to NZ's economy in 2012 (and more than double in terms of the benefits to the wider community). But the fact that water quality is declining in many water bodies put irrigation under scrutiny, as it poses a risk of over-applying water and increasing drainage of nutrients to water bodies.

c. Potential Solution

As Dillon *et al.* (2008) suggested, enhancing control of feed quality to overcome climatic and seasonal effects could play a critical role in grazing management in dairy farms. For doing this, precision irrigation could help.

In terms of irrigation, mapping the soils and the use of management of farm blocks/paddocks, measuring soil moisture and drainage, and utilising weather forecasts are proven methods to increase the irrigation efficiency (Hedley & Pinxterhuis, 2017). However, as these authors further stated, technical solutions are not the only answer: regulatory and irrigation scheme infrastructural factors also influence decision making, and therefore, have to be aligned to achieve efficient irrigation.

✓ **Precision Irrigation Systems**

New irrigation systems have been designed to deliver the correct amount of water at an appropriate intensity. Apart from providing greater flexibility for management, precision irrigation systems help to avoid irrigating raceways (reducing lameness in cows), wet boggy areas (e.g. around water troughs), and to give better control where systems move close to waterways and roads (Hedley & Pinxterhuis, 2017). As found out by Hedley *et al.* (2006), farmers have been considerable attracted as it is an investment that could pay for itself within the first year through water savings –between 10 and 20%–, by allowing irrigating a larger area with the same water allocation and equipment.

Figure 3-6: Sensors are being trialled to directly monitor plant water stress (Jafari *et al.*, 2016)

Other new technologies include customised wireless soil moisture sensor networks that provide data in near real-time to the farmers vial cell phone apps and web pages, and thermal cameras able to monitor water stress indirectly by monitoring leaf surface temperature (**Figure 3-6**) (Jafari *et al.*, 2016).

- ✓ **Genetic modifications in pasture breeding**

Genetically Modified (GM) forage grasses in NZ is restricted to herbicide-resistant lucerne (*Medicago sativa*) and a low-lignin trait in lucerne (James, 2014). Nevertheless, AgResearch scientists developed a GM ryegrass that could lower farming's environmental footprint, but because of NZ's strict GM laws, it has been sent to United States (US) for further field testing. Scientists hope the US trials will verify the results of lab work and modelling carried out at Palmerston North, which found that GM grasses could reduce methane emissions (between 10-15 per cent), cut pasture costs and increase production (up to 50 per cent more yield) on New Zealand dairy farms (Harris, 2016; Piddock, 2017). Barrett *et al.* (2015) additionally acknowledged that GM forage grasses could deliver substantive improvements in animal production.

3) Labour constraints

a. Introduction

Since 1990 the number of dairy herds in New Zealand farms has reduced by 60% and the average herd size has increased by around 160% (DairyNZ, 2016). Most of these farms are family owned and operated with a variable level of external labour. As a result of larger herds, today's dairy farmer no longer manages only cows, but increasingly as much (or maybe even more) people. Considering the dairy farm industry is characterized by its intense workload and high staff turnover, and that farm families desire every time more time off the farm, retaining staff is critical.

b. The problem

The cost, availability and skill level of farm labour are critical problems for dairy farmers nowadays. Migrants with little prior experience are often employed (Tipples & Verwoerd, 2006), leading to issues around farm management skills, animal husbandry, and staff retention. Also, with larger farms and increased herd size, major dairying countries are watching how labour input is growing significantly.

The availability of skilled labour and the demands of animal management under increasing herd sizes might limit future expansion in production and profitability (Clark *et al.*, 2016).

c. Potential Solution

Labour shortages are driving a need for automation and technologies to assist farmers with their daily management decisions (Jago *et al.*, 2013) while reducing the pressure on labour (especially in large herds). Automatic milking systems (AMS) present an opportunity for the dairy industry to either reduce labour costs and/or increase the effectiveness of the existing workforce by shifting labour from menial repetitive milking tasks to focus in farm management (Clark *et al.*, 2016).

✓ **Automatic milking systems**

First developed in Europe in the 1970s, the AMS initially focused on farm systems where cows were confined in barns, with the idea to offer relief from the demanding routine of milking (Rotz *et al.*, 2003). By 2008, AMS was adopted by 2400 farms worldwide, mainly in The Netherlands, Germany, Denmark, UK, Canada and the US (Schewe & Stuart, 2014).

AMS works using a robotic arm to attach and detach the milking system to a cow's udder without human assistance. According to De Koning & Rodenburg (2004), with one robot unit, 60-70 cows can be milked, resulting in a 20-30% reduction in total farm labour-hours. Bach & Cabrera (2017) further supported this finding, recommending that the number of animals per AMS should be around 60 to 70 cows, as this number stems from the time required to clean the AMS, unit attachment failures, periods of nonattendance, and technical maintenance. They also suggested that the goal should be maximizing milk yield per cow instead of increasing the number of cows.

The system allows cows to voluntary approach to the robot to be milked individually, when they desire, and at any time of the day. According to De Koning & Rodenburg (2004), this can be up to three times each day, which can increase milk production per cow by 6-35% over the common twice a day milking strategy. The main motivation for cows to approach to the robots is the feed (they will always choose to eat over milking), therefore allocating the correct amount of pasture is crucial to achieving voluntary cow traffic and minimize fetching (Bach & Cabrera, 2017; John *et al.*, 2016).

In addition to the installation of the robot, Woodford *et al.* (2015) pointed out how AMS require redesigning the whole farm system, including feed, labour, routines, and relationships to integrate the new technology into the system. This statement was supported by Lyons *et al.* (2013), who acknowledged that the introduction of AMS to farming systems in New Zealand is an ongoing learning process that requires new ways of thinking, as it represents a completely new way of farming. In a survey made in Canada to document the experiences of dairy producers during the transition to (and use of) AMS, it was found that the majority of producers experienced a positive transition, highlighting how AMS improve the quality of their lives in terms of more flexibility, less stress and physical demand and easier employee management (Tse *et al.*, 2018).

In terms of costs, AMS requires a large initial investment, averaging between US$175,000-US$250,000 per robot depending on the model and manufacturer (Hyde & Engel, 2002). As most farms need multiple robots and modifying or incorporating new structures to accommodate robots, typical capital investment ranges between 1.5 to several million US dollars, with monthly maintenance costs ranging from US$400-US$1200. In New Zealand, a single bail AMS unit, which milks about 70 cows around twice a day over 24 hours, costs up to $250,000 (Dela Rue, 2017). Estimates place the capital costs of AMS between 150 and 260% higher than conventional milking systems, but the increase in dairy production and savings in labour expenses are set to compensate these costs (Schewe & Stuart, 2014).

Figure 3-7: An automatic milking robot unit in practice (source: www.DeLaval.com)

In New Zealand, AMS was first introduced in 2001 with an emphasis on pasture-based grazing systems. Since its introduction, DairyNZ has been researching the use and implications of AMS. There are 20 AMS farms in New Zealand, where a third milk less than 200 cows, and half milk between 200 and 400 cows (an exception is a farm in South Canterbury, which milks around 1500 cows through 48 units in a housed system) (Dela Rue, 2017). Even though the integration of AMS into NZ pasture-based dairy farming brings new challenges different from those of indoor-based feeding systems (where cows tend to be more motivated to consistently visit the robot), it has been proven satisfactory that AMS can be incorporated into pasture-based production systems without compromising pasture utilisation (John *et al.*, 2016; Lyons *et al.*, 2013). However, walking distance is an important factor in cow attendance to the robot (John *et al.*, 2016). According to Islam *et al.* (2015), to maintain a predominantly pasture-based system, a large herd milked by AMS would be required to walk significant distances. As found out by these authors, walking distances of greater than 1-km are associated with an increased incidence of undesirably long milking intervals and reduced milk yield. Consequently, they proposed in their study to incorporate complementary forages into the pasture-based system to lift total home-grown feed in a given area, thus potentially 'concentrating' feed closer to the dairy.

In a study undertaken by Woodford *et al.* (2015) with six farms who have adopted AMS in NZ, production results showed that both production per hectare and per cow were considerably above regional averages. These farmers attributed the increases to the overall system changes rather than the robot technology per se, with increased milking frequency, use of supplements and less animal stress all contributing to specific situations.

According to Woodford *et al.* (2015), adapting AMS to a pasture-based grazing system is set to change the nature of the work rather than the quantity: hours spent at milking will be reduced, improving lifestyle for farmers while making dairy more appealing as a career and attracting a new class of employees. Yet, labour savings that AMS adoption brings are offset by maintenance costs of the robots and higher electricity costs. Labour requirement will not decline, but the increase in milk production from AMS reduces the labour inputs per unit of milk produced (Woodford *et al.*, 2015).

In terms of animal health, dairy farmers using AMS reported that cows appeared to be less stressed and quieter compared to traditional systems (Woodford *et al.*, 2015). However, the technology-driven change in the relationship between cows and farmers may trigger debates in society around animal welfare, as people could argue the ethics surrounding where technology ends and the animal begins in robotic milking (Eastwood, Klerkx, Ayre, & Dela Rue, 2017). Another concern raised up by Eastwood *et al.* (2016) is the fact that if a machine stops working, farmers require rapid access to technical support as this can cause a backlog in the milking process.

In Australia, despite the current low adoption of AMS (around 40 farms by mid-2017), in a survey undertaken by Gargiulo *et al.* (2018) this technology was ranked among the top 5 for expected adoption in the next 10 years, potentially because it not only addresses labour issues but also allows monitoring and management of several parameters at an individual cow level (Lyons *et al.*, 2013). In the case of New Zealand, due to lower costs of conventional milking and issues of scale, adoption of robotic milking has not proved popular, with only approximately 20 farms using milking robots by 2016 (Eastwood, Klerkx, Ayre, & Dela Rue, 2017). Also, according to Dela Rue (2017) some other barriers include needing to modify farm layout, gate systems and yard design for voluntary cow trafficking; adapting farm management practices; less manual work but more computer time, as well as the inability to trial the technology before committing.

4) <u>Environment & animal health social concerns (4)</u>

a. Introduction

Globally, the trade of milk is expected to increase strongly during the next decades mainly due to the increasing demands from China. The environmental impact will depend on how global agriculture expands in response to this rising demand. As Bai *et al.* (2018) observed, meeting China's milk demand will be translated into an increase in global dairy-related GHG emissions of 35% and nitrogen losses of 48%. In addition, as China also imports large amounts of soybean, maize and alfalfa to feed its increasing domestic pig, poultry, and dairy cattle populations (FAO, 2016), the additional environmental burden is also expected to be transferred to the exporting countries, as imported products carry their own environmental implications from extraction and manufacturing in their country of origin (i.e. conversion of indigenous rainforest to palm plantation from which palm kernel is obtained) (Foote *et al.*, 2015).

According to FAO (2016), the European Union (EU), New Zealand and United States of America (USA) were the three milk exporting region and countries, accounted for more than 80% of total export in 2013. In New Zealand only, the dairy industry has intensified growing from 3.5 million cows in 2000 to 5 million cows in 2015 (DairyNZ, 2016). The environmental impact of such intensification has been a topic of interest because of its contribution to CH_4, CO_2, and N emissions (Totty *et al.*, 2012). Below, **Figure 3-8** illustrates the emissions of a dairy production system lost to the environment.

Figure 3-8: Flowchart of New Zealand milk production from cradle to farm gate (Flysjö *et al.*, 2011)

b. The problem

The effect of intensive agricultural systems on the environment is of increasing global concern. Growth brought inevitable concerns linked with water quality and quantity, GHG emissions, and soil conservation (Doole & Romera, 2015). Consumers have expressed their worries about the impacts of intensification, demanding greater scrutiny and proof of farm practice relating to animals and the environment (Jay, 2006). They are also requiring that a connection is retained between the products they consume and the farms that produce it.

At a farm level, as dairy farms intensify more nutrients are added to increase production and compensate for losses, being urea the main nitrogen fertilizer used in NZ (Beukes *et al.*, 2014). Over-application of N from fertiliser and effluent is increasing the risk of N leaching, as well as poor irrigation management is also contributing to drainage (Pinxterhuis *et al.*, 2017). Additionally, GHG emissions already present in the atmosphere are causing great concern:

global temperature is expected to rise by at least 1°C over the next 30-40 years (OpenFutures, 2012). Almost half of NZ's GHG emissions are derived from agriculture (mainly methane and nitrous oxide) and about a quarter from dairy farming (Foote *et al.*, 2015).

In terms of animal welfare, there is a big concern associated with the transport and slaughter of bobby calves in the dairy industry. It is well-known that while a proportion of the females are normally retained as herd replacements, a large number of calves are sent for slaughter at around four-days-old. The main reason behind this is the little incentive for dairy farmers to rear additional calves, mainly due to a lack of viable alternatives.

c. Potential Solutions

Finding ways to reduce the environmental footprint while sustaining production and profit in dairy farming is a challenge. With milk demand projected to double between 2000 and 2050, the need to implement mitigation strategies will increase significantly (Aguirre-Villegas *et al.*, 2017). Also, as regional councils progressively implement nutrient loss limits at farm and catchment level –and consumers increase their scrutiny–, it is a fact that farmers must think hard about how to reduce their environmental inputs while retaining the fundamental principles of low-cost, pasture-based dairying systems.

Actual research found valid and proven ways of applying environmental mitigation strategies on-farm without compromising the associated reductions in profit. Further, research underway is called to play a vital role in presenting farmers with further viable options.

✓ **<u>Fertiliser variable rate application</u>**

In New Zealand, the government and fertilizers companies had been funding programmes to develop technologies to manage nutrient inputs. Some of the technologies researchers have been focusing are in the development of sensors capable to measure nitrogen deposition from dairy cows, as well as GPS technology to track fertiliser, sprays and effluent applications. Draganova *et al.* (2010) described how GPS collars and sensing equipment such as activity meters and urine sensors could be used to describe the redistribution of nutrient N around the dairy farm in an unbiased way.

Another important innovation is the use of Variable rate application (VRA) of fertiliser, which can create significant savings for farmers without compromising productivity while having the added benefit of environmental monitoring.

Additionally, recent innovations in using out-wintering pads and earth bank tanks on-farm have the potential to reduce housing and effluent management costs, while providing robust facilities for dairy herd management (Dillon *et al.*, 2008).

- ✓ **GPS collars for animal tracking**

In terms of animal welfare, to preserve economically sustainable dairy farming, the focus on the health of the cows is crucial. Animal tracking technologies –through the use of GPS-enabled collars– could provide farmers with management information on cow behaviour (which could also indicate health events such as heat detection), movement and nutrient re-distribution around the farm. At the same, this technology could potentially benefit consumers in terms of traceability, animal welfare and knowledge of product history (Jago *et al.*, 2013).

Figure 3-9: A calf shed using solar panels as a source of electricity (source: www.skyfireenergy.com)

- ✓ **Solar technologies**

In order to reduce dependence on external sources of energy, several farms have invested in solar technologies which convert energy from the sun into electricity, reducing energy sourced from the state's electricity grid and reducing energy emissions on the farm (AgricultureVictoria, 2017). Other advantages include: reduction in electricity bills, no running costs after installation, and systems can be expanded by adding more panels (DairyAustralia, 2014).

- ✓ **Bobby calves for the feed industry**

Traditionally, British breeds (Angus and Hereford) have been the main source of beef produced in New Zealand. Nevertheless, according to Collier *et al.* (2015) nowadays the use of dairy breeds have become more popular, with plenty of potentials to increase the amount of beef sourced from the New Zealand dairy herd in the future.

Typically, dairy farmers keep 20 per cent of calves as replacements. Accounting for losses, this leaves 75 per cent of calves surplus to requirements. Information gathered from Beef + Lamb New Zealand and DairyNZ suggests 2.3 million are processed as 'bobby calves' annually. Bobby calves are sold and transported at four days to a week old to a meat processor and marketed as veal. Per calf, dairy farmers can receive between $15-50, which is a relatively low value considering the time, energy, and cost of selling animals this way (also adding is a busy and stressful time of year on dairy farms) (Morrison, 2017).

Therefore, there is a huge opportunity to maximise the value of bobby calves to farmers and the whole supply chain by growing more of these animals into finished beef cattle, animals that are worth a lot more than bobby calves. Additionally, this also contributes to having a more sustainable, viable and ethical value chain (Jolly, 2016).

Massey University started an investigation on whether the dairy industry has the potential to drive a new class of beef product by rearing bobby calves that would ordinarily be sent to slaughter. The project, headed by Dr Nicola Schreurs of the School of Agriculture and Environment and named "New Generation Beef", aims to achieve a 'zero-bobbies policy' by turning a low-value product into a high-value product. The potential new product would see calves reared up to a year old (aiming to get to a 300 kg live weight which would put the carcass weight at around 150-160 kg) to develop a new, full red-meat (Piddock, 2018).

While this project still needs validation, it has the potential to spawn a brand-new beef industry which could pay phase-out the slaughter of bobby calves, along with achieving a great positive effect on the public perception of wasted livestock in the dairy industry.

- ✓ **Mobile milking system**

The Mobile Milking System (MMS) is a dairy farm system that utilises a portable herringbone cowshed, whose system enables farmers to set up a flexible dairy platform to milk their cows, using a fraction of the cost of a traditional dairy farm (Greenhalgh *et al.*, 2012).

According to Greenhalgh *et al.* (2012), because the cowshed can move after every milking, cows are not required to walk very far to get to the cowshed, providing lower rates of sore feet and the potential of higher milk production from the energy saved from walking to and from the cowshed. Furthermore, as found out by these authors, the mobile system may have potential environmental benefits from moving the platform, as it helps to avoid nutrient overload.

Figure 3-10: A picture of how a Mobile Milking System looks like when is set in a paddock (Greenhalgh *et al.*, 2012)

3.5.3 Implementation at a farm level

The implementation of the described innovations ultimately has to be considered at a farm level. According to Le Gal *et al.* (2011) this is level is the one "where farmers' decisions regarding the selection of alternatives, the allocation of resources between crops and livestock production, and the management of production processes determine their farms' impact on both the quantity and quality of agricultural products available to consumers and on the natural environment" (p. 715). **Figure 3-11** shows where the farm level is positioned on the different scales of engagement.

Figure 3-11: Different scales of engagement (Yule & Eastwood, 2012)

It is relevant to highlight that the implementation of innovations at a farm level involves many times critical systemic changes that may result in the partial or total redesign of the farm system, that includes changing the mode of working of farmers, transitioning from experiential decision-making to data-driven processes. Therefore, as suggested by Eastwood *et al.* (2009) support structures must be provided to help farmers interpret the information collected using precision technologies within the specific context of their farm system. These support structures may include private agronomists, producer groups, agriculture extension personnel, or associated software applications.

As testing new technologies and innovations is a risky, time-consuming, and costly procedure for farmers –as they have to go through trial and error process–, supporting them in designing innovate production systems at a farm level is critical.

To do this, modelling has become a useful tool as it evaluates *ex-ante* the multiple impacts of the application of some of the proposed innovations. Why do we build farm systems models? Because explorations would be extremely difficult to conduct using on-farm experimentation, and so modelling becomes a key tool to build our understanding. Moreover, the development and application of models to answer key industry questions are the only time- and resource-efficient way to provide direction through research for dairy farmers.

In the next chapter, the methodology chosen to undertake this study is explained.

Chapter 4: Method of analysis

The purpose of this research is to determine; what are the farm level implications of likely future scenarios. To achieve this, an appropriate research approach was needed. This chapter will provide an explanation to understand the motivation behind the research strategy selected. The analytical framework developed will be also outlined, as well as the case study farm chose to model and the modelling platform used. Afterwards, it would be explained how data was collected and used to build and calibrate the Base Farm System Model. Finally, the proposed farm systems are simulated and a description of the characteristics and assumptions for their design is provided.

4.1 Selection of research strategy

There are two main types of research strategies: quantitative and qualitative (Bryman & Bell, 2015). Quantitative research emphasizes on the collection and analysis of numerical research data, whilst qualitative research emphasizes in the collection and analysis of data. The core differences between these strategies can be seen in **Table 4-1**.

Table 4-1: Fundamental difference between quantitative and qualitative research (Bryman & Bell, 2015)

Fundamental differences between quantitative and qualitative research strategies		
	Quantitative	**Qualitative**
Principal orientation to the role of theory in relation to research	Deductive; testing of theory	Inductive; generation of theory
Epistemological orientation	Natural science model, in particular positivism	Interpretivism
Ontological orientation	Objectivism	Objectivism

Quantitative research uses a deductive approach which tests theories through research. It incorporates a natural science model, primarily positivism which is the philosophy that states that every claim can be justified scientifically, logically or mathematically and views social reality as an external and objective reality (Bryman & Bell, 2015). In contrast, qualitative research principally uses an inductive approach which means that emphasis is placed on the generation of theories through research, rather than testing theory. This strategy rejects scientific norms, practices and positivism, emphasising on the ways in which individuals interpret their social world. Additionally, it contemplates that social reality is a constantly shifting emergent property of an individual's creation, rather than the external and objective reality view, taken in quantitative research (Bryman & Bell, 2015).

Given the characteristics of these strategies, a combination between quantitative and qualitative research approach was used in this study. This strategy is known as mixed method research and in certain circumstances can provide more complete and comprehensive findings (Bryman & Bell, 2015).

4.2 Research method used

4.2.1 Modelling approach

In each type of research strategy there is an appropriate research method, which is the framework for the collection and analysis of data, ultimately used to create new knowledge (Bryman & Bell, 2015; Gillham, 2000). These include experimental, cross-sectional, longitudinal, case study or comparative designs.

In this thesis, using Massey Dairy No 1 as a single case study farm, a modelling approach was employed to, first, build a Base Farm System Model using the financial and biophysical data available for the 2016-17 season. Secondly, to simulate a series of farm system models that could best represent the changes described in the Future Scenarios section (Chapter 3). These proposed farm systems were named as the future scenario they are linked to: "Consumer is King System", "Governments Dictate System" and "Regulation Rules System". The modelling framework is illustrated below in **Figure 4-1**.

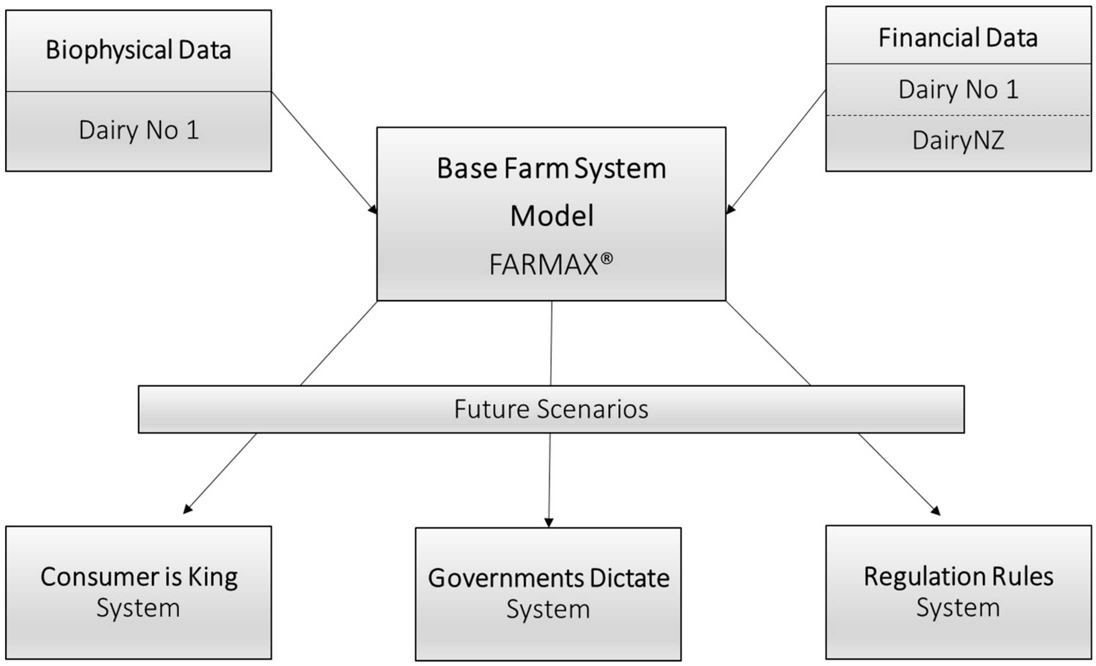


Figure 4-1: Modelling framework

4.2.2 FARMAX®

FARMAX® whole-farm system software was used as the main modelling platform for this study. This evidence-based modelling and decision support tool was developed for pastoral farmers in New Zealand and use monthly estimates of pasture growth, farm and herd information to determine the production and economic outcomes of managerial decisions (Bryant *et al.*, 2010). FARMAX® covers most of the input and output costs of the farming business and summarises it all in one place, facilitating the generation of informative reports. Additionally, FARMAX® allows building a wide range of 'what if' scenarios using simulations, helping farmers to assess different strategic, tactical and operational on-farm options for their farm systems. For farm consultants, FARMAX® provides a tool that can be used to undertake quite complex analyses very quickly, enabling them to offer advice based on a robust and proven model that uses a system custom built for New Zealand. One of the key benefits of using FARMAX® for both farmers and consultants is that it helps to increase the understanding of a farm system, while it also provides an independent and neutral perspective on a current situation.

The model has two modes – short-term (12 or 24-month projections) and long-term. The short-term mode can be used to model the impacts of tactical seasonal decisions while the long-term mode mimics status quo or balanced systems (where opening and closing stock numbers, liveweights and pasture covers are the same) for strategic decision-making (Bryant *et al.*, 2010). For this analysis, the long-term mode was used as the focus was at the strategic farm systems level.

In terms of its platform, FARMAX® is a Windows-based application developed with Delphi™, an integrated development environment for rapid application development of desktop, mobile, web, and console software. FARMAX® was conceived as a combination between the pasture module from Stockpol (Marshall *et al.*, 1991; Webby *et al.*, 1995), the animal components of MOOSIM (Bryant *et al.*, 2008), and recently developed animal representations and management options. The model contemplates the differences within regions of New Zealand, i.e. specific pasture growth rates, pasture types and expenses databases. Two scientific publications evaluated the model, one in the form of MOOSIM (Bryant *et al.*, 2008) and the other as FARMAX® (Bryant *et al.*, 2010), where it was simulated to a high degree of accuracy mean annual values for yields of milk, fat, protein and milk solids, as well as monthly pasture covers.

For the purpose of this study, FARMAX® allowed to set-up the Base Farm System Model of the case study farm by manually loading the financial and biophysical information provided by the farm for the 2016-17 season. Also, it allowed altering factors needed to simulate feasible dairy farm systems that could best represent the changes required in the Future Scenarios. This included modifications in the calving dates, milking frequency, supplement use, nitrogen application and drying-off dates, amongst many others. Furthermore, FARMAX® scenarios option enabled to test the farm systems proposed models to a climate change shock, which was represented by changing the pasture growth rates. Overall, FARMAX® provided a good grade of accuracy and realism.

4.3 Case selection

Modelling a single case study farm enabled the collection of in-depth evidence of the physical and financial data of the farm for the particular season selected that could not have been captured using other techniques.

Basically, case study research entails a detailed and intensive analysis of a case study data which is particularly useful in understanding the complexity and nature of the case (Bryman & Bell, 2015). Additionally, as Yin (1994) stated, this method contributes to gather detailed evidence to "illuminate a decision or set of decisions".

Case studies can be descriptive, explanatory or exploratory. These three types of case study are used to classify the purpose of the case study method: descriptive case studies look to describe a phenomenon in its real-world context; explanatory case studies look to explain how or why some conditions came to be; and, exploratory case studies look to provide insights which can be used to develop future research question or procedures (Yin, 1994). In this particular study, an exploratory case study type was used to discover the consequences that futuristic farm system changes can bring to a status quo farm system. In addition, the results obtained can be useful to identify future research questions.

Even though it is a preferred practice to include multiple cases in an investigation, for the analysis of the evidence and replication of design, and/or contrasting between the cases (Yin, 1994), in this study, a single case study was used to capture data-analysis and contrast results.

As one of the purposes of the modelling exercise presented on this research is to examine how a change to one or more variables of the case study farm system may impact the rest of the system, farm systems modelled have been built to be realistic and thus they are dynamic and capable of following management decisions that could be applied at a farm level.

4.3.1 Description of the case study farm

The chosen farm to model is the Massey University Agricultural Experiment Station Number 1 Dairy Farm (Dairy No 1) which is located adjacent to the Massey University campus, following the eastern bank of the Manawatu River –with 3.5 km of river frontage. As it can be appreciated in **Figure 4-2,** the city of Palmerston North, home to 83,500 people, is just across the river. Behind the farm, there are science research centres operated by Massey University, Fonterra, AgResearch and others.

Figure 4-2: A picture showing the proximity of Massey Dairy No 1 to the Manawatu River and the city of Palmerston North

Established in 1929, the farm is nowadays managed as a profitable, low input, sustainable pasture-based dairy farm with a once-a-Day (OAD) milking frequency system. Before converting to OAD in the 2013/2014 season, the farm was twice-a-day milking (TAD), having split calving that allowed all-year round milk supply. The decision to convert into OAD milking was part of Project Dairy One, which is a collaborative 'living research farm' project designed to address the issue of how to farm profitably and responsibly within resources limits (Kemp *et al.*, 2016). The main purpose of the project is to explore sustainability through OAD milking. So far results showed a decrease in farm costs, which partly compensated for the revenue lost from lower cow numbers. Other advantages that OAD milking brought to the farm were: per cow saving in animal health, labour and electricity costs, improvement in herd genetic merit, animal body condition score and pregnancy rates –which led to a reduction in the number of younger cows culled–, along with better work organization and more quality leisure time (Clark *et al.*, 2007; Guimaraes & Woodford, 2005; Kvapilik *et al.*, 2015).

In terms of the environment, nitrogen (N) leaching decreased as part of the re-design of the farm that included the constrained grazing in the paddocks adjacent to the river. The purpose of the farm and Project Dairy One is to leave a low environmental footprint while being financially sustainable. As seen also in **Figure 4-3**, the farm is divided into 65 paddocks. Those in pasture are managed to minimise leaching, which is done by limiting the non-grazing time the cows spent in the paddocks. While being on crops, cows are moved straight after they have finished grazing the break to minimise urination on the paddock. Stock drinking water on the farm is connected to the Massey University water supply and is reticulated to all paddocks. 18 paddocks (35.4 ha) can be irrigated (Kemp *et al.*, 2016; Lynch, 1990).

In 2016-17, the farm milked 258 cows on 142.7 ha, where 120 ha are effective milking area. The total milk solids (MS) production for the 2016-17 season was of 92.299 kgMS (358 kgMS/cow). The aim of Project One is to run all stock is on the dairy platform, however, 150 cows are grazing off the effective area actually.

Facilities on the farm include a 24 aside herringbone cowshed, 5 bay calf shed, an office, storage room, teaching room, effluent system and a concrete feed pad with a 280 cow capacity. River accretion soils of the Manawatu and Rangitikei silt loam series shape the farmland. These soils are of high natural fertility, excessively well-drained and subject to summer drought and infrequent flooding (Correa Luna *et al.*, 2017; Lynch, 1990).

The herd is split into Jersey, Friesian and Cross-bred for research purposes. In terms of genetics, the main objective of Project Dairy One is to develop cows that will be genetically suited for OAD as well as studying between the breeds and looking at variations between animals to find which breeds are more suited to OAD (Kemp *et al.*, 2016).

Following DairyNZ production systems standards, Dairy No 1 can be classified as a system in between 1 and 2, as there is a minimal amount of feed imported and dry stock graze off farm for a month before calving. Maize and grass silage are harvested off the effective milking area. It is the aim of the project to be a self-contained farm with no imported feed and stock wintering off-farm.

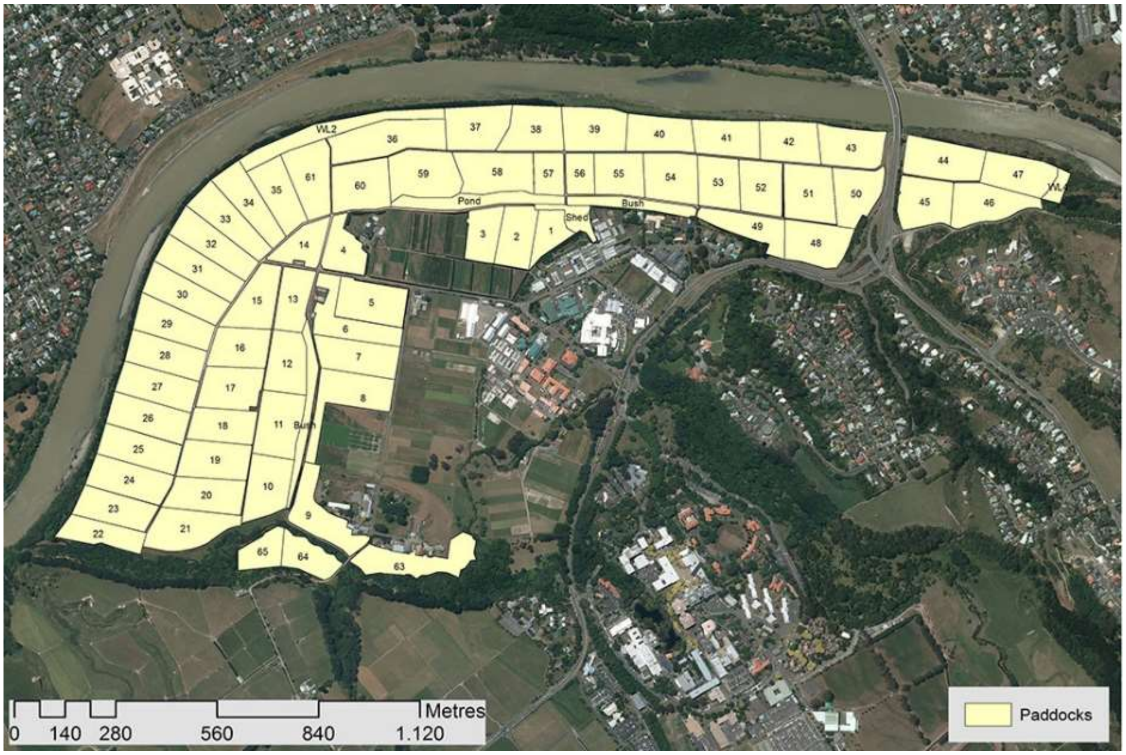


Figure 4-3: Massey Dairy No 1 Farm boundaries (source: www.massey.ac.nz)

As being a farm operating in the eyes of the town, Dairy No 1 is in a sensitive public location and therefore works proactively in linking with the community. With a daycare centre over one boundary, a walking/riding track along the riverside and the traffic driving by the property, the social licence to farm is in a spotlight. Therefore, one of the decisions adopted by the management in conjunction with the council was helping to bring the city closer to farmland. For example, schoolchildren frequently visit the farm as part of their education, to see where their food comes from. The farm is also used as a teaching resource for veterinary and agriculture students, research and extension (DairyExporter, 2017a).

4.4 Data

The base farm system has been calibrated in FARMAX® using 2016-17 biophysical and financial data.

The biophysical data used to build the Base Farm System Model was primarily sourced from the farm manager and the research technician currently working at Dairy No 1 farm. Massey website also provided useful information about the farm. Also, as the farm is part of a public project ("Project Dairy One"), information was also sourced from publications done by Kemp et al. (2016) and Correa-Luna et al. (2018), and from articles about the farm published in the DairyExporter magazine and Stuff website. These included additional information on stock numbers, reproductive performance, pasture covers and growth rates, area irrigated, crops harvested and offered, supplementary inputs used, fertilizer applied, calving and mating spread, animal enterprise information and milk production.

Financial data was obtained from Dairy No 1 database and from an Information Sheet report prepared by DairyNZ to help in the running of a focused and effective Discussion Group about OAD milking, which was presented as confidential information to the Discussion Group members only. Additionally, equivalent expenses per cow and per hectare from similar farming systems were extracted from a commercial database used for measuring and benchmarking farm economic performance in New Zealand (DairyBase, DairyNZ). Altogether, the financial data collected helped to calibrate the economic outcomes that FARMAX® predicted from the biophysical data loaded into the base model.

4.4.1 General assumptions

Assumptions used in the FARMAX® modelling and subsequent financial analysis are outlined in the respective sections. The key overarching assumptions being that average pasture cover, feed inventory, cattle numbers, and body condition score are the same at year open (1st of June) and close (31st of May). Also, even though the farm ran three different breeds in a single herd (Holstein-Friesian, Jersey and Kiwi Crossbred) in the analyzed season, a single breed was assumed along all the scenarios modelled.

4.5 Base model setup

4.5.1 Biophysical Calibration

- **Area**

The Base farm system was created based on the 2016-17 season, in which 120 hectares (ha) were part of the milking platform, with approximately 85 ha being rainfed and the remaining 35 ha under the effect of irrigation. FARMAX® was able to represent this distinction, which gave more accuracy to the model, as different pasture growth rates were expected in each block.

- **Stock Reconciliation and Grazing Off**

The milking herd in 2016-17 was composed of 258 mixed age (MA) dairy cows. 62 heifer calves were kept as a replacement (24%). A report on 'Removed Animals' from the 2016-17 season was obtained from MINDA®Live, an online platform that allows users to record and track the health of cows, gestation period, milk production, health, weights, and others, individually. According to the report, 59 MA cows were removed from the herd: 21 were sold and 38 were culled from the herd for various reasons. 18 animals died in total: 3 MA cows, 2 1-Year-old heifers, 7 bobby calves and 6 heifer calves. These figures were loaded into FARMAX® to build the stock reconciliation, which is shown below in **Table 4-2**.

Table 4-2: Stock Reconciliation for the 2016-17 season

Mob	Aged from	Open	Born	Die	Buy	Sell	Transfer		Close
							In	Out	
Cows		258		3		59	62		258
1-Year Heifers 16	Heifer Calves 17	64		2				62	
Bobby Calves 17			188	7		181			
Heifer Calves 17			70	6					64
Total		**322**	**258**	**18**	**0**	**240**	**62**	**62**	**322**

Figure 4-4 is a graphical output making a distinction between dry cows (light blue area) and milking cows (light orange) during the season. The shaded area represents 150 MA cows sent off-farm from the 1st of till the 8th of July. Young stock grazed off from weaning, returning as pregnant rising two-years-old in May (pre-calving).

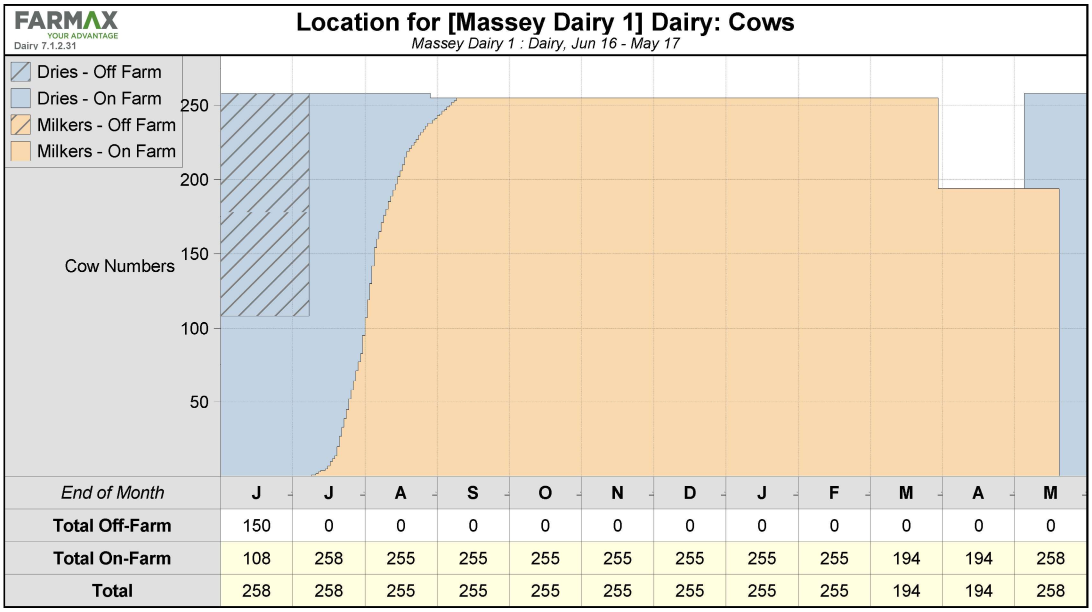


Figure 4-4: Total cows on & off-farm during the 2016/17 season

- **Pasture covers & growth rates**

On the 2016-17 season, pasture was measured two to three times a month by the farm manager using a rising-platemeter. These weekly measures were obtained from the farm and loaded into FARMAX® (**Figure 4-5**), which calculated growth rates and total pasture growth (kgDM/ha) automatically (**Figure 4-6**).

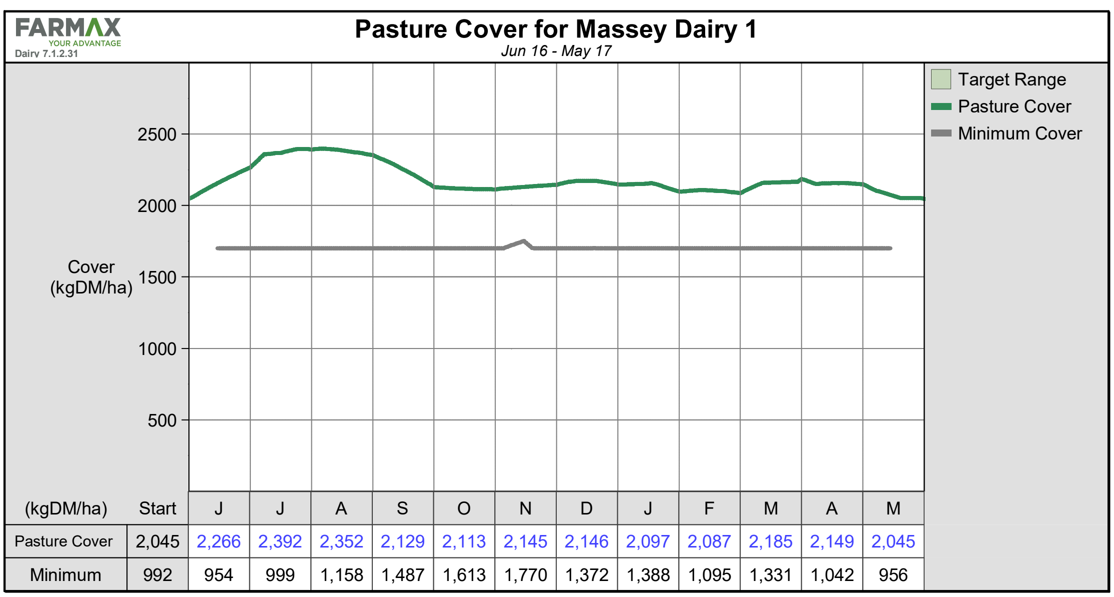


Figure 4-5: Pasture Covers (kgDM/ha) by month

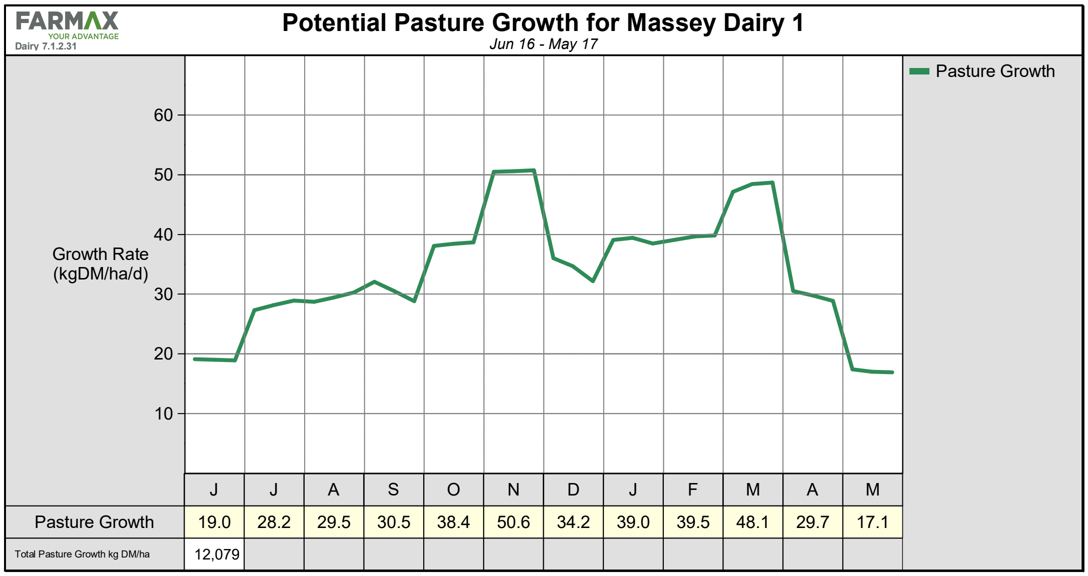


Figure 4-6: Pasture Growth Rate (kgDM/ha/day) by month

- **Crops**

As the graph in **Figure 4-7** illustrates, on 2016-17 the 258 cows on-farm were offered feed that included grazed pasture, 10 ha of Lucerne (mainly cut for silage and hay, only grazed once per year), and approximately 10 ha of herb mix (2 of which were sown on the irrigated block as shown in **Figure 4-8**). Regrassing policy of the farm: 20% (12 ha) resown annually.

A cut of Maize silage was done during the season which was stored and not used. Pasture silage, on the other hand, was needed by the end of 2016, along with turnips which were used as a summer crop.

The data on the yields of the crops that were part of the rotation during the 2016-17 season could not be obtained, therefore they will be assumed to be FARMAX® default values, which were calculated from region average yields sourced from DairyNZ database.

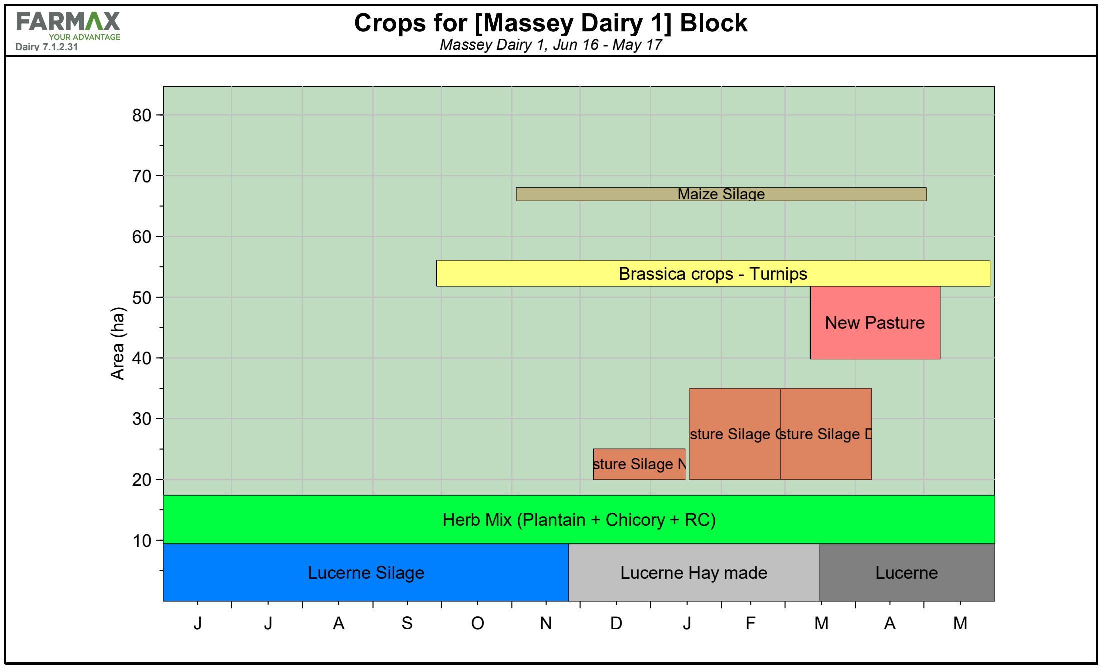


Figure 4-7: 2016-17 season crops for the rainfed block (85 ha)

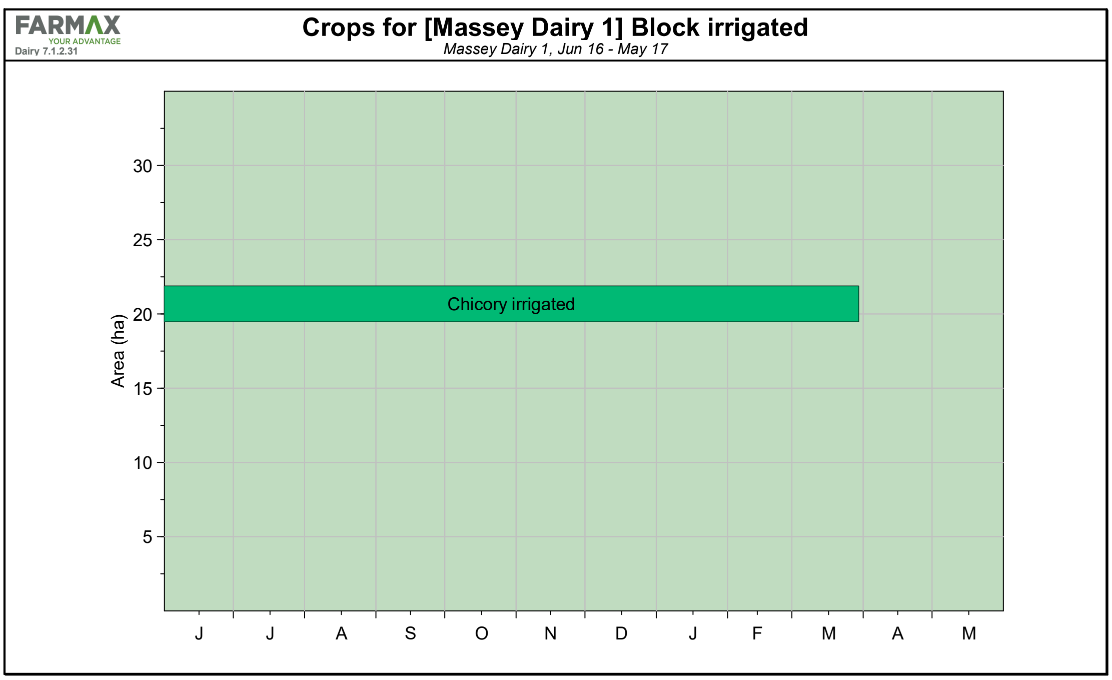


Figure 4-8: 2016-17 season crops for the irrigated block (35 ha)

- **Feed offered**

Information obtained from the farm on how the dairy cows diet was composed (**Table 4-3**) in the 2016-17 season is displayed below and it was used to load the amount of kg fed per day per cow into FARMAX®.

Table 4-3: Percentage of type of feed provided to cows on their monthly diet

	% on total cow diet per month										
Type of feed	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
RG-WC Pasture	100%	69%	100%	100%	100%	73%	68%	64%	48%	65%	44%
Plantain-Chicory	0%	0%	0%	0%	0%	27%	32%	21%	0%	16%	0%
Turnips	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%	0%
Grazing Lucerne	0%	0%	0%	0%	0%	0%	0%	0%	35%	0%	39%
Pasture Silage	0%	31%	0%	0%	0%	0%	0%	0%	17%	19%	17%

In August and from March to May, cows received 3.5 kg DM of pasture silage per cow per day. From December to February, cows grazed a mixed herb crop comprising chicory, red clover and plantain for three hours per day, at an allowance of 3.5 kg DM per cow. In February, cows were fed 2.6 kg DM per cow of turnips. Lucerne was grazed directly from the paddock in March and May at an allowance of 3 kg DM per cow per day.

- **Milk Production**

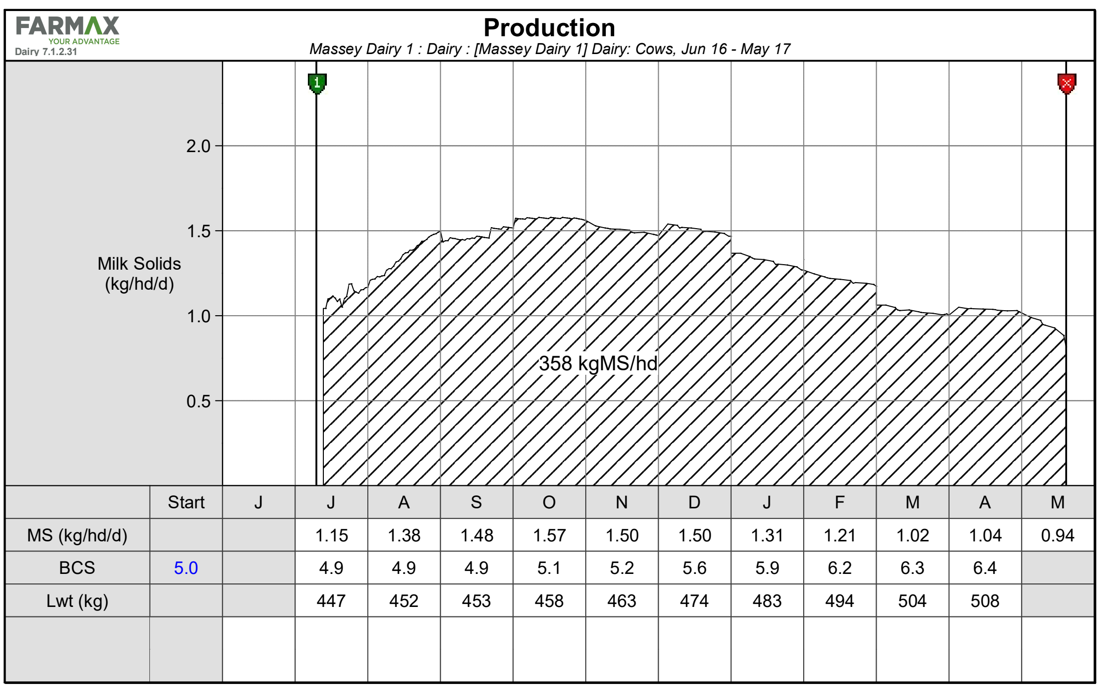


Figure 4-9: Milk production (kgMS/ha/cow) for the 2016-17 season

Milk production per cow in the model was calibrated to match with what was produced during the season (**Figure 4-9**). This was done by allocating an amount of feed to the herd (kgDM/cow/day) on the corresponding time of the year. Body condition score (BCS) is higher than it would really be, because current science behind OAD milking in FARMAX was based around short and end of the season periods of OAD milking rather than the full season, causing energy partitioning issues which overcompensate BCS.

- **Nitrogen applied**

The total fertiliser used during the 2016-17 season was sourced from the farm manager fertiliser plans. **Table 4-4** shows the amount of kg/ha of fertiliser was applied per month in each block of the farm. FARMAX® allowed to input each application into the model, distinguishing the Rate (kg/N/ha), Response (kgDM/kgN) and Duration (days) in the area (ha) which was applied.

Table 4-4: Fertiliser inputs for the 2016-17 season

Blocks	Month	Fertiliser/Area (ha)	N–P–K–S (kg/ha)	Applied (kg/ha)
Irrigated	August	Ammo 31 (13 ha)	31 – 0 – 0 – 14	100
	September	Ammo 31 (18.5 ha)	31 – 0 – 0 – 14	100
	October	Urea (12 ha)	37 – 0 – 0 – 0	80
	November	Urea (13 ha)	37 – 0 – 0 – 0	80
	December	Urea (30 ha)	37 – 0 – 0 – 0	80
	March	Ammo 31 (20 ha)	31 – 0 – 0 – 14	100
	May	Urea-Pot Mix (21 ha)	81 – 6 – 6 – 7	250
Rainfed	August	Ammo 31 (18 ha)	31 – 0 – 0 – 14	100
	September	Ammo 31 (27 ha)	31 – 0 – 0 – 14	100
	October	Urea (28.5 ha)	37 – 0 – 0 – 0	80
	November	Ammo 31 (16.5 ha)	31 – 0 – 0 – 14	100
		15% Potash Super (16.5 ha)	0 – 2 – 2 – 3	30
	December	Urea (29 ha)	37 – 0 – 0 – 0	80
	March	Ammo 31 (32 ha)	31 – 0 – 0 – 14	100
	April	Super + se 17 (21 ha)	0 – 44 – 0 – 54	200
	April	Pot Super + se 17 (16.5 ha)	0 – 44 – 41 – 52	275
Lucerne	December	50% Potash Super (10 ha)	0 – 4.5 – 25 – 5.5	188
Brassica	January	Urea (4 ha)	46 – 0 – 0 – 0	100
Mixed Herb	Oct & Mar	Ammo 31 (8 ha each month)	31 – 0 – 0 – 14	100
	December	Urea (8 ha)	37 – 0 – 0 – 0	80
	May	Urea-Pot Mix (21 ha)	81 – 6 – 6 – 7	250
Chicory	August	Ammo 31 (2.4 ha)	31 – 0 – 0 – 14	100
	Oct & Dec	Urea (2.4 ha each month)	37 – 0 – 0 – 0	80
	March	Cropmaster 11 (2.4 ha)	19 – 21 – 35 – 1	175
	April	Super + se 17 (2.4 ha)	0 – 44 – 41 – 52	200

According to FARMAX®, by applying the above fertilizers on the farm during the season, 111 kg of Nitrogen were finally used per ha in total.

- **<u>Physical Summary</u>**

Above, **Table 4-5** shows FARMAX® modelled physical outcomes summary for the 2016-17 season compared to the official DairyBase physical facts detail report for the same season. Similar results were obtained in most variables analysed.

Table 4-5: Physical Summary Comparison between FARMAX Base model and DairyBase data collected from the farm

Category	Description	FARMAX® Base Model	DairyBase	Units
		Value		
Farm	Effective Area	120	119.7	Ha
	Stocking Rate	2.2	2.2	Cows/ha
	Nitrogen Use	111	134	Kg N/ha
Herd	Peak cows milked	258	258	Cows
	Liveweight (LW)	1,004	1,042	Kg/ha
Production	Milk Solids Total	92,289	92,299	Kg
	Milk Solids per ha	771	771	Kg/ha
	Milk Solids per cow	358	358	Kg/cow
	Milk Solids as % of LW	76.8	74.0	%

4.5.2 Financial Calibration

All financial data is expressed in NZ dollars ($) unless otherwise stated. Detailed information on recent income from milk and livestock sales and expenses of the case study farm was collected from the farm and simulations were calibrated against these data.

- **Milk Revenue**

Total milk revenue for the 2016-17 season was of $545,435, which is composed of $514,052 from the milk sold to Fonterra plus $31,383 from the dividends paid for the shares owned by the farm. From this total figure, divided the total kgMS produced during the season, the price paid per kgMS was obtained, which was 5.91$/kgMS.

- **Stock Sales**

The revenue obtained by the farm from the total sale of animals for the 2016-17 was of $57,520. This figure was sourced from the farm financial results and is composed of $49,737 from the MA cows sold plus $7,783 from the bobbies sales.

To calibrate the model, a price per head was calculated by dividing each mob total income figure by the number of animals sold from each mob. As a result, each MA cow was valued at $843/head and bobbies $43/head. This calculation was done in order to be loaded into FARMAX® as a value per head for the Base Model and replicate it for the Proposed Models.

Change in Livestock Value was eliminated to keep it simpler to make comparisons with other scenarios, as changes in this variable were not acknowledged in the Future Scenarios.

- **Crops & Feed Inventory**

FARMAX® automatically sells the feed left at the end of the season at a default price. The final number obtained is then sum up to the total revenue under the concept "Capital Value Change". This is a financial adjustment for the change in supplementary feed held on hand at the start of each season. It is calculated by taking the Closing supplementary feed (DM tonnes) less Opening supplementary feed (DM tonnes) and multiplying by the value of the feed $/tonne DM as per the table below. These values were slightly adjusted in the model to match with Massey Dairy 1 Capital Value Change figure.

For example, because the cut of Maize and Lucerne silage done during the season was stored and not used, $310/tonnesDM and $200/tonnesDM was assigned to respectively. The same treatment was given to Lucerne Hay made ($75/tonnesDM) and Pasture silage

($200/tonnesDM). The Herb mix crop, irrigated Chicory and Turnips were fed out entirely in the 2016-17 season.

- **<u>Expenses</u>**

Expenditures incurred by Dairy No 1 were grouped and loaded into the model in totals ("$ Total"). FARMAX® then calculated expenditures in $/ha, $/cow and $/kgMS.

- **<u>Asset Values</u>**

Land: as the asset land value of Massey Dairy No 1 was not available, DairyBase® database value of $37,835/ha for the 2016/17 season was considered for the analysis (**Table 4-6**). DairyBase® calculates market values for land and buildings by using the most recent Rateable Valuations for each farm and adjusting these to 1 June 2016 and 1 June 2017 market values using sales data supplied by Quotable Value and REINZ plus discussions with regional real estate agents and valuers.

Table 4-6: Average Sales Price and Number of Dairy Farms Sold

	2012-13	2013-14	2014-15	2015-16	2016-17
Farms sold	197	312	244	192	217
Average $ sale price/kg MS	35.61	42.19	44.78	39.33	39.98
Average $ sale price/ha	33,557	36,369	39,577	36,557	37,835

However, is relevant to acknowledge that being a dairy farm located so close to town, the underlying real state value can potentially be much higher. Additionally, as Shadbolt *et al.* (2005) pointed out, land as a resource can be easily measured physically but its market value has traditionally been a combination of the underlying value of land and the production level achieved on that land plus the value of the co-operative shares required to be held for that level of production.

Livestock: Livestock asset value was calculated considering DairyNZ low input benchmarked farm for the lower north island region and on a per head basis. DairyNZ calculations contemplate the Inland Revenue herd value scheme NAMV (National Average Market Values).

Plant, machinery and vehicles: DairyNZ values for the benchmarked farm were used on a per ha basis.

Table 4-7: Profitability KPIs comparison

Season 2016-17	Massey No1	DairyNZ
Land & Buildings	4,741,230	5,854,250
Plant, machinery and vehicles	202,013	249,436
Livestock	508,512	815,984
Shares	546,720	-
Total Assets Value	5,998,474	6,919,670
Return on Assets (%)	2.5	3.3

4.5.3 KPIs

From the financial information collected, a series of KPIs were calculated and compared with data from 2016-17 DairyNZ Economic Survey. The benchmark group of farms selected for the comparison corresponded to the lower North Island, owner-operator and low input farm systems (System 1 & 2). However, this group of farms milk cows TAD compared to Dairy 1, therefore –and adding to their higher SR– they produced more MS. Additionally, as OAD milking requires cows to be moved just once, fewer labour units are needed, which is demonstrated in the difference in Cows/FTE between the case study farm and the benchmarked group of farms shown in **Table 4-8**.

Table 4-8: Biophysical KPIs summary of Massey Dairy No 1 compared with DairyNZ similar farm for the 2016-17 season

Season 2016-17	Dairy No 1	DairyNZ
Effective Dairying area (ha)	120	128
Peak cows milked	258	322
Stocking rate (Cows/ha)	2.2	2.5
Full-time labour equivalent (FTE)	1.3	2.4
Cows/FTE	198	134
Milksolids (MS)	92,299	112,538
MS/ha	771	881
MS per cow	358	349

For the 2016-17 season, Dairy No 1 had 1.3 total FTEs. The number of cows per FTE was of 198, whereas DairyNZ low input benchmarked farm was of 134. The reason behind this difference lies in the fact that DairyNZ farm is TAD.

Table 4-9 shows the Operating expenses KPIs comparison between Dairy No 1 and DairyNZ benchmark group. Because of inconsistencies related to Dairy 1 being part of a University research unit, and in an attempt to make the farm financial results for the analysed season more representative, the following adjustments were done:

- **Animal Health and Breeding costs:** as 2016-17 season costs incurred by the farm were considerably high respect DairyNZ values, 2015-16 were finally used for the analysis as they were more realistic and in line with benchmarked values. The reason behind Dairy 1's above average Animal Health and Breeding costs correspond to the fact that because the farm is used as a teaching resource for students, research and extension, the vets are called more often than normal when there are health issues episodes.
- **Overhead costs:** they were too low, therefore per ha value (308$/ha) from DairyNZ benchmark group was used to standardize this figure.
- **R&M costs:** 2016-17 value was higher than normal due to extraordinary expenses incurred, therefore DairyNZ per ha cost (606$/ha) was used as it was more representative.
- **Grazing & support block leasing:** DairyNZ cost per ha was used as the case study grazing cost was considerably high compared to the benchmark group.

Table 4-9: Operating expenses KPIs comparison between Dairy No 1 and DairyNZ similar farm

	Massey No1				DairyNZ			
Season 2016-17	**Total ($)**	**$/kgMS**	**$/ha**	**%**	**Total ($)**	**$/kgMS**	**$/ha**	**%**
Wages	123,946	1.34	1,035	26%	124,917	1.11	977	25%
Animal health & breeding	38,111	0.41	318	8%	41,639	0.37	326	8%
Supplementary feed	28,869	0.31	241	6%	60,771	0.54	476	12%
Grazing & support block	43,216	0.47	361	9%	46,141	0.41	361	9%
Fertiliser, irrigation, regrassing, W&P	69,203	0.75	578	15%	66,397	0.59	520	13%
Maintenance & running	79,002	0.86	660	17%	84,404	0.75	660	17%
Overheads	36,868	0.40	308	8%	39,388	0.35	308	8%
Depreciation	34,359	0.37	287	7%	39,388	0.35	308	8%
Operating Expenses	**453,574**	**4.91**	**3,789**	100%	**503,045**	**4.47**	**3,936**	100%

Table 4-10: Profitability KPIs comparison

Season 2016-17	**Massey No1**	**DairyNZ**
Gross Farm Revenue ($/ha)	5,045	5,705
Operating Expenses ($/ha)	3,789	3,934
Operating Profit ($/ha)	1,256	1,771
Operating Profit Margin (%)	25	31

4.6 Future system models

4.6.1 Description and assumptions at a farm level

Below, a table for each of the future system model designed will be displayed. Each table contains information on how each farm system was developed taking into consideration some of the key features that future farm systems will present according to the Future Scenarios chapter.

The design of each system model took into account technically feasible farm systems able to represent the characteristics that farm systems may have in the future.

As technologies from the future are not yet known, it was surmised based on technologies that already exist –reviewed previously in Chapter 3, section 3.5.3– and following soft signals. Each future scenario has very distinct characteristics. Some of the farm system changes introduced are backed up by the reviewed literature, but also many others are based on assumptions as they belong to the unknown.

Overall, pasture-based systems are the basis of all farm-systems proposed, all sitting between a production system 1 and 3. This corresponds also to a focus on environmental and animal welfare aspects that are linked to a closer relationship with consumers in the future. Besides, there is an increase in the adoption of technology across all scenarios, which in some cases allowed for higher pasture rates. As a consequence of these 'high-tech' farms, staff required must be highly trained and technology-savvy. Therefore, the investment in technology and staff will be assumed to increase across all three proposed farm systems compared to the Base.

All three proposed farm-systems scenarios have the same amount of feed and crops available as the Base farm system during the season, differing on how this feed is allocated according to each scenario needs.

Finally, after presenting each system model, **Table 4-14** will display a comparison summary of the three farm systems modelled for this study.

Table 4-11: Description of the set-up and design of the farm system required for the "Consumer is the King" future scenario

	Characteristics of the Future Scenario	Farm system design for the Scenario
Consumer is King (CK)	Entirely pasture-based system, producing maize silage for 'inside' feeding. Palm kernel expeller use banned as it is related to deforestation, biodiversity loss, and GHG emissions (Foote *et al.*, 2015). Research studies highlight significant health benefits of milk produced from cows fed entirely by grass. Consumers are willing to pay a premium for more fresh and organic products, reflecting a desire to purchase 'health' (Shadbolt *et al.*, 2017). Higher costs of inputs and animal feed. PKE associated with deforestation, as imported products carry their own environmental implications from extraction and manufacturing in their country of origin (Foote *et al.*, 2015). Jersey cattle were discovered to be more tolerant to OAD milking compared to Friesian cattle, with less of a reduction in milk yield Clark *et al.* (2007). Also, Feed conversion efficiency (FCE), derived from milk solids production and feed eaten, showed that over the last decade cows have become more efficient at converting feed (dry matter) into milk solids through improved genetics (DairyNZ, 2017b). Increased costs on labour, as staff with advanced qualifications & soft skills is required. Farmers also need to be better educated, technology savvy, business focused and more professional than ever before. Better connectivity and the use of precision agriculture tools will reduce the pressure and stress on the workforce, also improving the efficiency of operations. Smart irrigation in place to help increase pasture production (Hedley & Pinxterhuis, 2017). Animal health and welfare improved thanks to GPS collars that deliver meaningful information in near real-time (Jago *et al.*, 2013).	<u>System 1-2:</u> Assume milking all-year-round to supply the growing market looking for fresh milk. As a response to customers desire of naturalness, cows graze mainly on pasture, supplementing with maize and pasture silage grown on-farm to match the cows' increased energy requirements for maintenance and lactation over winter. Feeding PKE is avoided as this scenario contemplates higher costs on feed inputs and also consumers relate it to damage to the environment. GPS collars help to maximize the pasture grazing efficiency, allowing to offer individualised diets to cows. <u>Stocking rate:</u> Assume 2.0 cows per hectare, in response to a national focus in lowering nitrate leaching and GHG emissions to the environment. Dry stock stays on-farm. <u>Calving pattern:</u> Not seasonal. Assume running an autumn herd of 71 cows and a spring herd of 166 cows on-farm (30/70% split). <u>Milk price:</u> Assume an extra dollar per kg/MS is paid compared to the Base to reflect the market new value for milk harvested from pasture-grazing cows, totalling $6.91 kg/MS. Additionally, a premium of $3.15 kg/MS is paid on top of the milk price for the milk produced in winter (June and July). <u>Breed:</u> Assume Jersey breed adapts better to OAD milking, resulting in a higher Breeding worth (BW) and feed conversion efficiency (FCE) that enables cows to produce more milk. <u>Labour costs:</u> Assume it rises as a consequence of an extra 0.3 FTE needed to run the split-calving system, but more importantly, because of the higher salaries paid due to limited people available with communication and public relations skills in addition to farming skills. <u>Animal health & Breeding costs:</u> Assume 25% fewer animal health and breeding expenses as an all-year-round system is less intense on cows. Additionally, GPS collars allow tracking cows' movements, which helps monitor cow's activity and therefore anticipate any lameness or health issue. <u>Irrigation:</u> Assume an increase of 5% in total kg/year of Pasture Covers grown on-farm as a consequence of the benefits of Precision Irrigation (PI) system, which also halves the irrigation cost.

Table 4-12: Description of the set-up and design of the farm system required for the "Governments Dictate" future scenario

	Characteristics of the Future Scenario	Farm system design for the Scenario
Governments Dictate (GD)	High supplement costs pushed farmers to pasture-based dairy systems, focusing on producing milk at least possible cost. Consumers not concerned about the naturalness of food, therefore they are not willing to pay a premium for a higher value product (Shadbolt *et al.*, 2017). Due to low wages and difficult working conditions, the industry struggles to attract and retain talent. Heavy reliance on immigrant labour. Fully automated milking systems became a solution as it brought labour savings of 20-30% (De Koning & Rodenburg, 2004). On-farm technologies enable high per cow production while meeting animal welfare and environmental expectations. Larger and more automated farms help reduce human error. The introduction of AMS allowed the voluntary approach of cows to the robot to be milked individually, when they desire, and at any time of the day can be up to three times each day, lifting milk production per cow by 6-35% over the common twice a day milking strategy (De Koning & Rodenburg, 2004). AMS allows for an individualised monitor of cows (Woodford *et al.*, 2015). Cost per robot ranges US$175,000-US$250,000 (Hyde & Engel, 2002) and each robot can milk 60-70 cows (De Koning & Rodenburg, 2004). Introduction of robots increases maintenance and electricity costs (ranging from US$400-US$1200 monthly) (Eastwood *et al.*, 2016). Pastures are genetically modified in place, producing extra tonnes of DM/ha (Piddock, 2017).	System 2: Pasture-based system to reduce reliance on imported supplements, as this future scenario contemplates high input prices and low milk pay-out. Calving pattern/Breed: Assume they are the same as the Base farm system. Milking frequency: AMS allows cows to be milked twice- to thrice-a day. Assume each robot unit costs $200,000 and can milk up to 65 cows, making up a total investment of $1,000,000 (5 robots). Labour costs: Assume 33% fewer labour expenses as a consequence of the use of AMS that brought down the labour needed from 1.5 to 1.0 FTE. R&M and Energy costs: R&M are affected by the extra cost incurred from requiring rapid access to technical AMS support, as if a machine stops working it can cause a backlog in the milking process. Animal health & Breeding costs: Assume they increase as there is less attention on animal health in this scenario due to a focus in maximizing production. However, the expected increase in costs is smoothened as a consequence of the benefit that AMS brings, with cow's voluntary approach to the robots and less stress during milking. Irrigation/Nitrogen costs: 100% of the farm under irrigation, therefore cost of irrigation comes up respect to the Base. Assume Nitrogen cost is reduced as a consequence of improvements made in cultivars genetics.

Table 4-13: Description of the set-up and design of the farm system required for the "Regulation Rules" future scenario

	Characteristics of the Future Scenario	Farm system design for the Scenario
Regulation Rules (RR)	Bobby calves stay on-farm up to the end of the season instead of being sent to slaughter, as a red-meat new product turned the low-value Kiwi-cross meat product into a high-value product (Schreurs, 2018). The staff has more diverse skills and are rewarded accordingly, resulting in a positive view of farming as a career. Working hours limited to 37.5 hours a week. Ban on antibiotics: greater attention to cow health and longevity, with precision agriculture helping to improve animal health measures. Decreasing tolerance to farming and industry practices that have negative environmental, social and animal welfare impacts. Fertilizer and irrigation use tightly regulated. Farmers forced to open up their operations to the world via 24-hour real-time webcam surveillance. Technologies that track product from pasture to plate become commonplace. In order to reduce dependence on external sources of energy, several farms have invested in solar technologies which convert energy from the sun into electricity, reducing energy sourced from the state's electricity grid and reducing energy emissions on farm (AgricultureVictoria, 2017). Other advantages include: reduction in electricity bills, no running costs after installation, and systems can be expanded by adding more panels (DairyAustralia, 2014).	System 2-3: Maize grain and bailage bought to cover the feed budget deficits. Number of animals/Breed/Calving pattern/Milking frequency: Assume the same as the base farm system. Additionally, assume no stock are sent off-farm as the government prohibited due to cattle related diseases. Labour costs: Assume working hours limited to 37.5 hs a week, but wages higher as more diverse skills are needed from staff. Also, more labour input is needed to manage mixed calves mob. Animal health & Breeding costs: Assume animal health costs increase for the additional animals staying on-farm and the ban imposed on the use of antibiotics. Breeding costs also increased as beef straw are more expensive. R&M/Vehicle/Fuel costs: Assume the handling of extra animals' on-farm increase vehicle and fuel costs. Also, extra costs are incurred from repairing races, fences, machinery and equipment allocated to this new mob. Altogether represents a 30% increase. Energy costs: solar panels brought savings to the system, decreasing 25% of total energy costs. No bobby calves: Assume all bobby calves are kept and graze on-farm, being sold for meat as 10 and 11 month's age bulls/heifers. Fertilizer/irrigation: Assume regulatory requirements posed a ban on the use of fertiliser and irrigation.

Table 4-14: Summary of Base and Proposed farm systems set-up

Characteristics	Base Farm System Model	Consumer is King	Governments Dictate	Regulation Rules
Main system change	-	All-year-round milking	Automatic milking system	All stock on farm
Cows (milk peak)				
Spring-calving	258	166	330	220
Autumn-calving	-	71	-	-
Stocking rate	2.2	2.0	2.8	1.8
Grazing off	Dry mob and young stock	Only young stock	Dry mob and young stock	No
Milking Frequency	Once-a-day	Once-a-day	Twice to thrice-a-day	Twice-a-day
Breed	Cross- bred	Jersey	Cross-bred	Cross-bred
Calving pattern	Spring	Spring and Autumn	Spring	Spring
Production system	System 1- 2	System 1 - 2	System 2 - 3	System 2 - 3
Milk price (per kgMS)	$5.92	$7.92 + $3.15 (winter premium)	$3.92	$5.92

4.7 Summary

A farm system modelling approach applied to a single case study farm was chosen as the appropriate research method to undertake this study because it enabled to simulate with detailed information what are the farm level implications of likely future scenarios.

Massey Dairy 1 was selected to represent a current Manawatu dairy farm as a benchmark in developing the future scenario farm systems. The farm, which has some atypical attributes related to being a University research farm (acknowledged in the Model setup), was considered as the Base scenario or status quo farm with respect to its more generic attributes, rather than specifically.

Chapter 5: Results

This chapter describes the results obtained for the systems modelled in FARMAX for each likely future scenario. The rationale behind the physical and economic results obtained will be also outlined along with the assumptions made.

As the stocking rates vary between scenarios, the expenses from the Base Farm System Model database on FARMAX were fixed on a per cow basis.

The three farm system models will start with the same amount of feed on the inventory as the Base, differing on how this feed is allocated within each scenario according to the demand of energy required by the stock. If the feed is not used by the end of the season, the inventory close numbers are valued at the same price for all models. No extra crops were added to the models, therefore costs related to crop harvesting also remain the same for all scenarios on a per cow basis. Also, no extra cuts of silage were done.

For a matter of limitation of time, the systems modelled will only be compared against the Base.

5.1 CK System Model

5.1.1 Physical results

- **<u>Stock numbers</u>**

- ***<u>Stock Reconciliation</u>***

As the "Consumer is King" future scenario required a flexible system to adapt and deliver to changing international customer needs and to be part of more than one value chain, the aim was put in designing a model that will supply milk all-year-round. To achieve this, the herd was split into spring and autumn calving, which was done following a 70/30 split policy (70% of the whole herd calving during spring and the rest in autumn).

The stock reconciliation after the change made is outlined in **Table 5-9** and

Table 5-10.

Table 5-1: Spring herd numbers for the CK System Model

Spring Herd: Stock Reconciliation										
Month	Age (months)	Open	Calve	Dry Off	Die	Buy	Sell	Transfer		Close
								In	Out	
Jun 16	MA	166								166
Jul 16	MA	166	63				2			164
Aug 16	MA	164	93							164
Sep 16	MA	164	8							164
Oct 16	MA	164			1					163
Nov 16	MA	163								163
Dec 16	MA	163								163
Jan 17	MA	163								163
Feb 17	MA	163			2					161
Mar 17	MA	161								161
Apr 17	MA	161								161
May 17	MA	161		161			32	37		166
Total		166	164	161	3	0	34	37	0	166

Table 5-2: Autumn herd numbers for the CK System Model

Autumn Herd: Stock Reconciliation										
Month	Age (months)	Open	Calve	Dry Off	Die	Buy	Sell	Transfer		Close
								In	Out	
Jun 16	MA	71								71
Jul 16	MA	71								71
Aug 16	MA	71					14			57
Sep 16	MA	57								57
Oct 16	MA	57								57
Nov 16	MA	57								57
Dec 16	MA	57								58
Jan 17	MA	57		55				19		76
Feb 17	MA	76								76
Mar 17	MA	76	24							76
Apr 17	MA	76	46							76
May 17	MA	76	6				5			71
Total		76	76	55	0	0	19	19	0	71

- ***<u>Stocking Rate (SR)</u>***

Stock numbers for this system were calibrated so that the spring and autumn herds on-farm resulted in 2.0 cows per hectare. The low stocking rate responded to the environmental concerns coming from consumers around the world, which are more engaged with farmers and are willing to pay extra to contribute to lowering the dairy footprint.

- **Feed**

As a result of carrying a smaller stocking rate (2.0) compared with the Base (2.2), more grass was available to be offered to cows. Additionally, Precision Irrigation (PI) on place allowed an extra 5% pasture growth in this future scenario (**Figure 5-1**). Thoroughly, there was enough feed available in this scenario to run the split-calving and also to keep the dry mob on-farm during June compared to the Base scenario. Also, there was no need to import feed into the system, therefore it was avoided to incur into the high input costs this future scenario featured.

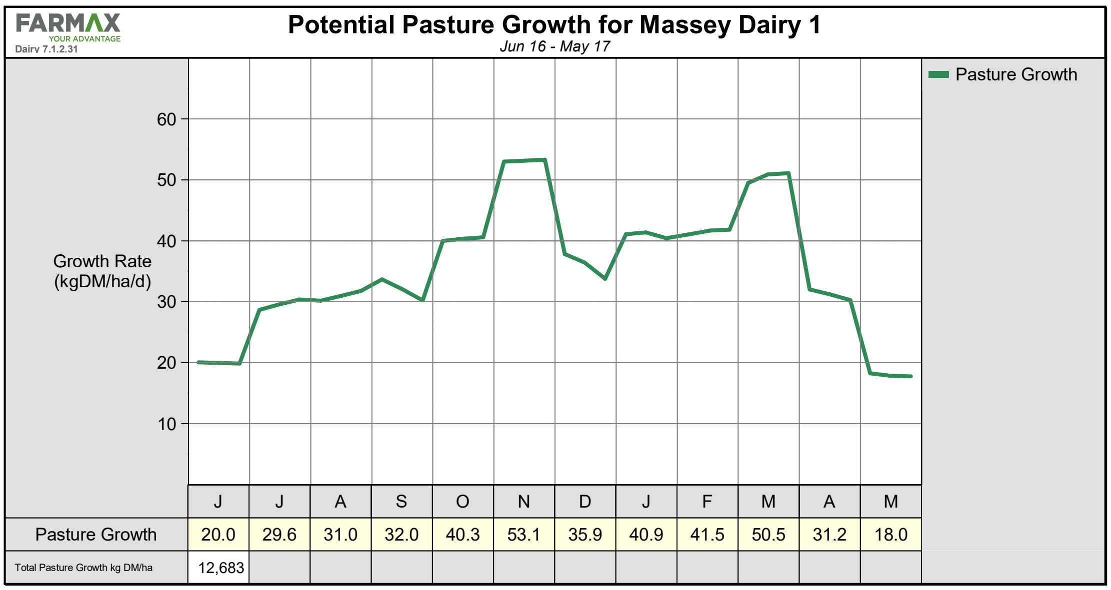


Figure 5-1: Pasture growth rates adapted to smart irrigation and GM pastures

- **Milk Production**

Total milk solids production increased as a consequence of cows being offered more feed compared to the Base. Additionally, BW values were increased on FARMAX from 90 (default) to 120. Increasing the BW values was translated into higher milk yields and therefore it allowed to simulate higher milk production from Jersey cows, appointed in this scenario to be the ideal breed for OAD milking. In addition, this was done to reflect how GPS collars helped to maximize the pasture grazing efficiency of cows.

- **Nitrogen levels**

They remained the same as the Base Model (111 kgN/ha), as there were no references regarding changes were made to the fertiliser applications.

5.1.2 Financial results

- **Milk price**

An extra 2 dollars per kg MS are paid in this scenario compared to the Base as farmers producing milk from pasture grazing systems are recognised and awarded accordingly globally. Additionally, a premium price of $3.15 kgMS is paid for the milk produced in winter (June and July).

As FARMAX was not applying this premium payment for the first month the Autumn herd was lactating, some modifications were needed to be introduced into the model. The workaround was to transfer the cows to another mob on the first day of the season. Therefore, the main mob started as “Cows 2”, then got transferred into “Cows” on the second day of the season. By doing this, the model recognized the milk produced during June, and thus, the premium paid for the winter milk.

- **Labour costs**

Even though there are fewer cows carried on-farm, an extra 0.3 FTE is required on this scenario for the additional workload that running the split-calving system and keeping dry cows on-farm brings. Additionally, an adjustment of an extra 40% was added on top of the total to reflect the impact of higher salaries paid as a result of highly skilled people needed on-farm (with communication and public relations skills required in addition to farming skills) and the scarcity of staff available to employ.

- **Animal Health & Breeding costs**

Animal health and welfare are a top priority in this future scenario. The implementation of GPS collars to cows allowed tracking their movements digitally, helping to monitor cow’s activity and therefore to anticipate any lameness or health issue while also studying their diet preferences. Also, all-year-round systems are less intense on cows and therefore it is beneficial for their health and reproductive performance. Split-calving also provided greater flexibility, as it allowed to reduce cull numbers and thus cutting costs while benefiting of the premium milk pay-out for producing winter milk.

For these reasons, plus the advantage of having a low stocking rate and milking once a day, it was assumed a decrease of 25% of the total Animal Health and Breeding costs.

- **Grazing-off cost**

Higher pasture available allowed keeping the dry mob on-farm compared to the Base scenario. Therefore, a reduction of 25% of the grazing costs was applied on the expenses sheet on FARMAX, which consequently brought a reduction of 25% in the freight cost.

- **Irrigation costs**

Assume a decrease of 50% as a consequence of the benefits that the advances in Precision Irrigation brought to the system.

- **R&M, Vehicle, Fuel & Electricity costs**

As crude oil prices increased substantially in this future scenario along with the price of imported goods –especially machinery–, these costs are affected with a 30% increase each.

- **Depreciation costs**

Assuming the capital expenditure needed for the Precision Irrigation system is of $45,000 (centre pivot or lateral irrigator cost is of around NZD$100/m. EG, a 450m) if the residual value is of $4,500 (10 years), the depreciation will be equal to $4,050. This figure was added to the existent value of depreciation from this scenario.

5.1.3 Comparison with Base

- **Physical Summary**

Table 5-3: Physical Comparison Summary between Base and CK System Models

Category	Description	CK System Model	Base System Model	Difference	Units
Farm	Effective Area	120	120	-	ha
	Stocking Rate	2.0	2.2	- 0.2	cows/ha
	Nitrogen Use	111	111	-	kg N/ha
	Feed Conversion Efficiency (offered)	13.7	14.9	- 1.2	kg DM offered/kg MS
Herd	Peak Cows Milked	237	258	- 21	cows
Production	Milk Solids total	97,638	92,289	+ 5,348	kg
	Milk Solids per ha	816	771	+ 45	kg/ha
	Milk Solids per cow	438	358	+ 80	kg/cow
	Peak Milk Solids production	1.85	1.60	+ 0.25	kg/cow/day
Feeding	Pasture Offered per cow	4.7	3.9	+ 0.8	t DM/cow
	Supplements Offered per cow	1.3	1.2	- 0.1	t DM/cow
	Off-farm Grazing Offered per cow	0.0	0.2	- 0.2	t DM/cow
	Total Feed Offered per cow	6.0	5.3	+ 0.7	t DM/cow

One of the main differences in the CK scenario is that it achieved a higher MS production with a 0.2 lower SR compared to the Base. As shown in **Table 5-3**, this was achieved through a 0.5 higher feed offered that, helped with the genetic improvement of the Jersey breed for OAD milking, increased the production per cow in 71 kgMS, totalizing 429 kgMS/cow.

- **Financial Summary**

In terms of total revenue, as outlined in **Table 5-4** the CK farm system delivered a higher return compared with the Base, mostly as a consequence of the extra milk earning perceived for the higher MS production. Additionally, the premium paid for the milk produced in June and July adds an extra $15,785 to the milk sales revenue. As expected from carrying a lower stocking rate, less income was obtained from livestock sales, considering cattle prices remained the same for both scenarios.

Table 5-4: Compare Total Gross Farm Revenue between CK and Base System Models

	CK System Model	Base System Model	Difference
Net Milk Sales + dividends ($)	788,422	546,353	+ 242,068
Net Livestock Sales (S)	52,075	57,520	- 5,445
Total Gross Farm Revenue ($)	**840,497**	**603,873**	**+ 236,623**

The contrast between the expenses of both scenarios are outlined in

Table 5-5. Overall, costs slightly decreased for each category in the CK scenario due to carrying a lower SR. The main savings on expenses occurred on Animal Health, Grazing, and Irrigation costs, as a response to this scenario requirements. However, these reductions were offset by the higher Wages paid, plus the significant increase in Administration, R&M, and Depreciation costs. Altogether, expenses of the CK scenario were $59,147 higher than the Base, even though the system carried a 0.2 lesser SR.

Table 5-5: Expenses comparison between CK and Base System Models

	CK System Model	Base System Model	Difference
Wages	196,017	123,946	+ 72,071
Animal Health	18,842	27,445	- 8,603
Breeding	7,288	10,666	- 3,378
Farm Dairy	1,185	1,197	- 12
Electricity	10,902	11,970	+ 1,068
Pasture Conserved	9,243	10,000	- 757
Feed Crop	27,018	29,384	- 2,366
Feed inventory Adjustment	- 21,791	- 18,948	+ 2,843
Calf Feed	7,821	8,433	- 612
Grazing	28,262	41,014	- 12,752
Fertiliser (Excl. N)	13,746	14,911	- 1,165
Nitrogen	26,307	28,533	- 2,226
Irrigation	4,622	10,000	- 5,378
Regrassing	8,532	9,385	- 853
Weed & Pest Control	5,925	6,374	- 449
Vehicle Expenses	1,541	1,197	+ 344
Fuel	1,541	1,197	+ 344
R&M Land/Buildings	74,252	62,244	+ 12,008
Freight & Cartage	1,600	2,202	- 602
Other Expenses	1,185	1,197	- 12
Administration Expenses	22,041	23,940	+ 1,899
Insurance	5,451	5,985	- 534
ACC Levies	4,503	4,788	- 285
Rates	1,896	2,155	- 259
Depreciation	35,571	34,359	+ 1,212
Total Operating Expenses	**493,498**	**453,574**	**+ 39,924**

Table 5-6, demonstrates that the CK scenario farm system is more profitable than the Base farm system, being the higher milk production paid at a higher milk price the main driver for its better performance.

Table 5-6: Farm Profit Comparison between CK and Base farm System Models

	CK System Model	Base System Model	Difference
Total Gross Farm Revenue ($)	840,497	603,873	+ 236,624
Total Operating Expenses ($)	493,498	453,574	+ 39,924
Economic Farm Surplus (EFS)	346,999	150,299	+ 196,700
Operating Profit ($/ha)	2,899	1,256	+ 1,643
Operating Profit Margin (%)	41	25	+ 16
Return On Assets (%)	4.2	2.5	+ 1.7

GD System Model

5.2.1 Physical results

- **Stock numbers**

- ***Stock Reconciliation***

Table 5-7: MA herd numbers for GD System Model

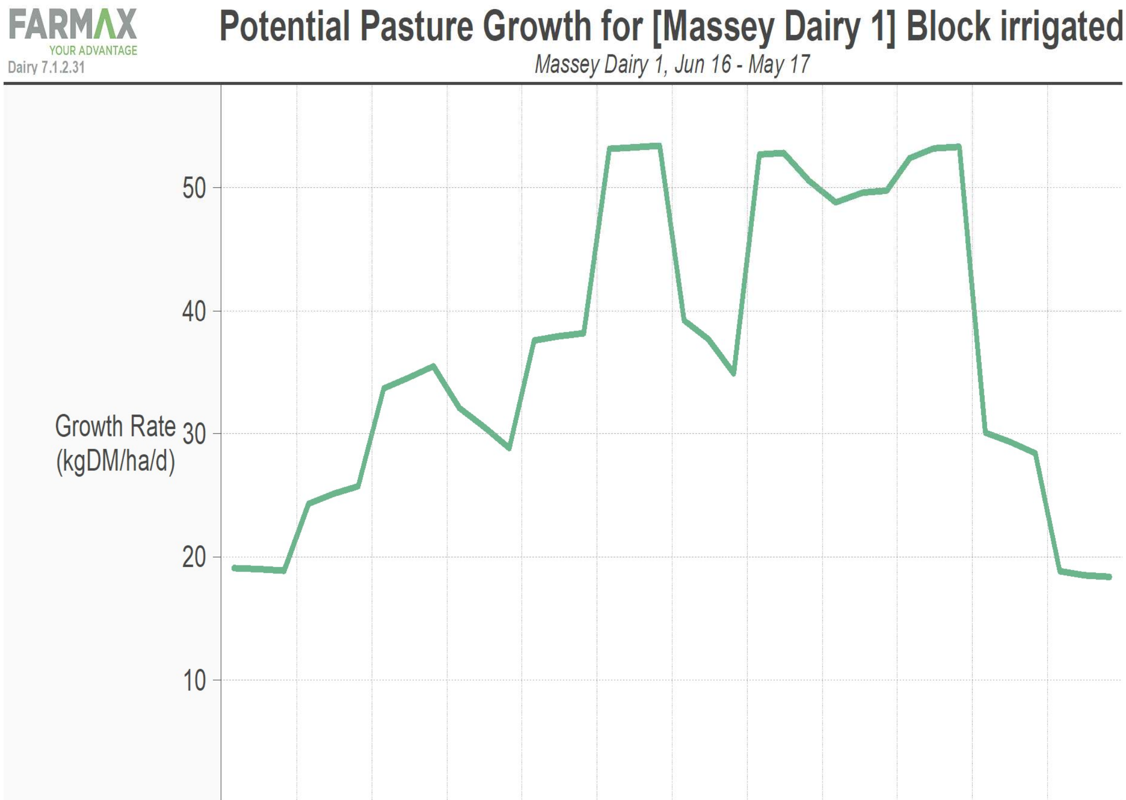
MA cows: Stock Reconciliation										
Month	Age (months)	Open	Calve	Dry Off	Die	Buy	Sell	Transfer In	Transfer Out	Close
Jun 16	MA	331								331
Jul 16	MA	331	125							331
Aug 16	MA	331	191		1					330
Sep 16	MA	330	14							330
Oct 16	MA	330								330
Nov 16	MA	330								330
Dec 16	MA	330			1					329
Jan 17	MA	329								329
Feb 17	MA	329			1					328
Mar 17	MA	328			1		56			271
Apr 17	MA	271					14			257
May 17	MA	257		257				74		331
Total		331	330	257	4	0	70	74	0	331

- ***Stocking rate (SR)***

Was set in 2.8 per ha by increasing the Base milking herd of 258 to 331 cows. Replacement rate was adjusted by the new number of cows, and therefore an extra 11 cows surplus to requirements were sold in contrast with the Base.

- **Pasture Growth**

The "Rainfed Block" composed by 85 ha was deleted on FARMAX making the "Irrigated Block" of 35 ha absorb its hectares which allowed to simulate the whole farm under irrigation that this scenario required. As the pasture growth rates from the Irrigated block were higher than the Rainfed, the impact on the growth rates of the whole farm (120 ha) was higher, increasing pasture production to 13,351 kgDM/ha (**Figure 5-2**). This desired effect allowed to feed the extra cows on-farm without the need of importing many supplements into the system.



	J	J	A	S	O	N	D	J	F	M	A	M
Pasture Growth	19.0	25.1	34.6	30.5	37.9	53.3	37.2	52.0	49.4	53.0	29.3	18.6
Total Pasture Growth kg DM/ha	13,351											

Figure 5-2: Pasture growth rates adapted to full irrigation and GM pastures

- **Milk Production**

Compared to the Base, total milk solids production increased as a consequence of carrying more cows and milking them twice- to thrice-a-day. Feed requirements from extra cows demanding additional energy because of the increase in milking frequency was satisfied by using most of the inventory feed for the season that it was not used on the Base System Model. An extra 15% milk production was added on top of the per cow production value obtained milking cows twice a day. This was done to reflect the effect of a third milking event that AMS offers, which cannot be selected on FARMAX. However, FARMAX offers the possibility of increasing milk production by changing the BW values of cows. Therefore, BW values were increased from 85 (default) to 5,000, an exaggerated value which is out of a real range, but permitted the effect desired. However, it is relevant to acknowledge that by doing this 'adulteration' the extra energy that cows milking more frequently demands it is not contemplated.

- **<u>Nitrogen levels</u>**

Nitrogen application was reduced automatically by deleting the Rainfed block, as both blocks had their own fertiliser plan. As a consequence of this Nitrogen use decrease from 111 kgN/ha to 80 kgN/ha. This reduction was not compensated, as this scenario contemplates the use of GM cultivars which will bring better pasture growth rates to the farm without the need for extra Nitrogen boost.

5.2.2 Financial results

- **<u>Milk price</u>**

Milk payout for this system was of $3.92 kgMS as global crisis led to consumers searching for a commodity product, without paying attention to any naturalness.

- **<u>Labour costs</u>**

It was assumed that the extra cows on farm on this scenario rise the FTE from 1.3 to 1.5. However, as the literature points out that AMS brings labour savings to the system, it was also assumed that the FTE needed with robots comes down to 1.0 FTE. Altogether, total labour cost was reduced a 33%, in line with what the literature stated.

- **<u>R&M costs</u>**

An extra 10% per annum is incurred from requiring rapid access to technical AMS support as if a machine stops working it can cause a backlog in the milking process.

- **<u>Energy costs</u>**

Higher energy costs were incurred due to the extra power needed to run the AMS.

- **<u>Irrigation</u>**

50% increase due to the farm being completely under irrigation.

- **<u>Nitrogen costs</u>**

Decrease from $36,630 to $26,400 as a consequence of lowering the amount of kg of Nitrogen applied per ha during the season from 111 kgN/ha to 80 kgN/ha.

- **<u>Bought Feed</u>**

Palm Kernel was imported at $280/tonnesDM, adding $16,792 to the total Operating Expenses.

- **<u>Animal Health & Breeding costs</u>**

25% higher total costs as less attention is paid to animal health & breeding due to a focus in maximizing production. Cows increase lameness due to waking up to three times a day to the cowshed.

- **Depreciation**

Assuming the capital expenditure needed for the AMS is of $1,000,000 (5 robots at $200,000 per unit) if the residual value is of $200,000 (typical after 10 years (typical useful life range is 7 to 12 years), the depreciation will be equal to $80,000. This figure was added to the existent value of depreciation from this scenario.

5.2.3 Comparison with Base

- **Physical Summary**

Table 5-8: Compare Physical Summary between Base and Governments Dictate System Models.

Category	Description	GD System Model	Base System Model	Difference	Units
Farm	Effective Area	120	120	-	ha
	Stocking Rate	2.8	2.2	+ 0.6	cows/ha
	Nitrogen Use	80	111	- 31	kg N/ha
	Feed Conversion Efficiency (offered)	12.0	14.9	- 2.9	kg DM offered/kg MS
Herd	Peak Cows Milked	330	258	+ 72	cows
Production	Milk Solids total	136,385	92,289	+ 44,095	kg
	Milk Solids per ha	1,139	771	+ 368	kg/ha
	Milk Solids per cow	413	358	+ 56	kg/cow
	Peak Milk Solids production	2.31	1.60	+ 0.71	kg/cow/day
Feeding	Pasture Offered per cow	3.2	3.9	- 0.7	t DM/cow
	Supplements Offered per cow	1.6	1.2	+ 0.4	t DM/cow
	Off-farm Grazing Offered per cow	0.2	0.2	-	t DM/cow
	Total Feed Offered per cow	5.0	5.3	- 0.3	t DM/cow

One of the main differences of the GD scenario is that it achieved a significantly higher MS production, which it is expected with a 0.5 higher SR compared to the Base, but also because of the benefits in milk yield that the use of AMS offers. As shown in **Table 5-8**, cows were offered 0.2 fewer tons of DM/cow, but 0.3 extra tons of DM/ha of supplements. This was achieved by using most of the feed available on the inventory.

- **Financial Summary**

Even though a higher milk production was obtained through milking 73 extra cows more frequently than the Base, total Gross Farm Revenue (GFR) –as outlined in

Table 5-9– was slightly lower for the GD system model. The reason is that $2 per kgMS less was paid for the milk sold to the factory. Net Livestock Sales increased as a consequence of the extra sales that a higher stocking rate permitted.

Table 5-9: Compare Total Gross Farm Revenue between Government Dictates and Base Scenarios

	GD System Model	Base System Model	Difference
Net Milk Sales + dividends ($)	534,627	546,353	- 11,726
Net Livestock Sales (S)	69,158	57,520	+ 11,638
Total Gross Farm Revenue ($)	**603,785**	**603,873**	**- 88**

Table 5-10 shows a comparison between the expenses of both scenarios. Overall, costs slightly increase for each category in the GD scenario due to carrying a higher SR. The main savings on expenses occurred on Wages and Nitrogen, as a consequence of the use of AMS and Precision Irrigation. However, these technologies implied a significant increase in the depreciation cost, as well as in R&M.

Table 5-10: Expenses comparison between GD and Base farm system model

	GD System Model	Base Farm System Model	Difference
Wages	105,600	123,946	- 18,347
Animal Health	43,725	27,445	+ 16,280
Breeding	16,913	10,666	+ 6,247
Farm Dairy	1,650	1,197	+ 453
Electricity	15,180	11,970	+ 3,210
Pasture Conserved	12,870	10,000	+ 2,870
Feed Crop	37,620	29,384	+ 8,236
Feed inventory Adjustment	594	- 18,948	+ 19,542
Bought Feed	16,792	-	+ 16,792
Calf Feed	10,890	8,433	+ 2,457
Grazing	52,470	41,014	+ 11,456
Fertiliser (Excl. N)	19,140	14,911	+ 4,229
Nitrogen	26,400	28,533	- 2,133
Irrigation	17,199	10,000	+ 7,199
Regrassing	11,880	9,385	+ 2,495
Weed & Pest Control	8,250	6,374	+ 1,876
Vehicle Expenses	1,650	1,197	+ 453
Fuel	1,650	1,197	+ 453
R&M Land/Buildings	87,483	62,244	+ 25,239
Freight & Cartage	2,970	2,202	+ 768
Other Expenses	1,650	1,197	+ 453
Administration Expenses	30,690	23,940	+ 6,750
Insurance	7,590	5,985	+ 1,605
ACC Levies	6,270	4,788	+ 1,482
Rates	2,640	2,155	+ 485
Depreciation	128,890	34,359	+ 89,531
Total Operating Expenses	**668,062**	**453,574**	**+ 214,488**

Table 5-11, demonstrates that the GD System Model farm system is $1,076/ha less profitable than the Base system model, being the low milk payout the main driver for this result (as well as high operating expenses from using AMS technology).

Table 5-11: Farm Profit Comparison between GD Scenario and Base farm system model

	GD System Model	Base Farm System Model	Difference
Total Gross Farm Revenue ($)	603,785	603,873	- 88
Total Operating Expenses ($)	668,062	453,574	+ 214,488
Economic Farm Surplus (EFS)	- 64,871	150,299	- 215,170
Operating Profit ($/ha)	- 542	1,256	- 1,798
Operating Profit Margin (%)	- 11	25	- 36
Return On Assets (%)	- 1.1	2.5	- 3.6

5.2 RR System Model

5.3.1 Physical results

- **Stock numbers**

- ***Stock Reconciliation***

For this scenario, bobby calves were kept and run on-farm as a single 'beef calves' mob as a response to a ban on the slaughter of Bobby Calves in NZ. They were reared until 9-10 months when they were finally sold to the meat industry (**Table 5-12**).

Table 5-12: Beef calves mob numbers

Beef Calves Mob: Stock Reconciliation									
Month	Age (months)	Open	Born	Die	Buy	Sell	Transfer		Close
							In	Out	
Jun 16	-1								
Jul 16	0		46						46
Aug 16	1	46	110						152
Sep 16	2	152	10						162
Oct 16	3	162							162
Nov 16	4	162		1					161
Dec 16	5	161							161
Jan 17	6	161							161
Feb 17	7	161							161
Mar 17	8	161							161
Apr 17	9	161				88			73
May 17	10	73				73			
Total		0	162	1	0	161	0	0	0

- ***Stocking Rate (SR)***

This scenario required setting the SR at 1.8 cows per ha. The low SR responded to tighter environmental regulations imposed in the pursuit of entirely pasture-based dairy systems, as research proved that cows raised on pasture have significantly better animal welfare outcomes. Additionally, this system is self-contained (no stock sent off farm), as in this likely future a regulation imposed by the government prohibits moving cattle between farms to avoid the risk of spreading diseases.

- **<u>Land</u>**

- ***<u>Irrigation</u>***

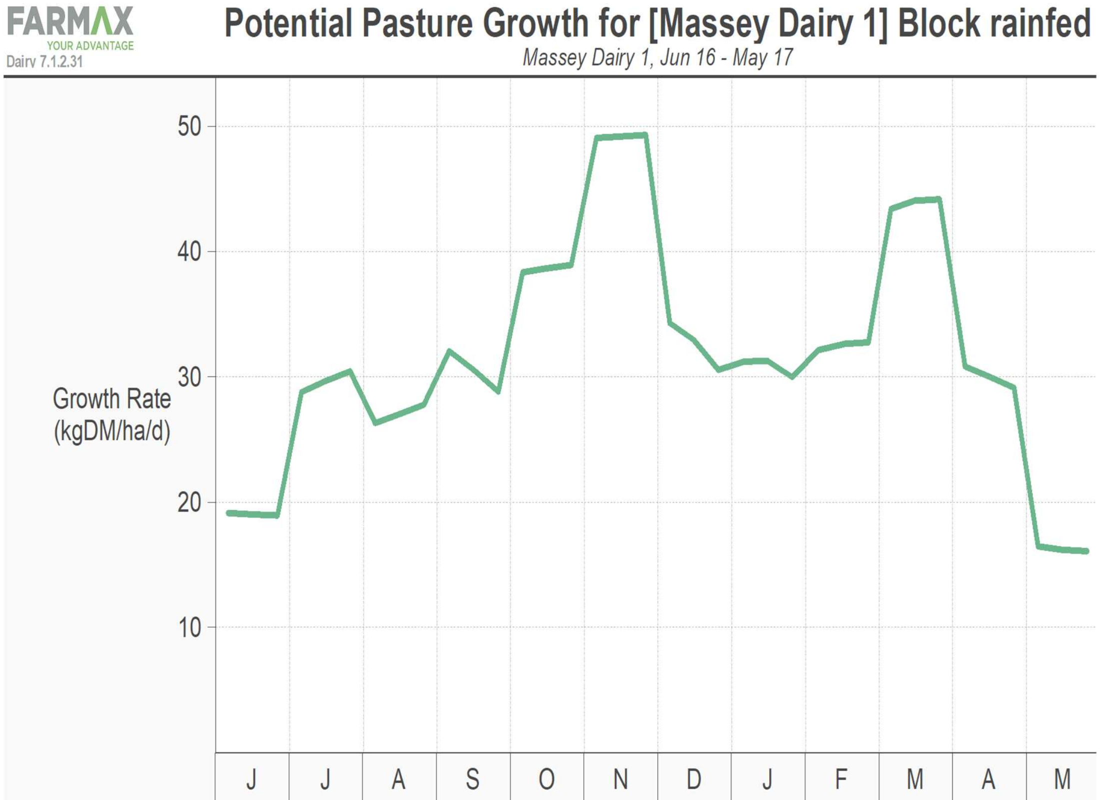
No irrigation was allowed for this scenario, therefore on FARMAX® the Irrigated area was deleted. By doing this, the rainfed area automatically absorbed the area deleted. As the growth rates for the irrigated block were higher, there was a drop in the total pasture per ha compared with the Base.

- ***<u>Fertiliser use</u>***

This future scenario contemplates a ban on the use of fertilisers as part of stricter environmental regulatory policies. Therefore, on FARMAX® the applications were eliminated, affecting the total pasture produced.

- **<u>Feed</u>**

Cows were offered less pasture and more supplements harvested as a consequence of the fewer pasture available, which was translated in a drop in milk production. Also, as young and dry stock remained on farm, extra feed was needed. Inventory feed available helped to feed all stock on-farm, however, Maize grain and Baleage were needed to be purchased to keep the feed budget feasible.



	J	J	A	S	O	N	D	J	F	M	A	M
Pasture Growth	19.0	29.7	27.0	30.5	38.7	49.2	32.5	30.8	32.5	43.9	30.0	16.3
Total Pasture Growth kg DM/ha	11,553											

Figure 5-3: Pasture Growth Rate (kgDM/ha/day) by month

- **Milk Production**

Total milk production decreased as a consequence of reducing the amount of milking cows and remaining cows being fed less compared to the Base. However, there was an increase in Milk Production per cow compared to the base as more feed was available to offer to a smaller number of cows compared to the Base.

5.3.2 Financial results

- **Milk price**

As this future contemplated a context with robust global demand of dairy products but with constrained supply due to high regulatory requirements, a $5.92 per kgMS milk pay-out was assumed for this scenario (considered to be an average milk pay-out)

- **Labour costs**

An extra 0.3 Full-Time Equivalent (FTE) was added to the existent 1.3 FTE on-farm as a consequence of the additional staff needed to manage the young stock on-farm all year round. Moreover, an extra 10% was added on top to reflect the impact of higher salaries paid as a result of more skilled people needed on-farm, with communication and public relations skills required in addition to farming skills.

- **Animal Health & Breeding costs**

Beef straws increase Breeding costs by 25%. Also, there is a 25% increase in Animal Health because of the ban imposed on the use of antibiotics and the additional costs that carrying young and dry stock on-farm demands.

- **Feed costs**

220 bales of Baleage were bought at $75/bale ($16,500) and 15 tonnes of Maize Grain at $580/tonnesDM (total $8,700).

- **Fertilizer costs**

Total cost was divided by 2 as a response to the application of half of the amount applied for the Base.

- **Grazing off**

No cost as all stock remains on farm. Freight and cartage are also saved by keeping the animals on farm.

- **Administration costs**

This scenario contemplates that future bureaucracy ends up increasing Administration costs in an extra 50%.

- **Beef calves sales**

This system kept 159 bobbies to be reared til 10-11 months-old. 52 were sold as Yearling heifers at $300/head and 107 Yearling steers were sold for $1.8/kg ($541/head).

5.3.3 Comparison with Base

- **Physical Summary**

Table 5-13: Compare Physical Summary between Base and Regulation Rules Scenarios

Category	Description	RR System Model	Base System Model	Difference	Units
Farm	Effective Area	120	120	-	ha
	Stocking Rate	1.8	2.2	- 0.4	cows/ha
	Nitrogen Use	-	111	-	kg N/ha
	Feed Conversion Efficiency (offered)	16.5	14.9	+ 1.6	kg DM offered/kg MS
Herd	Peak Cows Milked	220	258	- 38	cows
Production	Milk Solids total	69,100	92,289	- 23,189	kg
	Milk Solids per ha	577	771	- 194	kg/ha
	Milk Solids per cow	314	358	- 44	kg/cow
	Peak Milk Solids production	1.67	1.60	+ 0.07	kg/cow/day
Feeding	Pasture Offered per cow	3.2	3.9	- 0.7	t DM/cow
	Supplements Offered per cow	2.0	1.2	+ 0.8	t DM/cow
	Off-farm Grazing Offered per cow	-	0.2	- 0.2	t DM/cow
	Total Feed Offered per cow	5.2	5.3	- 0.1	t DM/cow

The RR System Model delivered a significant lower MS production respect to the Base (-23,189 kgMS). The driver of this reduction was the fewer cows on-farm (-38 cows) with lower pasture offered per head (-0.7 t DM/cow). The low pasture offer responded to a need of keeping the feed budget feasible in order to allow the system to maintain all animals on farm (dry cows, young stock, beefies). The use of the supplements (+0.8 t DM/cow) was also important to stabilize the feed budget.

- **Financial Summary**

Total Gross Farm Revenue (GFR) in the RR System Model delivered a slightly higher return compared with the Base (+ $1,501). The extra earning perceived for the sell of the bobby calves to the beef industry (+ $42,468) compensated the reduction on the Net Milk Sales (- $22,920) and the Feed Inventory (- $18,948) respect to the Base.

Table 5-14: Compare Total Gross Farm Revenue between RR and Base Scenarios

	RR System Model	Base System Model	Difference
Net Milk Sales + dividends ($)	409,074	546,353	- 137,279
Net Livestock Sales (S)	78,829	57,520	+ 21,309
Total Gross Farm Revenue ($)	**487,903**	**603,873**	**- 115,970**

Table 5-15 shows a comparison between the expenses of both scenarios. Overall, costs slightly decrease for each category in the RR System Model due to carrying a lower SR respect to the Base. The main savings on expenses occurred on Grazing, Irrigation, Fertiliser and Nitrogen, as a consequence of keeping all stock on farm and eliminating the use of Fertiliser and Irrigation.

Table 5-15: Expenses comparison between RR and Base Scenarios

	RR System Model	Base Farm Model	Difference
Wages	178,708	123,946	+ 54,762
Animal Health	34,980	27,445	+ 7,535
Breeding	13,530	10,666	+ 2,864
Farm Dairy	1,100	1,197	- 97
Electricity	5,060	11,970	- 6,910
Pasture Conserved	14,511	10,000	+ 4,511
Feed Crop	30,024	29,384	+ 640
Feed Inventory	32,813	- 18,948	+ 51,761
Calf Feed	11,186	8,433	+ 2,753
Grazing	-	41,014	- 41,014
Fertiliser (Excl. N)	-	14,911	- 14,911
Nitrogen	-	28,533	- 28,533
Irrigation	-	10,000	- 10,000
Regrassing	7,920	9,385	- 1,465
Weed & Pest Control	5,500	6,374	- 874
Vehicle Expenses	1,430	1,197	+ 233
Fuel	1,430	1,197	+ 233
R&M Land/Buildings	68,926	62,244	+ 6,682
Freight & Cartage	-	2,202	- 2,202
Other Expenses	1,100	1,197	- 97
Administration Expenses	25,575	23,940	+ 1,635
Insurance	5,060	5,985	- 925
ACC Levies	4,180	4,788	- 608
Rates	1,760	2,155	- 395
Depreciation	33,310	34,359	- 1,049
Total Operating Expenses	**478,103**	**453,574**	**+ 24,529**

Table 5-16, demonstrates that the RR System Model farm system is $695/ha more profitable than the Base, being the reduction in Total Operating Expenses the main driver for its better performance.

Table 5-16: Farm Profit Comparison between CK scenario and Base farm system

	RR System Model	Base Farm Model	Difference
Total Gross Farm Revenue ($)	487,903	603,873	- 115,970
Total Operating Expenses ($)	478,103	453,574	+ 24,529
Economic Farm Surplus (EFS)	9,800	150,299	- 140,499
Operating Profit ($/ha)	82	1,256	- 1,174
Operating Profit Margin (%)	37	25	- 23
Return On Assets (%)	0.2	2.5	- 2.3

5.3 KPI Summary

Table 5-17: Physical KPI summary

Category	Description	Base System Model	CK System Model	GD System Model	RR System Model	Units
Farm	Effective Area	120	120	120	120	ha
	Peak Cows Milked	258	237	330	220	cows
	Stocking Rate	2.2	2.0	2.8	1.8	cows/ha
	Nitrogen Use	111	111	80	-	kg N/ha
Production	Milk Solids total	92,289	97,638	136,385	66,100	kg
	Milk Solids per ha	771	816	1,139	577	kg/ha
	Milk Solids per cow	358	438	413	314	kg/cow
	Peak Milk Solids production	1.60	1.85	2.31	1.55	kg/cow/day
Feeding	Pasture Offered per cow	3.9	4.7	3.2	3.2	t DM/cow
	Supplements Offered per cow	1.2	1.3	1.6	2.0	t DM/cow
	Off-farm Grazing Offered per cow	0.2	-	0.2	-	t DM/cow
	Total Feed Offered per cow	5.3	6.0	5.0	5.2	t DM/cow

Table 5-18: Financial KPI summary

	Base System Model	CK System Model	GD System Model	RR System Model
Gross Farm Revenue ($/kgMS)	6.54	8.61	4.43	7.33
Farm Working Expenses ($/kgMS)	4.54	4.69	3.96	5.75
Gross Farm Revenue ($/ha)	5,045	7,022	5,044	4,076
Operating Expenses ($/ha)	3,789	4,123	5,586	3,994
Operating Profit ($/ha)	1,256	2,899	- 542	82
Operating Profit Margin (%)	25	41	- 11	2
Return On Assets (%)	2.5	4.2	- 1.1	0.2

- **<u>Operating profit</u>**

Operating profit is a measure of farm profitability used for benchmarking comparison of operating efficiency between dairy farms. Is calculated by doing the Total Gross Farm Revenue less Total Operating Expenses, where non-cash adjustments have been made (such as depreciation and feed inventory) to ensure that businesses are being compared on an equivalent basis. How the business is financed is not included, leases for cows or milking platforms and debt-servicing are excluded from calculations.

As shown in **Figure 5-4**, CK System Model outperforms the rest of the systems on Operating Profit, mainly driven by higher Gross Farm Revenue obtained with the milk produced during winter and paid as a premium.

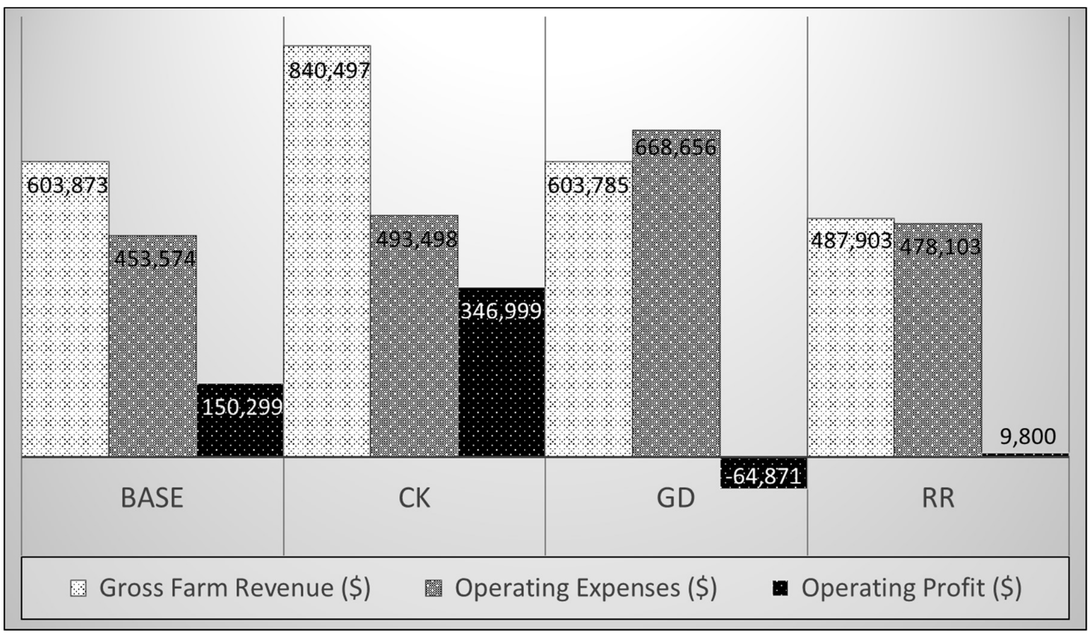


Figure 5-4: Operating Profit Margin and Return on Assets for the systems modelled

- **<u>Operating profit margin</u>**

The operating profit margin indicates the gap between operating expenses and gross farm revenue and is calculated by dividing the Gross Farm Revenue by the Operating Profit. This KPI is a risk measure and having as wide a gap as possible helps cope with fluctuations in milk prices, milk production and input prices.

The CK System Model delivered the highest Operating Profit Margin, outperforming the rest of the models.

- **Return on Assets**

Assets values shown in **Table 5-19Error! Reference source not found.** were referenced from DairyNZ Economic Survey 2016-17. Land & Buildings values assumed were adjusted accordingly for each model based on the Gross Farm Revenue to result in a common constant Asset Turnover ratio across all the models.

Average Gross Farm Income being higher, this was capitalised in Assets Values as a reflection of productivity.

Table 5-19: Assets values and financial ratios

Category	Base System Model	CK System Model	GD System Model	RR System Model
Land & Buildings	4,741,230	6,841,230	3,891,230	3,741,230
Plant, machinery and vehicles	202,013	232,013	898,679	232,013
Livestock	508,512	467,121	650,422	433,615
Shares	546,720	773,293	534,629	409,072
Total Assets Value	5,998,474	8,313,657	5,974,960	4,815,929
Gross Farm Revenue	603,873	840,497	603,785	487,903
Operating Expenses	453,574	493,498	668,656	478,103
Operating Profit	150,299	346,999	-64,871	9,800
Return on Assets (%)	2.5%	4.2%	-1.1%	0.2%
Asset Turnover (%)	10.1%	10.1%	10.1%	10.1%

The CK System Model had a higher ROA driven by its greater Operating Profit compared to the rest of the models. The inclusion of the AMS equipment to the asset value of the GD System Model ended up reducing the ROA value for this model, delivering the lowest value amongst the models.

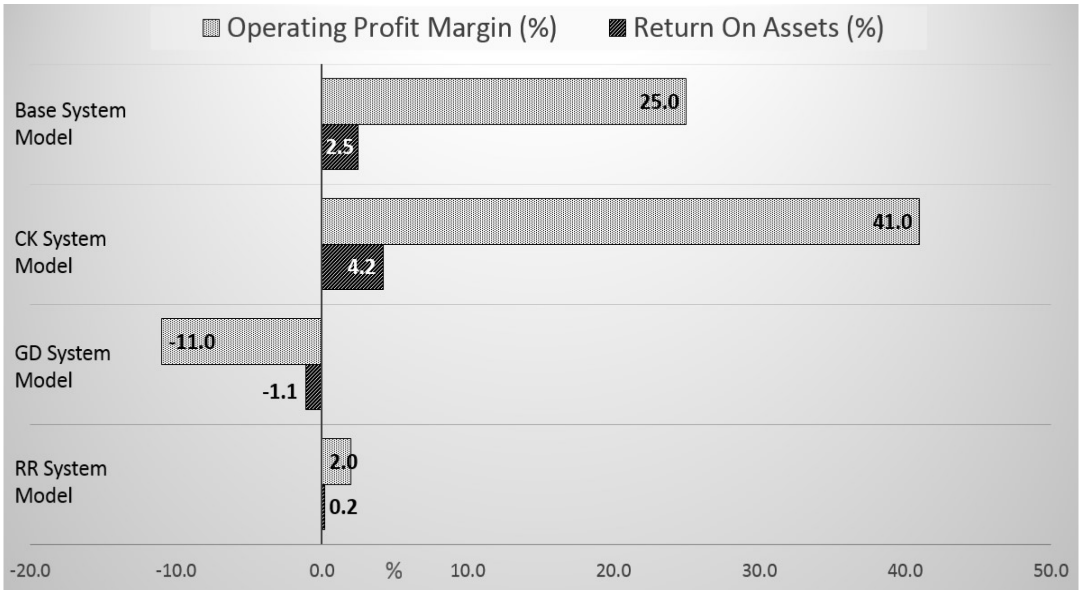


Figure 5-5: Operating Profit Margin and Return on Assets for the systems modelled

Chapter 6: Discussion

In this chapter, three questions will be used as a trigger for the discussion around the main findings obtained by this study in an attempt to quantify the bio-economic implications of likely future scenarios. As no similar studies were undertaken in modelling future dairy farms yet, the literature on future perspectives about the dairy industry was used to enrich the discussion.

6.1 What adjustments were needed for each future scenario?

6.1.1 CK System Model

The “Consumer is King” future scenario conceptually developed by Shadbolt *et al.* (2017) required a flexible system at a farm level that can adapt and deliver to changing international customer needs and that can be part of more than one value chain. It also needed to be heavily supported with data recording systems, to allow for a close relationship between the products the consumers buy and the animals that produce it (with smarter technologies that can capture real-time farm facts to be shared with the consumer instantly). Additionally, as these authors observed, in this likely future consumers are expected to consume more fresh and organic products, reflecting also a desire for purchasing ‘health’.
The approach taken in this study assumed that a way of achieving these requirements was by designing a model focused on running a split calving system, as this would allow delivering fresh liquid milk all-year-round. The background for this assumption was supported by Dillon *et al.* (2008), who pointed out that milking all-year-round can have a huge potential in relation to the value that can be added to milk.

To model this likely future scenario, the case study base milking herd was split in FARMAX into spring and autumn calving following a 70/30 split policy (Mandriaza, 2018). As expected, this system change automatically collapsed the feed budget, as the autumn milking herd peak feed demand coincides with a period where the farm had a low offer of pasture due to the season of the pasture growth explained by Garcia & Holmes (2000). In an attempt to maintain a system mainly fed by pasture, no supplements were brought in. Research studies highlight the significant health benefits of milk produced from cows fed entirely by grass, and therefore consumers are expected to demand pasture-based systems (Shadbolt *et al.*, 2017). Additionally, this future scenario expects higher scrutiny regarding how cow supplements are produced. In a study held by Foote *et al.* (2015), it was claimed that feeds such as PKE are associated with deforestation, as imported products carry their own environmental implications from extraction and manufacturing in their country of origin.

Considering the need for a pasture-based system with no supplements brought in, a slight reduction of the SR (-0.2) was needed to help combat the lack of pasture availability. Additionally, a Precision Irrigation system was introduced into the system model, which helped to grow an extra 5% of pasture, allowing to remove fewer animals than initially was needed.

In conclusion, the changes introduced enabled the cows to be fed mainly by grass, and thus to respond to one of the main requirements coming from consumers globally. O'Brien *et al.* (2012) observed how pasture-based milk production has the advantages of harvesting milk from the cheapest possible feed and being associated with greater global sustainability and increased product quality. In the model, the feed that was kept on inventory from the previous season (maize, lucerne silage and hay) was also used, enabling to increase total MS production by 5,339 kgMS compared to the Base. This increase was also partly driven by carrying an entire Jersey herd, as it was researched that this breed is more tolerant and has better adaptability to OAD systems compared to Friesian cattle, with less of a reduction in milk yield (Clark *et al.*, 2007). According to Britt *et al.* (2018), dairy cows of the future will tend to be more robust, with improved health and longevity mostly driven by improvements in genomic selection schemes.

6.1.2 GD System Model

For the "Governments Dictate" conceptual future scenario, which required high levels of commodity milk to be produced at any expense, the main farm systems changes modelled in the case study farm were the inclusion of robotic milking units and the increase of the SR (+0.6). Firstly, five robotic milking units were bought at $200,000 each (Hyde & Engel, 2002), as according to De Koning & Rodenburg (2004) each robot can milk up to 60-70 cows. As a consequence of the adoption of this technology, higher milk yields were obtained in the model compared to the Base (+136,385 kgMS). This increase is in production is also in line with De Koning & Rodenburg (2004) findings, who pointed out that production per cow can lift by 6-35% over the common twice a day milking strategy due to the fact that cows can be milked up to three times each day with the use of robots.

As a higher number of cows on farm (+72) being milked more often demanded a higher intake of food, the feed budget in the model became unfeasible. Two main things were done to fix this issue: all feed on inventory was fed out and extra pasture production (+13%) was modelled to simulate the effect of Genetic Modified cultivars on farm. This desired effect allowed to feed the extra cows on-farm without the need of importing many supplements into the system (only PKE), while also reducing the application of Nitrogen from 111 kgN/ha to 80 kgN/ha. Financially, the main savings on expenses occurred on Wages (-$18,347) due to the use of AMS. However, the use of this technology implied a significant increase in the depreciation cost (+$ 89,531), as well as in R&M (+$25,239).

6.1.3 RR System Model

The "Regulation Rules" future scenario required a system where all bobby calves and dry stock was kept on farm as a biosecurity regulation prohibit the transport of cattle within farms and killing of bobby calves was banned. As the common practice is that bobby calves are sold and transported at four days to a week old to a meat processor and marketed as veal –where dairy farmers can receive between $15-50 per calf, a relative low price considering the time, energy, and stressful time of year for dairy farmers–, it was assumed that the bobby kept (reared until they get to 10-11 months old) were turned into high value beef animals (breeding costs were increased by +$2,864 because of this), obtaining a higher price per head when sold (altogether +$21,309 was achieved from the livestock sales in the model). This assumption was based on Schreurs (2018) current studies who is researching on the development of a red-meat new product that can potentially turn the low-value bobby meat product into a high-value product. Moreover, as stated by Jolly (2016) there could be an extra benefit in the decision of keeping bobbies, as it also contributes to having a more sustainable, viable and ethical value chain while achieving a great positive effect on the public perception of wasted livestock in the dairy industry.

At a farm level, in order to keep all these animals on farm the SR was reduced by 0.4 and extra feed was purchased to fill the feed deficits. In addition, due to a restriction on the use of antibiotics in this scenario, animal health costs increased (+$7,535). However, the non-use of antibiotics could have an indirect social benefit, as according to Cardoso *et al.* (2016) one of most common concerns of people not affiliated with the dairy industry is related to the use of antibiotics and its impact on dairy. This was supported by Britt *et al.* (2018) who claimed that many concerns of consumers are focused on practices that they perceive to be unnatural, which includes the overuse of antibiotics.

Along with the restriction on the use of antibiotics, the use of fertilisers and irrigation were also limited in this future scenario. Fertiliser application was reduced from 111 kg N/ha to none, generating significant savings in expenses of around $42,000 confirming Glassey *et al.* (2013) findings in a study in which profitable milk production systems were achieved without N fertiliser applications on well-established dairy pastures.

6.2 Were the adjustments feasible?

6.2.1 CK System Model

Precision Irrigation technology in place for this model was assumed to contribute to higher pasture production, as it allowed for a more efficient management of the area irrigated, avoiding raceways, wet boggy areas such as around water troughs and enabling for better control close to waterways and roads (Hedley & Pinxterhuis, 2017). This extra pasture growth was important for the feasibility of the feed budget, as extra feed was needed to allow to carry a split calving pattern where the grass was demanded on a period where it does not grow. According to Shalloo *et al.* (2018), accurate grass growth is one such area where significant adoption of existing technologies would likely be beneficial, supporting the idea of introducing this technology to this system model.

Additionally, this system also modelled the effect of GPS-enabled collars on cows, observed by Jago *et al.* (2013) to be important in explaining the individual animal behaviour (i.e. grazing conduct, health events such as lameness detection). Shalloo *et al.* (2018) further stated that the fact that this technology provides cow health feedback is highly important for pasture-based dairy systems, as it can also help to explain within paddock variation and its impact on performance. The additional benefit of having this technology in place according to Jago *et al.* (2013) is that it could potentially benefit consumers in terms of traceability, animal welfare and knowledge of product history. However, as found out by Shalloo *et al.* (2018) there are other technologies less burdensome on batteries such as ground-based triangulation with multiple base stations that should be also considered in the future.

Besides, a disadvantage found in this scenario is that technology did not provide a solution in terms of the scarcity of labour. On the contrary, the lack of skilled staff available able to operate with the new precision technologies was translated into very high salaries offered, raising the total operating expenses (+$72,071) compared to the Base. As pointed out by Eastwood *et al.* (2018), new technologies (e.g automation tools, communication technologies, and the Internet of Things) can potentially offer further options for current and future farmers to attract and engage staff while enhancing the image of dairying as an innovative workplace for future employees.

In terms of systems based on grass feeding as the one required in this scenario, as observed by Britt *et al.* (2018), in the future increased focus on technologies able to improve digestibility of feeds and soil fertility will be key for improving the sustainability of these type of systems.

6.2.2 GD System Model

In this model, technology use through AMS helped to decrease labour expenses by 17%, whereas according to De Koning & Rodenburg (2004), fully automated milking systems can bring labour savings of 20-30%. Also, as shown previously AMS technology helped to obtain productivity gains, mainly through increasing the time's cows are milked per day (twice to thrice). In a study undertaken by Woodford *et al.* (2015) with six farms who have adopted AMS in NZ, production results showed that both production per hectare and per cow were considerably above regional averages. However, as found out in this study, the increase in costs associated with the use of robots (mainly depreciation and R&M costs from the rapid access to technical support needed if a machine stops working for not to cause a backlog in the milking process) offset the reduction in wages paid. This is in line with Steeneveld *et al.* (2015), who found that the reduction in profit in automated systems are mostly attributable to higher depreciation costs and, contrary to expectations, only modest recorded reductions in labour costs. Woodford *et al.* (2015) also included maintenance costs of the robots and higher electricity costs in the discussion. However, even though these authors agreed that the labour savings brought by the adoption of AMS are offset by these costs, they acknowledged that the increase in milk production reduces the labour inputs per unit of milk produced. Also, as adapting AMS to a pasture-based grazing system is set to change the nature of the work, it is expected that it will contribute in improving the lifestyle for farmers, while also making dairy more appealing as a career and attracting a new class of employees. Therefore, it is expected that in the future automation will lead to continued growth in the size of dairy farms, because economies of scale will be needed to pay for automated systems (Britt *et al.*, 2018). Because in New Zealand the commercial imperative of low-cost grazed pasture systems has driven dairy farmers to remain relatively low-tech compared to their competitors (Kamphuis *et al.*, 2015), efforts will be needed to engage farmers to adopt new technologies. Eastwood, Klerkx, Ayre, & Dela Rue (2017) distinguished that some farmers resist technology adoption because they see a potential consequence of future 'de-skilling' of staff in animal handling and decision making (along with other fears such as power failure or internet disruption). Other reasons for dairy farmers not to invest in new technologies include the perception that current commercially available technologies are unproven, unreliable, and have an uncertain return on investment (Kamphuis *et al.*, 2015). Shalloo *et al.* (2018) were not optimistic about future technology adoption, claiming that there will be a tendency towards lower capital expenditure on pasture-based systems.

Therefore, as suggested by Bewley & Russell (2010), new farming technologies will require support structures to facilitate learning and reduction of uncertainty in the implementation and adaptation process. Some of these new technologies that farms of the future will utilize on-farm include remote sensors, driverless feeding vehicles, and automation to improve management of herds, comply with regulations, and reduce the farm's environmental footprint (Britt *et al.*, 2018). As these authors pointed out, data from sensors, robots, and automated equipment will be converted through artificial intelligence to actionable outputs that will inform managers.

6.1.3 RR System Model

In order to reduce dependence on external sources of energy, this model included solar technologies on farm which convert energy from the sun into electricity. The use of solar panels allowed this model to save money on the electricity bill ($7,000), in line with DairyAustralia (2014) findings which also highlighted other advantages from this technology such as the fact of having no running costs after installation, and the potential expansion of the solar network by adding more panels.

Even though savings were not significant, the use of this technology could have potential extra benefits in the future, as in a highly-regulated context energy sourced from the state's electricity grid could become more expensive. As found out by AgricultureVictoria (2017), the future could restrict energy emissions from dairy farms. Also, as suggested by Britt *et al.*

(2018) changes in sources of energy could influence where dairy farms are located if energy cost is reduced substantially for desalination of seawater.

As this system model kept all stock on farm, there was a need to buy more supplements (at a higher cost) to feed a larger number of animals. Technologies that could enable the farm to grow extra feed from the milking platform could have delivered better results in this scenario. Examples of technology that enable improvements in pasture utilisation was studied by French *et al.* (2015) and included digitally-enabled plate meters which streamline and automate aspects of collecting the data required to generate pasture budgets. Additionally, as observed by Britt *et al.* (2018), the development of crops that need less fertilization and the use of precision farming technologies that match application rates with fertility could help to face the issue of feed shortages in the future.

6.3 What were the economic implications?

6.3.1 CK System Model

This scenario delivered the highest operating profit ($2,899/ha), mostly driven by the higher revenue obtained from selling milk at a high milk pay-out ($7.92 per kgMS), plus the premium earned for the milk sold in winter. The high milk-pay out assumed was related to the added value that dairy products are expected to have in this likely future scenario in response to consumers expectations, which are willing to pay for a milk that is safe, nutritious, and produced with high ethical standards. This statement is supported by a study made by the Ministry for the Environment (2011) on the value of NZ's 'clean green' image, in which a survey done to international consumers found out that they would purchase 54% fewer dairy products if NZ's environment was perceived as degraded. Additionally, in a study carried out by Cardoso *et al.* (2016) to assess the views of people not affiliated with the dairy industry on what they perceived to be the ideal dairy farms, the authors found out that some of the most common concerns are related to cow treatment and cow access to pasture and open space. In this system model, as OAD milking was used, animal welfare benefits were obtained as cows walk less during the day, spending more time in the paddocks. In terms of financial benefits were obtained such as per cow saving in animal health, labour and electricity costs improvement in herd genetic merit, animal body condition score and pregnancy rates –which led to a reduction in the number of younger cows culled–, along with better work organization and more quality leisure time (Clark *et al.*, 2007; Guimaraes & Woodford, 2005; Kvapilik *et al.*, 2015). From an environmental point of view, as Chobtang *et al.* (2017) found out in a Life Cycle Assessment study, OAD farming system showed a lower environmental impact relative to TAD farming systems, reflecting a potential of having an important role in the future.

6.3.2 GD System Model

In this scenario, the global sustained deceleration in economic growth constrained the demand for dairy products affecting the milk pay-out, which was assumed to be of $3.82 per kgMS. In addition, consumers globally have less disposable income due to increases in their cost of living, and therefore are more price sensitive. As a consequence of this, in this future dairy farms are asked to produce commodity products with no value added.

Therefore, the farm system modelled for this likely future focused in maximizing milk production, which was mainly achieved through the increase in the stocking rate and supplementary feed, along with the inclusion of AMS (that allowed to increase the frequency in which cows are milked per day). However, even though a high milk production was achieved (136,385 kgMS), the combination of the low milk-pay out and high operating expenses was driven by high feed prices and AMS-related costs (such as R&M and depreciation), resulted in a negative operating profit (-$542/ha).

As the rest of the feed needed to balance the feed budget was brought into the system at very high prices, due to the global issues involved in importing feed, feed expenses increased dramatically. This is line with Ramsbottom *et al.* (2015), who observed that reliance on bought-in supplements implies exposure to the vagaries of international commodity prices, and care must be taken as purchased feed is the greatest operating expense on dairy farms. Additionally, as observed by Clark *et al.* (2007) there is an urgent need to reduce the capital and operating costs associated with the use of imported feeds.

In conclusion, GD System Model farm system was $1,076/ha less profitable than the Base system model, being the low milk payout the main driver for this result (as well as high operating expenses triggered by the use of AMS technology).

6.3.3 RR System Model

As this future contemplated a context with robust global demand of dairy products but with constrained supply due to high regulatory requirements, a $5.92 per kgMS milk pay-out was assumed for this scenario (considered to be an average milk pay-out). Even though milk pay-out was reasonable, the low milk production obtained (69,100 kgMS) as a consequence of fewer milking cows carried on farm (imposed by an environmental regulation), lead to a minimal operating profit ($82/ha). Additionally, as this scenario demanded that all stock must be reared on farm due to both a biosecurity regulation and a 'zero-bobbies' policy, operating expenses increased significantly, mainly driven by high feed prices paid for the extra supplements brought into the system.

When compared with the Base, the RR system model generated an extra income from the sale of the bobby calves to the meat industry (+$42,468) which helped the gross farm revenue to compensate for some of the loss in income from less milk sold to the factory (-$22,920) due to having fewer milking cows and retaining more milk to feed the bobby calves staying on farm longer.

An increase in the price paid for the beef calves will benefit the RR system model. Nevertheless, a fall in this price will affect the potential of the system of earning more with the milk production, due to the milk is taken from the vat to feed the extra animal carried on farm. In addition, the costs of the extra feed required to maintain them on farm plus the additional expenses in animal health, breeding, R&M and wages, offset all of the extra income provided by the bobbies.

Higher labour costs were assumed in this system model, as the management of the two herds can be more intensive and with no clear break when allowing for two sets of breeding, calving and weaning calves.

In terms of animal welfare, while rearing bobby calves does not solve the cow-calf separation –pointed out by animal rights groups such as SAFE as a distressing practice for the animals–, it provides a positive effect on the public perception of wasted livestock in the dairy industry and a way of moving away from the controversial practice.

6.4 What further adjustments might be required under each future scenario?

6.4.1 CK System Model

Even though this model had the best performance at a farm level and offers an opportunity for New Zealand –whose international recognised pasture-based farming systems can be adapted to provide milk all-year round– it is important to acknowledge that this future scenario will require a significant investment in value chain development, as it will be forced to innovate and evolve at all levels in order to deliver products highly tailored. As NZ exports processed products (very little fresh liquid milk is exported to a niche consumer in China at a very high cost), something else must occur beyond the farm gate to capture the value added and turned it into a product that can be exported. The farm level really other than responding with production systems and stacks of recordings, will need to find a way to deliver specificity to the consumer. The challenge for a NZ cooperative system will be that, as everybody is supposed to be treated the same in terms of prices paid, differentiation (e.g., organic, grass-fed, local, A2A2) will cause fragmentation. Science is, therefore, called to play an important role, as future adjustments most likely will occur off-farm rather than on-farm. The real winner in this scenario will be those who can create brilliant value chains to the consumer.

This statement is in line with Britt et al. (2018), who observed that because in the future importing countries will seek products that are designed for their specific tastes and customs, a shift away from shipping surpluses to shipping value-added products for consumers in targeted nations must occur. Additionally, in a study conducted a decade ago by Dillon et al. (2008) about the future of the Irish dairy industry, they conclude that the main strategy for the future will be to increase the proportion of output away from commodity type-products. However, as Webster et al. (2015) observed, this will have to be done meeting the public expectations regarding animal welfare, as it will be a necessity to retain the freedom to operate and achieve market success.

6.4.2 GD System Model

Further refinement is needed for this model to be economic. An assumption was already made on land values, which fell as a consequence of being related to gross farm revenue. Yet, the system modelled is still unviable and needs further adjustments. A possibility is through scale: as current farm size and structure is not allowing metrics to work, this dairy farm could potentially merge with others. This is supported by Britt *et al.* (2018) who observed that in the future smaller dairy farm enterprises will collaborate and adopt practices of larger enterprises to remain economically competitive, leading to a more vertically integrated structural consolidation of dairy farming. These authors also suggested that lateral integration could also be a possibility in the future, where farmers could potentially share resources and specialize in managing specific animal units.

Additionally, it is important to acknowledge that the system modelled assumed current AMS costs. This ended up having a significant impact in total operating expenses of the model, as current prices are still high considering is a relatively new technology. Nevertheless, if technology becomes more affordable in the future, AMS could potentially become a solution to reduce costs of labour, which is the single highest cost after feed expenses in a dairy farm in NZ (DairyNZ, 2017a). Moreover, considering that the availability of skilled labour and the demands of animal management under increasing herd sizes might limit future expansion in production and profitability (Clark et al., 2016), AMS can be a valuable solution in the future.

6.4.3 RR System Model

Even though this system model delivered the second highest gross farm revenue, high operating expenses lead to very low margins and, thus, will be forced to further adjustments. Finding a market niche for the potential new class of beef product –derived from rearing bobby calves that would ordinarily be sent to slaughter– may become a solution in the future for this system to deliver a more consistent result.

Besides, economies of scale through the fusion with another dairy farm could also become an alternative solution for the metrics to work in this model, as this can help to reduce the relative cost of feed because of the efficiencies of scale (larger farms spread their fixed costs over more units of milk). As observed by Dillon *et al.* (2008), as many dairy farms are constrained by farm size and farm fragmentation, economies of scale through vertical integration will have to happen, as failure to acquire additional land adjacent to the milking area will result in expansion through the proliferation of intensive indoor high input systems which is undesirable from an environmental viewpoint. According to Britt *et al.* (2018), demographic shifts to urban areas could potentially free up land and resources for farming in the future. Dillon *et al.* (2008) further claimed that it will be important that measures which facilitate long-term leasing of land are put in place and ensure land transfers are not constrained by regulations.

Chapter 7: Conclusion

This conclusion chapter details major conclusions and the main findings for each system model, discusses the implications of this research, evaluate the methodology and outlines future research opportunities.

This study was undertaken to answer the research question: 1) what are the farm level implications of likely future scenarios?

7.1 Major conclusions

Irrespective of the likely futures analysed in this study, a constant –both in the scenario analysis itself and then in this subsequent on-farm analysis– is that technology will be critical to the adjustments that are required at a farm level. Concurrent with the strong need for smart systems, the assumption was made that all farms will continue to be pasture-based, as this has been New Zealand dairy farming's competitive advantage since inception. As specificity of consumer requirements mostly happens beyond the farm –and farm level bio-economic models cannot address questions faced by society that transcend agriculture– some really clear and defined value chain development must occur, which could, for the New Zealand dairy industry, mean fragmentation of current chains and structures.

7.1.1 CK System Model

There was a crucial requirement for this system model: to ensure that everything was done to deliver what the consumers want and are prepared to pay for. The farm system model, therefore, was designed strictly thinking in building a close relationship with costumers', fulfilling their expectations: entire pasture-based system away from any type of confinement that restricts natural behaviour, OAD milking to take advantage of it animal and human welfare benefits, GPS collars to deliver meaningful information about the cows in near real-time for both farmers and consumers, split calving to allow for all-year-round milking that provides constant supply of consumer products and flexibility to the system (cows not get in-calf kept as 'carry-overs'), and precision irrigation technologies to enable better pasture production while helping to meet environmental regulations, improving the efficiency of operations, and reducing the pressure and stress on the workforce.

To apply all these changes at a farm level, a reduction in the stocking rate was needed. However, milk production was not affected by having fewer cows, as it was assumed that Jersey cows in this future will provide better milk yields as a consequence of advances in genetics. In addition, the increase of the pasture growth assumed to simulate the benefits of precision irrigation allowed to cover the feed deficits of the split-calving system while maintaining a system based on grass feeding.

On the downside, labour costs assumed for this model were significantly high as the aim was to simulate how the scarcity of workforce available with the training required to operate new precision technologies and with the soft skills needed to work on farms more visible and open to public affected the wages paid.

In conclusion, as the milk payout assumed was high in response to the increasing global demand for high-value dairy products, this system model delivered the highest operating profit and ROA metrics among the models analysed in this study. However, as discussed previously in this study, this future scenario will require a significant investment in value chain development, as it will be forced to innovate and evolve in order to deliver the highly tailored products consumers demanded.

7.1.2 GD System Model

The rationale behind this system model was simple and grim: to get as much production as possible from the cows and land available, at the lowest possible cost and without caring about how it is produced. In response to this, the farm system model was designed to maximise milk production: stocking rate was increased, additional supplements were bought-in to push production, and robotics that increased the cow's milking frequency were introduced into the system. Expenses were increased accordingly and milk payout assumed was low in response to a context where a global crisis reduced consumer ability to purchase dairy products. The use of genetically modified cultivars modelled on the system helped to sustain the higher stocking rate, allowing also to decrease the amount of nitrogen applied into the farm. Labour costs savings brought by the fewer staff needed on farm were offset by the costs related to operating with robots, as on one side technical support is needed to service the units regularly to prevent any stoppage which could end up with a loss in milk production, but also depreciation and electricity costs pushed the operating expenses further.

Even though the system modelled allowed for more bulk milk to be harvested due to carrying a larger milking herd which visited the robots more often, metrics ended up being uneconomic fuelled by higher feed costs and higher costs related to the use of the robots. There is a need for further adjustments to make this farm system work. A possibility suggested is through scale by merging the farm with other/s, to achieve the size needed to spread the high fixed costs that running this type of intensive system involves. Another alternative observed is the potential of technology becoming more affordable in the future, which could end up contributing in replacing much of the manual labour on farm, which is the single highest cost after feed expenses in a dairy farm in NZ.

7.1.3 RR System Model

This system model was related to a highly regulated future, where the governments have an active presence in dairy farming, being very strict on the use of energy, fertilizers, water, and antibiotics. Slaughter of bobby calves is prohibited due to a greater focus on animal and human welfare, and the transport of cattle within farms is banned as a consequence of a biosecurity regulation in place. There is also pressure from society that affects what can be done or not at a farm level, thus greater transparency and compliance are expected from farmers.

To model this system all the stock that in normal practice are sent off farm, stayed on the milking platform, increasing the load per hectare and the feed requirements. In order to allow for this system change, the milking herd was reduced and extra feed was purchased to fill the feed deficits. Renewable energy was introduced to the model through the use of solar panels which helped to buffer electricity costs and to comply with regulatory energy-use schemes. The application of fertilisers was reduced to zero, increasing the need for importing supplements. There was a new income originated from the sale of calves to the meat industry that helped to compensate for some of the costs incurred to feed the extra animals' on farm. However, even though this system model assumed a reasonable milk payout, it delivered the lowest gross farm revenue. The main driver of this decline was the low volume of milk sold to factory as a consequence of the fewer cows being milked and the extra milk from the vat used to feed the surplus calves staying on farm. As the operating expenses base was high due to higher expenditures in supplements, a minimal operating profit was obtained for this farm system model. Therefore, this system model requires further refinement. Finding a market niche for the beef product derived from bobbies may become a potential solution in the future for this system to deliver a more consistent result. Besides, economies of scale through the fusion with another dairy farm could also become an alternative solution for this model to work.

7.2 Implications of this research

Though conceptualised future scenarios rendered a sensible insight about likely future, it is important for decision makers to know how a current dairy farm system would look like at a farm level if these future scenarios occur. Through the approach taken (the bio-economical analytical framework), this study was able to quantify the impact of the proposed farm system changes at a farm level for the likely future scenarios, allowing in-depth analysis of the potential bio-economic outputs of likely future scenarios.

This research has some implications for the dairy industry. Firstly, it acknowledges that the status quo will be challenged. Second, the vision of the future may be too simplistic, and thus there is a need to explore more diverse futures.

In addition, the findings from this research could be useful for the management of Massey Dairy No 1 and similar farms, as research on how to modify the current farm system to adapt to different futures provided useful bio-economic outcomes on the flexibility and potential of the current farm system.

7.3 Assessment of the method

Modelling a case study farm was an appropriate method for answering the research question and meeting the research objectives of this thesis, as bio-economic simulations enabled in-depth analyses and the impact of likely future scenarios to be quantified. FARMAX® whole-farm system platform helped in modelling the physical changes needed to simulate the likely future scenarios at a farm level. Studying a single case study farm offered an opportunity to gain in-depth insight as, due to the fact of being a University research farm, there was access to a great volume of data. The high volume of data sourced from the farm, enabled to build the Base model with accuracy in FARMAX. Additionally, using FARMAX® whole-farm system platform helped in validating the physical changes needed to simulate the likely future scenarios at a farm level, as FARMAX® feed budgeting warns the user about the feasibility or not of the systems model.

7.4 Limitations of the research

The modelling approach used to predict how changes that will potentially occur in the future can impact on the behaviour of the case study current farm system was based on a whole-farm system modelling computer-based software (FARMAX®). As Woodward *et al.* (2008) pointed out, abstracting a farm system into a model has the risk of losing relevance of farming practice in the real world. Also, as modelling represents a simplified representation of reality, it was hard to simulate every aspect of the dynamic complexity that a real farming system could face in the future.

Aditionally, as technologies from the future are not yet known, some of the challenges presented on the future scenarios could be delivered quite differently to how it was analysed. The technologies surmised were based on those that already exist to avoid pure conjecture, as it would be hard to put a price to an unknown technology.

A field trial may have different results compared with that predicted by FARMAX®, which was developed exclusively for NZ conditions and has an extensive field research background underpinning how the outcomes are calculated. However, experimentally testing the scenarios examined in this study would require the farm systems to be operated for several years to ensure the accuracy of the data created, which is often costly and take time.

Lastly, even though modelling a case study farm and bioeconomic simulations enabled in-depth analysis and allowed quantifying the impact of likely future scenarios, it only reflected how the scenarios performed physically and financially, without being able to demonstrate how social or market metrics behave as models cannot address questions faced by society that transcend agriculture. Taking into account what soft signals are already happening, a broader scope from modelling tools is needed in the future which can allow the inclusion of social elements that surrounds the farm systems, moving beyond just including economic and sustainability issues.

7.5 Future research

For a matter of time restriction regarding the Masters deadline, the environmental effect behind the farm system changes introduced for each model and the likely variability of for example milk production and feed price was not assessed. A greater in-depth analysis could be achieved through the use of existing modelling tools such as OVERSEER® and @Risk®.

Additionally, Massey Dairy No 1 quite unique low input sustainable farming system with low stocking rate and all-season OAD milking allowed to explore the different changes needed to simulate the likely future with its own sole implications. Further studies could adopt this approach to apply the possible, plausible scenarios to other commercial farming systems –i.e. high input dairy farm systems–, and extend the analysis to explore the impact of the breadth of likely climate and economic variability.

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Chapter 9: Appendices

DairyBase® is a web-based package that records and reports standardised dairy farm business information - both physical and financial. DairyBase® is owned and managed by DairyNZ on behalf of the dairy farmers of New Zealand. The purpose of DairyBase® is to improve the financial understanding and performance of dairy farmers using a benchmarking approach and is designed to link the production and financial performance of farms. DairyBase® contains financial data from annual farm accounts as well as physical data supplied by the farmer and estimated current market values of fixed assets. Farmers wishing to benchmark their farm performance have access to a wide range of statistics in DairyBase® including (where numbers permit) regional, district, herd sizes and production system data. Accredited accountants and other rural professionals enter the data on behalf of their clients and the data is validated within DairyBase® (DairyNZ, 2010b).

DairyBase

Physical Detail A

Massey University No.1 Dairy Farm (Farm ID: 626701)
Dairy Season ended: 2017 Printed: 18 January 2018

Physical Description	Units	Farm
Milking area	ha	119.7
Support block effective area	ha	0.0
Percent of farm at different height to dairy		0%
Peak cows milked		258
Stocking rate	cows/ha	2.2
Cow breed		Crossbred
Cow liveweight	kg	484
Liveweight/ha	kg/ha	1,042
BW/reliability		87 / 47 LIC
PW/reliability		108 / 71 LIC
Season's rainfall	mm	1352
NIWA 10 Year average rainfall	mm	960
Production system		2
Calving season		Spring only
Nitrogen applied for year	kg/ha	134
Milksolids (MS) Production to factory - (Seasonal year)		
Milksolids/ha	kg/ha	771
Milksolids/cow	kg/cow	358
MS/ha to 31st Dec	kg/ha	448
MS as % of liveweight		74%
10 day peak per cow	kg/day	1.85
Average Milksolids/cow/day	kg/day	1.3
Monthly production drop: Peak to 31Dec		6.7%
Days in Milk per cow		265

Production	Total	Per ha	Per cow	Composition
Milk Litres:	975,239	8,150	3,780	
Fat kg:	52,420	438	203	5.4%
Protein kg:	39,879	333	155	4.1%
Financial year - Milksolids kg:	92,299	771	358	9.5%
Production year - Milksolids kg:	92,299	771	358	

Figure 9-1: DairyBase Physical Detail of 2016-17 Massey Dairy 1 season

Physical Detail A

DairyBase

Massey University No.1 Dairy Farm (Farm ID: 626701)
Dairy Season ended: 2017 Printed: 18 January 2018

Number in Benchmark Group: 49
Benchmark Group Selected by: Physical analysis Region : Lower North Island
Benchmark Group Ranked by:

		2016-17		2015-16	2014-15
Physical Description	**Units**	**Farm**	**Benchmark**	**Farm**	**Farm**
Milking area	ha	119.7	156.9	119.7	119.7
Support block effective area	ha	0.0	56.1	0.0	0.0
Percent of farm at different height to dairy		0%	14%	0%	0%
Peak cows milked		258	407	259	246
Stocking rate	cows/ha	2.2	2.6	2.2	2.1
Cow breed		Crossbred	Crossbred	Crossbred	Crossbred
Cow liveweight	kg	484	453	487	480
Liveweight/ha	kg/ha	1,042	1,175	1,054	986
BW/reliability		87 / 47 LIC		131 / 48 LIC	135 / 43 LIC
PW/reliability		108 / 71 LIC		163 / 74 LIC	169 / 57 LIC
Season's rainfall	mm	1352	1497	1214	949
NIWA 10 Year average rainfall	mm	960	1,066	950	960
Production system		2		1	1
Calving season		Spring only	Spring only	Spring only	Spring only
Nitrogen applied for year	kg/ha	134	97	90	100
Milksolids (MS) Production to factory - (Seasonal year)					
Milksolids/ha	kg/ha	771	971	775	759
Milksolids/cow	kg/cow	358	375	358	369
MS/ha to 31st Dec	kg/ha	448	550	465	476
MS as % of liveweight		74%	83%	74%	77%
10 day peak per cow	kg/day	1.85	1.73	1.75	1.83
Average Milksolids/cow/day	kg/day	1.3	1.5	1.3	1.4
Monthly production drop: Peak to 31Dec		6.7%	6.0%	5.8%	7.2%
Days in Milk per cow		265	249	269	261
Feed Eaten feed KPIs based on 11.0 ME Pasture.					
Pasture & Crop eaten	MJME/ha	101,437	116,413	118,245	107,211
Pasture & Crop eaten	t DM/ha	9.2	10.6	10.8	9.7
Imported supplements eaten	t DM/ha	1.1	1.4	0.0	0.1
Grazing off dry cows eaten	t DM/ha	0.5	0.8	0.3	0.2
Total feed eaten	t DM/ha	10.5	12.8	10.8	10.0
Feed exported	t DM/ha	0.4	0.0	0.3	0.0
Imported supplements eaten	kg DM/cow	516	532	0	59
Imported supplements & grazing eaten	kg DM/cow	753	859	146	145
Average utilisation imported supplement		70%	82%	0%	90%
Average ME imported supplements	MJ/kgDM	10.0	10.4	0.0	11.0
Crops Grazed & Harvested					
Farm area in grazed winter crop	ha	0.0	1.3	0.0	0.0
Farm area in grazed summer crop	ha	14.5	9.3	11.0	22.0
Farm area in harvest crop	ha	1.8	0.6	10.0	0.0
Percent of farm harvested for hay & silage		87%	9%	25%	33%
People					
Cows/Labour unit	cows/FTE	198	131	185	164
Milksolids/Labour unit	kg/FTE	70,999	49,138	66,273	60,561

Physical Data Summary

DairyBase

Massey University No.1 Dairy Farm (Farm ID: 626701)
Dairy Season ended: 2017 Printed: 18 January 2018

This information was collected in the level-1 questionnaire. It is used to generate adjustments and KPI's in both Financial and Physical Detail reports. Please check that it is correct.

Dairy Co Supplied:	Fonterra		
Production System:	2 Feed imported for dry cows 4-10%		
Business Type:	Owner operator	**Balance Month:**	May
Calving Season:	Spring only	**Milking Interval:**	Once a day full season
Winter Milk:	No	**Organic:**	No
Region:	Lower North Island	**District**	Manawatu
% Milking Area Irrigated:	Less than 30%	**Season's rainfall (mm):**	1352
Farm Dairy Type:	H24	**NIWA 10 Yr Av Rainfall (mm):**	960

Stock

Predominant dairy breed:	Crossbred
Peak Cows Milked:	258
Stocking rate (Cows/ha):	2.2
Replacement Calves Reared:	62

Land Area (ha)

Total Dairying area:	142.7
less Ungrazeable area:	23.0
Effective Dairying area:	119.7
Support block effective area:	0.0
Defined Young Stock area:	1.3
Non-dairy effective area:	0.0

Labour

Full time paid labour equivalents:	1.3
Full time unpaid labour equivalents:	0.0
FTE unpaid management:	0.0
Total FTEs:	1.3
Milking Cups per FTE	18

Production

	Total	Per ha	Per cow	Composition
Milk Litres:	975,239	8,150	3,780	
Fat kg:	52,420	438	203	5.4%
Protein kg:	39,879	333	155	4.1%
Financial year - Milksolids kg:	92,299	771	358	9.5%
Production year - Milksolids kg:	92,299	771	358	

Number in Benchmark Group:	49	
Benchmark Group Selected by:	Physical analysis	Region : Lower North Island
Benchmark Group Ranked by:		

Data entered by:	**Financial:**	**Extended Physical: DairyBase Support Centre 9 (HD)**

Validation Messages: None

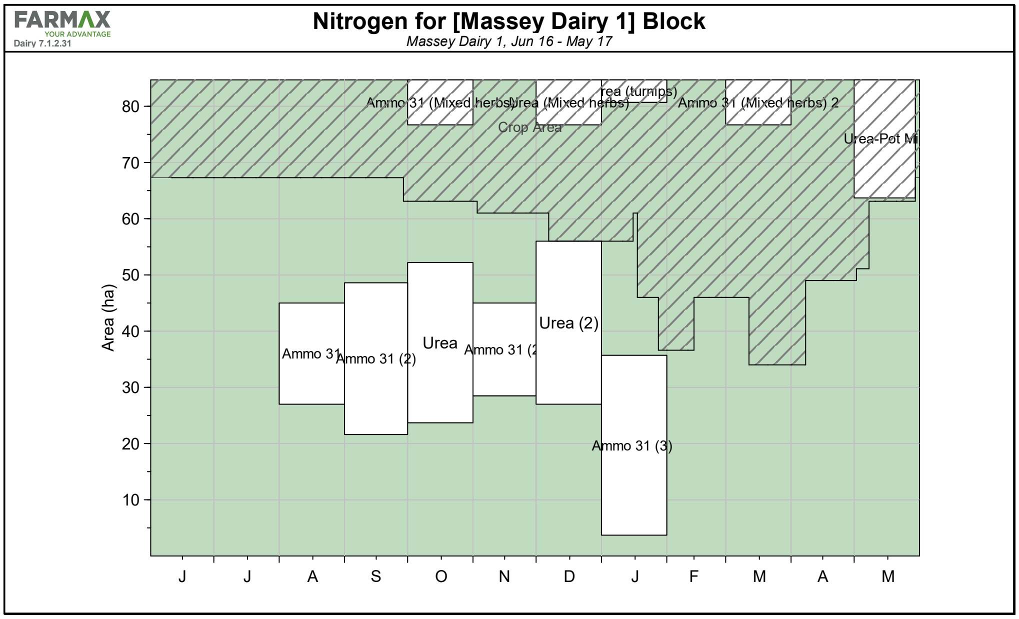

Figure 9-2: Area (ha) and date where the different types of Fertiliser were applied in the Rainfed Block

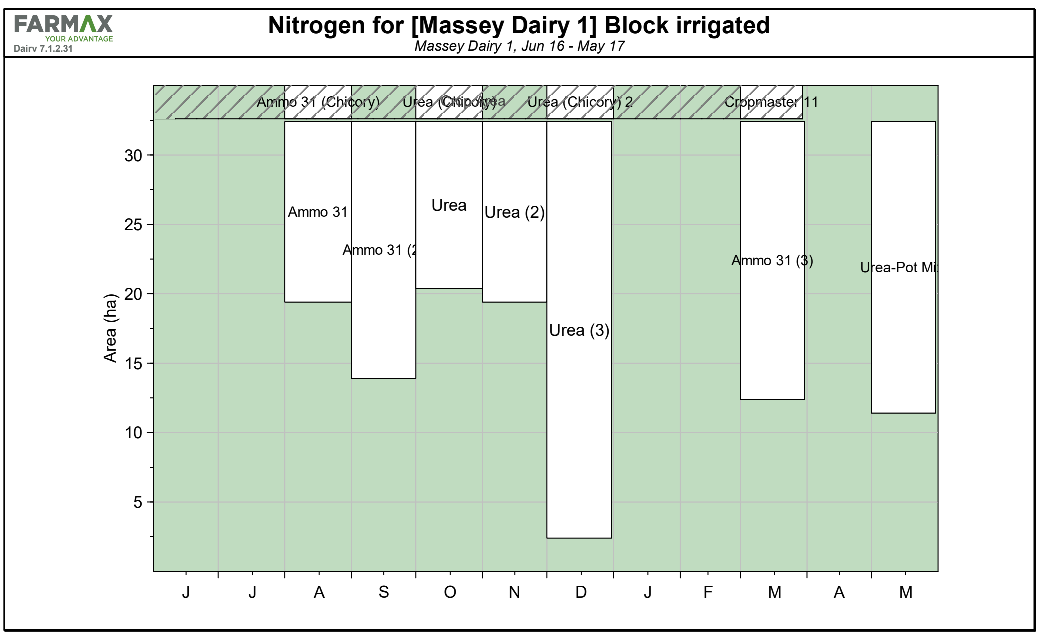

Figure 9-3: Area (ha) and date where the different types of Fertiliser were applied in the Irrigated Block

Figure 9-2 and **Figure 9-3** demonstrate how the rainfed (85 ha) and irrigated (35 ha) blocks look like after applying the fertiliser plan shown in **Table 4-4**. By loading the amount of fertiliser applied, FARMAX® increases the yields (kgDM/ha) to the area it was assigned.