Dietary crude protein and nitrogen utilisation in two contrasting dairy systems

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Dietary crude protein and nitrogen utilisation in two contrasting dairy systems

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Abstract

This thesis evaluated the efficiency of crude protein utilisation (ECPU) in dairy cows and nitrogen (N) utilisation efficiency (NUE) of two pasture-based dairy systems differing in intensification levels in New Zealand. During two consecutive seasons, in the low-intensity production system (LIPS), 257 cows were milked once-daily with low supplementation, and in the high-intensity production system (HIPS), 210 cows were milked twice-daily with higher supplementation. At every herd test, ECPU was calculated as protein yield (PY) divided by crude protein intake (CPI), estimated from feed intake. Milk urea (MU) was measured in early-, mid-, and late-lactation. Urinary N was estimated by back-calculation from estimated faecal N, taking into consideration N contained in milk and in body tissues. Pasture allocation represented 93% and 65% of the total intake for LIPS and HIPS cows, respectively, resulting in higher CPI for LIPS cows throughout the lactation. Compared to HIPS cows, LIPS cows produced 22% and 16% less milk and protein, with 32% higher MU, and 25% lower ECPU. Urine N was 34% higher in LIPS cows but faecal N was 5% higher for HIPS cows. A multivariate predictive model of ECPU was developed, including milk production performance, live weight variation, diet composition and quality along with climatic variables. The model accurately predicted the ECPU in an internal validation dataset (RPE = 6.96%, $R^2 = 0.95$). Milk urea was not selected as a predictive variable of ECPU, considering that cows of higher ECPU also had higher MU. Compared with cows of high MU genetic merit, cows of lower MU genetic merit had lower milk production and similar ECPU. A whole-farm assessment of NUE, N losses and financial analysis was undertaken. On whole-farm level, LIPS produced 23% less milk and NUE was 31% lower when compared to HIPS. The lower MY along with the 35% higher N fertiliser applied on LIPS produced a higher N surplus per ha causing higher N losses when compared to HIPS. Despite the higher feed costs of HIPS, profitability was 16% higher because of milking more cows with higher MY when compared to LIPS.

Dedicated to Manu.

Declaration

This thesis contains no material that has been accepted for a degree or diploma by the University or any other institution. To the best of my knowledge no material previously published or written by another person has been used, expect where due acknowledgement has been made in text.

This thesis has been written with chapters formatted as papers for publication. Therefore, there is some repetition of introductions, methods sections and references employed. Each chapter contains a full discussion, with the final chapter providing a general discussion of key findings of this thesis.

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List of abbreviations

ADF = acid detergent fibre
BCS = body condition score
BCS_{loss} = body condition score loss
CH_4 = methane
CO_2 = carbon dioxide
CP = crude protein
CPB = crude protein balance
CPI = crude protein intake
CSI = cold stress index
DIM = days in milk
DM = dry matter
DMI = dry matter intake
ECPU = efficiency of crude protein utilisation
F = Holstein-Friesian
F×J = Holstein-Friesian × Jersey crossbred
FN = faecal nitrogen
FY = fat yield
GHG = greenhouse gas
HIPS = high-intensity production system
J = Jersey
LIPS = low-intensity production system
LW = live weight
LWc = live weight change
LW_{loss} = live weight loss
LY = lactose yield
MDSM = Moorepark Dairy System Model
ME = metabolisable energy
MF = milking frequency
MJ = megajoules
MLW = metabolic live weight
MPE = mean prediction error
MSPE = mean square prediction error
MSY = milk solids yield
MU = milk urea
MUBV = milk urea breeding value
MUY = milk urea yield
MY = milk yield
N = nitrogen
N_2O = nitrous oxide
NDF = neutral detergent fibre
NUE = nitrogen utilisation efficiency
OAD = once-daily
OMD = organic matter digestibility
PY = protein yield
RDP = rumen-degradable protein
RPE = relative prediction error
SCC = somatic cell count
SCS = somatic cell score
SD = standard deviation
SR = stocking rate
TAD = twice-daily
THI = temperature-humidity index
UDP = undegradable protein
UN = urinary nitrogen
WSC = water-soluble carbohydrate

Chapter 1

General introduction

Grazing livestock systems make extensive use of ecosystem services and eliminate many of the problems of confinement (housed) livestock systems. Unlike humans, ruminants can convert high-fibre forages directly into high-protein food, including dairy products and meat (Tilman et al. 2002; Waghorn and Clark 2004). Therefore, land that is unsuitable for cropping or horticulture to directly produce food for humans can still provide food indirectly (i.e. through the grazing ruminant). Additionally, grazing dairy systems are socially well perceived because they are associated with better animal welfare when compared to housed dairy systems (Macdonald et al. 2008). However, grazed pastures of New Zealand and other temperate regions are high in crude protein (CP; nitrogen (N) concentration × 6.25) concentration in early spring and late autumn, at levels that regularly exceed milk production requirements (Kolver and Muller 1998; Waghorn and Clark 2004). This excess dietary CP can result in a decrease in the efficiency of CP utilisation (ECPU), defined as CP captured as milk as a percentage of total CP intake in grazing dairy cows.

Excess dietary CP can also become an animal health issue, especially in cattle, as the rumen converts it into ammonia, which is toxic (Jonker et al. 1998; Jonker et al. 1999). Under such conditions, to avoid poisoning, ruminants synthesize urea (Nousiainen et al. 2004; Nennich et al. 2006). This urea is transported from the blood to other fluids such as saliva in order to be recycled, and to urine in order to be excreted, but due to its molecular weight and neutral charge, it also easily diffuses across cellular membranes where it is incorporated into milk as milk urea (MU) (DePeters and Ferguson 1992). Therefore, MU has been proposed as an indicator for detecting excess CP in diets (Broderick and Clayton 1997), and as a tool to indicate inefficiencies of N utilisation in dairy systems (Jonker et al. 1998; Jonker et al. 1999). However, most of the studies on MU have been performed under controlled conditions (i.e. housed cows fed total mixed rations), and so there is a need to explore its usefulness as a tool to indicate inefficiencies of N utilisation under grazing conditions.

In New Zealand, cows are raised outdoors year-round so most of their excreta is returned to pasture, increasing the nitrate-N levels in soil solution and groundwater. This is an important environmental problem, as well as being wasteful in terms of utilisation of plant nutrients (Ledgard et al. 1996; Peyraud and Delaby 2006). Compared to housed dairy systems, there are fewer options available to farmers in pasture-based systems to regulate dietary CP, and therefore manage potential animal health and environmental issues (Mulligan et al. 2004; Hills et al. 2015).

In response to global demand for dairy products, the New Zealand dairy industry has expanded rapidly since the 1990's (Ministry for Primary Industries 2018), with dairy companies processing 7,077 million litres of milk in 1990 and 20,702 million litres of milk in 2016 (LIC and DairyNZ 2017). This expansion of the dairy industry was achieved through genetic improvement of animals by implementing a well-defined national breeding program, by increasing the amount of bought-in supplementary feeds, and by increasing the use of N fertiliser, with a concomitant increase in the number of cows per ha (Macdonald et al. 2017). Some aspects of the intensification process have reduced the farm N utilisation efficiency (NUE) and increased nutrient losses from these systems. This has led to increasing pressure on soil and water resources, endangering native vegetation reserves and wetlands, and jeopardising the long-term sustainability of these intensified farming systems (Jay 2007; de Klein et al. 2010; Parsons et al. 2016).

Milking frequency, defined as the number of milking events per cow within a day, is typically twice-daily (TAD) in modern dairy systems, including those in New Zealand. Previous studies comparing once-daily milking (OAD) vs TAD showed that individual cows milked OAD for short periods could lose, on average, 19% of milk yield (Davis et al. 1999), with this loss as high as 35 to 50% for extended periods of time depending on the cow's suitability for OAD (Stockdale 2006). Nevertheless, some farmers are adopting OAD as a system throughout a full lactation considering the obvious lifestyle advantages (Bewsell et al. 2008), the opportunity to reduce production costs (Phyn et al. 2010), and because of the well-documented improvement of reproductive performance (Stelwagen et al. 2013) and animal welfare and animal immune status (Clark et al. 2006). Currently, approximately 9% of New Zealand dairy farmers milk OAD for the entire season (Edwards 2018). Although OAD systems are typically associated with lower intensification, especially lower use of supplementary feeds, and reduced labour (Stockdale 2006; Stelwagen et al. 2013), there is little to no information regarding the environmental implications of OAD systems, especially in terms of ECPU, N balance and N losses at both a cow and a whole-farm level. Previous research analysing milking frequency has focused on animal performance and economic outcomes (Lynch et al. 1991; Clark et al. 2006; Edwards 2018), and in addition, OAD has often been studied as a strategic change within a lactation (e.g. cows are milked OAD for the first, or last, few months of lactation in an otherwise TAD system), rather than the focus of an entire lactation. Therefore, there is a need to quantify and to compare the NUE at the farm level, along with the ECPU at the cow level, of a low-intensity production system (i.e. cows milked OAD with lower supplementation) with a higher-intensity production system (i.e. cows milked TAD with higher supplementation). The hypothesis of this thesis is that the de-intensification of a dairy farming operation will increase the NUE at both the cow and farm level.

The objectives of this thesis were:

1. To evaluate the ECPU at the cow level, and the NUE at the farm level, of pasture-based dairy systems differing in intensification (i.e. milked OAD and fed low level of supplements, milked TAD and fed higher level of supplements);
2. To evaluate the usefulness of MU as a tool to indicate the ECPU under grazing conditions, in these same systems; and
3. To analyse some key environmental and financial implications of an OAD, low supplementary feed pastoral dairy system, vs a ‘standard’ TAD, higher supplementary feed pastoral dairy system, at the whole-farm level.

Thesis outline

This thesis consists of eight chapters including this introduction, and a review of literature. Chapters 3 and 5 examine the relationship of ECPU and cow performance of two herds under grazing conditions, with one milked OAD with lower supplement inclusion and the other milked TAD with higher supplementation. In these chapters, MU is evaluated as a non-invasive biomarker of NUE and N partitioning for these two research herds. Chapter 4 focusses on identifying the effect of multiple variables including dietary and breed characteristics, farm management, and climate conditions of pasture-based dairy cows on ECPU. In Chapter 6, the ECPU of these two research herds is compared with a new proposed measure of NUE, the CP balance throughout a grazing season. A modelling analysis is implemented in Chapter 7, focussing on the NUE and considering all productive inputs and outputs at the whole-farm level, arriving at a description of N losses and financial implications for the two research farms. Finally, the main conclusions from this research are discussed and summarised in Chapter 8.

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Chapter 2

Literature review

2.1 Introduction

The majority of world dairy production comes from the Northern Hemisphere, specifically North America, Europe, Russia and China, and a smaller proportion comes from the Southern Hemisphere, particularly South America, Australia and New Zealand (FAO 2017). A large variation in climate, edaphic and social conditions in these regions results in a wide variation in dairy systems. For example, notwithstanding the tolerance to low temperature of cows, in most high latitude regions cows are housed indoors during the winter period for a number of reasons, including the protection of soils in wetter periods, animal welfare, and the lack of capability to grow feed in winter time (Armstrong 1994; Jones and Kammel 2017; Christensen et al. 2018a). In high latitude regions, low temperatures will limit dairy production not only by restricting feed availability, but also by driving cows' energy requirements towards maintenance rather than milk production (Jones and Kammel 2017). On the contrary, in the temperate zones with mean minimum and mean maximum temperatures averaging 9°C and 18°C animals can have outdoor access all year round with their performance not being compromised by extreme temperatures (Armstrong 1994). Depending on rainfall patterns and soil fertility, longer periods of active growth of pastures and crops enable grazing year-round (Dillon et al. 2005; Hills et al. 2015). Additionally, grazing systems are socially well perceived because they are associated with better animal welfare than housed systems (Macdonald et al. 2008).

Pasture-based dairy systems have some advantages over housed systems associated with improved animal welfare, increased product quality and higher socially acceptability (Dillon et al. 2005; Macdonald et al. 2008). However, pasture changes in availability and quality throughout the year due mainly to climatic variation and plant reproduction, and because leaves have a limited lifespan, if they are not grazed or harvested in time, they will die and be wasted (Fulkerson and Donaghy 2001; Chapman 2016). The key to a successful pasture-based system is the conversion of large amounts of low-cost grass into milk (Kolver 2000; Beukes et al. 2019). A common management strategy is to match animal demand to peak seasonal pasture growth (Penno 1998). Despite the low operating cost of pasture-based systems, land is the main capital component and is a limiting resource. A key focus of pasture-based systems, is to 'dilute' the cost of the land by increasing milk production per area (Macdonald et al. 2017).

Driven by increasing global food demand, New Zealand farmers have steadily increased milk production since the 1990's through intensification including an increase in number of cows per farm, use of nitrogen (N) fertiliser to boost pasture production, and incorporation of supplementary feed, mainly to meet the increase in feed demand as a consequence of the increase of milking cows, but also to extend lactation length and pasture productivity (Macdonald et al. 2017, Wales & Kolver 2017). In both early spring and late autumn, fresh-grazed temperate pastures may be high in crude protein (CP; N concentration × 6.25), containing mainly rumen-degradable protein at levels that regularly exceed milk production requirements (Kolver and Muller 1998). This imbalance results in poor efficiency of CP utilisation (ECPU) by grazing cows, and is expressed in increased N excreta, particularly urinary N (Kebreab et al. 2001; Mulligan et al. 2004) which impacts on ground and surface water quality (Di and Cameron 2002a). Associated with this intensification process mentioned beforehand, there is a reduction in whole-farm N utilisation efficiency (NUE) and an increase in N losses from the farm. The increase of both fertiliser N use and stocking rate (SR; i.e. number of cows/ha), and the inclusion of more land for farming, are increasing the pressure on ecosystems and jeopardising the long-term sustainability of the New Zealand dairy industry. Some catchments are more sensitive to nutrient contamination than others, and some are specifically sensitive to phosphorous whilst others may be more sensitive to N (Monaghan et al. 2008). With stringent environmental regulations currently being imposed on New Zealand dairy farmers by Regional Councils, particularly modelled N losses from farm, it is imperative to identify ways of reducing N excreta and to improve the N use efficiency of pastoral dairy systems (Horizons 2016). Thus, the objective of this review of literature is to describe major aspects of the intensification of New Zealand pasture-based dairy systems, and the implications of this on the ECPU at the cow level, and on the NUE at the farm level, and on resulting N losses to the environment.

2.2 The role of New Zealand in global dairy production

Since the year 2006 milk production has continuously increased in the USA and India, the two leading milk-producing nations (FAO 2017). A second group with a smaller proportion of global milk production, led by Brazil and China, slightly reduced milk volume between 2015 and 2016 (Figure 2.1). New Zealand, the eighth largest global milk producer has had increasing milk production, and it is also the principal milk producer from pasture-based dairy systems (Ministry for Primary Industries 2016).

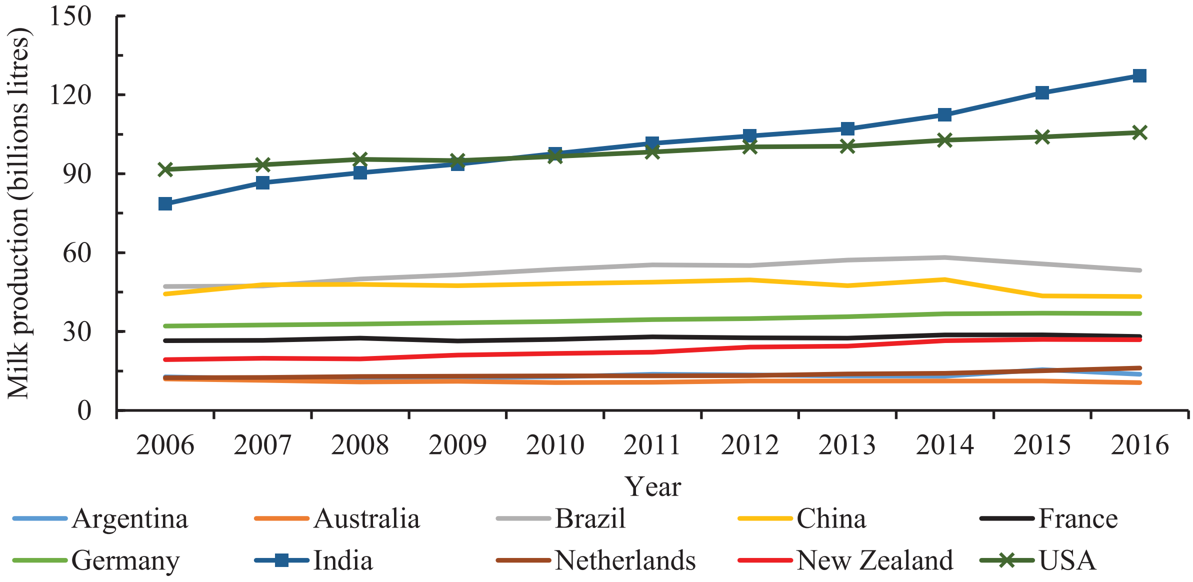

Figure 2.1. Trends in global milk production for the main dairy producer countries (FAO 2017).

Although some milk-producing nations have high milk production levels, their domestic demand is also high, and so they are net importers of milk products from a range of countries, with New Zealand being a major supplier. For example, China, Australia and the USA all import substantial amounts of dairy products from New Zealand. Thus, the participation of countries in the global milk trade is different compared with their primary production. For example, New Zealand, with a population of around 4.8 million people, has a dairy industry comprising 4.5 million cows producing a total of 26 billion litres per annum, and is a major exporter, especially of butter and milk powder. In turn, New Zealand accounts for about 4% of world dairy trade, mostly due to having a 67% share of the whole milk powder market (Figures 2.2 and 2.3). Moreover, the contribution of dairy exports to the New Zealand economy was 28% of the total merchandise exports in 2016, representing NZ$16.7 billion, and this is expected to increase by 3% for the milking season ending in June 2019 (Ministry for Primary Industries 2018). From the 11 milk companies operating within New Zealand, Fonterra processes 95% of the local production into more than 600 products (e.g. desserts, milk powders, cheeses, etc.) and trades around 50% of the milk marketed globally.

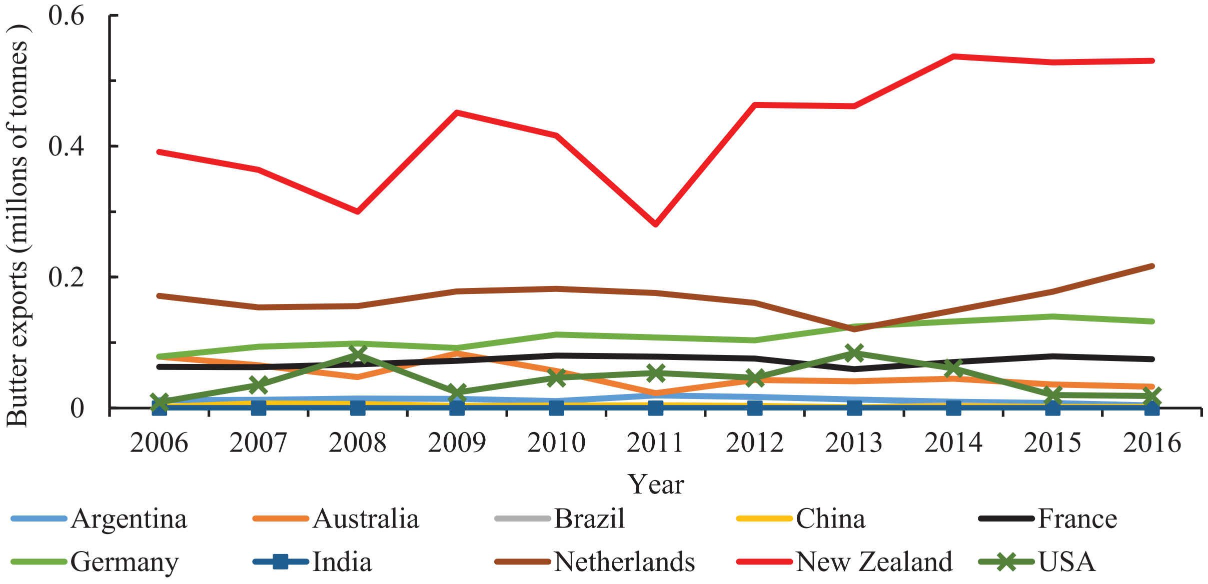

Figure 2.2 Estimates of butter exports for the main dairy producer countries (FAO 2017).

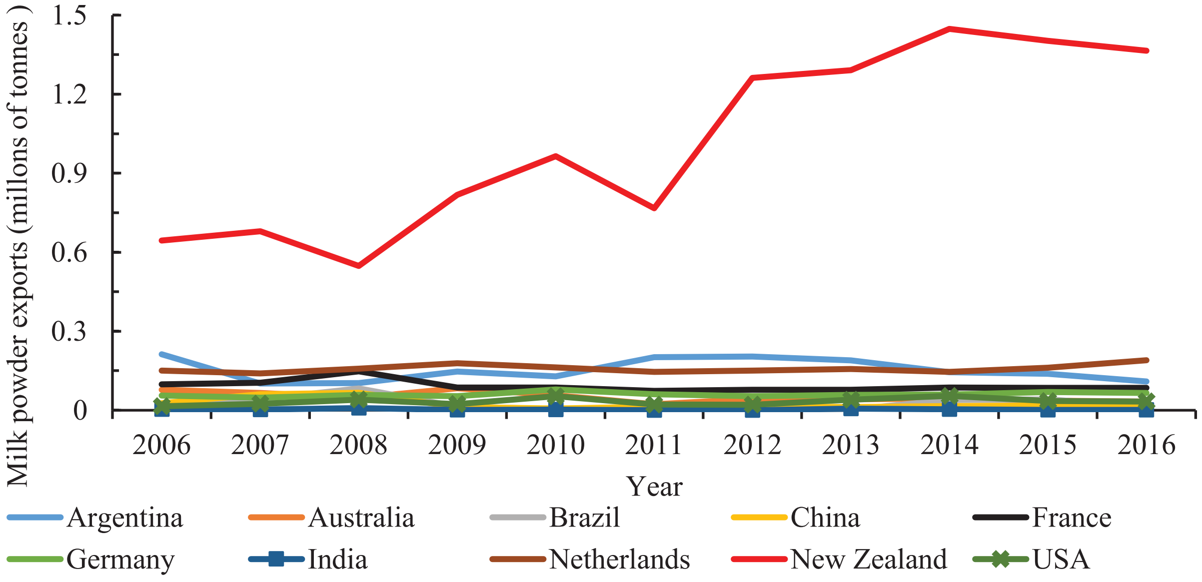

Figure 2.3 Estimates of milk powder exports for the main dairy producer countries (FAO 2017).

2.3 Dairy industry intensification in New Zealand

The term intensification refers to the increasing use of inputs (e.g. fertiliser, energy, water for irrigation, knowledge or capital) into farming systems to produce more food from the same area of land (Foote et al. 2015; Macdonald et al. 2017). The intensification process of the traditional low input pasture-based dairy systems is at several levels. In response to global demand of dairy products, the New Zealand dairy industry has expanded rapidly since the 1990's (Ministry for

Primary Industries 2018) with dairy companies processing 7,077 million litres of milk in 1990 and 20,702 million litres of milk in 2016 (LIC and DairyNZ 2017). This almost 3-fold increase is mostly a result of more cows per farm, and more milk per cow which was achieved through the implementation of a well-defined genetic national program.

2.3.1 Dairy herd genetic improvement and herd dynamics

The New Zealand dairy industry breeding objective is to identify animals whose progeny will be the most efficient converters of feed into profit at the farm level, and ranks male and female animals for their genetic ability for breeding replacements (DairyNZ 2017). Compared to dairy cow strains of the 1970's, the genetic improvement of contemporaneous strains resulted in increases of 16%, 21% and 26% increases in yields of milk, fat and protein, respectively at an expense of only 2% increase in maintenance requirements (Macdonald et al. 2017). This highlights the progress made, as the result of a methodical national breeding program, in the cow's biological efficiency for converting feed into milk (López-Villalobos et al. 1999; Montgomerie 2004; Ministry for Primary Industries 2016; Johnson et al. 2018). As such, dairy cows increased their average milk production from 259 to 368 kg of MS per cow and from 653 to 1,048 kg of milksolids per ha (Figure 2.4) (LIC and DairyNZ 2017).

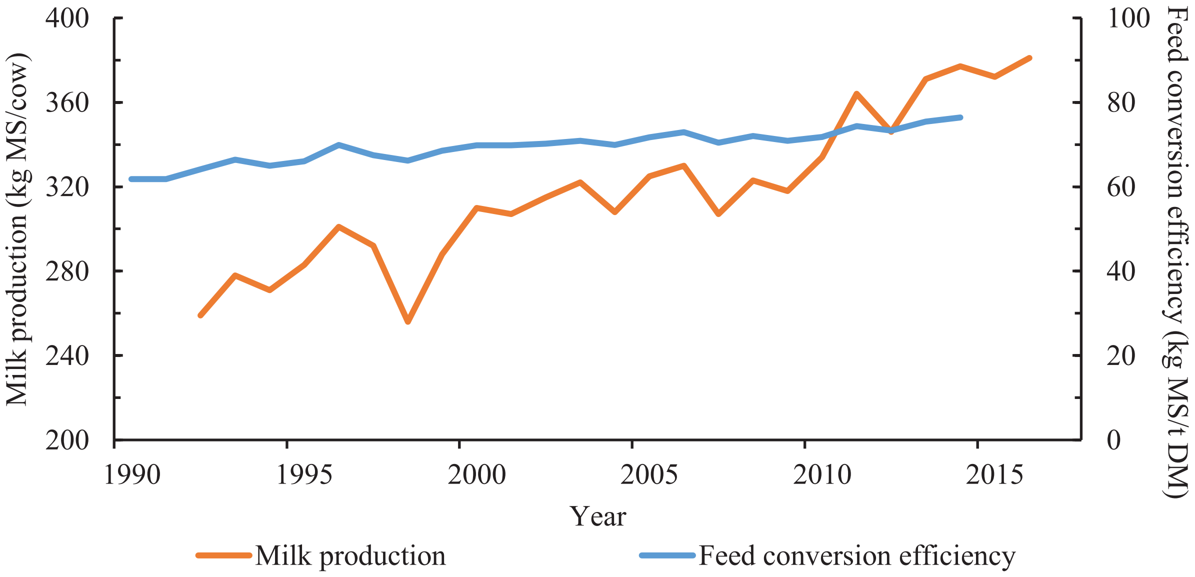

Figure 2.4 Gain in milk production per cow and feed conversion efficiency over the past 15 years (Ministry for Primary Industries 2016; LIC and DairyNZ 2017).

As well as an increased number of more efficient milking cows, the average number of cows per farm has also increased (Figure 2.5) (LIC and DairyNZ 2017). Between 1990 and 2007, 3,249 milking herds were removed from the national population but at the same time, the national number of cows increased, due to a rearrangement into larger herds. For example, the average dairy farm size has almost doubled since 1990, and in the same period stocking rate (SR) increased from 2.3 to 2.8 cows per ha (Figure 2.6). This occurred across New Zealand, with more emphasis in the South Island, specifically in the Canterbury region. The increase in dairy cow numbers has come at the expense of clearing of land previously under native vegetation or sometimes plantation forestry, and large-scale conversion of sheep and beef farming (Ministry for the Environment and Stats NZ 2019) for both immediate dairying, as well as for rearing of young stock and growing crops to support dairying.

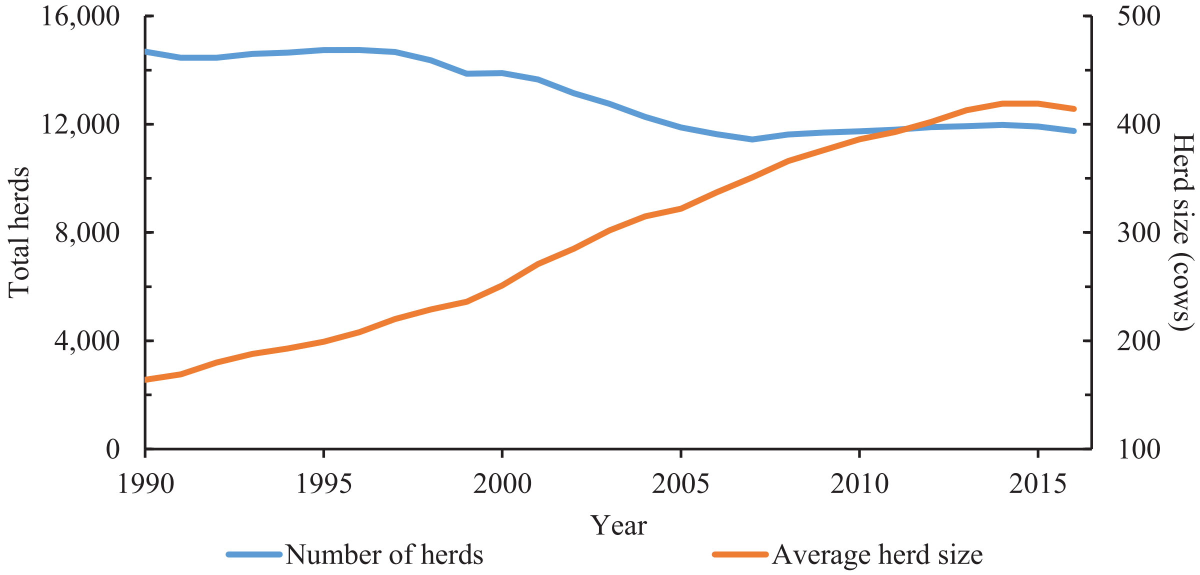

Figure 2.5 Trend in the number of herds and average herd size from 1990 to 2016 (LIC and DairyNZ 2017).

In addition, the increase in milk yield per ha, is underpinned by an increase in feed grown per ha on farm as well as an increase in supplementary feed imported from off-farm (Figure 2.7).

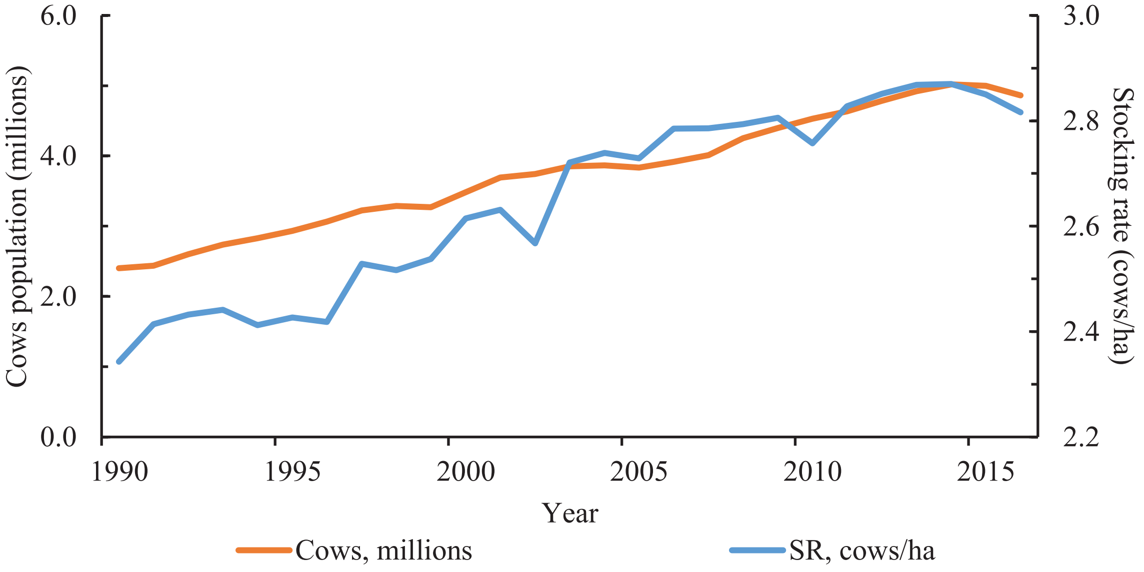

Figure 2.6 Population of milking cows and average estimated stocking rate (SR) for the last two decades (LIC and DairyNZ 2017).

2.3.2 Supplementary feed inclusion

As dairy farms became larger, they also increased in complexity of feeding management (Wales and Kolver 2017). In response to high milk and land prices, farmers started including supplementary feeds to direct-grazed pasture, in the form of annual crops, by-products and silages made both on and off farm to underpin higher SR and to increase lactation length (Macdonald et al. 2017; Roche et al. 2017).

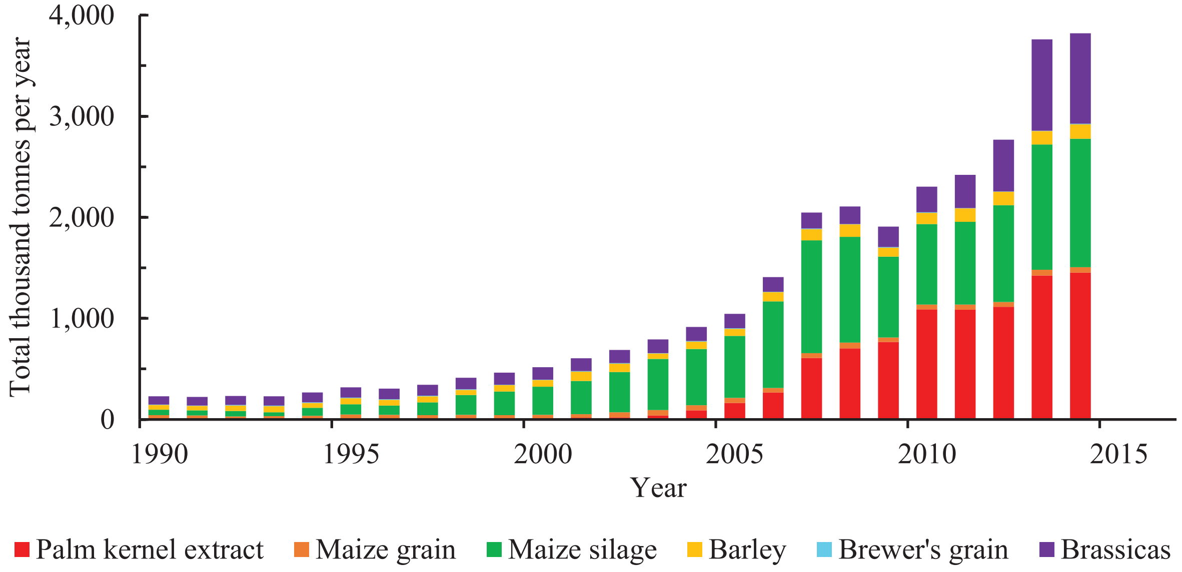

Figure 2.7 Main types of supplementary feeds incorporated into New Zealand dairy farms from 1990 to 2014 (Ministry for Primary Industries 2016).

The provision of additional feed grown off farm was accompanied by an increase in yield of perennial pastures, underpinned by an increase in levels of N and phosphorous fertiliser (Fertiliser Association of New Zealand 2017) (Figure 2.8). While phosphorous fertiliser use peaked in the early 2000's, the use of N fertiliser has continually increased since 1990, with the exception of some periods of drought as was the case in 2008 (Wales and Kolver 2017).

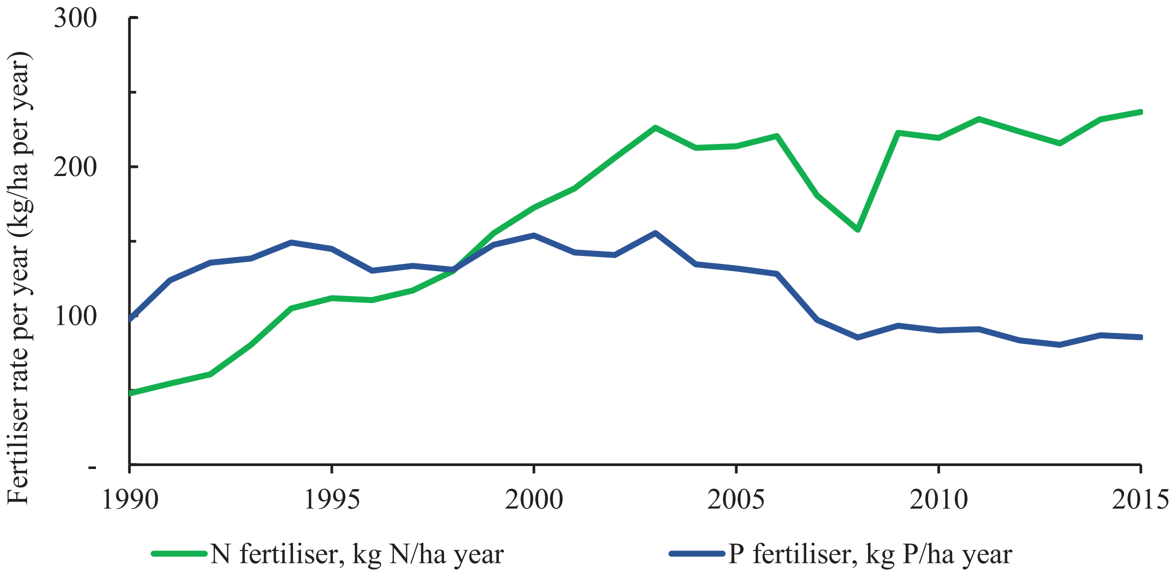

Figure 2.8 Estimated use of fertiliser in New Zealand to dairy and arable/horticulture land from 1990 to 2015. Adapted from Fertiliser Association of New Zealand (2017).

2.3.3 Milking frequency

There is a trend in the New Zealand dairy sector to return to traditional grazing systems with lower inclusion of supplements due to a fall of dairy products prices since 2014 (Wales and Kolver 2017; DairyNZ 2018). Milking frequency (MF), defined as the number of milking events per cow within a day, is typically twice-daily milking (TAD) in modern dairy systems, with the interval between milkings as equal as practicable. These systems are perceived as an efficient approach to achieve high milk production by maximising the use of grazed grass with variable levels of non-pasture supplementary feed inclusion (Ramsbottom et al. 2015). Extra supplementation is influenced by seasonal pasture growth, genetics of the herd, and SR, but it can also be influenced by MF (Beukes et al. 2008). Shortening the interval between milkings generally increases milk yield through an increase in secretory cell activity, whereas extending milking intervals generally decreases nutrient uptake in the mammary gland (Delamaire and Guinard-Flament 2006), resulting in a decrease in milk production. As such, once-daily milking (OAD) over short periods was demonstrated as a tool to alleviate the negative energy balance that cows undergo during the early post-partum period (McNamara et al. 2008; Phyn et al. 2010; Khaembah et al. 2013). Moreover, reducing the MF from TAD to OAD in late lactation was identified as a tactical option to overcome periods of low pasture availability and high supplementary feed prices in pasture-based systems (Bewsell et al. 2008; Armstrong and Ho 2009).

Systems based on OAD for the entire season are typically pasture-based, with few or no supplementary feeds used (Davis et al. 1998) as a response to lower feed demand along with the expected lower milk production. Once-daily milking offers the opportunity to reduce costs associated with milk harvesting, consumables, the dependence of larger farms on higher numbers of staff (Davis et al. 1998) and, importantly, bought-in feed (Phyn et al. 2010), which is strongly associated with financial performance (Dillon et al. 2005). Additionally, in OAD dairy systems, there are documented benefits in terms of animal welfare and animal immune status (Clark et al. 2006; O'Driscoll et al. 2010), reproductive performance (McNamara et al. 2008; Stelwagen et al. 2013), and reductions in cow culling associated with infertility and lameness (O'Driscoll et al. 2010). Moreover, the noticeable changes in the whole structure of the working day by reducing time spent in milk harvesting was associated with staff lifestyle improvements (Stelwagen et al. 2013). While the New Zealand dairy industry is strongly focused on increasing productivity, there is a small but increasing numbers of farmers milking OAD that challenges this trend (Bewsell et al. 2008). Currently, approximately 9% of dairy farmers in New Zealand farm OAD for the entire season (Edwards 2018).

The major barrier to the adoption of OAD systems is a reduction in milk production compared with TAD systems. Figure 2.9 summarises the effect of MF on milk production performance within the three main breeds used in New Zealand, where the interaction between breed and MF can be observed. The Holstein-Friesian (F) cows experienced the largest loss in milk yield with an average of 28% less milk per cow when switching from TAD to OAD. The decline in milk production is lower in Jersey (J) and crossbreed (F×J) cows, with between 17 to 24% less milk production per cow. In a review of MF on cow productivity, Stockdale (2006) reported losses between 35 and 50% and these were attributed to the suitability of cows to OAD for extended periods of time. In the study by Stockdale (2006), it was recognised that J cows have an advantage when milked OAD, as they produce a relatively concentrated milk, and therefore have a capacity to accumulate milk for extended periods compared to F cows. An interaction between breed and MF was reported in a farmlet study by Clark et al. (2006), and recently confirmed by Lembeye et al. (2016) who performed an analysis on commercial herds. Given the lower production level expected in OAD, and because of the increased use of F×J cows in New Zealand herds, profitability of OAD farmers will be improved by including crossbred cows with higher proportion of J (Clark et al. 2006; Stockdale 2006; Lembeye et al. 2016).

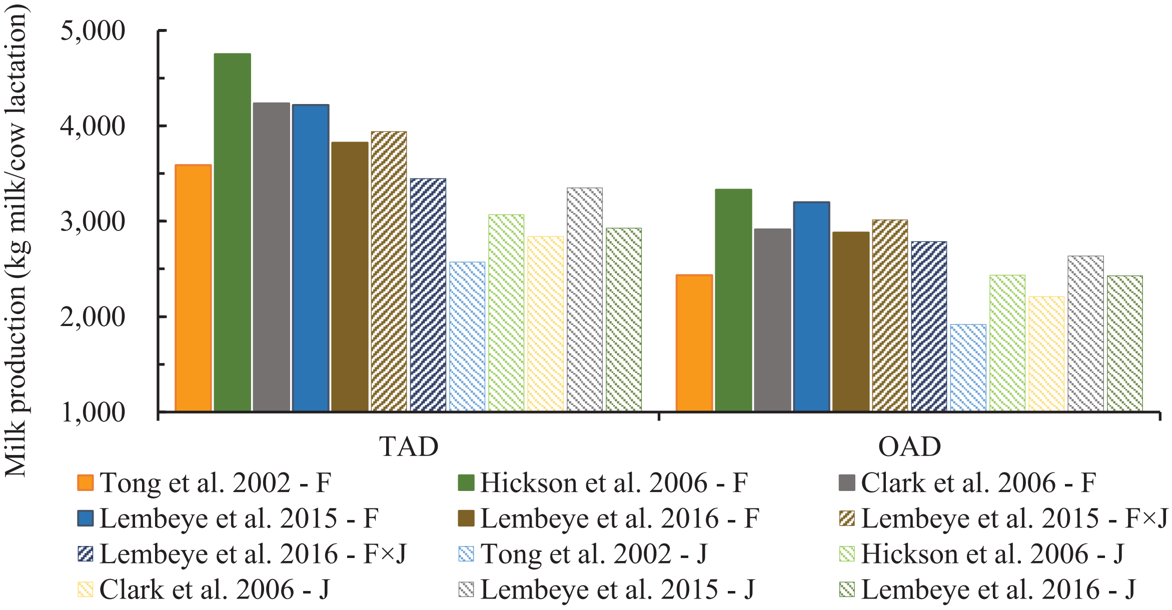

Figure 2.9 Milk production per cow in Holstein-Friesian (F), Jersey (J) and crossbreed (F×J) cows milked once-daily (OAD) and twice-daily (TAD) within grazing conditions of New Zealand.

The efficiency of milk production was defined by Holmes and Macmillan (1982) as a result of feed utilisation efficiency tailored to management, and feed conversion efficiency related to genetic merit of milking cows. The essence of a well-designed dairy system relies on the feed quantity and quality allocated to meet cow requirements for maintenance and milk production and the efficiency with which it is converted into milk. Stocking rate, defined as cows per unit of area, plays a major role in balancing sufficient feed allowance to each cow to express genetic milk production ability, without compromising pasture utilisation and persistence, in order to optimise farm profitability (Penno 1998; Penno 1999; Macdonald et al. 2001; Macdonald et al. 2008; Macdonald et al. 2011). It is a common practice for OAD farmers to increase their SR to overcome an anticipated loss in milk production (Clark et al. 2006; Beukes et al. 2008), but some considerations must be addressed beforehand.

Persistency of lactation denotes the ability of the cow to produce milk constantly over the lactation period and it can be calculated as the rate of decline in daily yield after peak yield of lactation (López-Villalobos et al. 2005). In experimental conditions, Hickson et al. (2006) reported shorter lactation length and higher peak yield in F cows milked OAD vs F cows milked TAD. In parallel, Hickson et al. (2006) observed a longer lactation length and a smaller peak yield in J evidencing differences in persistency between F and J when milked OAD vs TAD. On the contrary, Lembeye et al. (2016) reported higher persistency of lactation of F, J and F×J cows on OAD when compared to TAD in commercial herds, but the differences were attributed to the selection of cows more suitable for OAD in this case. These indications suggest that OAD has an impact on lactation length and days to peak yield. By observing interactions between breed and MF, and between persistency of lactation of the different breeds and MF, extra adjustments of SR would need to be executed according to feed grown on farm and breed utilised (Clark et al. 2006; Stockdale 2006; Beukes et al. 2004). Considering the expected yield loss of OAD systems, farm operations may need to be restructured to reduce costs in order to improve the net profit of the business (Edwards 2018). To achieve comparable profitability to TAD, OAD systems need to ensure high pasture utilisation to keep feed costs low (Armstrong and Ho 2009).

2.3.4 Environmental impact of dairy systems

All livestock production activities have an impact on the environment, either by extracting resources or by creation of waste, or both (Foote et al. 2015) and the intensification process accentuates the environmental footprint. In grazing systems, there are two main sources of environmental footprint: greenhouse gas (GHG) emissions linked to global warming, and the negative impact of excreta on the quality of surface and ground water. In New Zealand, both rearing and producing dairy animals graze outdoors year-round, meaning that most excreta is discharged onto pastures (Jay 2007).

The three main GHG are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide is produced by all aerobic organisms metabolising carbohydrates and lipids to produce energy by respiration, whereas CH_4 emissions are produced from rumen fermentation (de Klein and Clark 2002). Nitrous oxide is produced mainly from livestock manure and fertilised agricultural soils, and as a natural by-product of soil fungi and bacteria (Bolan et al. 2004). The CO_2-equivalent is the unit employed to assess the potential of each GHG to contribute to global warming. Releasing one kg of CH_4 into the atmosphere is equivalent to releasing 25 kg of CO_2 and releasing one kg of N_2O is equivalent to 298 kg of CO_2. However, the lifespan of the effect of CH_4 on global warming is substantially less than that of CO_2. According to New Zealand's National Greenhouse Gas Inventory, of the total 55,953 kilotonnes CO_2 equivalent emitted, 44% is CO_2, 43% is CH_4, and 13% is N_2O along with other gases such as sulphur hexafluoride, perfluorocarbon, hydrofluorocarbon and nitrogen trifluoride (Ministry for the Environment 2018). In 2016, 35,810 kilotonnes of CO_2 equivalents were estimated to be produced by dairy cattle, which comprise 64% of the livestock population of New Zealand (Ministry for Primary Industries 2018).

Notwithstanding uncertainties in global warming metrics (Reisinger et al. 2010), there is substantial evidence for the role of anthropogenic actions on climate change, particularly the contribution of livestock and agricultural activity (IPCC 2014; Ministry for the Environment 2018). New Zealand received NZ$13.3 billion in export revenue from the dairy industry in 2016, representing 28% of total exports. While there are no plans for large reductions in livestock production activities (Ministry for Primary Industries 2018), strategic and tactical mitigation solutions must be studied and identified considering that New Zealand ratified the Paris Agreement in 2016 and is committed to reduce GHG emissions to 5% below 1990 levels by 2020 (Ministry for the Environment 2018).

Drinking water for New Zealand's population is sourced from rivers, ground water and lakes. Section 69A of the Health Act (1956) states that the purpose of this part of the Act is to protect the health and safety of people and communities by promoting adequate supplies of potable and wholesome drinking water from all drinking water supplies, which requires drinking water suppliers to take all practicable steps to comply with the drinking water standards. The drinking-water standards for New Zealand specify minimum compliance criteria for bacteria, protozoa, cyanotoxins, chemicals, and radioactive materials of public health significance in drinking-water (Ministry of Health 2018). Water quality is showing a declining trend and this was linked to the intensification of grazing livestock activity (Ledgard et al. 1996). Specifically, intensive dairy farming was associated with an increase in water usage, increased SR, riparian grazing, native vegetation removal, and wetland drainage, which led to increased faecal contamination, and an excess of nutrients and sediments in water (Foote et al. 2015).

2.4 Nitrogen use efficiency and losses in grazing dairy systems

Proteins are functional biomolecules consisting of one or more long chains of amino acids which are essential nutrients for any living organism and intervene in the vital processes of living organisms according to the sequence of these amino acids and their specific three-dimensional structure. According to the Kjeldahl method, most proteins are comprised of 16% of N, thus the conversion factor is 6.25. Forage CP in grasses varies widely, while tropical grasses typically contain values of 6-8% CP (Waghorn and Clark 2004), CP values in temperate pastures average 16-22% (Kolver and Muller 1998). The N recovered in milk protein as a proportion of CP intake over a given period, is able to be assessed, and is termed ECPU. An excess of CP for animal requirements, frequently encountered under grazing conditions in New Zealand (Waghorn and Clark 2004; Pacheco and Waghorn 2008), results in a decrease in the ECPU (Tamminga 1992; Castillo et al. 2000; Kebreab et al. 2001). This results in increased excreted N, predominantly in urine (Kebreab et al. 2001), leading to elevated nitrate-N levels in soil solution and groundwater (Ledgard et al. 1996; Di and Cameron 2002b; de Klein et al. 2010). Moreover, the inclusion of supplementary feeds, discussed previously, introduces more nutrients to the farm system, and also results in farmers increasing stock numbers, all resulting in an intensified N load in the urine patch which compromises the NUE at the farm level for pasture-based dairy systems (Di and Cameron 2002b). These management strategies are identified as part of the intensification of pasture-based dairy systems (de Klein et al. 2010; Monaghan and de Klein 2014).

2.4.1 Nitrogen flow on pasture-based dairy systems

The natural N cycle of grazing ecosystems is characterised by numerous transformations, passing through the atmosphere, the soil, the plant, and the grazing animal. The amount of N in pasture plants is expressed as a concentration of CP on a dry matter (DM) basis, and in grasses and forbs this typically ranges from 10-24 % CP, and in legumes from 20-30% (Waghorn and Clark 2004). Nitrogen is vital for temperate plant growth and function, and is principally contained in an enzyme named Rubisco (ribulose 1,5-biphosphate carboxylase), responsible for photosynthetic activity, the first step of carbon fixation, a process in which atmospheric CO_2 is converted by plants and other photosynthetic organisms to water-soluble carbohydrates (Fulkerson and Donaghy 2001).

In New Zealand, pastures utilised in dairy systems are mainly comprised of perennial ryegrass (*Lolium perenne*) with a minor proportion of legumes, usually white clover (*Trifolium repens*) (Ledgard 2001). In the case of ryegrass, the accumulation of forage mass involves several processes including the expansion of leaves to the formation of tillers in order to increase light interception. In turn, the mobilisation of carbon assimilates through the plant, root growth and senescence includes the re-translocation of some constituents of old leaves, especially N, to support the expansion of new leaves (Chapman 2016).

In the pastoral N cycle, the principal sources of N are through the wet and dry depositions as a direct consequence of ruminant's grazing activities (McNeill and Unkovich 2007) and through the fixation of atmospheric N via biological fixation process (Ledgard et al. 1996). In this process, genera of specialised microorganisms have the enzyme complex nitrogenase which reduces atmospheric N to ammonia (NH_3). These are free-living organisms, but some, such as Rhizobium or Bradyrhizobium, are able to live in close association with plants, from which the plants may benefit. As a result of this symbiotic relationship, microorganisms obtain energy from the plant and, at the same time, plants sequester NH_3 from microbes. Such exchange occurs within root nodules on perennial and annual legumes (Ledgard et al. 2001; McNeill and Unkovich 2007). It was estimated that between 100 and 300 kg of N can be incorporated to the soil in ryegrass/white clover pastures per annum from biological fixation (Ledgard et al. 1996), depending on the N content of the soil and activity of legumes growing along with grasses, among other factors (Schwinning and Parsons 1996). However, increasing N fertiliser application often interferes with the N fixation activity of legumes (Ledgard et al. 1997; Ledgard et al. 1999) and affects the ability of legumes to compete with grasses (Figure 2.10).

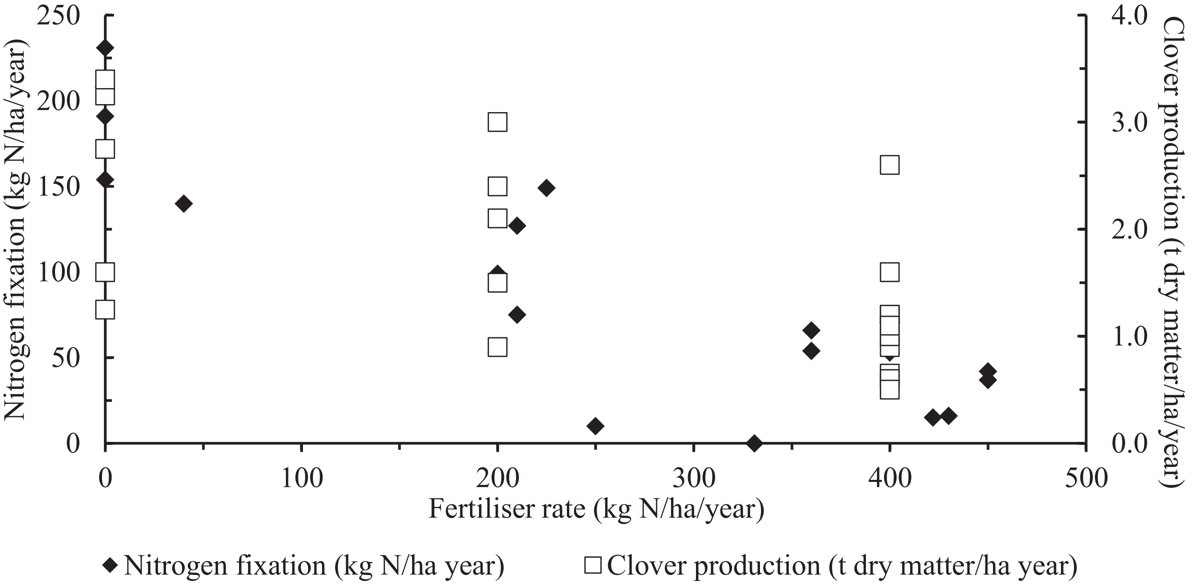

Figure 2.10 Relationship between nitrogen (N) fixation activity and N fertiliser rate in New Zealand mixed-pastures conditions (Ledgard et al. 1997; Ledgard et al. 1999).

The largest pool of N in soil is contained in the organic matter located principally in the root zone (McNeill and Unkovich 2007). As part of a decomposition process undertaken by soil biota termed mineralisation, organic matter and plant residues become sources of plant-available N, in the form of ammonium and nitrate. Grass growth rate increases under conditions of high N supply (Peyraud and Astigarraga 1998) at the expense of root development (Fulkerson and Donaghy 2001). Pastures may lack N in the summer months because of reduced mineralisation activity and diminished clover activity (Ledgard et al. 1999). Additionally, typical summer conditions include low soil water content along with higher temperatures in soils, and these conditions might promote the retention of ammonium and nitrate by soil microbes in a process known as N immobilisation (Cranswell 1978; Saggar et al. 2013).

The oxidation of ammonia to nitrate in a process known as nitrification is performed by a relatively small number of autotrophic and heterotrophic microbial species (McNeill and Unkovich 2007). Edaphic factors such as pH, moisture, temperature, and aeration determine the gross amount of N oxidised and also which microbe species will participate in this process (Saggar et al. 2013). Under anaerobic conditions, bacteria reduce nitrates to dinitrogen, nitric oxide, and N_2O, in a process known as denitrification (Bolan et al. 2004). A study conducted by Saggar et al. (2013) found that the rate of denitrification depends on a complex interaction between soil properties, soil microorganisms, climatic factors, and management practices.

Nitrous oxide gas plays a central role in ozone decomposition of the stratosphere and contributes to global warming (Bollmann and Conrad 1998).

2.4.2 Dairy cow crude protein utilisation efficiency

Grazing activity by ruminants and other herbivores has major consequences for the nutrient flow in pasture ecosystems (Chaneton et al. 1996). In the case of the N cycle, the majority of N eaten (around 70%) is excreted (Whitehead 1995). Fresh grazed pasture and supplements provide the substrates for ruminal microbiota. The 'nutritive value' of a feed refers to the nutrients required by the animal including CP, lipids, fat-soluble vitamins, macro-elements including sodium, calcium, potassium and phosphorus, microelements and energy (Waghorn and Clark 2004). Forage CP, which is usually expressed on a DM basis, includes amino acids, peptides, nucleic acids and other molecules such as nitrate, nitrites and condensed tannins. Considering that non-protein N accounts for more than 75% of plant N, the term CP overestimates the true protein content of plants. Crude protein can be influenced by a number of factors, including soil N (Peyraud and Astigarraga 1998), plant species (Cosgrove et al. 2014), plant composition (Waghorn and Clark 2004) and pasture phenology as affected by grazing management (Gregorini et al. 2010; Chapman 2016).

Dietary CP can be categorised as ruminal degradable (RDP) or undegradable protein (UDP) fractions. Rumen microbes only have access to the RDP and a fraction of non-protein N to support growth, activity, and reproduction. These fractions will be converted into the true source of protein to ruminants, the microbial CP. The RDP fraction is made up of both quickly-degradable protein and slowly-degradable protein. Only 80% of the quickly-degradable protein is available for the microbes and the sum of the discounted quickly-degradable protein and slowly-degradable protein constitutes effective RDP (Chamberlain and Wilkinson 1996). The UDP along with the microbial CP plus a remaining portion of recycled endogenous N is assimilated in the duodenum of the small intestine (AFRC 1993; Chamberlain and Wilkinson 1996; NRC 2001). Undigested CP is excreted in faeces, while the digested CP is either converted into milk protein or protein body tissues, or converted to urea in the liver and excreted via urine urea from the kidney (Satter et al. 2002). When feeds are of high digestibility, increases in feed intake will increase the speed of feed passage through the rumen, implying less time for the feed to be exposed to microbes and this could limit the CP degradability. On the other hand, increasing UDP with industrial processes such as heat or tanning to reduce the CP degradation in the rumen, may be beneficial to the uptake of N in the small intestine (Dufreneix et al. 2019). Reductions in the ECPU of dairy cows were observed to increase N in excreta, predominantly in urine (Kolver and Muller 1998; Castillo et al. 2000; Kebreab et al.

2001; Satter et al. 2002). When solely feeding fresh-grazed pasture, the opportunity for dietary manipulation is limited, and so supplementation with concentrate feeds high in energy and low in CP may be an option to dilute the high portion of CP present in pastures (Whelan et al. 2012; Hills et al. 2015). Supplementation should be planned according to the nutritional requirements of the grazing cows and the seasonal condition of pastures. In short, not all supplements are suitable for grazing conditions and the indicated source of supplements will vary from one situation to another (Kolver 2000; Hills et al. 2015). Moreover, any reduction in CP needs to ensure that the quantity and quality of essential amino acids for milk production and function of the animal are not compromised (Higgs et al. 2015).

Ruminants have an effective internal N recycling system where all excess dietary N is converted to urea in the liver in a process called ureagenesis to overcome poisoning from NH_3 present in the systemic circulation. The liver along with the portal-drained viscera are tissues of high internal N metabolic activity and, representing less than 10% of live weight (LW), are responsible for the major N metabolic exchange in ruminants (Lapierre et al. 2005). In turn, urea is transported from the plasma to other body fluids such as saliva to be recycled, and in urine to be excreted, but due to its molecular weight and neutral charge, urea easily diffuses across cellular membranes where it is incorporated to milk (Jonker et al. 1998). From the total non-protein N in milk, approximately 46% is in the form of milk urea (MU) (DePeters and Ferguson 1992). This labile N pool is highly influenced, amongst other factors, by feeding management and types of supplement feeds included (Spek et al. 2013).

In a study conducted by Jonker et al. (1998), increasing dietary CP from 13.5 to 19.4% resulted in increased MU and reduced NUE. Thus, it was concluded that MU could be used to explain differences in NUE. As such, MU has been proposed as a proxy to identify excess dietary CP (Broderick and Clayton 1997; Jonker et al. 1998), and because of the negative relationship between N intake and NUE (Castillo et al. 2000), MU has been proposed as a predictor of N excreta at the cow level (Jonker et al. 1998; Kauffman and St-Pierre 2001; Nousiainen et al. 2004; Burgos et al. 2007; Hynes et al. 2016). Considering that milk companies are providing bulk tank MU records to farmers, a study conducted by Gourley et al. (2012) suggested to use this indicator as a management tool to assess the CP level of diets fed. However, caution must be taken when using MU across herds because other non-nutritional factors, such as methodologies of laboratory analysis, might interfere (Aguilar et al. 2012).

The complexities of the N recycling system described, explains the adaptation of ruminants to low CP diets, but with CP values lower than 8-10% seen as limitations to microbial growth

(Waghorn and Clark 2004), but in order to sustain moderate to high levels of milk production, lactating dairy cows require a higher proportion of CP (above 14%) according to production level and stage of lactation (Kolver 2000).

Nitrogen excreta in dairy manure is a precursor to N_2O and nitrate. While N_2O is a major contributor to GHG emissions, nitrates, which are water-soluble, move inside the soil dynamically and are incorporated in both ground and surface water in a process identified as N leaching loss (Di and Cameron 2002b; Di and Cameron 2005; Houlbrooke et al. 2008; Matthew et al. 2010; Horne et al. 2012). Total N excreta includes N contained in faeces and urine during a given period. Normally urine N is the main component of the N excreta accounting for 40 to 70% (Castillo 1999). Faecal N is the main fate of undigested feed N, undigested microbial N and endogenous N (Tamminga 1992). Compared to urine N, faecal N is less labile (Powell and Rotz 2015) and likely to remain in soil for a longer period, providing more time for plants to access it, rather than be lost to the environment (Woodward et al. 2009). For this reason, there is much interest in methods to increase the N excreta partitioned towards faecal N rather than urine N (Yamulki et al. 1998; Satter et al. 2002; Hristov et al. 2005; Hynes et al. 2016; Mutsvangwa et al. 2016).

An ideal scenario to assess the NUE of dairy cows would include a complete N balance where the partitioning of N intake towards N in faeces, urine, milk, retention in body tissues, and the foetus could be examined (Castillo et al. 2000). Unfortunately, these studies cannot be undertaken on large numbers of cows under grazing conditions. However, in grazing herds, the ECPU can indicate the proportion on N captured in milk from total N intake (Higgs et al. 2009; Powell et al. 2010; Zamani 2012). Additionally, a CP balance can be calculated on a daily basis as the difference between CP intake and milk protein synthesis (Zamani 2012), with higher values indicating ‘inefficient cows’.

The NUE of milking cows has been described under a range of farming conditions by a number of authors (e.g. Castillo 1999; Castillo et al. 2000; Powell et al. 2010; Gourley et al. 2012; Powell and Rotz 2015). The most significant action to increase NUE at a cow level is to reduce dietary N intake (Figure 2.11).

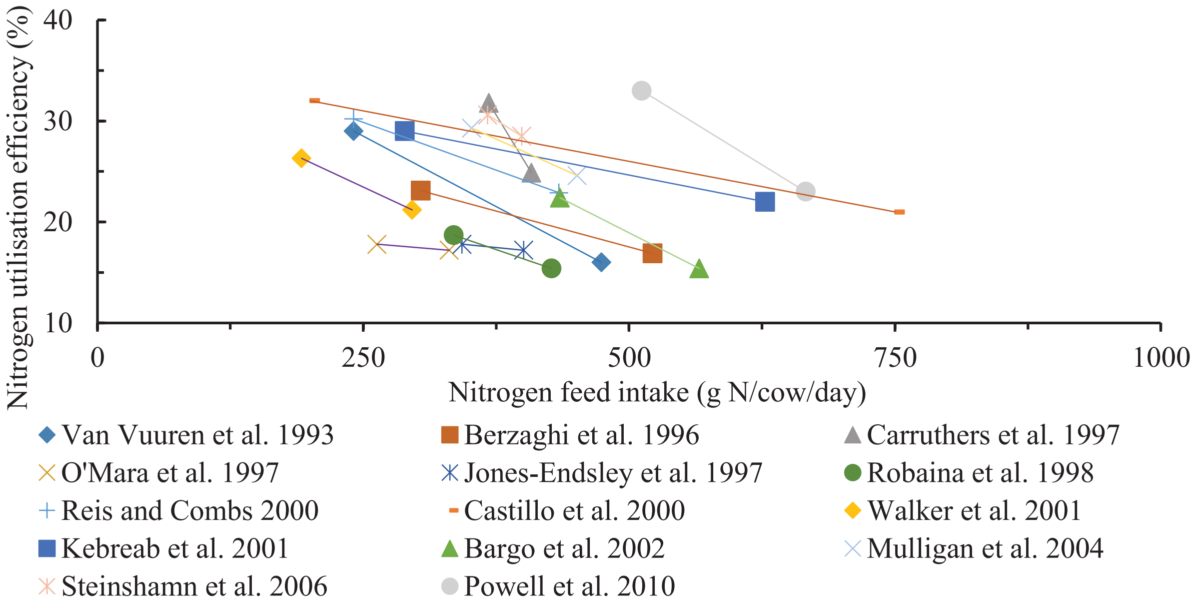

Figure 2.11 Relationship between nitrogen (N) feed intake (g N/cow/day) and N utilisation efficiency.

The mobilisation of body protein during lactation should be included in determining the protein balance in a lactating cow (Daniel et al. 2017). Based on this, and given that 160 g of CP is used to produce 1 kg of LW (Huhtanen et al. 2015), any gain in LW during lactation represents a ‘capture’ of N in tissues and similarly, any LW loss would mobilise CP. A study conducted by Berry et al. (2007) concluded that cows with high milk yield lost more body condition and LW and this was accentuated in early lactation. As such, the efficiency of CP use will be influenced by the kinetics of LW variation during lactation.

In addition to the negative economic impact of feeding excess nutrients (Kalantari et al. 2016; Wales and Kolver 2017), the extra N discharged from excreta as a consequence of reduced NUE has detrimental effects on the environment, particularly under year-round grazing conditions as is the case in New Zealand.

2.4.3 Whole-farm level nitrogen utilisation efficiency

Inefficiencies in the N cycle at a farm level result in N losses to the environment, and this is recognised as a major negative impact of dairying (de Klein et al. 2010). Moreover, as dairying has intensified, so has its environmental impact (Jay 2007; Foote et al. 2015). The difference between farm N inputs, and N outputs in saleable products such as milk and meat, is termed ‘N surplus’.

At a paddock or whole-farm level, all nutrients input into or output from the system are considered (Ledgard et al. 1999; Peyraud and Delaby 2006; de Klein et al. 2016). Figure 2.12 displays the N flows in dairy grazing systems including the N inputs (i.e. fertiliser, supplementary feeds, legume symbiotic fixation), the internal N flows, and N outputs as saleable products such as pasture silage, and N contained in milk and meat. Peyraud and Delaby (2006) propose that inefficiencies of N utilisation are a result of surplus N, calculated as the difference between outputs and inputs. The N surplus does not take account of the internal N flows but higher figures indicate that more N is available to be lost.

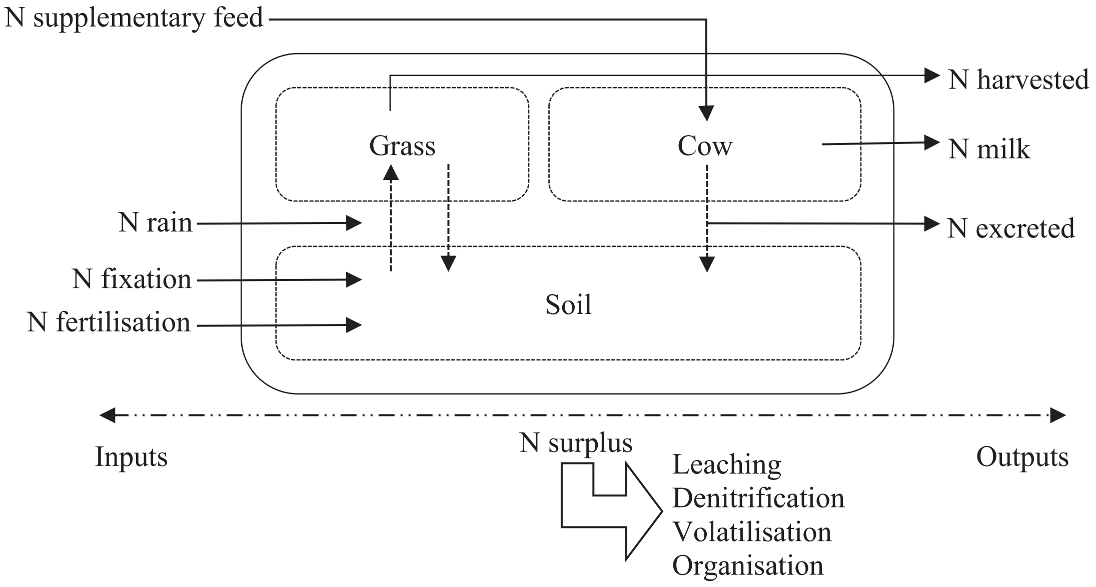

Figure 2.12 Inside and outside nitrogen (N) flows at the paddock level on dairy grazing systems (Peyraud and Delaby 2006).

A study of NUE at the whole-farm level by de Klein et al. (2016), which included dairy systems of New Zealand, Australia, USA and Ireland among others, reported a large variation in NUE with values between 29% and 45.5%, mostly due to system-level differences (e.g. housed vs pasture, amount of supplementary feed, fertiliser levels, milk production and breeds).

The positive response of pasture growth to N fertiliser applied is widely recognised (Thomson et al. 1991; Harris and Clark 1996; Monaghan et al. 2005). Nitrogen fertiliser would affect pasture productivity and the botanical composition of pastures (Peyraud and Astigarraga 1998). Also, soil type (Powell and Rotz 2015), climatic conditions, amount of fertiliser applied (Smith et al. 2000; Shepherd and Lucci 2013), botanical composition (Totty et al. 2013), and grazing management (Macdonald et al. 2001) drive pasture N uptake.

Smith et al. (2000) evaluated the effect on total pasture production and length of response (days after application) when N fertiliser was applied at different times of the year in the South Island of New Zealand, and concluded that applications in late winter-early spring had a better pasture growth response, and had a larger carryover effect measured in days after fertiliser application. An increased pasture growth response to N fertiliser results in increased NUE, by diluting herbage CP as a result of increased pasture growth (‘dilution effect’).

Peyraud and Astigarraga (1998) reviewed the impact of N fertiliser on total productivity and quality of perennial and annual herbage species. In Figure 2.13, Peyraud and Astigarraga (1998) propose two levels of N fertilisation. While the 200 kg N/ha applied per cut reflects experimental conditions, the 30 kg of N/ha per cut reflects N fertiliser rates more in line with the standard practices in New Zealand farming conditions (Figure 2.8). Increased intake of pasture by dairy cows was mainly explained by increases in herbage allowance. An almost linear relationship between herbage CP and N fertiliser application occurred for the period considered in the study by Peyraud and Astigarraga (1998). Grazing management has an important effect on herbage N concentration. Herbage N concentration peaks in early regrowth due to plants taking up more N than is required for their immediate needs (‘luxury uptake’). This luxury uptake is followed by a steady decrease in herbage N concentration as regrowth progresses. Therefore, cows eating herbage at an early stage of regrowth will ingest greater amounts of CP than if they graze later in regrowth, and this is exacerbated by N fertiliser application (Gregorini et al. 2010; Shepherd and Lucci 2013). These management practices would be accompanied by a reduced NUE at both cow and farm level.

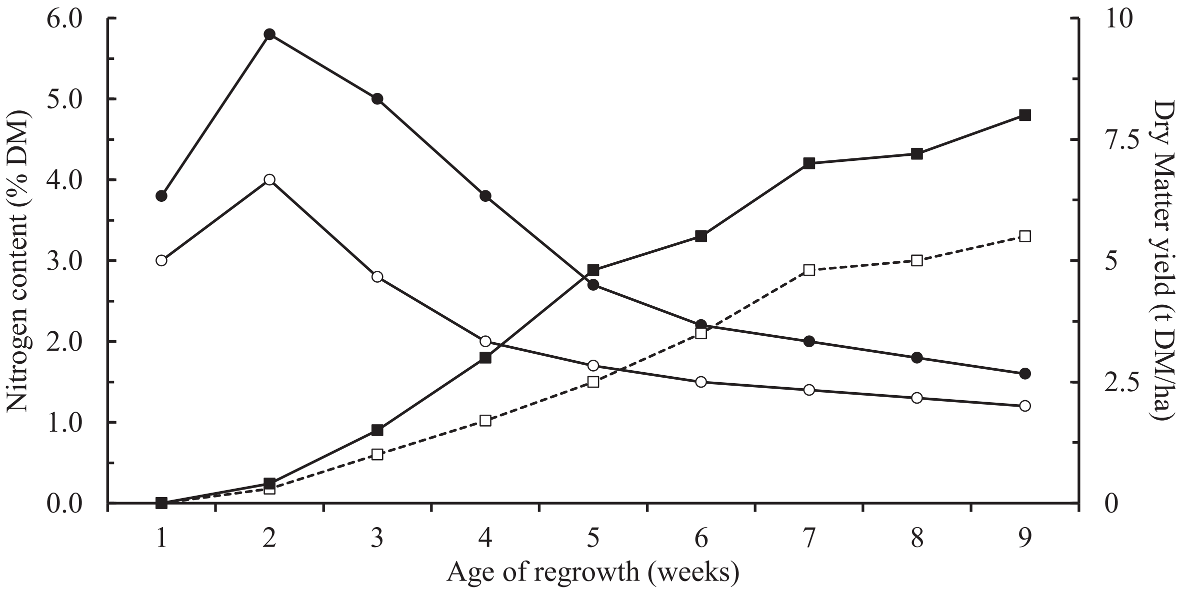

Figure 2.13 Effect of two nitrogen (N) fertiliser rates on pasture N content and pasture production on a ryegrass pasture. Pasture production accumulated [t dry matter (DM)/ha] (□) and grass N content (%) (○) at 30 kg N/ha per cut, and pasture production accumulated (t DM/ha) (■) and grass N content (%) (●) at 200 kg N/ha per cut (Peyraud and Astigarraga 1998).

The N in faeces may be regarded as being more stable, as it is likely to move from excreta into the soil at a slower rate than the N in urine (Satter et al. 2002). A typical urination from a dairy cow covers an area ranging from 0.15 m^2 to 0.50 m^2 (Cichota et al. 2018), and contains the equivalent of between 500 to 1000 kg N per hectare (Whitehead 1995). Urea from urine rapidly converts to NH_3 in soil and moves into the surrounding soil where it becomes available to the pasture (Decau et al. 2003). Urinary N deposition is generally far in excess of immediate plant requirements for N (Di and Cameron 2002a; Di and Cameron 2005; Houlbrooke et al. 2008; Matthew et al. 2010; Horne et al. 2012). Moreover, pasture growth rates of the typical unirrigated New Zealand perennial pastures are likely to decline in late summer-early autumn and are still exposed to urination events so N in soil 'builds up' in the urine patches. With autumn rainfall, soils become wet and pasture growth initially increases but then decreases again as winter progresses. As soils become wet, the N is dissolved and moves with the soil water increasing N leaching from the urinary N sourced in late summer/early autumn (Christensen et al. 2018a; Christensen et al. 2018b). The effect of overlapping urinary patches would exacerbate N leaching, but the probability of occurrence is low, with values between 2 to 3% in homogeneous grazing conditions (Li et al. 2012). Nevertheless, Betteridge et al. (2010) demonstrated a strong urinary behaviour with more than 30% of depositions concentrated in flat sections of the paddock usually associated with stock camping areas.

The increase in both SR and N fertilisation in New Zealand as part of the intensification process has resulted in increased N leaching from dairy systems. Figures 2.14 and 2.15 present a selection of studies undertaken in New Zealand and Ireland where correlation of N leaching is analysed along with SR and N fertilisation level, respectively. Both variables influence N losses, but fertiliser application rate appears to have a larger impact probably due to a small increase in N uptake by pastures relative to the amounts of N applied as a consequence of the seasonal variation in N uptake by plants (Shepherd and Lucci 2013). Additionally, when comparing the effect of fertiliser N inputs vs increasing SR on N captured in milk, Ledgard et al. (1999) concluded that the increase in milk-N equated to only 6.7 and 4.3% of fertiliser N applied in the farmlets with 200 and 400 kg N per ha, respectively. Increasing SR from 3.24 to 4.48 cows per ha augmented the N captured in milk by 9.6%.

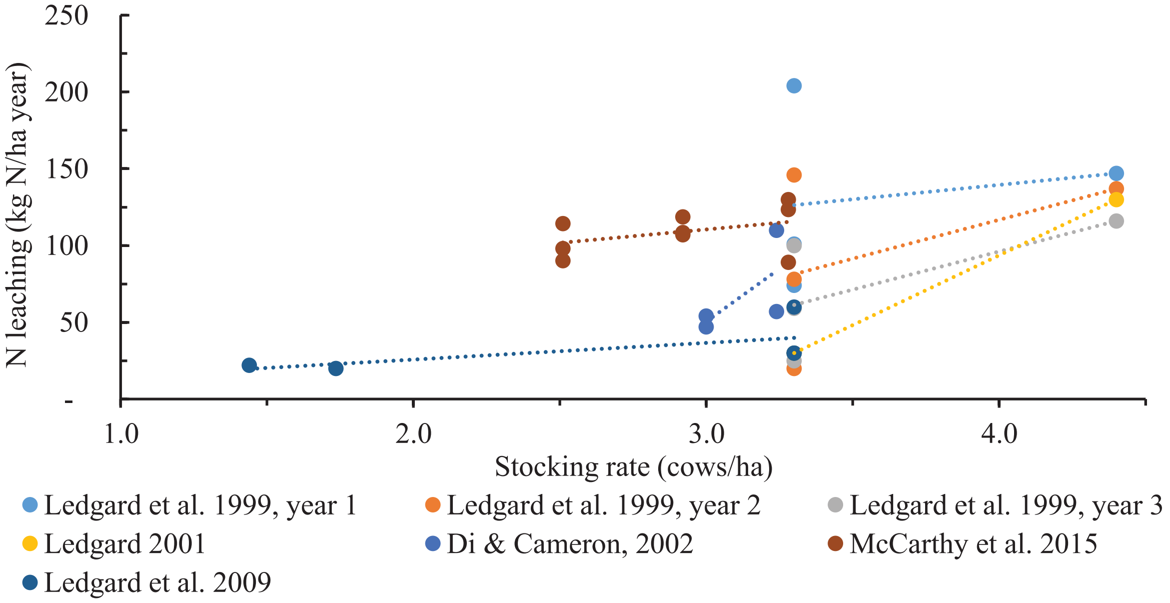

Figure 2.14 Relationship between nitrogen (N) leaching (kg N/ha/year) and stocking rate (cows/ha).

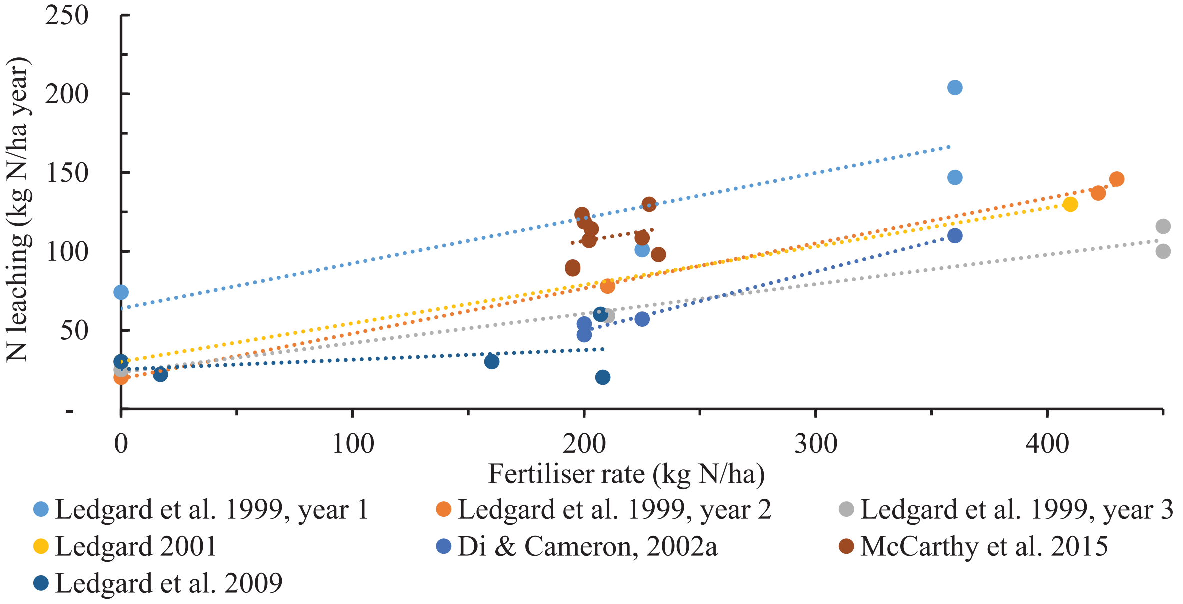

Figure 2.15 Relationship between nitrogen (N) leaching (kg N/ha/year) and N fertiliser rate (kg N/ha/year).

An increase in SR is not always associated with an increase in N leaching, as there are many factors that influence N leaching. For example, by increasing the number of cows, there will be less pasture available for each cow (Macdonald et al. 2008), and therefore a greater efficiency of N used and less surplus N to be leached (Roche et al. 2016). At higher SR, larger quantities of supplements are often fed (Hills et al. 2015), and the inclusion of high-energy concentrate supplements, which are usually also low in N content, (Kolver et al. 1998; Reis and Combs 2000), reduces the intake of CP, subsequently reducing N losses (Mulligan et al. 2004) and increasing NUE (Castillo 1999; Castillo et al. 2000; Powell et al. 2010; Gourley et al. 2012; Powell and Rotz 2015). On the other hand, if the increase in N fertiliser and inclusion of supplements are used to support an increased SR and to extend the lactation, then the increase in SR would be associated with an increase in N leached. But if the higher SR is accompanied with low to moderate inclusion of supplements, cows generally have a shorter lactation and so less animals are grazing over the late summer to autumn period (Roche et al. 2016) which is the key period over which N accumulates in soil prior to leaching (Christensen et al. 2018a; Christensen et al. 2018b).

In comparison to the lack of a simple relationship between SR and N leaching, Figure 2.15 displays N leached with fertiliser N applied. Compared to Figure 2.14, the positive regression slope for each study in Figure 2.15 indicates a strong relationship between N fertiliser application, and N leached (Ledgard et al. 1999).

Many strategies have been explored to reduce nutrient losses from grazing systems including the utilisation of riparian strips in order to capture nutrients before exiting the farm (Monaghan et al. 2008), implementation of best-practice management for N fertiliser use (de Klein and Eckard 2008), and by improving the SR management according to the time of the year (Di and Cameron 2002b). The adoption of housing where cows are kept indoors for a limited period of time in order to maintain animals off pastures during the sensitive period (late summer-early autumn), and to collect excreta and spread it homogeneously during optimum periods is another technique studied (Christensen et al. 2018b; Christensen et al. 2018a). However, adoption of the use of housing would be limited to regions were serious soil and pasture damage are likely to threaten the business, given the considerable increase in total and running costs of buildings (DairyNZ 2015).

The New Zealand dairy industry is facing a challenge to develop farm systems that can maintain or increase production and profitability to meet increasing global food demand, while reducing their environmental footprint. Even though there is evidence of sound research identifying potential step-changes in the mitigation of N losses from dairy systems, there has been relatively low adoption of strategies at the farm level (Rawnsley et al. 2018). Management decisions at the farm level have traditionally focused on improving efficiency, lowering costs, and maximising profit (Lovett et al. 2008). On the other hand, environmental mitigation strategies are complex to understand and quantify. Additionally, if these practices increase the complexity of already-busy dairy systems and increase costs, or reduce milk production, then they are unlikely to be implemented.

Modelling both production and mitigation strategies on a whole-farm scale requires careful consideration of complex farm systems, where different factors such as animal breed (Ryan et al. 2011), climate conditions (Cabrera et al. 2005), forage alternatives (Beukes et al. 2018), and management techniques (Foskolos and Moorby 2018; Van der Weerden et al. 2018) all need to be taken into account. Van der Weerden et al. (2018) proposes ‘improved’ dairy systems for New Zealand, taking account of regional differences in soil type and climate conditions. The mitigation options that they propose include reducing SR and the use of higher-producing cows with superior efficiency of feed conversion, reducing N fertiliser, reducing milking cow replacement rates, and increasing the use of high-energy supplementary feed low in N. Additionally, they proposed the use of off-paddock facilities to lessen the time cows spend on paddocks. The theoretical economic trade-off in implementation of these changes is that the potential reduction in milk production per hectare by reducing SR is balanced by more milk per cow. In their analysis, reducing N fertiliser reduced pasture production, and this is accounted for by fewer cows better utilising the pasture. Improving the efficiency of milking cows is expected to reduce the replacement cows required, as there would be less non-pregnant cows. Incorporating off-farm supplements aiming to reduce the N intake at a cow level and to reduce the ingress of N at the farm level, will result in less surplus of N at both levels. The purchase of high-energy supplements low in N can increase direct costs of production, but this is expected to be balanced by the reduction in N fertiliser purchased, and by feeding fewer cows that are more efficient in converting feed to milk. This analysis of Van der Weerden et al. (2018) concludes that there are alternatives to reduce the environmental footprint while maintaining profitability. However, these mitigation strategies cannot be applied at the same time and with similar magnitude in all instances.

While recognising the relevance of the nutritional management of the dairy herd in reducing N losses, lifespan analysis of NUE from dairy systems in the United Kingdom emphasised the benefits of reducing the replacement rate of the herd on several economic and environmental aspects (Foskolos and Moorby 2018). Reducing the replacement rate reduces the cost and environmental impacts associated with rearing of new replacement animals. Additionally, having fewer primiparous cows in the milking herd increases average milk production per cow and this improves the efficiency of feed and N usage at a herd level. In the study by Foskolos and Moorby (2018), total replacement costs account for 15 to 20% of total milk production costs, with the majority of lifespan N losses (and lower NUE) detected in the proportion of N not captured in milk by accounting for the reduced milk production of primiparous cows. Foskolos and Moorby (2018) concluded that the NUE at a farm-level was enhanced by improving the management of diet and aspects of fertility and animal health.

2.5 Conclusions

Throughout this chapter, positive and negative environmental aspects of the intensification of the New Zealand pasture-based dairy systems were described (i.e. supplementation, fertilisation, milking frequency). The ongoing intensification of New Zealand dairy farming systems is increasing pressure on soil and water resources, and, at the same time, jeopardising long-term environmental sustainability. At the same time, it was identified that an increasing number of New Zealand farmers may be choosing to adopt OAD systems throughout the season which are generally associated to less intensity (i.e. fewer inputs) when compared to traditional TAD systems of higher input inclusion. According to the levels of input inclusion in each system, different outcomes in NUE would be expected. Inevitably, future dairy systems need to be focused on the reduction of their environmental footprint but in order to be more attractive to farmers (i.e. readily implemented), these mitigation practices should not be associated with a reduction in profitability.

It is important to consider that global food demand from emerging markets is increasing, so the alleviation of environmental footprint cannot only focus on reducing food production aiming to reduce the pressure on natural resources, but needs to take a more holistic approach.

There is increasing social concern in many countries regarding the high dependency on feed sources suitable for human nutrition as feed for dairy cows (e.g. soybeans, cereal grains). In addition, because of the negative public perception of dairy farming on animal welfare (e.g. removal of calves from their mothers soon after being born, culling of male calves), more regulations are being implemented in the dairy industry globally.

There is substantial interest internationally in adopting grazing systems, not only due to farmers wanting to reduce feed costs, but also wanting to comply with regulations from governmental authorities on animal welfare and environmental impact. Additionally, there might be an opportunity to add value to milk produced from grazing dairy systems as it is positively perceived by society (compared with housed cows), but there must be a collective effort from all the dairy industry participants in order to achieve this.

The reduced use of N fertiliser, culling unproductive animals, and increased use of diets designed to increase the efficiency of nutrient utilisation, may provide part of the solution. Both high and low input dairy systems would need a different arrangement of mitigations strategies according to level of milk production, region and design of the dairy system.

The challenge is to identify mitigation practices for pasture-based dairy systems of different intensification levels that can maintain or increase production while reducing the environmental footprint.

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Chapter 3

Phenotypic correlations of milk urea and the efficiency of crude protein utilisation with milk yield traits and cow performance in two contrasting dairy systems in New Zealand

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3.1 Abstract

The objectives of the present study were to investigate phenotypic correlations of milk urea (MU) and efficiency of crude protein utilisation (ECPU) with milk production and cow parameters in two contrasting herds differing in intensification levels in New Zealand. In the low-intensity production system (LIPS), 257 cows were milked once-daily and fed diets with low supplementary feed inclusion during the lactation (304 kg pasture silage/cow). In the high-intensity production system (HIPS), 207 cows were milked twice-daily with higher supplementary feed inclusion (429 kg pasture silage and 1,695 kg concentrate/cow). In early, mid and late lactation, milk samples were collected to measure MU. At every herd test date, ECPU was calculated as protein yield (PY) divided by crude protein intake (CPI); this last variable derived from intake estimations of metabolisable energy requirements. Positive correlations between milk yield (MY) and both dry matter (DM) intake (DMI) and CPI were observed in LIPS and HIPS. The ECPU only correlated positively with MY traits in LIPS, and there was no correlation of CPI with MU in either herd. A moderate negative correlation of ECPU with live weight (LW) was observed in both herds, but it was stronger in LIPS. In LIPS, offering a diet higher in CP due to the higher fresh pasture fed and suppressing MY due to the reduced milking frequency, these cows gained LW, had higher body condition score, and lower PY, reducing the ECPU. No correlation between ECPU and MU was detected.

Keywords: phenotypic correlations, intensification, crude protein utilisation, milk urea.

3.2 Introduction

In New Zealand, temperate climate and natural soil fertility enable pastoral farming all year round. Driven by increasing global food demand, farmers have steadily intensified milk production over the past several decades. Although these systems are perceived as having low inputs when compared to those of countries in Europe and North America, a range of intensification among New Zealand farmers is detected when considering levels of inclusion of supplementary feed and nitrogen (N) fertilisation.

Inefficiencies in N fertilisation (de Klein et al. 2010), extra N incorporated through supplementary feeds (Powell et al. 2015) and low efficiency of N utilisation by ruminants (Ryan et al. 2012) are linked to N losses. Moreover, the high loading rate of N under the urine patch of cows is exacerbated by the application of N fertilisers and waste effluents (Di and Cameron 2002), aggravating surface and ground water pollution. Because of this, regional authorities have incorporated regulatory limits for N leached from farms. For example, in the Manawatu region the Regional Council have imposed limits on N leached according to Land Use Capability class (Horizons 2016). Exploring mitigating strategies will contribute to the development of sustainable production systems.

Nitrogen utilisation can be estimated as the ratio of protein present in milk to the intake of crude protein (CP) from feed consumed by lactating cows (Castillo et al. 2000), and is expressed as the efficiency of CP utilisation (ECPU). Milk urea (MU), as the main non-protein source of N in milk, has been proposed as an indicator of dietary level of CP because of its direct relationship with blood urea N, which refers directly to the natural releases of excess N from metabolism (Gustafsson and Palmquist 1993). Milk urea concentration has been proposed as an index to identify inefficiencies of N utilisation in dairy systems (Jonker et al. 1998).

The objectives of the present study were to compare phenotypic correlations of MU and the ECPU with milk production performance and cow parameters throughout one entire season in two contrasting dairy systems of low and high supplementary feed inclusion.

3.3 Materials and methods

This study was conducted at Massey University in Palmerston North NZ, from June 2016 to May 2017. In response to a different management approach a different feeding plan was implemented in each research farm. The Massey University No. 1 dairy farm is managed as a low-intensity production system (LIPS) with cows milked once-daily throughout the season, with low SR (2.1 cows/ha) and feed strategy includes restricted supplementation and grazing crops are utilised in summer while fresh ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture is the main diet component throughout the year. On the other hand, Massey University No. 4 dairy farm is managed as a high-intensity production system (HIPS) with cows milked twice-daily throughout the season, with higher SR (2.8 cows/ha) and fresh pasture is fed with higher supplementation level is included throughout the year.

In LIPS, cows were milked once daily at 6:30 am. In August and from March to May, cows received 3.5 kg of dry matter (DM) of pasture silage per cow per day. From December to February, cows grazed a mixed herb crop comprising chicory (*Cichorium intybus*), red clover (*Trifolium pratense*) and plantain (*Plantago lanceolata*) for three hours per day, at an allowance of 3.5 kg DM per cow. In February, cows were allocated 2.6 kg DM per cow of turnip (*Brassica campestris* ssp. *rapifera*). Lucerne (*Medicago sativa*) was grazed directly from the paddock in March and May at an allowance of 3 kg DM per cow per day.

Cows in the HIPS herd were miked daily at 5:30 am and 2:30 pm. Maize silage (*Zea mays*) and grain-based concentrate were fed during the lactation at 3.5 kg DM per cow per day before the afternoon milking and 2 kg DM per cow per day inside the parlour, respectively. In January, pasture silage was fed in the paddock at 3 kg DM per cow per day. In March, 0.75 kg DM per cow of dried distillers grain was fed during the morning milking, and cows were also allocated turnip crop at 2 kg DM per cow per day.

Herbage mass measurements of ryegrass-white clover pasture were taken before and after each grazing event with a rising-plate meter following a ‘W’ pattern across the grazing area, using a global positioning system. Three quadrat cuts (0.1 m^2) were taken both before and after grazing to quantify kg DM per ha of the grazing crops. These measurements enabled calculation of apparent pasture and crop utilisation, and also the proportion of herbage allocated to cows before each herd test.

Samples (approximately 1,500 g of wet weight) of fresh pastures and crops were taken by hand-plucking, and these, along with samples of silage and concentrate, were freeze-dried and ground (Wiley mill) to pass through a 1.0 mm screen. All samples were then analysed by the near infrared reflectance spectroscopy technique (Corson et al. 1999) to evaluate metabolisable energy (ME) and CP content.

Daily live weight (LW) measurements were generated with an automatic race walkover scale and body condition scores (BCS) were assigned in synchrony with each herd test by a single research technician using a 10-point scale (Macdonald and Macmillan 1993). Yields of milk (MY), fat (FY) and protein (PY) and somatic cell count (SCC) were collected from herd test records. The SCC were log-transformed to somatic cell score (SCS). Lactation curves for milk production traits and cow performance were obtained using Legendre polynomials of third order generating daily records for each cow during the season.

Additionally, milk samples from each cow were taken in early (September), mid (December) and late (March) lactation using herd test milk meters provided by Livestock Improvement Corporation. These samples were analysed by MilkTestNZ (Hamilton, NZ) using the CombiFoss technique (Arunvipas et al. 2003) for MU (mg/dL) content and lactose percentage. Each MU record was converted into MU yield (MUY) (g MU/cow/day) using daily MY.

Apparent DM intake (DMI) (kg DM/cow/day) was estimated based on total ME requirements for maintenance, pregnancy, production and daily LW change (LWc), divided by the ME content of any feed offered (López-Villalobos et al. 1999). Concentration of CP (%) from feed quality analysis was utilised to calculate CP intake (CPI). Since herbage quality assessment was undertaken only on herd test days, daily ECPU was calculated by dividing PY by CPI.

Least-squares means of the variables were obtained using the general linear model procedure of SAS using a mixed model that included the fixed effects of dairy system, lactation number and as co-variables deviation from median calving date, proportion of Holstein-Friesian (F) and heterosis effect between F and Jersey (J), and the random effects of cow. Partial correlations between the dependent traits were obtained using MANOVA to obtain the phenotypic correlations adjusted by the factors included in the model. Partial correlation coefficients between two traits for a herd were compared to the other correlation coefficients for the other herd using the Fisher r-to-z transformation.

3.4 Results

Descriptive statistics of the dependent variables for each of the dairy system are presented in Table 3.1. The difference between LIPS and HIPS in kg milk yield per cow per day was 26% and this gap was reduced to an average of 17% in milksolids yield (MSY) between herds over the lactation (Figure 3.1). Values for MU were predominantly higher in LIPS. The larger cow size of HIPS was reflected in higher LW, however, BCS was higher in the LIPS cows during the season.

Table 3.1 Descriptive statistics for milk production traits, milk urea, live weight and body condition score in grazing cows at the low-intensity production system (LIPS) and at the high-intensity production system (HIPS) during season 2016-17.

	Production system									
	LIPS					HIPS				
Variable[1]	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
MY, kg/day	2,286	15.7	6	0.9	36.6	1,218	21.2	5.5	3	37.7
FY, kg/day	2,286	0.8	0.3	0.1	2.5	1,218	1	0.2	0.2	1.5
PY, kg/day	2,286	0.6	0.2	0.1	1.3	1,218	0.8	0.2	0.2	1.4
LY, kg/day	728	0.8	0.3	0.1	1.9	558	1.1	0.3	0.5	1.9
FP, %	2,286	5.34	0.9	1.77	8.8	1,218	4.64	0.87	2.46	8.86
PP, %	2,286	4.19	0.53	2.88	6.51	1,218	3.85	0.55	2.75	5.77
LP, %	728	4.99	0.16	4.37	5.36	558	5.16	0.15	4.74	5.57
SCS	2,278	5.8	1.6	0.0	12.4	1,218	5.1	1.5	1.6	12
MU_{am}, mg/dL	727	28.05	10.06	9.1	61.7	587	20.67	7.61	2.3	46.6
MU_{pm}, mg/dL	-	-	-	-	-	578	21.06	5.67	0.3	38.7
MUY_{am}, g/day	727	4.44	1.76	0.71	10.67	587	2.95	1.04	0.21	6.65
MUY_{pm}, g/day	-	-	-	-	-	574	1.74	0.62	0.01	3.88
LW, kg	2,361	487	70	320	684	1,998	502	61	352	770
BCS	2,065	4.62	0.44	2.5	6.5	1,408	4.16	0.42	3	5.5

[1] MY = milk yield, FY = fat yield, PY = protein yield, LY = lactose yield, FP = fat percentage, PP = protein percentage, LP = lactose percentage, SCS = somatic cell score calculated as SCS = log2 (somatic cell count), MU = milk urea, LW = live weight, BCS = body condition score.

Table 3.2 describes the diet composition in the present study, and indicates higher usage of supplementary feed in HIPS. Pasture allocation represented 93% and 65% of the total feed intake during the season for LIPS and HIPS cows, respectively. In the HIPS herd, the inclusion of more supplements, with lower CP, led to a reduction in the total CPI. Conversely, in the LIPS herd, due to a higher allowance of pasture with a greater CP content there was an overall greater dietary CPI and higher MU.

Table 3.2 Feed quality (mean ± standard deviation) allocated to cows before each milk sampling, expressed in MJ ME/kg dry matter (DM) feed and in percentage of crude protein (CP) and milk urea (MU) concentration (mg/dL) in early, mid- and late-lactation stage in grazing cows at the low-intensity production system (LIPS) and at the high-intensity production system (HIPS) during season 2016-17.

Production system	Lactation stage	Feed composition	ME (MJ ME/kg DM)	CP (% CP)	MU (mg/dL)
LIPS	Early	100 % pasture	11.700 ± 0.004	18.300 ± 0.017	22.86 ± 0.35
	Mid	68 % pasture 32 % mixed herb crop	11.083 ± 0.004	19.943 ± 0.017	22.37 ± 0.35
	Late	48 % pasture 17 % pasture silage 35 % grazing lucerne	9.457 ± 0.005	21.082 ± 0.018	40.08 ± 0.35
HIPS	Early	65 % pasture 26 % maize silage 9 % concentrate	11.193 ± 0.005	14.512 ± 0.019	17.92 ± 0.45
	Mid	44 % pasture 20 % maize silage 20 % pasture silage 16 % concentrate	10.965 ± 0.005	14.893 ± 0.019	20.44 ± 0.46
	Late	51 % pasture 23 % maize silage 11 % concentrate 11 % turnips 4 % DDG[1]	10.626 ± 0.005	16.247 ± 0.020	25.81 ± 0.46

[1] Dried distillers grain.

Table 3.3 presents least-squares means adjusted for lactation number, deviation from median calving date, proportion of F and F×J heterosis effects for milk production and cow performance per herd. Milk yield and MSY were both greater ($P < 0.05$) for HIPS cows, with an additional 22% in MY and an additional 14% in MSY. Adjusted means of LW and BCS records resulted in higher LW ($P = 0.013$) and in greater BCS ($P < 0.001$) for the LIPS herd. Apparent DMI was 12% greater for HIPS ($P < 0.001$), but CPI was 9% higher for LIPS ($P < 0.001$). In HIPS, ECPU was higher ($P < 0.001$) and MU was lower ($P < 0.001$), but no differences were found in MUY between herds (Table 3.3).

Table 3.3 Least-squares means (± standard errors) of lactation length, total yield of milk, fat and protein, somatic-cell score, live weight and live weight change accumulated along the lactation, BCS, DM intake (DMI), crude protein intake (CPI), efficiency of crude protein utilisation (ECPU), milk urea (MU) and milk urea yield (MUY) measured at the low-intensity production system (LIPS) and at the high-intensity production system (HIPS) during season 2016-17.

	Production system		
Item	LIPS	HIPS	P-value[2]
N	258	210	
Breeding worth	89	67	
Lactation length, days	270 ± 2	272 ± 3	0.636
Milk yield, kg	4,205.9 ± 55.1	5,387.5 ± 75.9	<0.001
Milksolids yield, kg	385.4 ± 4.5	448.1 ± 6.2	<0.001
Fat yield, kg	215.9 ± 2.6	246.6 ± 3.5	<0.001
Protein yield, kg	169.5 ± 2	201.8 ± 2.8	<0.001
Lactose yield, kg	211.3 ± 2.9	300.2 ± 4.12	<0.001
SCS[1]	5.74 ± 0.07	4.94 ± 0.1	<0.001
Live weight, kg	487 ± 3	476 ± 4	0.013
Live weight change, kg	24.3 ± 2.8	15.8 ± 3.3	0.051
BCS	4.61 ± 0.02	4.23 ± 0.02	<0.001
DMI, kg/day	12.9 ± 0.06	14.71 ± 0.11	<0.001
CPI, kg/day	2.47 ± 0.01	2.24 ± 0.02	<0.001
ECPU, %	25.29 ± 0.12	33.58 ± 0.31	<0.001
MU_{am}, mg/dL	28.3 ± 0.36	21.42 ± 0.51	<0.001
MU_{pm}, mg/dL	-	21.4 ± 0.36	-
MU, mg/dL	28.29 ± 0.34	21.3 ± 0.48	<0.001
MUY_{am}, g	1,207.76 ± 20.04	831.85 ± 27.57	<0.001
MUY_{pm}, g	-	473.04 ± 9.17	-
MUY, g	1,207.92 ± 22.56	1,269.28 ± 31.04	0.111

[1]The somatic cell count records were log-transformed to SCS. [2]Differences between treatment were considered significant at $P < 0.05$. BCS on a 1-10 scale.

Partial correlation coefficients between milk production traits and cow performance across scenarios are detailed in Table 3.4. There was a strong correlation between DMI and milk production traits. Milk yield traits correlated positively with ECPU in LIPS but not HIPS cows. Lastly, there were no significant correlations between MU and ECPU across both herds.

Table 3.4 Partial correlation coefficients between production traits, cow performance, efficiency of crude protein utilisation and MU in grazing dairy cows at the low-intensity production system (LIPS) above the diagonal and at the high-intensity production system (HIPS) below the diagonal during season 2016-17.

Trait[1]	MY	FY	PY	LY	FP	PP	LP	SCS	BCS	LW	LWc	DMI	CPI	ECPU	MU	MUY
MY		0.71	0.93	0.99	-0.13	-0.14	0.08	-0.19	-0.09	0.10	-0.21	0.74	0.72	0.52	-0.03^{ns}	0.54
FY	0.74		0.71	0.70	0.48	-0.03^{ns}	0.17	-0.06^{ns}	-0.01^{ns}	0.08^{ns}	-0.15	0.64	0.62	0.24	0.01^{ns}	0.44
PY	0.94	0.72		0.91	-0.11	0.09	0.12	-0.10	-0.03^{ns}	0.11	-0.17	0.70	0.68	0.62	0.01^{ns}	0.52
LY	0.99	0.74	0.93		-0.14	-0.16	0.29	-0.23	-0.09	0.10	-0.20	0.73	0.71	0.51	-0.02^{ns}	0.55
FP	-0.13	0.49	-0.14	-0.12		0.33	0.00^{ns}	0.18	0.06^{ns}	0.00^{ns}	0.01^{ns}	0.01^{ns}	0.01^{ns}	-0.30	-0.09	-0.14
PP	-0.02^{ns}	-0.05^{ns}	0.24	-0.04^{ns}	0.00^{ns}		-0.25	0.27	0.09	0.21	0.08^{ns}	-0.02^{ns}	-0.01^{ns}	-0.04^{ns}	-0.08^{ns}	-0.23
LP	0.16	0.17	0.12	0.29	0.00^{ns}	-0.25		-0.33	-0.05^{ns}	-0.03^{ns}	0.11	0.08	0.07^{ns}	-0.01^{ns}	0.03^{ns}	0.14
SCS	-0.17	-0.07	-0.14	-0.18	0.05^{ns}	-0.01^{ns}	-0.14		0.12	0.04^{ns}	-0.01^{ns}	-0.16	-0.15	-0.09^{ns}	-0.11	-0.23
BCS	0.00^{ns}	0.10^{ns}	0.01^{ns}	0.01^{ns}	0.15	0.01^{ns}	0.06^{ns}	-0.05^{ns}		0.32	-0.17	-0.07^{ns}	-0.05^{ns}	-0.15	0.11	0.03^{ns}
LW	0.13	0.13	0.12	0.13	0.05^{ns}	0.08^{ns}	0.05^{ns}	0.01^{ns}	0.20		-0.07^{ns}	0.35	0.36	-0.26	0.07^{ns}	-0.01^{ns}
LWc	-0.06^{ns}	-0.04^{ns}	-0.04^{ns}	-0.06^{ns}	-0.02^{ns}	0.04^{ns}	-0.01^{ns}	0.02^{ns}	-0.10^{ns}	0.14		0.07^{ns}	0.05^{ns}	-0.34	0.01^{ns}	-0.12
DMI	0.49	0.40	0.46	0.49	0.06^{ns}	0.03^{ns}	0.14	-0.11	0.08^{ns}	0.29	0.22		0.99	0.28	0.00^{ns}	0.39
CPI	0.41	0.31	0.42	0.42	-0.01^{ns}	0.11^{ns}	0.19	-0.08^{ns}	0.01^{ns}	0.13	0.17	0.79		0.26	0.00^{ns}	0.39
ECPU	0.00^{ns}	-0.03^{ns}	0.00^{ns}	0.00^{ns}	-0.08^{ns}	-0.13	-0.06^{ns}	-0.05^{ns}	0.04^{ns}	-0.13	-0.26	-0.37	-0.73		0.00^{ns}	0.32
MU	0.11	0.07^{ns}	0.15	0.11	-0.08^{ns}	0.11	0.01^{ns}	-0.02^{ns}	0.03^{ns}	-0.02^{ns}	0.04^{ns}	-0.07^{ns}	0.07^{ns}	-0.04^{ns}		0.71
MUY	0.56	0.41	0.57	0.55	-0.15	0.05^{ns}	0.10	-0.09^{ns}	0.04^{ns}	0.04^{ns}	0.02^{ns}	0.16	0.23	0.00^{ns}	0.85	

[1] MY = milk yield, FY = fat yield, PY = protein yield, LY = lactose yield, FP = fat percentage, PP = crude protein percentage, LP = lactose percentage, SCS = somatic cell score calculated as SCS = log2(somatic cell count), BCS = body condition score, LW = live weight, LWc = live weight change, DMI = dry matter intake, CPI = crude protein intake, ECPU = efficiency of crude protein utilisation, MU = milk urea, MUY = milk urea yield. ^{ns}Correlation between variables not different from zero ($P > 0.05$) within production system.

3.5 Discussion

Once a day milking and low levels of supplements fed to LIPS cows led to lower MY compared to HIPS cows (Table 3.1). Moreover, the lower dietary CP in HIPS cows resulted in lower levels of MU and higher ECPU (Table 3.2 and 3.3). The lower MY of cows milked once daily was expected (Phyn et al. 2012), and this lower MY resulted in more nutrients (energy and protein) available for higher BCS and increases in LW (Table 3.3). This is why ECPU correlates positively with DMI and CPI, and negatively with BCS, LW and LWc (Table 3.4). Holmes et al. (1992) observed similar increases in LW and BCS in herds milked once a day. A diet higher in CP, along with lower MY, resulted in LIPS cows having simultaneously higher CPI and lower PY, which reduced the ECPU.

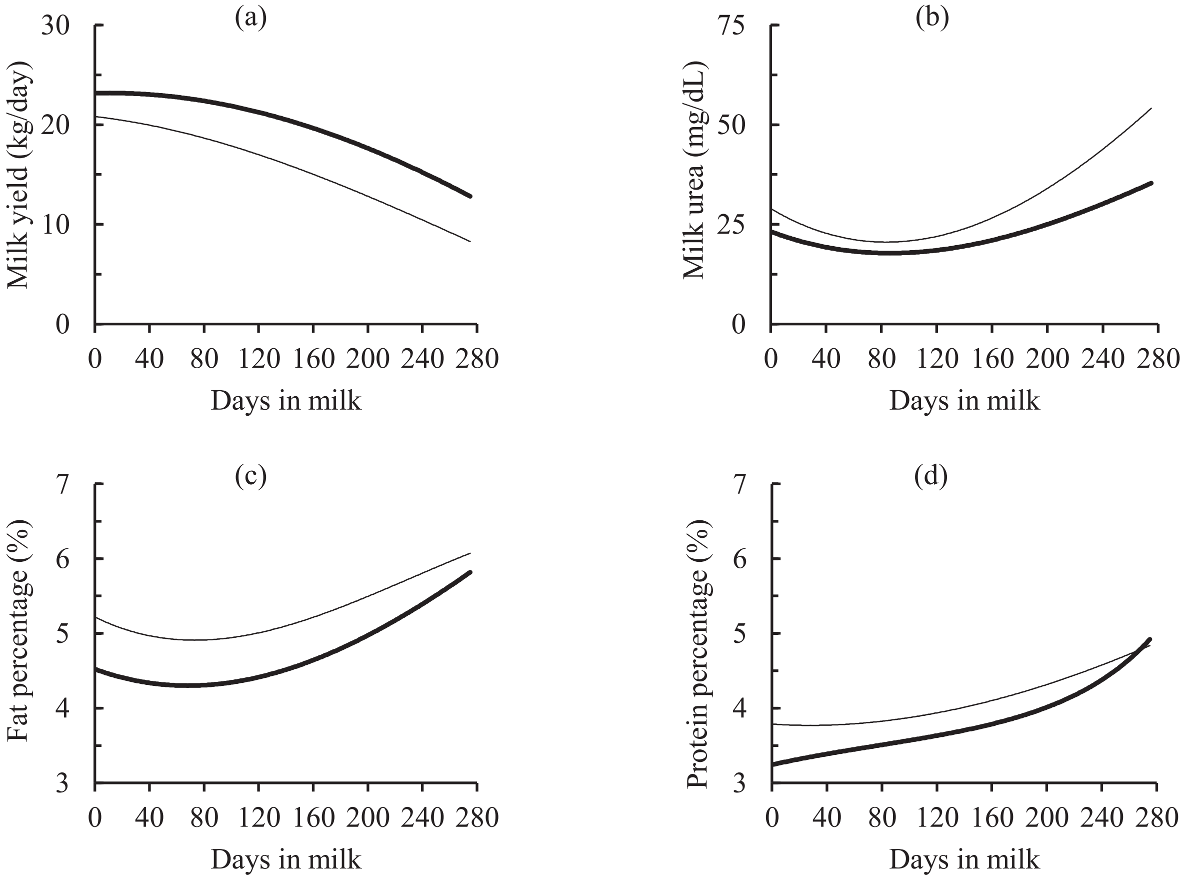

Figure 3.1 Predicted lactation curves of (a) milk yield, (b) milk urea, (c) fat percentage and (d) protein percentage in a low-intensity production system (LIPS) (—) and in a high-intensity production system (HIPS) (▬) during season 2016-17.

In this study, the CP percentage of the diet was between 18.3% and 21.1% and between 14.5% and 16.2% for LIPS and HIPS herds, respectively. An increase in CP percentage of the diet was accompanied by higher MU concentration throughout the lactation. Cosgrove et al. (2014) measured significant increases in MU in cows when forage CP percentage was above 19 along with reduced rumen degradable protein in both once- and twice-daily milking frequencies. In Table 3.4, no correlations between MU and ECPU were detected. Conversely, Aizimu et al. (2013) found a negative relationship between MU and ECPU only when dietary CP percentage did not exceed 19%. However, results in the present study were confounded, since high MU levels and lower MY of LIPS cows, and lower MU levels and higher MY of HIPS cows, resulted in similar accumulated MUY (Table 3.3).

Increasing levels of MU towards the end of the lactation in both herds (Table 3.2) may be explained by reduced MY along with increasing dietary CP during this period. Trevaskis et al. (1999) detected lower levels of MU in early lactation because of increasing tissue mobilisation using more of the N available as a mechanism to deliver more nutrients for increasing MY in peak lactation.

3.6 Conclusions

The ECPU of LIPS cows was reduced by limiting MY and by offering a diet higher in CP, compared to HIPS cows. Milk urea yield failed to predict the inefficiency (or otherwise) of N use, because of a compensation between MY and MU levels, which resulted in similar MUY in both herds. At the industry level, a benchmark of ECPU may be useful to compare nutrition management practices between farms (Gourley et al. 2012). From an environmental perspective, unless ECPU is modified to include N captured in tissues and body reserves, the use of this indicator as a tool to assess N use efficiency and N losses in grazing cows may not be effective, considering that animals may be storing part of this nutrient rather than discharging it in the form of excreta. Additional measurements of N losses from grazing cows along with an enhanced ECPU will help on a better understanding N cycle of these systems.

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Chapter 4

A model describing the efficiency of utilisation of dietary crude protein in seasonal-calving, pasture-based dairy cows

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4.1 Abstract

The efficiency of crude protein utilisation (ECPU), defined as protein output in milk as a percentage of crude protein intake, in grazing systems is generally low and this has consequences for the environment. Identifying drivers of ECPU in grazing conditions can provide farmers with tools to improve nutrients usage while reducing the environmental impact. The aim of the present study was to describe and evaluate a multivariate model to predict ECPU in grazing dairy cows. A large dataset of two contrasting dairy systems differing in milking frequency (MF) and supplementation level including milk production performance, live weight (LW), LW variation and metabolic LW, diet composition, and quality and climatic records was utilised to select suitable predictive variables of ECPU. The model was built by using a stepwise selection procedure enabling simultaneous inclusion and exclusion of dependent variables in the framework of a general linear model with a training sub-dataset allocated to validate the model. The model accurately predicted the ECPU in lactating grazing dairy cows with a relative prediction error (mean prediction error divided by the mean actual values) of 6.96% and $R^2 = 0.95$. The final model included breed and parity of the cow and milking frequency and feeding management strategy.

Keywords: nitrogen use efficiency, milking frequency, pasture, supplements.

4.2 Introduction

Dairy production systems of New Zealand are based on grazed pastures with strategic inclusion of conserved forages when pasture does not meet animal demand, usually at the end of the winter period and again in summer. A compact calving occurs in spring in order to match animal feed demand with seasonal supply of pasture. To ensure a short calving period and a 365 day calving interval, the breeding season must not exceed 12 weeks. Compared to housed systems, direct grazing dairy systems are relatively simple to operate, with low operating costs (Macdonald et al. 2017).

Nutritive value of a feed refers to a measure of available nutrients required by the animal including nitrogen (N), expressed as crude protein (CP; N concentration × 6.25), lipids, fat-soluble vitamins, macro-elements such as sodium, calcium potassium and phosphorus among others, microelements, and energy (Waghorn and Clark 2004). In both early and late lactation, fresh grazed pastures may be high in CP, containing mainly rumen-degradable protein at levels that regularly exceed milk production requirements (Kolver and Muller 1998). As a consequence of this imbalance there was an increase in N excreta, particularly in urine (Kebreab et al. 2002; Mulligan et al. 2004) which can affect ground and surface water quality (Di and Cameron 2002). In an extensive review of published studies, Castillo et al. (2000) reported a recovery of approximately 25% in milk protein (expressed as milk N) and 72% of N intake was excreted with an exponential increase in urine N beyond a threshold of 400 g of N (2.5 kg of CP) intake per day. With stringent regulations currently being imposed on New Zealand dairy farmers by Regional Councils (Horizons 2016), it is imperative to identify ways of reducing N excreta and to improve efficiency of crude protein utilisation (ECPU), which is defined as the proportion of milk protein with respect to CP intake (CPI).

A wide range of factors including feeding level, diet type, weather, breed, and genetics impact on the amount of milk protein produced by cows (Mackle et al. 1999). For example, Rook et al. (1992) increased the amount of concentrate fed to multiparous pasture-based dairy cows from 3 to 9 kg per day, which increased protein yield by 0.20 kg per day. Additionally, a study conducted by Bryant et al. (2003) reported differences in energy partitioning towards milk production in cows with dissimilar genetic merit in interaction with feeding level, and attributed this to genetic differences in mobilising body reserves. Additionally, climate factors including high and low temperature, humidity and solar radiation impact cow performance (Bryant et al. 2007).

From the total non-protein N in milk, approximately 46% is in the form of milk urea (MU) (DePeters and Ferguson 1992), which is sourced from blood urea N as part of a complex metabolic process to deal with excess N in the diet. Thus, MU has been proposed as a proxy to identify excess CP in diets (Broderick and Clayton 1997), as a predictor of N excreta (Jonker et al. 1998) and as an indicator of N use efficiency (Olmos Colmenero and Broderick 2006). In this later study, increasing CP in the diet from 13.5 to 19.4% accounted for sustained increases in MU with a consequent reduction in ECPU.

Milking frequency (MF) can be defined as the number of milking events per cow within a day. A typical modern dairy system in New Zealand mostly operates twice-daily milking (TAD) (Clark et al. 2006; Stelwagen et al. 2013). The negative effect of reducing MF is a reduction in milk production, associated with a drop of nutrient uptake in the mammary gland (Delamaire and Guinard-Flament 2006). Notwithstanding, once-daily milking (OAD) for the entire lactation is increasing in New Zealand for a number of reasons. Once-daily milking offers the opportunity of substantial changes in overall farm operations by reducing costs associated with milk harvesting and consumables (Davis et al. 1998) and by decreasing feed costs (Phyn et al. 2010). Systems based on OAD are typically pasture-based, with low supplementary feed inclusion. Additionally, OAD was associated with improvements in animal welfare and immune status (Clark et al. 2006; O'Driscoll et al. 2010), and reproductive performance (McNamara et al. 2008) along with improvements in lifestyle (Stelwagen et al. 2013). Clark et al. (2006) reported persistent increases in milk fat and protein concentration, accompanied by increases in live weight (LW) and body condition score (BCS) irrespective of breed and parity associated with OAD. Considering these variations in milk composition caused by reductions in MF, it would be expected they affect the ECPU. There have been a number of studies of MF effects on animal performance and economic efficiency (Lynch et al. 1991; Clark et al. 2006; Edwards 2018), but to our knowledge there is little research on reduced MF on ECPU at a cow level.

The complex interrelationships between factors previously mentioned makes it difficult to determine key drivers to predict ECPU in contrasting grazing dairy farms. Machine-learning algorithms are used in development of prediction models for different biological processes, including the prediction of conception in dairy cows (Hempstalk et al. 2015), body weight (Song et al. 2018) and feed intake (Delgado et al. 2019). The accuracy of a model relates to its ability to predict the actual values (Tedeschi 2006). Accuracy and robustness of models are obtained via evaluation and validation process (Rawlings et al. 1998). Internal validation processes can identify weaknesses in the model. The aim of the present study was to describe and evaluate a model to predict the ECPU in grazing dairy cows developed using a machine-learning procedure and to illustrate some implications of the model throughout the milk production season.

4.3 Materials and methods

Data were generated at two Massey University research dairy herds sited in Palmerston North located in the lower North Island of New Zealand (longitude 175°, latitude −40°) throughout two consecutive milk production seasons. The first production season occurred between the second half of July 2016 and the end of May 2017, and the second production season commenced in the second half of July 2017 and continued up to the end of May 2018. The planned start of calving was the second half of July through to the first week of September of each production season.

In the first production season, cow records from 467 cows were available: 117 Holstein-Friesian (> 13/16; F), 58 Jersey (> 13/16; J) and 292 crossbred (< 13/16 F or < 13/16 J; F×J) with 17, 5, and 45 primiparous cows, respectively. In the second production season, 459 cows were involved in this study: 167 F, 62 J and 231 F×J with 65, 17, and 53 primiparous cows, respectively.

4.3.1 Feeding system and cow management

Cows were split in two herds following different system approaches. The Massey University No. 1 dairy farm is managed as a low-intensity production system (LIPS) with cows milked OAD throughout the production season, with low SR (2.1 cows/ha). Fresh ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture is the main diet component throughout the year, and the feed strategy includes restricted supplementation, with grazed crops utilised in summer. On the other hand, Massey University No. 4 dairy farm is managed as a high-intensity production system (HIPS) with cows milked TAD throughout the production season, with higher SR (2.8 cows/ha) and higher supplementation level included throughout the production season. Each herd had access as a single group to fresh ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture after each milking.

Cows of LIPS were milked OAD at 6:30 am throughout the two studied milk production seasons and were fed after each milking a fresh strip of pasture comprised of ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) with the strategic inclusion of crops and supplements according to pasture availability, driven by seasonal changes in weather. A herb crop consisting of plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*) and red clover (*Trifolium *pratense*) was fed up to 3 hours a day from December to March at an allowance of 3.5 kg dry matter (DM) per cow, a lucerne crop (*Medicago sativa*) was available for direct grazing in March of the first season at an allowance of 3 kg DM per cow per day and a turnip crop (*Brassica campestris* ssp. *rapifera*) was fed at an allowance of 2.6 kg DM per cow from January to February of both milk production seasons. From December to March of the second milk production season, due to severe pasture shortage, cows were offered 3 kg DM per cow of maize (*Zea mays*) silage, 0.75 kg DM per cow of dried distillers grain and 2 kg DM per cow of tapioca (*Manihot esculenta*) pellets, on a feed pad after each milking. Pasture silage was fed directly in the paddock in August and from March to May at a rate of 3.5 kg of DM per cow per day in both milk production seasons.

In the HIPS herd, cows were miked daily at 5:30 am and 2:30 pm throughout this study, with the exception of the second half of the second milk production season where cows were milked once daily because of pasture shortages. Maize silage and a grain-based concentrate were fed during the milk production season at 3.5 kg DM per cow per day before the afternoon milking and 2 kg DM per cow per day inside the parlour in both milk production seasons, respectively. Pasture silage was fed directly during the first milk production season in the paddock from January to March at a rate of 3 kg of DM per cow per day and in the second milk production season from September to November at the same rate. Dried distillers grain was fed in the first milk production season in March at a rate of 0.75 kg DM per cow during the morning milking, and during the second milk production season from September to November at a rate of 1 kg DM per cow per day. In the first milk production season, this group of cows was allocated turnips at 2 kg DM per cow per day and in March of the second milk production season were allocated 3 kg DM per cow per day of a chicory crop.

4.3.2 Feed quality measurements

Estimated pasture eaten (kg of DM/cow per day) was calculated by measuring pre-grazing DM minus post-grazing DM on the grazing area assigned per day divided by the total number of cows. Grazing area was measured using a global positioning system. Pre- and post-grazing pasture heights were measured with a rising-plate meter (Jenquip, New Zealand) following a ‘W’ pattern across the grazing area on a basis of 3 sets of 50 readings on each occasion. Pasture mass was subsequently estimated using the following the New Zealand national calibration equation for perennial ryegrass-white clover [kg DM/ha = 140 × compressed height (in 0.5 cm) + 500] (L'Huillier and Thomson 1988). Estimated crop eaten was calculated as crop cover pre-grazing minus crop cover post-grazing, measured by harvesting three 0.1 m^2 quadrats to ground level within the area allocated to cows on a daily basis. Those measurements enabled calculation of apparent pasture and crop utilisation, and also the proportion of herbage allocated to cows before each herd test.

Fresh pasture and crop samples (1,500 g of wet weight) were taken by the hand-plucking method (Baker 2004) from about 50 sites on each walking transect to mimic herbage grazed by cows. Samples of maize and pasture silage were taken from the bunker on the day before the herd test. Samples of concentrate and tapioca pellets were taken directly from the feeders while cows were milked. All samples were freeze-dried and ground (Wiley mill) to pass through a 1.0 mm screen. The levels of ash, CP, lipid, neutral detergent fibre (NDF), acid detergent fibre, organic matter digestibility, metabolisable energy (ME), and soluble sugars were estimated by near infrared reflectance (NIR) spectrometry (Corson et al. 1999). Calibrations for each component had been previously developed (Massey University Nutrition Laboratory, Palmerston North, New Zealand) using NIR spectrometry after scanning finely-ground pasture samples in the range of 400 to 2500 nm. A Bruker MPA NIR spectrophotometer (Ettlingen, Germany) was used to scan the samples and the resulting NIR spectra were analysed using Optic user software (OPUS) version 5.0. (Ettlingen, Germany). Based on proportions of each forage allowed and each individual feed ME, the dietary ME content [megajoules (MJ) of ME per kg DM] was calculated.

A supplementary subset of pasture and crops samples was taken for botanical composition measurement. Samples were sorted into “ryegrass”, “other grasses”, “white clover”, “red clover”, “weeds” (predominantly broadleaf species) and “dead material” (of any species). When performing botanical composition of crops each sown species was recorded as a single class (i.e. plantain, chicory, lucerne, turnips), with the remainder sorted into “other grasses”, “weeds” and “dead material”, as previously.

4.3.3 Animal measurements

Cows were identified using a radio frequency electronic identification system (Allflex New Zealand Ltd., Palmerston North, New Zealand) enabling daily live weight (LW) and daily LW change (LWc) measurements generated with an automatic race walkover scale (WoW xR-3000, Tru-Test Ltd. Auckland, New Zealand). Body condition scores were assigned in synchrony with each herd test by a single research technician using a 10-point scale (Macdonald and Macmillan 1993). Yields of milk (MY), fat (FY) and protein (PY), were determined using a Fossomatic FT120 (Foss Electric, Hillerød, Denmark) on composite afternoon and morning aliquots where two milking events occurred on a sampling date and from a unique sample when one milking event occurred on a sampling date. Macciotta et al. (2005) identified that the mathematical properties of the Legendre polynomials functions were able to recognize a large number of curve shapes, enabling the lactation curves of large groups of animals in contrasting productive conditions to be modelled. In this study, the lactation curves for milk production traits, LW and BCS were modelled using Legendre polynomials of third order generating daily records from calving to drying-off date for each cow.

Additionally, individual milk samples were taken using mechanical milk meters (Tru-Test Field Collection meter WB HI) provided by Livestock Improvement Corporation in early (September), mid (December) and late lactation (March) stages of both seasons. These samples were analysed by MilkTestNZ (Hamilton, NZ) using a CombiFoss™ 7 instrument (Foss Electric, Hillerød, Denmark) following the CombiFoss technique (Arunvipas et al. 2003) for MU (mg/dL) content and lactose percentage. Each MU record was converted into MU yield (MUY) (g MU/cow/day) using daily MY.

Values of net energy requirements for maintenance, pregnancy, production and daily weight variation were based on the French net energy system where 1 unité fourragère lait is the net energy requirement for lactation equivalent to 1 kg of standard air-dried barley (Jarrige et al. 1986), equivalent to 7.11 MJ of net energy or 11.85 MJ of ME. Net energy requirements were calculated from following equation by Jarrige (1989) with modifications by Berry et al. (2006) and López-Villalobos et al. (2008) for dairy cows in grazing conditions:

$$NEreq = NEm + NEl + NEg + NEp,$$

where NEreq is daily net energy requirements for each cow in each herd testing date, NEm is daily net energy requirements for maintenance including activity calculated as (1.4 + 0.6 × LW/100) × activity allowance factor of 1.2 for grazing conditions, NEl is the net energy for milk production calculated as 0.054 × (FY/100) + 0.031 × (PY/100)+ 0.028 × (LY/100) - 0.015) × MY, NEg accounted for daily live weight variation assuming an addition of 3.5 units when LWc is positive and a -4.5 when LWc is negative, and NEp is daily net energy requirements for pregnancy where unité fourragère lait requirements for the 6th, 7th, and 8th month of pregnancy were 0.9, 1.6, and 2.6, respectively. Total net energy requirements were transformed to metabolisable energy requirements by multiplying NEreq by 11.85 MJ of ME. The DM intake (DMI) (kg DM/cow/day) for all herd test occurrences was estimated by dividing total ME requirements by the dietary ME content. Crude protein intake was calculated by multiplying DMI by the CP in the diet. The ECPU was calculated as a proportion of CPI and records of PY obtained from each herd test instance, as:

$$\text{ECPU} = \frac{\text{PY}}{\text{CPI}} \times 100$$

4.3.4 Climate records

Meteorological data were obtained from land-based station 21963 (observing authority AgResearch). The indices for temperature-humidity (THI) and cold stress (CSI) were calculated according to Bryant et al. (2007) and included amongst the climate variables.

4.3.5 Statistical analyses

4.3.5.1 Modelling strategy

The regression multivariate model was developed in the following steps: continuous variables were checked for distribution and analysed for outliers, then compared for Pearson correlation coefficient using the PROC CORR procedure of SAS (SAS Institute Inc., Cary, NC). Subsequently, a random forest procedure using the PROC HPFOREST was run, including all nominal and continuous variables, in order to identify the most predictive variable candidates for the model (Breiman 2001).

4.3.5.2 Model building

The dataset was randomly partitioned for model training and validation processes by operating the PROC SURVEYSELECT statement of SAS. This command allocated 30% of the dataset exclusively to the validation process by using simple random sampling. The training sub-dataset included 3,627 from the total 5,177 records. Then, the model was built by operating the PROC GLMSELECT of SAS with the stepwise option enabling simultaneous inclusion and exclusion selection of dependent variables in the framework of a general linear model, allowing both quantitative and qualitative variables.

4.3.5.3 Model validation

The goodness of fit of the model to test the ECPU prediction accuracy was evaluated in the validation sub-dataset based on the mean square prediction error (MSPE), mean prediction error (MPE) and the relative prediction error (RPE) as proposed by Rook et al. (1990) with the PROC REG of SAS.

The MSPE is defined as:

$$\text{MSPE} = (\text{A}_\text{m} - \text{P}_\text{m})^2 + \text{S}_\text{P}^2(1\text{-b})^2 + \text{S}_\text{A}^2(1\text{-r}^2),$$

where A_m and P_m are the means of the actual and predicted ECPU, respectively; S_A^2 and S_P^2 are the variances of the actual and predicted ECPU, respectively; b is the slope of the regression of actual on predicted, and r is the correlation coefficient of actual and predicted.

The MSPE consists of three components; mean bias $(A_m - P_m)^2$ indicating model robustness, line bias $S_P^2(1-b)^2$ which refers to the line slope of the regression of actual on predicted values and the random variation $S_A^2(1-r^2)$ which is a function of the coefficient of variation of the regression of actual on predicted and the variance of the actual data (Fuentes-Pila et al. 2003).

A large mean bias indicates that predicted values are higher or lower than the actual values. The slope refers to the adequacy of the structure of the model to determine the ECPU. If the slope is greater than 1.0, the model tends to over-predict at low actual values and under-predict at high actual values (Rook et al. 1990). The random variation denotes the model accuracy to identify and predict deviations due to animal and/or experimental variation.

The MPE is calculated as follows:

$$\text{MPE} = \sqrt{\text{MSPE}}$$

The RPE is the ratio between the positive root square of the MSPE and the mean of the actual measured ECPU:

$$\text{RPE} = \left(\frac{\sqrt{\text{MSPE}}}{A_m}\right) \times 100$$

In prediction models, Fuentes-Pila et al. (2003) suggest that RPE lower than 10% is an indication of satisfactory prediction, whereas RPE between 10% and 20 % indicates a relatively acceptable prediction, and RPE greater than 20% indicates poor prediction.

Table 4.1 Dataset descriptive statistics including mean, standard deviation (SD) and range of animal performance, diet and pasture characteristics and quality, and climate records of the total database on the herd testing date and mean values for three lactation stages; early (first 100 days of lactation), mid (from day 100 to day 200 of lactation) and late (last 100 days of lactation).

	Total				Lactation stage		
Parameter	Mean	SD	Min	Max	Early	Mid	Late
Cow							
Lactation length	271.5	35.0	84.0	321.0	-	-	-
*Parity	2.8	1.2	1.0	4.0	-	-	-
*Milk yield, kg/day	17.4	6.5	1.3	38.3	21.2	17.1	11.2
Milksolids yield, kg/day	1.5	0.5	0.2	3.6	1.8	1.5	1.1
*Fat yield, kg/day	0.9	0.3	0.1	2.5	1.0	0.8	0.6
*Protein yield, kg/day	0.7	0.2	0.1	1.3	0.8	0.7	0.5
Lactose yield, kg/day	1.0	0.3	0.1	2.0	1.2	0.9	0.7
Milk urea, mg/dL	24.2	8.1	3.4	61.7	21.0	22.9	32.7
Milk urea yield, g/day	4.2	1.5	0.7	13.2	4.6	3.9	4.2
Live weight, kg	487	64	334	689	480	484	503
*Metabolic live weight, ME[1]	103	10	78	135	102	103	106
*Live weight change, kg/day[2]	0.08	0.23	-1.47	1.52	-0.10	0.18	0.25
Body condition score[3]	4.5	0.4	2.9	5.9	4.5	4.4	4.5
Dry matter (DM) intake, kg/day	16.99	2.67	8.68	27.53	16.92	17.00	17.08
Crude protein intake, kg/day	3.12	0.60	1.43	5.81	3.06	3.07	3.32
Efficiency of crude protein utilisation, %	22.16	6.38	4.16	41.47	26.03	22.38	15.20
Dietary nutrients							
*Metabolisable Energy, MJ ME/kg of DM	11.1	0.6	9.5	12.0	11.5	11.0	10.6
*Crude protein, g/kg of DM	18.5	2.5	12.4	23.3	18.1	18.1	19.5
Acid detergent fibre, g/kg of DM	21.4	2.1	18.6	26.7	21.1	21.2	22.5
Neutral detergent fibre, g/kg of DM	40.6	3.7	35.0	50.2	41.2	39.6	41.0
Diet composition							
Proportion of pasture, %	69.2	23.2	22.9	100.0	84.8	62.1	53.0
Proportion of supplements, %	17.7	18.2	0.0	60.2	14.5	18.1	22.5
Proportion of crops, %	13.1	15.3	0.0	41.6	0.7	19.9	24.5

Table 4.1 (continued)

Parameter	Total				Lactation stage		
	Mean	SD	Min	Max	Early	Mid	Late
Pasture quality							
Metabolisable Energy, MJ ME/kg of DM	10.98	0.83	9.21	12.10	11.59	10.69	10.36
Crude protein, g/kg of DM	19.0	2.9	11.8	24.1	18.8	17.8	21.2
Water-soluble carbohydrates, g/kg of DM	123.0	7.7	104.6	133.2	119.8	122.8	128.9
Botanical composition							
Lolium perenne, %	68.91	14.66	40.45	96.33	77.01	63.45	63.01
Trifolium repens, %	8.37	9.82	0.00	41.39	7.81	8.28	9.47
Trifolium pratense, %	5.18	8.57	0.00	30.61	1.21	6.86	9.56
Other grasses, %	7.33	8.21	0.00	34.81	7.40	9.06	4.68
Weeds, %	4.49	3.66	0.00	26.16	3.40	5.09	5.48
Dead material, %	5.72	6.58	0.54	30.08	3.18	7.26	7.81
Proportion of grasses, %	76.24	15.17	42.73	97.52	84.40	72.51	67.69
Proportion of legumes, %	13.55	12.89	0.00	45.15	9.02	15.14	19.02
Proportion of other broadleaf species, %	10.20	8.25	1.61	48.03	6.58	12.35	13.29
Daily climate records							
Rainfall, mm	3.3	7.3	0.0	31.6	2.0	5.0	3.1
Max temperature, °C	18.5	3.3	12.0	25.3	16.6	20.9	18.3
Min temperature, °C	9.0	3.8	1.8	17.6	7.2	11.4	8.8
Mean temperature, °C	13.8	3.1	6.8	21.2	11.8	16.3	13.7
Radiation, MJ/square meter	16.3	8.1	4.5	31.5	15.0	20.7	11.9
Mean relative humidity, %	78.8	6.9	63.8	88.2	80.4	75.3	81.0
*Temperature-humidity index	64.3	4.5	54.1	74.1	61.3	67.5	64.6
Cold-stress index	1091.3	81.3	896.2	1326.6	1120.2	1052.6	1098.4

[1] Metabolic live weight (LW) calculated as $LW^{0.75}$. [2] Live weight change with respect to previous day. [3] Body condition score on a 1-10 scale. Values of temperature-humidity index and cold-stress index corresponds to mean value for the day of herd testing and 2 days prior. *Parameter used as continuous variable in the model.

4.4 Results

There was a large range in the animal, pasture and feeding input variables in the database (Table 4.1). Considering the herds together, a wide range in lactation length (84 to 321 days), parity (1 to > 4 lactations), live weight (334 to 689 kg), MY (1.3 to 38.3 kg/day) and DMI (8.7 to 27.5 kg/day) were observed. Dietary ME ranged from 9.46 to 11.96 MJ ME/kg of DM and CP ranged from 12 to 23 g/kg of DM. There was a large variation in supplementary feed allowance, ranging from nil to 60%. Similarly, the inclusion of crops ranged from nil to 42% of DMI. Pasture quality varied throughout the study, with ME ranging from 9.21 to 12.10 MJ ME/kg of DM, and CP concentration from 12 to 24%, although water-soluble carbohydrates (WSC) of pasture was relatively constant. Climatic conditions on the herd test date varied, with maximum temperatures ranging from 12 to 25°C, minimum temperatures ranging from 2 to 18°C, mean relative humidity ranging from 64 to 88% and rainfall ranging from nil to 32 mm per day. In contrast, there was little variation in THI and CSI between herd testing dates across lactations. The ECPU averaged 22%, with a minimum of 4.2% and a maximum of 41.5%.

4.4.1 Model overview

This multiple regression model of ECPU prediction was designed with the aim of reduced complexity without compromising predictive power. It was set to account for animal, nutritional and environmental factors (Figure 4.1).

The prediction occurs from a sequence of phases, where animal performance and characteristics along with nutritional and environmental variables are incorporated progressively. This model begins by determining an intercept modified by MF while simultaneously recognising breed and cow lactation. Therefore, the level of milk production and PY, considered one key driver of the N captured, will be determined by the model. Subsequently, the metabolic LW (MLW), is accounting for the energy partition towards maintenance. There will be an influence on the body reserve mobilisations determined by the LWc and by the BCS. Next, nutritional factors account for the linear and quadratic effect of dietary CP and ME and its interaction on the ECPU prediction. Lastly, climate variables accounting for the effect on cow performance are included.

Slopes for nested effects of breed, parity and milking frequency resulted in coefficients of the same magnitude without significant differences reason why each effect was included separately in the model. Random effects of season and each animal were 0.001497 and 0.04299, respectively.

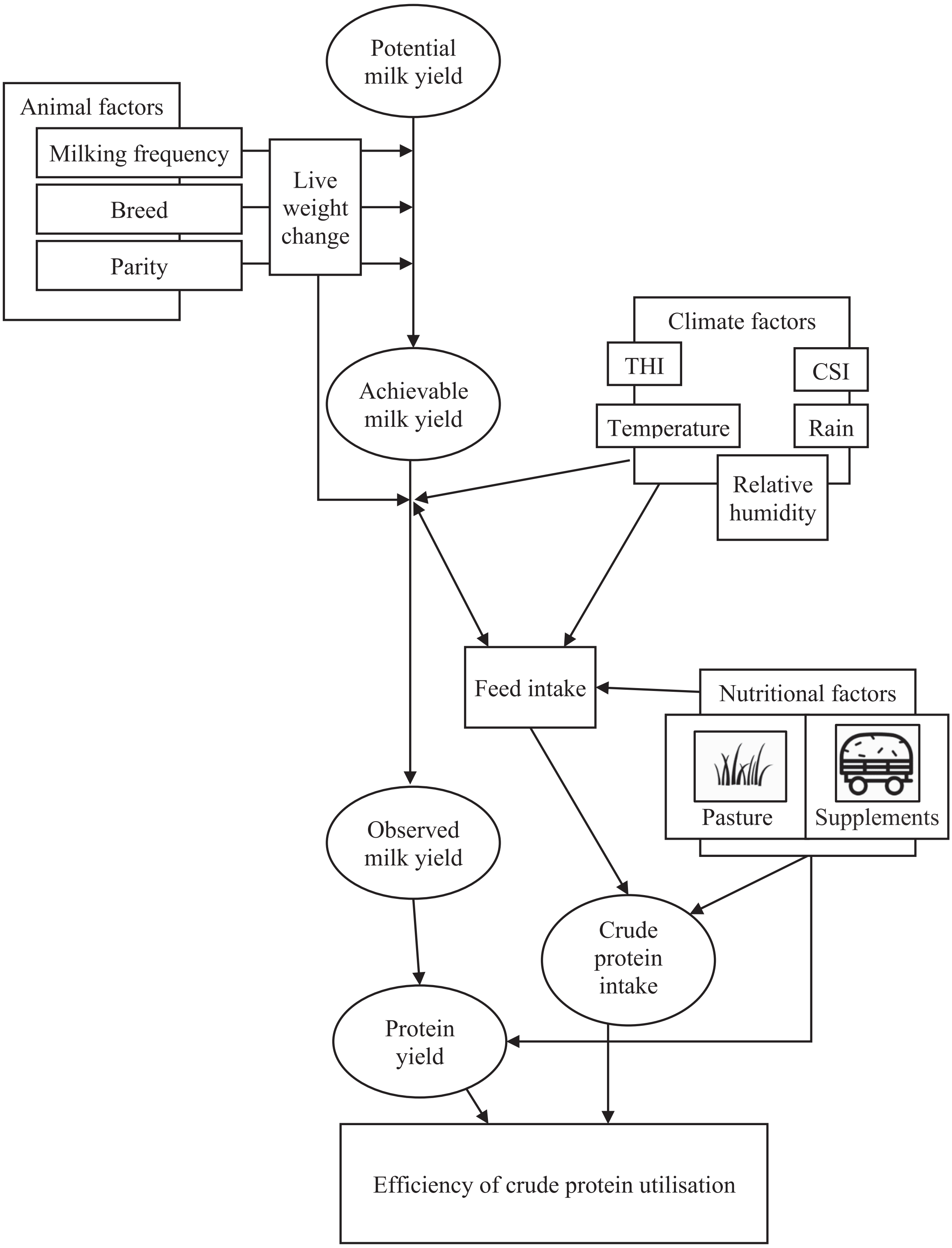

Figure 4.1 Structure of multiple regression model of the efficiency of crude protein utilisation prediction.

4.4.2 Model validation

The model over-prediction was almost nil with a difference of 0.058 with respect to the actual ECPU (Table 3.2). The prediction accuracy was satisfactory (Figure 4.2), with a RPE of 6.96%. The high R^2 and the low RPE denote the satisfactory accuracy of the model in predicting the ECPU on the three stages of the milk production season in contrasting dairy grazing systems. In early- and mid-lactation stages, an over-prediction was observed with a larger difference in mid-lactation. Probably a large difference from one cow to another occasioned larger variation in shapes of lactation curves between LIPS and HIPS cows, which could be affecting the PY (information not shown). In late lactation stage the model under-predicted the ECPU with almost minimal differences. Considerable differences in performance of cows in early lactation, (e.g. LWc, milk production, energy and protein intake), may account for the lower R^2 and a larger random bias. Nevertheless, the low RPE encountered denotes the accuracy of the model to predict ECPU for lactating cows of contrasting management (i.e. feeding system, milking frequency) throughout the lactation.

Table 4.2 Goodness of fit of the prediction model for efficiency of crude protein utilisation (ECPU) (%) of grazing dairy cows in full lactation and in early (first 100 days of lactation), mid (from day 100 to day 200 of lactation) and late lactation stage (last 100 days of lactation).

		Lactation stage		
Item	Overall model	Early	Mid	Late
N	1550	619	540	391
Observed ECPU	21.960	26.320	22.102	14.862
Predicted ECPU	22.018	26.338	22.262	14.846
R^2	0.947	0.905	0.946	0.913
Slope	1.005	0.989	1.003	1.028
Mean bias	0.00336	0.00030	0.02553	0.00026
Slope bias	0.00098	0.00270	0.00029	0.01045
Random bias	2.33215	2.21706	1.59518	1.35854
MSPE	2.34	2.22	1.62	1.37
MPE	1.53	1.49	1.27	1.17
RPE, %	6.96	5.66	5.76	7.87

4.5 Discussion

The model predictions had a high degree of accuracy (RPE < 7%, $R^2 = 0.95$) in simulating daily ECPU with a slight and imperceptible over-prediction in early- and mid-lactation and an under-prediction in late lactation (Table 4.2). Nevertheless, by including more variables in the model, the accuracy was higher than that obtained by Jonker et al. (1998), who based their prediction of N use efficiency considering only N intake and N in milk.

In the present study the increase in CP was accompanied by higher MU concentration and a strong negative correlation between CP and ECPU was observed. Although these evident relationships have been encountered, MU was rejected from the model. It should be considered that DMI estimations are based on pasture and crops collective allocation. There may be cow-related characteristics (Huhtanen et al. 2015) and management factors (Wattiaux et al. 2005) affecting MU and ECPU. A review of factors affecting the relationship between MU and urinary urea (Spek et al. 2013) suggested that confounding factors such as differences in DMI and dietary protein intake make drawing of a solid relationship between ECPU and MU difficult to draw.

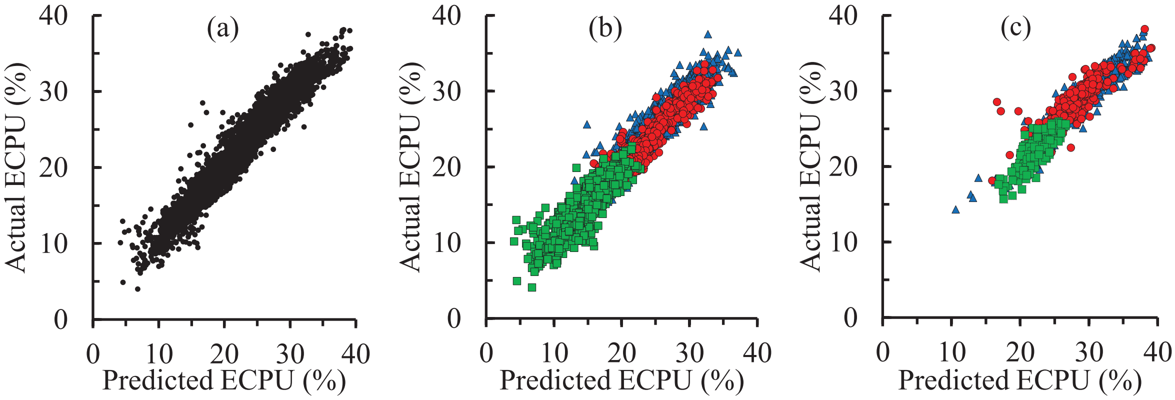

Figure 4.2 Relationship between (a) overall predicted and actual Efficiency of crude protein utilisation (ECPU); predicted and actual ECPU in (b) once and (c) twice a day milking in early (▲), mid (●), and late (■) lactation stage.

Goodness of fit of the model was higher than a model built from a meta-analysis by Phuong et al. (2013), which included a range of nutritional feed characteristics along with limited cow performance variables. The N use efficiency model developed by Phuong et al. (2013) only accounted for LW and days in milk (DIM) and this present multiple regression model was built from a larger database including LW, LWc, DIM, parity, breed and milking frequency which enhanced the accuracy in predicting the ECPU. Besides, it should be noted that the present model was constructed from a dataset where N excreta (Jonker et al. 1998; Kebreab et al. 2002; Vibart et al. 2013) and more complex metabolic kinetics (Daniel et al. 2017) were not available to be accounted for in predicting N efficiency. However, it is important to note that the present model deals with interactions between milking frequency and dietary N use efficiency, an area where literature is scarce. Usually, OAD systems are predominantly pasture-based with low supplementary feed inclusion, and are regarded as low intensity (Stelwagen et al., 2013). The feeding strategy employed in these systems aims to reduce feed, in anticipation of milk production declining (Davis et al. 1998; Clark et al. 2006). By decreasing consumption of supplements, milking cows would be expected to have lower milk yields due to the decreased metabolisable intake and reduced DMI, and this will increase their fat-to-protein ratio because the diet, reduced in energy (starch), will be limiting the production of glycogenic nutrients in the rumen, which in turn will be restricting protein and lactose synthesis (Reis and Combs, 2000). This effect, along with the increased CPI as more pasture is fed, would lead to unavoidable reduction in ECPU in OAD cows (Figure 4.2).

The model highlights the negative impact that CP level has on ECPU, at both MF, and all the levels of breed, parity, and lactation stage. Under farming conditions, a number of factors affect the CPI. For example, pastures grazed in the present study contained varying amounts of legumes (Table 4.1), which are naturally higher in CP content than grasses (Waghorn and Clark 2004). Low level of CP in diets in pastures are generally associated with grazing conditions during extended dry periods. Similarly, the amount and type of supplementary feed varied for both LIPS and HIPS cows during lactation, and this is also another source of dietary CPI variation. The inclusion of supplementary concentrate high in ME and low in CP was suggested as a tool to reduce protein intake which will enhance N use efficiency (Castillo et al. 2000; Kebreab et al. 2001), to increase milk production (Baudracco et al. 2010; Kolver and Muller 1998; Macdonald et al. 2017) and to alter the N excreta partitioning towards increases in faecal N (Bargo et al. 2002; Mulligan et al. 2004). However, the opportunity to accurately balance the diet in terms of energy:protein in pasture-based systems is more complex compared to housed systems (Mulligan et al. 2004).

Throughout the present study, dietary CP levels were rarely below 14%. Cows fed diets with low levels of CP has been identified as a nutritional limitation for milk production (Barros et al. 2017). In this study, there were higher daily levels of milk production in early lactation and this matched the higher body reserve mobilisation. This premise could help in understanding why the LWc is represented in the model with a negative coefficient (Table 4.3). This coefficient pinpoints the role of body reserve mobilisation in regard to nutritional supply of energy and protein to high-producing dairy cows (Berry et al. 2006).

Table 4.3 Parameter estimates and regression analysis information of a multivariate model to predict the efficiency of crude protein utilisation in lactating cows milked once-daily with lower level of supplementation and twice-daily with higher level of supplementation.

Variable[1]	Parameter estimates	Standard errors	P-value
Intercept	29.439	1.522	<0.001
MF			
OAD	-2.792	1.456	0.055
TAD	0.000	-	-
DIM	-0.007	0.001	<0.001
Breed			
F	0.097	0.063	0.125
J	-0.216	0.085	0.011
F×J	0.000	-	-
Lactation			
1	0.173	0.099	0.082
2	0.254	0.074	0.001
3	0.168	0.072	0.019
4+	0.000	-	-
Milk production × MF			
MY × OAD	-0.209	0.021	<0.001
MY × TAD	-0.017	0.035	0.617
FY × OAD	-2.720	0.138	<0.001
FY × TAD	-2.776	0.390	<0.001
PY × OAD	25.776	0.649	<0.001
PY × TAD	20.692	1.182	<0.001
MLW	-0.073	0.004	<0.001
LWc	-4.102	0.166	<0.001
ME × OAD	3.674	0.199	<0.001
ME × TAD	2.042	0.738	0.006
CP × OAD	-1.817	0.065	<0.001
CP × TAD	-3.067	0.403	<0.001
CP × CP × OAD	0.078	0.005	<0.001
CP × CP × TAD	0.075	0.027	0.006
ME × CP × OAD	-0.251	0.024	<0.001
ME × CP × TAD	0.515	0.173	0.003
THI_{accum}	0.040	0.008	<0.001

[1] Definitions: MF = milking frequency; OAD = once-day milking; TAD = twice-day milking; DIM = days in milk; F = Holstein-Friesian; J = Jersey; F×J = crossbred (½ or higher F and ½ or higher J); MY = milk yield (kg milk/day); FY = fat yield (kg fat/day); PY = protein yield (kg protein/day); MLW = metabolic live weight calculated as $LW^{0.75}$; LWc = kg of LW difference to previous day; ME = dietary energy content (megajoules metabolisable energy/kg dry matter); CP = dietary crude protein concentration (%); THI_{accum} = mean temperature-humidity index from herd test date plus two previous days.

4.5.1 Limitations of the model

Regardless of parity, the ECPU of OAD cows was lower due to lower MY (Holmes et al. 1992; Phyn et al. 2010; Stelwagen et al. 2013). The breed effects on MY have been reported in OAD cows by Lembeye et al. (2016) and in TAD cows by Baudracco et al. (2010). The breed effects on the ECPU would be explained by levels of milk production and feed intake relative to CP offered in line with requirements. Contrary to Woodward et al. (2011) the model did not distinguish the effect within each breed due to genetic merit.

Water-soluble carbohydrates did not rank satisfactorily among other variables and for this reason were not included in the model. In this study the relationship between ECPU and WSC was found to be strongly negative, probably due to the percentage of pasture inclusion rather than the effect of feeding pastures of increasing levels of sugars on ECPU. In literature, the relationship between WSC and ECPU was found from nil (Tas et al. 2006) to positive (Pacheco et al. 2007). A reason for the low sensitivity of this variable in this study could be that WSC was low and a very low variation in concentration was observed (105 to 133 g/kg of DM). Another explanation could be based on nil effect of higher WSC pastures on milk production (Tas et al. 2006) and this, along with a diet composed mostly of pasture might be resulting in a negative relation between WSC and the ECPU. Pacheco et al. (2007) observed a positive effect of WSC on ECPU, but it was mainly explained by decreases in CP, rather than the solely effect of WSC, which was previously confirmed by Taweel et al. (2005).

Extreme weather conditions reduce cow performance (Bryant et al. 2007). This model only included THI. However, it lacked sensitivity to increases in THI, due to low variation in meteorological conditions yielding values of THI with a mean of 64.4 ± 4.5. To further develop the current model, it would be desirable to use a dataset that includes more extreme weather conditions.

A recent study by Daniel et al. (2017) confirmed that protein mobilisation during lactation should be included in determining the protein balance in a lactating cow. Based on this, and given that mobilisation of 1 kg of LW could represent 160 g of crude protein available (Huhtanen et al. 2015), any gain in LW during lactation represent a ‘capture’ of N in tissues and any LW loss would mean CP readily available. For example, in the present study OAD cows had lower MY and ECPU but higher BCS and less LWc during both lactations. This represents a limitation to the ECPU to capture the sensitivity of N retained if this efficiency measure is to be associated with N losses to the environment or if economically the N captured represents sales in beef product rather than solely milk.

4.6 Conclusions

The model accurately predicted the ECPU in grazing dairy cows by employing a set of quantitative and qualitative variables commonly described in New Zealand dairy farms. It accounted for the main dairy cow breeds in New Zealand, along with the milking frequency effect combined with different levels of supplementation and this could aid in the understanding of the complexity of the N cycle in grazing systems. For example, considering that OAD farmers might reduce supplementation to reduce feed costs, the model pinpointed specific areas were the ECPU could be improved (e.g. stage of lactation, feed allocation, and type of supplements to be strategically included). This might be useful as a decision support tool with regard to the feeding management of grazing dairy cows while reducing their environmental footprint.

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Chapter 5

Effect of genetic merit for milk urea on milk production and efficiency of crude protein utilisation of grazing cows with contrasting supplement inclusion

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5.1 Abstract

Milk urea (MU) has been proposed as a predictor of nitrogen excreted through urine into the environment. The objective of this study was to evaluate milk production performance and efficiency of crude protein utilisation (ECPU) of cows with low and high MU breeding values (MUBV) in two contrasting herds differing in intensification levels in New Zealand. Metabolisable protein (MP) requirements and N excreta were also explored. In the low-intensity production system (LIPS), 257 cows were milked once-daily and fed diets with low supplementary feed inclusion during the lactation (304 kg pasture silage/cow). In the high-intensity production system (HIPS), 207 cows were milked twice-daily with higher supplementary feed inclusion (429 kg pasture silage and 1,695 kg concentrate/cow). Cows within each herd were ranked as low, intermediate, or high for MUBV. The dataset consisted of 2,318 records of milk production collected from monthly herd tests of both herds; and 853 additional milk samples obtained at early, mid, and late lactation to measure MU. The ECPU was calculated as the proportion of protein yield (PY) with respect to crude protein intake (CPI); with CPI derived from feed intake estimates based on energy requirements. The MP requirements were modelled according to the equations provided by Givens et al. (2004) and the N excreta partitioned to faeces (FN) and to urine (UN) was estimated by back-calculating UN from FN considering dietary N, and from N retained in body tissues taking into account live weight change during the lactation. Cows in the HIPS herd had superior milk yield (MY) and milksolids yield (MSY) [MSY= PY + fat yield (FY)] ($P < 0.001$). Feed intake was less in LIPS cows ($P < 0.001$) but CPI was superior compared to HIPS. The ECPU was better in HIPS ($P < 0.001$) because of higher PY ($P < 0.001$) along with lower CPI ($P < 0.001$). Levels of MU were higher for LIPS cows because of higher CPI and this led to higher MP balance. Cows with low MUBV had significantly lower MU along with lower total daily excretion of MU during the lactation ($P < 0.001$) but this was not linked to significantly less UN. Irrespective of supplementary feed level employed in each herd, cows with low MUBV had lower MY ($P < 0.001$). Low MUBV did not result in improved ECPU for either herd: in LIPS, ECPU was inferior in cows of low MUBV ($P < 0.001$), and this was explained by reduced PY ($P < 0.001$). Feeding a more energy:protein balanced ration was found to be an effective tool to reduce N losses and to increase the ECPU.

Keywords: milk urea, breeding values, crude protein utilisation, supplementation.

5.2 Introduction

New Zealand dairy systems are predominantly grass based, although the proportion of supplementary feed has increased in recent decades (Wales and Kolver 2017). The positive response in milk production from grazing cows fed supplements (Berry et al. 2006) has resulted in farmers increasing supplement allocation to milking cows. Fresh grazed pastures are high in crude protein (CP) concentration in early and late lactation (early spring and late autumn, respectively), containing mainly rumen-degradable protein at levels that regularly exceed milk production requirements (Kolver and Muller 1998). Efficiency of CP utilisation (ECPU), defined as nitrogen (N) output in milk protein as a percentage of CP in the diet of grazing cows, is generally low. Low ECPU results in increases in excreted N, predominantly in urine (Hristov et al. 2005), and this is associated with increases in soil solution and groundwater nitrate-N and contributes to greenhouse gas emissions. Supplements are typically higher in energy content and lower in CP than pasture (Kolver and Muller 1998) and their inclusion can improve the ECPU of a cow by diluting the dietary CP, and increasing milk production.

Metabolisable protein (MP) refers to the true protein absorbed from the small intestine supplied by dietary rumen-undegradable protein (UDP), and by microbial protein synthesized in the rumen supplied by dietary rumen-degradable protein (RDP) (Haque et al. 2012; Amanlou et al. 2017). A surplus in the MP balance (supply minus demand) occurs by feeding CP in excess of protein requirements. In turn, this leads to increases in N excreta through urea production, whereas milk protein yield increases modestly (Lapierre et al. 2005). On the contrary, decreasing CP supply below cow requirements triggers mobilisation of body reserves in order to meet protein requirements (Amanlou et al. 2017; Kaufman et al. 2018).

The excess of ruminal N is rapidly converted to urea to avoid harm from the excess of ammonia. Urea is transported from the plasma and subsequently is transported to other fluids such as saliva in order to be recycled, or to be excreted in urine but it can also be found in milk. Hence, milk urea (MU) has been proposed as a non-invasive tool to assess inefficiencies of N use and as a predictor of N excreted through urine into the environment (Nousiainen et al. 2004; Jonker et al. 1998). Recently, it was suggested that selecting cows of low MU breeding values (MUBV) would reduce N leaching by 20% over 20 years as more N would be captured in milk true protein (Beatson et al. 2019), but literature is scarce in regard to milk production performance of these low-MUBV cows.

The objective of the current study was to evaluate the milk production performance and ECPU of cows with low and high MUBV in two contrasting herds differing in intensification levels in

New Zealand. Additionally, the balance of MP was modelled, and N excreta partitioning was estimated in order to explore its relationship with MU.

5.3 Materials and methods

The current study was carried out in the lower North Island of New Zealand from June 2016 to May 2017 on a herd of 210 cows managed as a high-intensity production system (HIPS) with cows milked twice-daily (TAD) throughout the season, with higher non-pasture supplementary feeds included throughout the year and on a herd of 257 cows managed as a low-intensity production system (LIPS) with cows milked once-daily (OAD) throughout the season, with restricted supplementation and fresh ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture comprising the main diet component throughout the year. Planned start of calving commenced in the second half of July for both herds.

In LIPS, cows were milked once daily at 6:30 am throughout the season and had daily access to an herb crop [mix of plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*) and red clover (*Trifolium pratense*)] at an allowance of 3.5 kg dry matter (DM) per cow from December to April. In March and May, lucerne (*Medicago sativa*) was grazed at an offered allowance of 3 kg DM per cow per day. Turnip crop (*Brassica campestris* ssp. *rapifera*) was fed at an allowance of 2.6 kg DM per cow in February. Pasture silage was fed directly on paddock in August and from March to May at a rate of 3.5 kg of DM per cow per day.

In HIPS, cows were miked daily at 5:30 am and 2:30 pm throughout the season and maize silage (*Zea mays*) and grain-based concentrate were fed during the lactation at 3.5 kg DM per cow per day before the afternoon milking and 1 kg DM per cow per day inside the parlour at each milking, respectively. Pasture silage was fed directly on paddock in January at a rate of 3 kg of DM per cow per day. In March, dried distillers grain was fed at a rate of 0.75 kg DM per cow during the morning milking and turnip crop was grazed in strips at an allowance of 2 kg DM per cow per day.

Herbage mass measurements of ryegrass-white clover pastures was assessed with a rising-plate meter following a ‘W’ pattern across the grazing area before and after each grazing event. Three quadrat cuts (0.1 m^2) were taken both before and after grazing to quantify pre- and post-grazing herbage mass (kg DM per ha) of the grazed crops. These measurements enabled calculation of apparent pasture and crop utilisation, and also the proportion of herbage allocated to cows before each herd test.

Samples (approximately 1,500 g of wet weight) of fresh pastures and crops were taken by hand-plucking (Baker 2004), and these, along with samples of silage and concentrate, were freeze-dried and ground (Wiley mill) to pass through a 1.0 mm screen. All samples were analysed by the near infrared reflectance spectroscopy technique (Corson et al. 1999) to evaluate metabolisable energy (ME) and CP.

Daily live weight (LW) measurements were available and body condition scores (BCS) estimated at each herd test by a single research technician using a 10-point scale (Macdonald and Macmillan 1993). Yields of milk (MY), fat (FY) and protein (PY) and somatic cell count were collected from monthly herd test records. Lactation curves for milk production traits and cow performance were obtained using Legendre polynomials of third order generating daily records for each cow during the season (Silvestre et al. 2006). Live weight loss (LW_{loss}) and BCS loss (BCS_{loss}) were calculated as the sum of LW (or BCS) loss between day of reference with respect to a previous day in the first 100 days of lactation.

Additionally, milk samples from each cow were taken in early (September), mid (December), and late (March) lactation using herd test milk meters provided by Livestock Improvement Corporation. These samples were analysed by MilkTestNZ (Hamilton, NZ) using the CombiFoss technique (Arunvipas et al. 2003) for MU (mg/dL) content and lactose percentage. Each MU record was converted into MU yield (MUY) (g MU/cow/day) using daily MY.

Total net energy requirements for maintenance, pregnancy, production, and daily LW variation were calculated using the equations provided by Berry et al. (2006). Apparent DM intake (DMI) (kg DM/cow/day) was estimated by dividing the daily ME expenditure by the ME content of any feed offered on the day of the herd test after multiplying total net energy requirements by 11.85 MJ ME. Concentration of CP (%) in feed was used to calculate CP intake (CPI). Daily ECPU was calculated by dividing PY by CPI.

The MP balance estimations were undertaken using Rumen8 (Morris et al. 2018), a software designed as a decision support tool for dairy nutrition advisors and farmers as part of a collaborative project between Western Dairy and Dairy Australia. This software calculates the MP supply and demand using the equations provided by Givens et al. (2004). The a, b, and c values for fractions of the protein degradability (Van Soest 1994) for each of the feeds were used from the reference values provided by the Rumen8 library.

A back-calculation for N excreta estimation was undertaken, considering the retention of N in body tissues as constant (160 g of CP per kg of LW change) (Huhtanen et al. 2015). Total N excreta comprises N contained in faeces and urine during a given period. Compared to N concentration in urine (UN), N excreted in faeces (FN) is constant relative to DMI in lactating cows (Peyraud et al. 1995). Faeces are the main fate of undigested feed N, undigested microbial N and endogenous N (Tamminga 1992). Considering this, FN (g N excreted per day) was estimated employing a formula of Reed et al. (2015):

$$\mathrm{FN} = 72.7 - 11.8 \times \mathrm{ME} - 0.4 \times \mathrm{NDF} + 3.5 \times \mathrm{CP} + 0.2 \times \mathrm{ForR} + 9.3 \times \mathrm{DMI} - 0.1 \times \mathrm{DIM}$$

where ForR is the proportion of forage in the diet. Subsequently, UN (g N urine per day) was estimated as:

$$\mathrm{UN} = \mathrm{IN} - \mathrm{FN} - \mathrm{MN} - \mathrm{RetN}$$

where IN is intake of N (g of N per day), MN is milk N (g of N in milk per day) and RetN corresponds to N retained in body tissues according to LW variation (g N retained per day).

Each cow's MUBV was estimated from the dataset of this study using a single-trait repeatability animal model as described by López-Villalobos et al. (2018). The PROC RANK procedure of SAS was utilised to obtain three MUBV categories within cows of the same age and breed in each herd: low, intermediate, and high. Only cows of high and low MUBV were considered in this study. Least-squares means of the variables were obtained using the PROC MIXED procedure of SAS with a mixed model that included the fixed effects of herd, lactation number, MUBV category and as co-variables deviation from median calving date, proportion of Holstein-Friesian (F) and heterosis effect between F and Jersey (J), and the random effect of cow.

5.4 Results

Table 5.1 presents milk production least-squares means of cows with low- and high-MUBV in each herd (LIPS and HIPS) after adjustment for lactation number, deviation from median calving date, proportion of F and F×J heterosis effects. An increase in MY for high-MUBV cows was observed, irrespective of herd (Figure 5.1 a). The difference in MY between high versus low MUBV was 11% and 7% for LIPS and HIPS, respectively ($P < 0.001$). With respect to milksolids yield (MSY) the same trend was observed as in the case of MY but the differences remained at a significant level only in LIPS (Table 5.1). Lactation length was the same for low and high MUBV on both LIPS and HIPS. While the ECPU of low and high MUBV in the HIPS herd was similar, in the LIPS herd the mean ECPU was one percentage point lower for the low MUBV when compared to high MUBV ($P < 0.001$) (Figure 5.1 b).

Table 5.1 Least-squares means (± standard errors) of production, live weight, intakes and crude protein efficiency in grazing cows of low and high milk urea breeding value (MUBV) on production systems of low intensity (LIPS) and high intensity (HIPS) during season 2016-17.

	Production system			
	LIPS		HIPS	
Trait	Low MUBV	High MUBV	Low MUBV	High MUBV
N	82	86	68	70
MU breeding value	-0.57	3.24	0.11	3.11
Lactation length, days	274 ± 3	277 ± 3	269 ± 4	273 ± 4
Milk yield, kg	3,900 ± 86^{d}	4,369 ± 83^{c}	4,934 ± 99^{b}	5,282 ± 99^{a}
Milksolids yield, kg	368 ± 7^{c}	397 ± 7^{b}	420 ± 8^{a}	431 ± 8^{a}
Fat yield, kg	208 ± 4^{c}	222 ± 4^{b}	231 ± 5^{ab}	236 ± 5^{a}
Protein yield, kg	160 ± 3^{c}	175 ± 3^{b}	188 ± 4^{a}	195 ± 4^{a}
Lactose yield, kg	198 ± 5^{c}	221 ± 5^{b}	280 ± 5^{a}	291 ± 5^{a}
SCS[1]	5.71 ± 0.13^{a}	5.65 ± 0.13^{a}	4.93 ± 0.15^{b}	5.2 ± 0.2^{b}
Live weight, kg	475 ± 6	479 ± 6	479 ± 7	473 ± 7
Live weight loss[2], kg	13 ± 4^{c}	19 ± 4^{bc}	34 ± 4^{a}	30 ± 4^{ab}
BCS	4.73 ± 0.03^{a}	4.53 ± 0.03^{b}	4.31 ± 0.04^{c}	4.19 ± 0.04^{d}
BCS loss[3]	0.28 ± 0.02^{c}	0.41 ± 0.02^{b}	0.42 ± 0.03^{b}	0.49 ± 0.03^{a}
DM[4] intake, kg/day	15.67 ± 0.07^{c}	16.19 ± 0.07^{b}	18.12 ± 0.14^{a}	18.19 ± 0.14^{a}
CP[5] intake, kg/day	3.03 ± 0.02^{b}	3.13 ± 0.02^{a}	2.69 ± 0.04^{c}	2.71 ± 0.04^{c}
Milk urea, mg/dL	23.78 ± 0.53^{b}	33.08 ± 0.52^{a}	17.5 ± 0.6^{c}	24.44 ± 0.62^{b}
Milk urea yield, g	911.4 ± 25.3^{b}	1,355.1 ± 24.4^{a}	921.7 ± 29.1^{b}	1,332.1 ± 29.1^{a}
ECPU[6], %	19.28 ± 0.22^{c}	20.27 ± 0.22^{b}	27.2 ± 0.4^{a}	27.26 ± 0.42^{a}

[1] The somatic cell count records were log-transformed to SCS. [2] Sum of live weight loss between day of reference with respect to a previous day in the first 100 days of lactation. Body condition score (BCS) on a 1-10 scale. [3] Sum of BCS loss between day of reference with respect to a previous day in the first 100 days of lactation. [4] Dry matter. [5] Crude protein. [6] Efficiency of crude protein utilisation. ^{abcd}means with different superscripts within rows indicates that were significantly different ($P < 0.05$).

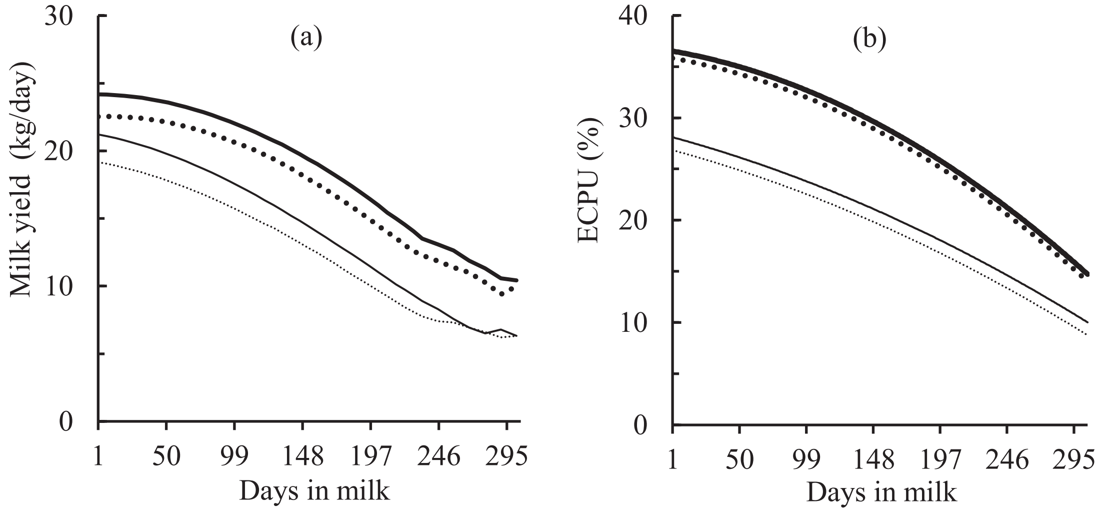

Figure 5.1 Predicted lactation curves of (a) milk production (kg milk/cow) and (b) efficiency of crude protein utilisation (ECPU) (%) of grazing cows of low and high milk urea breeding value (MUBV) on production systems of low intensity (LIPS) and high intensity (HIPS) during season 2016-17. Legend: LIPS_Low MUBV (.....); LIPS_High MUBV (—); HIPS_Low MUBV (•••); HIPS_High MUBV (▬).

Irrespective of MUBV category, cows of HIPS had significantly higher DMI. In the LIPS herd, the DMI of low-MUBV cows was 3% less when compared to high-MUBV cows ($P < 0.001$) and these differences were reflected in CPI. A higher proportion of pasture allocated to the cows of the LIPS herd during the lactation (92% vs 60% of total feed intake) led to a diet higher in CP (19.3% vs 15.1%) that resulted in higher CPI ($P < 0.001$) for the LIPS herd (Table 5.1). Values of CP for LIPS were 21.0, 19.7, and 21.2 in early, mid-, and late lactation, and 14.4, 14.9 and 16.1 in HIPS, respectively (Table 5.2).

Table 5.2 Milk production, cow performance and dietary characteristics expressed in kg of dry matter (DM) intake per cow per day in pasture-based cows of low and high milk urea breeding value (MUBV) on production systems of low intensity (LIPS) and high intensity (HIPS) during season 2016-17.

	Production system											
	LIPS						HIPS					
Item	Low MUBV			High MUBV			Low MUBV			High MUBV		
Stage of lactation	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
Milk yield, kg/day	19.0	15.8	10.8	21.1	17.4	12.1	23.7	20.7	16.6	24.8	21.9	17.9
Milksolids yield, kg/day	1.7	1.5	1.1	1.8	1.6	1.2	1.9	1.7	1.6	1.9	1.8	1.6
Fat yield, kg/day	1.0	0.8	0.6	1.0	0.9	0.7	1.0	1.0	0.9	1.0	1.0	0.9
Protein yield, kg/day	0.7	0.6	0.5	0.8	0.7	0.5	0.8	0.8	0.7	0.9	0.8	0.7
Live weight, kg	473	476	494	477	477	494	478	492	509	485	503	525
Live weight loss[1], kg/day	-0.13	0.13	0.25	-0.20	0.16	0.24	0.01	0.33	0.26	0.01	0.32	0.29
BCS[2]	4.8	4.6	4.6	4.6	4.4	4.4	4.3	4.1	4.2	4.1	4.0	4.1
Ryegrass-white clover pasture, kg DM/day	16.3	11.0	8.8	17.0	11.4	9.2	11.1	7.7	10.2	11.1	7.7	10.5
Herb-mix crop, kg DM/day		4.0			4.2							
Turnips crop, kg DM/day									1.8			1.8
Pasture silage, kg DM/day			3.2			3.3		4.0			4.0	
Lucerne crop, kg DM/day			6.4			6.7						
Maize silage, kg DM/day							4.4	4.0	5.1	4.5	4.0	5.3
Concentrate, kg DM/day							3.0	3.4	2.5	3.0	3.5	2.6
DDG, kg DM/day									1.0			1.1
Dry matter intake, kg DM intake/day	16.3	15.0	18.4	17.0	15.6	19.2	18.5	19.1	20.6	18.6	19.2	21.3
Energy, MJ ME[3]/kg DM	11.4	11.9	9.5	11.4	11.8	9.5	11.3	11.3	10.6	11.3	11.3	10.6
CP, %	21.0	19.7	21.2	21.0	19.9	21.2	14.4	14.9	16.1	14.4	15.0	16.3
Estimated UDP[4], g/kg DM	1003	933	1086	1059	984	1154	759	829	941	759	832	976
Estimated RDP[5], g/kg DM	2420	2038	2809	2511	2106	2916	1910	2028	2398	1918	2048	2474
CP intake, kg CP intake/day	3.4	3.0	3.9	3.6	3.1	4.1	2.7	2.8	3.3	2.7	2.9	3.5

[1] Live weight loss between day of reference with respect to a previous day. [2] Body condition score. [3] Megajoules of metabolisable energy. [4] Undegraded protein in rumen. [5] Rumen-degradable protein.

Compared to high-MUBV cows, lower MU on low-MUBV cows was observed regardless of herd (Figure 5.2 a). The difference in MU between low- and high-MUBV cows was 9.30 and 6.92 mg/dL in LIPS and HIPS along the lactation, respectively. Mean values of MUY were similar for low-MUBV cows in LIPS and HIPS herds, and for high MUBV cows in LIPS and HIPS herds and this was attributed to the compensation between MY and MU observed in each treatment within each herd (Figure 5.2 b).

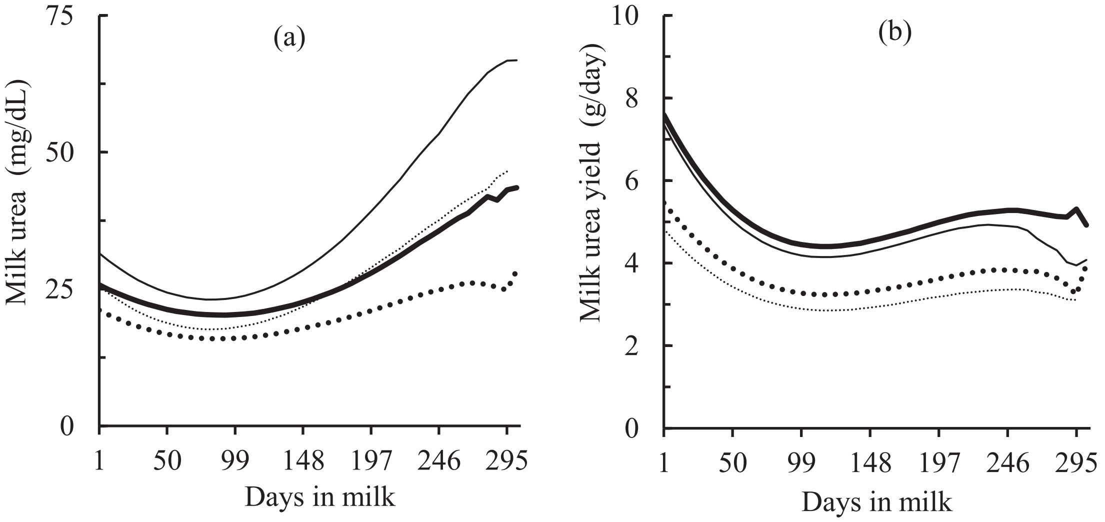

Figure 5.2 Predicted lactation curves of (a) milk urea (mg/dL) and (b) milk urea yield (g) of grazing cows of low and high breeding value for milk urea (MUBV) on production systems of low intensity (LIPS) and high intensity (HIPS) during season 2016-17. Legend: LIPS_Low MUBV (.....); LIPS_High MUBV (—); HIPS_Low MUBV (•••); HIPS_High MUBV (▬).

There were no significant differences of LW between treatments (Table 5.1 and Figure 5.3 a). An interaction between MUBV categories and feeding system employed in each herd with respect to BCS and its correspondent mobilisation in the first 100 days of lactation was observed. In the LIPS herd, cows of low MUBV had lower LW_{loss} when compared to high-MUBV cows, and in the HIPS herd, cows of low MUBV had higher LW_{loss} when compared to high-MUBV cows, but significant differences were only observed between herds. Irrespective of herd, BCS was higher in low-MUBV cows compared to high-MUBV cows, and this was accompanied by a minor BCS_{loss} in the first 100 days of lactation in each instance ($P < 0.001$) (Figure 5.3 b).

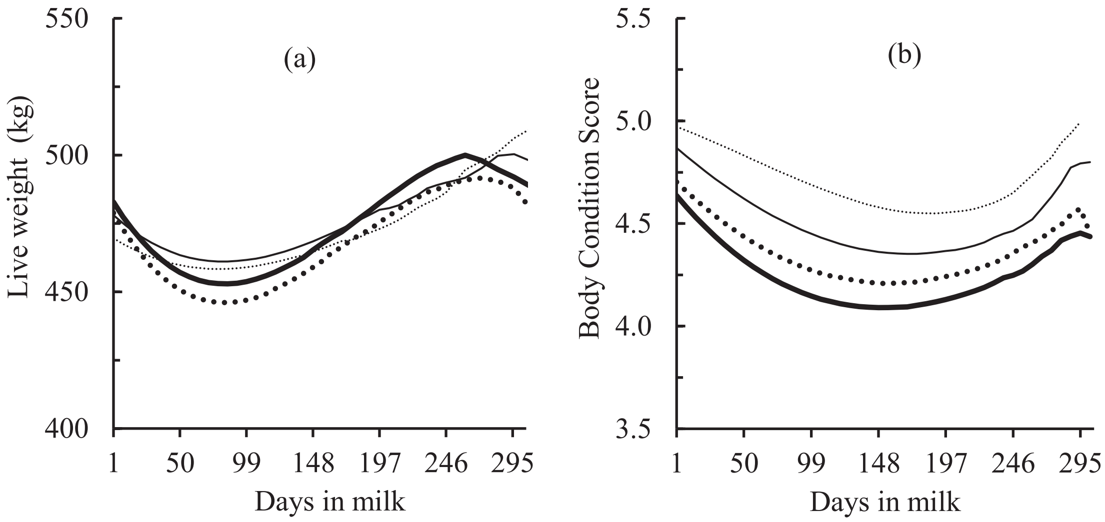

Figure 5.3 Predicted lactation curves of (a) live weight (kg) and (b) body condition score of grazing cows of low and high breeding value for milk urea (MUBV) on production systems of low intensity (LIPS) and high intensity (HIPS) during season 2016-17. Legend: LIPS_Low MUBV (.....); LIPS_High MUBV (—); HIPS_Low MUBV (•••); HIPS_High MUBV (▬).

5.5 Discussion

The aim of the current study was to compare the effect of low and high MUBV in cows on milk production performance and ECPU under grazing conditions with two supplementation levels. It was confirmed that cows with low MUBV produce milk with low concentrations of MU at both supplementation levels (Figure 5.2 a). Notwithstanding this, at each level of supplementation in each herd, cows with low MUBV produced less milk than cows with high MUBV. Additionally, ECPU was not better for low-MUBV cows than for high-MUBV cows with either of the two levels of supplementation (Table 5.1 and Figure 5.1 b). On the contrary, a marginal improvement in ECPU in cows of high MUBV fed LIPS was observed, but this was explained by higher increases in PY (9%) than the increase observed in the CPI (3%), when compared to cows of low MUBV fed LIPS. Literature is scarce in regard to the genetic effect of MUBV on MY, but in line with the current study, Sebek et al. (2007) reported the absence of a relationship between MUBV and ECPU by analysing more than 15,700 records from 723 cows in 26 experiments. In a study by Wood et al. (2003) the heritability for MU ranged from 0.44 to 0.59, indicating that MU can be included in a genetic selection plan, but there is a lack of estimates for genetic correlations of MU with production and fertility traits in grazing cows. Selection for low MUBV might result in unfavourable effects on other traits, such as the reduction in MY observed in both HIPS and LIPS herds in the current study. Berry et al. (2006) corroborated a moderate heritability of energy balance and energy partition towards milk production by selecting high genetic merit cows. In the current study, energy balance was not calculated, but it can be reflected indirectly in LW_{loss} and BCS_{loss}. In both LIPS and HIPS herds, a lower BCS_{loss} for low-MUBV cows in the first 100 days of lactation resulted in lower MY when compared to high-MUBV cows. In regard to LW_{loss}, only in the LIPS herd a lower LW_{loss} for low-MUBV cows was accompanied by a lower MY, compared to high-MUBV cows. Cows in the HIPS herd had no differences in LW_{loss} irrespective of MUBV, but MY was higher for the high-MUBV cows. There might be an interaction between energy balance of cows with different milking frequency (McNamara et al. 2008) and energy content of the different diets offered to both LIPS and HIPS herds (Kolver and Muller 1998).

In agreement with the current study, a significant reduction in milk production was reported when comparing cows milked OAD vs TAD (Figure 5.1 a) (Clark et al. 2006). By increasing the milking interval in cows of the LIPS herd, a suppression of nutrients partitioned towards the mammary gland would lead to a reduction in milk production (McNamara et al. 2008), compared to the cows of the HIPS herd. The difference in MY between low-MUBV cows of LIPS, compared to the HIPS herd, was 1034 kg of milk and a similar value was observed with high-MUBV cows of LIPS when compared to HIPS. Additionally, OAD cows fed a larger proportion of pasture had a lower DMI, and this was anticipated in line with previous experiments (Holmes et al. 1992).

Irrespective, from the lower DMI of cows in LIPS, CPI was increased due to a larger proportion of dietary pasture allocation with higher degradable N and this, along with a reduced PY, resulted in a lower ECPU for cows of LIPS when compared to cows of HIPS. A negative, strong relationship between dietary CP and N use efficiency has been previously reported (Hristov et al. 2005). Diets comprised mainly of ryegrass pasture of good quality are moderate in ME and high in CP, and the lower inclusion of concentrate on such diets would reduce the total ME intake. This represents an imbalance of energy:protein ratio in the rumen, interfering with the uptake of CP towards microbial protein synthesis (Kolver and Muller 1998). Additionally, the diet provided in HIPS was more energy-dense and had less CP, lowering the CPI while increasing the DMI, which resulted in higher PY, and this exacerbated the difference in ECPU between the LIPS and HIPS herds.

Milk urea was effectively diminished by reducing CP in the diet (Figure 5.2 a). Ureagenesis occurs in the liver and is a vital mechanism to overcome poisoning from the excess of ammonia present in the systemic circulation. This labile N pool is highly influenced, amongst other factors, by feeding management (Nousiainen et al. 2004). In turn, urea is transported from the plasma to other fluids such as saliva in order to be recycled, and urine to be excreted, but due to its molecular weight and neutral charge urea easily diffuses across cellular membranes where is incorporated to milk. As such, the relationship between urine urea and MU was previously recognised by Jonker et al. (1998). A problem is that these associations are from housed conditions with diets controlled (and reduced) in CP. While finding no improvements in the ECPU by reducing MU in the current study it is imperative to verify the implications of different MUBV with respect to blood urea nitrogen and to the total release of N in excreta in pasture-fed cows.

5.5.1 Metabolisable protein balance and nitrogen excreta partitioning

Irrespective of MUBV, the higher CPI observed in LIPS, resulted in a MP surplus which resulted in a lower ECPU when compared to HIPS (Table 5.3). Reducing the MF to OAD over short periods was demonstrated as a tool to alleviate the negative energy balance that cows undergo during the early post-partum period (McNamara et al. 2008). Notwithstanding the reduced MF of cows in LIPS, a more pronounced negative energy balance was observed throughout the season when compared to the HIPS herd. Particularly, a negative energy balance was seen in early lactation in the LIPS herd (Table 5.3). Cows in LIPS had an excess of effective RDP which resulted in insufficient fermentable metabolisable energy for the rumen microbes. All the excess RDP would have resulted in elevated levels of ammonia which is converted into urea and mainly excreted in urine (Van Soest 1994). Compared to the HIPS herd, the lower energy balance of the LIPS herd was probably due to the extra energetic cost spent in eliminating the excess N (Reed et al. 2017), which also explained the higher measured MU and the higher predicted UN (Table 5.3). In turn, these higher N losses and MU observed in both low- and high-MUBV cows fed LIPS were in line with the higher MP surplus and with the inferior ECPU when compared to their counterpart low- and high-MUBV HIPS cows. Moreover, both low- and high-MUBV cows of the HIPS herd were offered excess RDP towards late lactation because of reduced MP requirements as MY decreased.

Table 5.3 Balances of energy and protein along with nitrogen (N) partitioned to faeces and urine in pasture-based dairy cows of low and high milk urea breeding value (MUBV) on production systems of low intensity (LIPS) and high intensity (HIPS) during season 2016-17. Requirements and supply of metabolisable protein (MP) were calculated using Rumen8 software (Morris et al. 2018). Fractions of N partitioned to faeces and urine were estimated using equations by Reed et al. (2015).

	Production system											
	LIPS						HIPS					
Item	Low MUBV			High MUBV			Low MUBV			High MUBV		
Stage of lactation	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
ME requirements, MJ ME[1]/day	185.4	178.4	174.0	194.0	184.0	182.0	209.2	216.3	219.2	209.8	216.8	225.6
ME balance, MJ ME/day	-5.4	6.9	13.3	-8.3	8.5	12.8	0.0	17.6	13.9	0.5	17.1	15.5
MP[2] requirements, g/day	1525	1509	1344	1619	1494	1432	1792	1797	1700	1806	1805	1756
MP supply, g/day	2000	1915	1967	2106	2013	2079	1739	1843	2115	1744	1857	2190
MP balance, g/day	475	406	623	487	519	647	-53	46	415	-62	52	434
ECPU[3], %	21.6	21.7	12.6	22.1	22.2	13.0	31.5	27.8	21.4	31.8	28.1	21.3
CP balance[4], kg CP/day	2.68	2.31	3.41	2.78	2.42	3.54	1.83	2.05	2.61	1.83	2.07	2.73
Milk urea, mg/dL	18.95	19.62	33.11	25.72	25.64	45.31	15.33	17.15	21.76	19.95	22.39	30.20
N in faeces, g N/day	160	134	190	167	139	198	156	159	185	156	159	189
N in urine, g N/day	272	228	341	282	232	352	128	145	224	126	146	230

[1] Megajoules of metabolisable energy. [2] Metabolisable protein. [3] Efficiency of crude protein (CP) utilisation. [4] Crude protein balance calculated as daily CP intake minus daily protein yield.

The observed negative MP balance in early lactation of low- and high-MUBV cows fed HIPS (Table 5.2) was attributed to a reduced CPI. Nevertheless, cows were still able to achieve moderate levels of milk production (Table 5.2). The supply of protein through mobilising body reserves has been previously reported (Amanlou et al. 2017; Kaufman et al. 2018).

The relationship between MU and CP was positive (Jonker et al. 1998; Nousiainen et al. 2004). Moreover, MU was also reported to be positively related to RDP (Tacoma et al. 2017), and to UDP (Amanlou et al. 2017). Milk urea was found to be positively correlated with both estimations of RDP and UDP. The relationships between MU with MP balance, ECPU, and UN (predicted g of N in urine per day) are shown in Figure 5.4. It seems that when MU reaches values above 20 mg/dL per day, the relationships with MP balance (surplus), ECPU, and UN becomes less responsive. In New Zealand, cows are regularly fed pasture diets high in CP (Waghorn and Clark 2004; Pacheco and Waghorn 2008), consequently elevated values of MU would be expected and this could be part of the explanation of the nil effect of low MUBV in improving the ECPU.

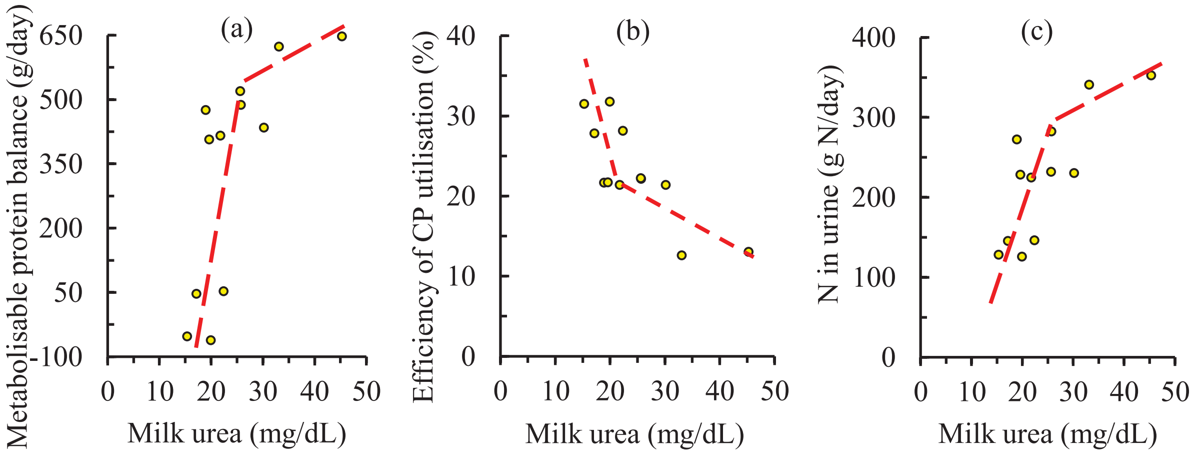

Figure 5.4 Relationship of milk urea with a) metabolisable protein balance, b) efficiency of crude protein (CP) utilisation and c) nitrogen (N) in urine.

Regardless of the genetic merit of cows to produce less MU, the reductions of MU observed during the lactation were not associated with improvements in the ECPU or with reduced N partitioned towards excreta. Feeding a more energy:protein balanced ration was a more effective tool to reduce N losses and increase the ECPU. In order to reduce wastage of CP, the focus needs to be on matching the RDP supply with the fermentable metabolisable energy (Baldwin and Denham 1979; Van Soest 1994; Alderman and Blake 1995). It has also been suggested that shifting the site of digestion from the rumen to the large intestine, by increasing the UDP, has the potential to reduce urinary N excretion (Castillo et al. 2000).

5.6 Conclusions

Irrespective of dietary supplementation allocated to each herd, cows of low MUBV had lower MY. Additionally, MSY was lower in low-MUBV treatments, but this was only significant in the LS. Regardless of dietary CP, reductions of MU during the lactation were not associated with improvements in the ECPU. On the contrary, cows that had higher ECPU also had higher mean MU during the lactation. The relationships between MU with MP balance and with UN predictions were positive but the relationship becomes less responsive when MU increased and, considering the expected higher MU levels in grazing conditions, this might be part of the explanation to a lack of improvement in ECPU when selecting cows of low MUBV.

Work is still needed to verify whether the reduction of MU of pasture-based dairy cows would result in less N excreted to the soil. In the meantime, identifying feeding strategies aimed to reduce the CP intake appears to be more efficient than selecting cows of low MUBV in enhancing the ECPU and in reducing the N losses from grazing dairy systems.

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Chapter 6

Lactation curves of efficiency of crude protein utilisation and milk urea of spring-calving pastured dairy cows milked once or twice daily

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6.1 Abstract

The efficiency with which pastured dairy cows utilises the dietary crude protein (CP) is a key aspect of environmentally and economically sustainable agricultural production systems. This study compared lactation curves of two measures of nitrogen (N) use efficiency along with milk urea (MU) and total MU secretion (MUY) of milking cows of two contrasting spring-calving pasture-based production systems differing in intensification levels in New Zealand. The partitioning of N in excreta was also explored. In the low-intensity production system (LIPS), 257 cows were milked once-daily and fed diets with low supplementary feed inclusion during the lactation (304 kg pasture silage/cow). In the high-intensity production system (HIPS), 207 cows were milked twice-daily with higher supplementary feed inclusion (429 kg pasture silage and 1,695 kg concentrate/cow). At every herd test date, N use efficiency was calculated for each cow as the efficiency of CP utilisation (ECPU), defined as protein yield divided by CP intake (CPI); with CPI derived from intake assessments based on metabolisable energy requirements for measured individual milk yields. Additionally, CP balance (CPB) was calculated as the difference between CPI and protein yield for each cow of both production systems. Milk urea was measured individually in early-, mid- and late-lactation. Total N excreta partitioned to faeces (FN) and to urine (UN) was estimated by back-calculating UN from FN considering dietary N, and from N retained in body tissues taking into account live weight change during the lactation. The LIPS cows had 21% lower milk production (1,100 kg milk/cow less) than the HIPS cows. Compared to the HIPS cows, the LIPS cows had 8% higher CPI (2.7 vs 2.5 kg CP/day) because of higher fresh pasture inclusion in the diet. The higher CPI along with the reduced milk yield of the LIPS cows led to a lower ECPU (23% vs 31%) and to a higher CPB (2.1 vs 1.8 kg CP/day) when compared to the HIPS cows. Values of MU were significantly less in HIPS, but MUY showed no significant differences between LIPS and HIPS. Mean N excreta was significantly higher in LIPS cows and this was explained by the higher proportion of UN ($P < 0.001$). Both ECPU and CPB demonstrated that feeding diets with higher fresh pasture proportions, such as those employed in low-intensification dairy systems, led to an excess of dietary CP with greater N partitioned towards urine which is sensitive in terms of body water eutrophication.

Keywords: nitrogen utilisation efficiency; milk urea; excreta; intensification.

6.2 Introduction

A typical New Zealand dairy system utilises twice-daily milking frequency (MF) with the interval between milkings as similar as practicable (Clark et al. 2006). These systems are perceived as an efficient approach to achieve high milk production by maximising the use of grazed grass with variable levels of non-pasture supplementary feed inclusion (Ramsbottom et al. 2015). The addition of feed concentrates is a common intensification management practice in grazing systems to extend lactation length and to fulfil nutritional requirements in peak lactation and can be influenced by seasonal pasture growth, genetics of the herd, stocking rate but it can also be influenced by MF (Stockdale 2006; Beukes et al. 2008). Shortening the interval between milkings generally increases milk yield through an increase in secretory cell activity, whereas extending milking intervals generally decreases nutrient uptake in the mammary gland (Delamaire and Guinard-Flament 2006), resulting in a decrease in milk production. Reduced MF was found to be directly associated with the alleviation of the negative energy balance in early lactation (McNamara et al. 2008). Despite the well-documented milk yield loss on cows milked once-daily (Davis et al. 1999; Clark et al. 2006; Stelwagen et al. 2013; Edwards 2018), the implementation of once-daily milking full-lactation regime as a production system increased among New Zealand farmers from approximately 4% in 1999 (Davis et al. 1999) to approximately 9% in 2018 (Edwards 2018). This trend was motivated for a number of reasons including, amongst others, the improvements of quality of life for workers (Stelwagen et al., 2013); better animal welfare, reproductive performance and immune status of the cows (Clark et al. 2006); and the reductions in cow culled from one season to another (O'Driscoll et al. 2010). In order to maintain profitability once-daily production systems are typically pasture-based with little or no supplementary feed inclusion aiming to reduce feed costs foreseeing a reduction in milk income (Stelwagen et al. 2013).

The efficiency with which lactating cows convert dietary crude protein (CP) into milk protein can be measured by different criteria. For instance, it can be measured as the efficiency of CP utilisation (ECPU) calculated as the protein in milk (PY) in a day divided by the daily CP intake (CPI), or calculated considering an approximation of CP balance (CPB) estimated as CPI minus PY (Zamani 2012). Compared to diets formulated from total mixed rations, diets comprised of predominantly fresh grazed temperate pastures may be high in CP, containing mainly rumen-degradable protein at levels that regularly exceed animal requirements (Kolver and Muller 1998; Waghorn and Clark 2004). Therefore, lower efficiency of nitrogen (N) utilisation, with values ranging from 13% to 33%, would be expected in grazing conditions and this would result in increases in excreted N, predominantly in urine (Kebreab et al. 2001) which disturbingly elevates the nitrate-N levels in soil solution and groundwater (Tamminga 1992; Ledgard et al. 2009). Within grazing conditions, manipulating the dietary CP is limited, but when low-N energy-dense concentrate is fed to pastured dairy cows it was proven as a strategy to provide more energy for microbes to increase the microbial protein synthesis. A study conducted by Mulligan et al. (2004) tested the effect of supplementing pastured dairy cows with low vs high protein concentrate and demonstrated that low protein supplementation increased milk yield and reduced the CP intake and this was observed in improvements in the ECPU. By including low CP concentrates, minor changes in milk protein composition were documented (Mackle et al. 1999), along with an increase of N excreted in faeces rather than urine (Mulligan et al. 2004; Hristov et al. 2005).

The excess of dietary CP (N concentration × 6.25) is rapidly converted to urea to avoid harming from the excess of ammonia. Urea is transported from the plasma and subsequently is transported to other fluids such as saliva in order to be recycled, or to be excreted in urine but it can also be found in milk as milk urea (MU). The relationship between MU and dietary CP was reported positive in housed conditions (Broderick and Clayton 1997; Jonker et al. 1998; Nousiainen et al. 2004) and in grazing conditions (Bargo et al. 2002; Totty et al. 2013). Hence, MU has been proposed as a proxy to identify excess CP in diets (Broderick and Clayton 1997), as an indicator of N use efficiency (Broderick and Clayton 1997; Gourley et al. 2012) and as a predictor of N excreted through urine into the environment (Jonker et al. 1998; Nousiainen et al. 2004).

Considering that dairy production systems of reduced intensification level, such as once-daily full-lactation systems, would perceive higher proportion of dietary CP as a consequence of more pasture fed in combination with restricted low-protein concentrate supplementation a decrease in the efficiency of N utilisation would be expected. Under these productive management conditions, cows are expected to have a positive energy balance and there might be a link with the CPB. Thus, the objective of this study was to describe and compare lactation curves of two measures of N use efficiency along with MU concentration and secretion of milking cows of two spring-calving pasture-based production systems differing in intensification level. Nitrogen excreta partitioning of these intensification management practices identified (supplementation and MF) was also explored.

6.3 Materials and methods

The present study was carried out on two Massey University research dairy farms sited in Palmerston North, in the lower North Island of New Zealand (longitude 175°, latitude −40°) throughout an entire seasonal lactation. In response to a different management approach a different feeding plan was implemented in each research farm. The Massey University Dairy 1 farm is managed as a low-intensity production system (LIPS) with 257 cows milked once-daily throughout the season, with low stocking rate (2.1 cows/ha) and feed strategy includes fresh ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture as the main diet component with restricted supplementation and the sporadic use of grazing crops are utilised in summer. On the other hand, Massey University Dairy 4 farm is managed as a high-intensity production system (HIPS) with 207 cows milked twice-daily throughout the season, with higher stocking rate (2.8 cows/ha) and ryegrass-white clover pasture is also fed as main feed source but, in this case, higher supplementation level is included throughout the year.

6.3.1 Herd management in each production system

6.3.1.1 Low-intensity production system

The LIPS herd consisted of 66 Holstein-Friesian (> 13/16; F), 55 Jersey (> 13/16; J), and 136 Holstein-Friesian/Jersey crossbred cows (< 13/16 F or < 13/16 J; F×J) with 12, 15, and 15 primiparous cows, respectively. Calving commenced on July 11th and continued up to October 3rd. Cows were milked daily at 06:30 throughout the season.

After calving, milking cows had daily access as a single group to a new strip of pasture after each milking and were contained in their allocated forage area through the use of temporary electric fences. From December to March and in April, cows had daily access to a perennial herb-mix crop [mixture of plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*), and red clover (*Trifolium pratense*)] at an allowance of 3.5 kg dry matter (DM) per cow. In March and May, alfalfa (*Medicago sativa*) was grazed at an allowance of 3 kg DM per cow per day. Turnips (*Brassica campestris* ssp. *rapifera*) were grazed at an allowance of 2.6 kg DM per cow only in February. Pasture silage was fed directly on the paddock in August and from March to May at a rate of 3.5 kg DM per cow per day.

6.3.1.2 High-intensity production system

The HIPS herd was comprised of 51 F and 156 F×J cows, with 5, and 9 primiparous cows, respectively. Calving commenced on July 1st and continued up to September 26th. Cows were milked daily at 05:30 and 14:30 throughout the season.

After calving, milking cows had daily access as a herd to a new strip of pasture after each milking. During the lactation, maize (Zea mays) silage and grain-based concentrate was fed during the lactation at a rate of 3.5 kg DM per cow per day before the afternoon milking; and 2 kg DM per cow per day was fed inside the parlour. Pasture silage was fed directly on the paddock in January at a rate of 3 kg DM per cow per day. In March, dried distillers grain was fed at a rate of 0.75 kg DM per cow during the morning milking; and turnips were grazed in strips at an allowance of 2 kg DM per cow per day.

6.3.2 Feed quality measurements

Each feed component allocated to cows in the period of 24 hours before each herd test was sampled in order to measure nutritional quality. Estimated pasture eaten (kg DM per cow per day) was calculated from pasture disappearance by measuring pre-grazing DM minus post-grazing DM on the grazing area assigned per day divided by the total number of cows. Grazing area was measured using a global positioning system. Pre- and post-grazing pasture heights were measured with a rising-plate meter (Jenquip, New Zealand) following a ‘W’ pattern across the grazing area on a basis of 3 sets of 50 readings on each occasion. Pasture mass was subsequently estimated using the following New Zealand national calibration equation for perennial ryegrass-white clover (L'Huillier and Thomson 1988):

$$\text{kg DM/ha} = 140 \times \text{compressed height (in 0.5 cm)} + 500$$

Estimated crop (Herb-mix, lucerne, turnips) consumption was calculated as crop cover pre-grazing minus crop cover post-grazing, measured by harvesting three 0.1 m^2 quadrats to ground level within the area allocated to cows on a daily basis. Those measurements enabled calculation of apparent pasture and crop utilisation, and also the proportion of herbage allocated to cows before each herd test.

Fresh pasture and crop samples (approximately 1,500 g of wet weight) were harvested using the hand-plucking method (Baker 2004) from about 50 sites on each walking transect, to mimic herbage grazed by cows. Samples of maize and pasture silage were taken from the bunker; and concentrate and dried distillers grain were sampled directly from the feeders while cows were being milked. All samples were collected in the period of 24 hours prior to the milk sampling at 09:00 am. All samples were freeze-dried and ground (Wiley mill; Arthur H. Thomas, Philadelphia, PA) to pass through a 1.0 mm screen. The levels of ash, CP, lipid, neutral detergent fibre (NDF), acid detergent fibre, organic matter digestibility, metabolisable energy (ME), and starch and soluble sugars were estimated by near infrared reflectance spectrometry (NIR) (Corson et al. 1999). Water-soluble carbohydrate concentration was calculated by NIR for directly grazed pasture. Calibrations for each component had been previously developed (Massey University Nutrition Laboratory, Palmerston North, New Zealand) using NIR spectrometry after scanning finely-ground pasture samples in the range of 400 to 2500 nm. Those samples had been analysed previously for each of the above components by wet chemistry methods. A Bruker MPA NIR spectrophotometer (Ettlingen, Germany) was used to scan the samples and the resulting NIR spectra were analysed using Optic user software version 5.0. (Ettlingen, Germany). The resulting NIR calibration typically had a correlation of 0.90 when compared to the wet chemistry results for each component. Based on the proportions of each forage allowed and each individual feed ME content, the dietary ME content (megajoules of ME per kg DM) was calculated. Table 6.1 resumes the annually feed allocation (diet composition) of each production system with its chemical composition.

6.3.3 Animal measurements

Cows were identified using a radio frequency electronic identification system (Allflex New Zealand Ltd., Palmerston North, New Zealand) enabling daily live weight (LW) and daily LW change measurements to be generated using an automatic race walkover scale (WoW xR-3000, Tru-Test Ltd., Auckland, New Zealand). Yields of milk (MY), fat (FY) and PY, along with somatic cell count (SCC), were determined in a single herd test done in a monthly basis throughout the lactation using a Fossomatic FT120 (Foss Electric, Hillerød, Denmark) on composite afternoon and morning aliquots for HIPS and from a unique sample for LIPS on each sampling date. Somatic cell count was converted to somatic cell score (SCS) as SCS = log2(SCC), where SCC is cells per microlitre. Additionally, individual milk samples were collected using mechanical milk meters (Tru-Test Field Collection meter WB HI / Pullout) provided by Livestock Improvement Corporation (Hamilton, New Zealand) in early (September), mid- (December), and late (March) lactation stages. Those samples were analysed by MilkTestNZ (Hamilton, New Zealand) using a CombiFoss™ 7 instrument (Foss Electric, Hillerød, Denmark) following the CombiFoss technique (Arunvipas et al. 2003) to determine milk urea (mg/dL) content and lactose percentage and lactose yield (LY). Each MU record was converted into MU yield (MUY) (g MU/cow/day) using daily MY. In synchrony with each herd test, BCS was assigned to each cow by a single research technician using a 10-point scale (Macdonald and Macmillan 1993).

Table 6.1 Feed allocation throughout the full lactation and mean feed quality offered to cows before each herd test, expressed in metabolisable energy (ME, MJ ME/kg DM), and in percentages of crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and organic matter digestibility (OMD) of grazing cows in two dairy systems; Low-intensity production system (LIPS) and High-intensity production system (HIPS) during season 2016–17.

	Production system										
	LIPS					HIPS					
Item	Pasture[1]	Pasture silage	Brassica	Herb-mix[2]	Lucerne	Pasture[1]	Pasture silage	Brassica	Maize silage	Concentrate[3]	DDG[4]
Feed allocation, %	92	3	1	3	1	60	8	1	15	15	1
ME, MJ ME/kg DM	11.0	10.7	11.7	12.1	9.9	10.5	10.9	7.8	10.4	12.6	9.5
CP, % of DM	20	14	16	20	25	19	12	22	7	17	21
ADF, % of DM	22	34	22	15	21	24	40	18	28	2	11
NDF, % of DM	44	50	34	29	34	46	56	31	37	23	28
OMD, % of DM	75	67	79	83	68	73	68	81	-	-	-

[1] Perennial ryegrass (*Lolium perenne*)-white clover (*Trifolium repens*) pasture. [2] Herb-mix crop comprised of plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*), and red clover (*Trifolium pratense*). [3] Grain-based concentrate. [4] Dried distillers grain.

Lactation curves for milk production traits, MU, MUY, LW and BCS were modelled from day 1 to day 275 of lactation contemplating the maximum DIM of each cow using random regression models with Legendre polynomials of third order, with the MIXED procedure of the Statistical Analysis System version 9.4 (SAS Institute Inc., Cary, NC, USA). Predicted daily values for each day were obtained from the polynomial function for each cow. The polynomial utilised was described in equation as:

$$Y_{it} = \alpha_{i0}P_{i0} + \alpha_{i1}P_{i1} + \alpha_{i2}P_{i2} + \alpha_{i3}P_{i3}$$

where Y_{it} represents the level of production of a trait $_i$ on day $_t$ of the lactation from calving with α being the regression coefficient to predict each trait mentioned above. The Legendre polynomials' functions of P_y were calculated as:

$$P_0(t) = 1,$$

$$P_1(t) = x,$$

$$P_2(t) = \frac{1}{2}(3x^2\text{-}1), \text{ and}$$

$$P_3(t) = \frac{1}{2}(5x^3\text{-}3x), \text{ where}$$

$$x = \text{-}1 + 2\frac{(t\text{-}t_{min})}{(t_{max}\text{-}t_{min})},$$

according to Silvestre et al. (2006).

Prediction of individual daily values of milk production traits along the lactation were accumulated in order to obtain the total lactation yield per cow for MY, milk solids yield (MSY; FY+PY), FY, PY, MU and MUY.

6.3.4 Energy requirements and intake estimates

Values of net energy requirements for maintenance, pregnancy, production, and daily LW variation were based on the French net energy system where 1 unité fourragère lait is the net energy requirement for lactation equivalent to 1 kg of standard air-dried barley (Jarrige et al. 1986), equivalent to 7.11 MJ of net energy or 11.85 MJ of ME. Net energy requirements were calculated using the following equation with modifications by Berry et al. (2006) for dairy cows in grazing conditions:

$$NEreq = NEm + NEl + NEg + NEp$$

where NEreq is daily net energy requirements for each cow on each herd test date, NEm is daily net energy requirement for maintenance including activity calculated as (1.4 + 0.6 × LW/100) × activity allowance factor of 1.2 for grazing conditions, NEl is the net energy for milk production calculated as 0.054 × (FY/100) + 0.031 × (PY/100)+ 0.028 × (LY/100) - 0.015) × MY, NEg accounted for daily live weight variation assuming an addition of 3.5 units when LW change is positive and a -4.5 when LW change is negative, and NEp is daily net energy requirements for pregnancy where unité fourragère lait requirements for the 6th, 7th, and 8th month of pregnancy were 0.9, 1.6, and 2.6, respectively. Total net energy requirements were transformed to ME requirements by multiplying NEreq times 11.85 MJ of ME. Then, apparent DMI (kg DM/cow per day) for all herd test occurrences was estimated by dividing total ME requirements by the dietary ME content in each instance.

6.3.5 Definitions of nitrogen utilisation efficiency and nitrogen excreta estimates

Two different assessments of N utilisation efficiency were used in this study. The ECPU was calculated as a proportion of CPI and records of PY obtained from the monthly herd tests, as:

$$\mathrm{ECPU} = \frac{\mathrm{PY}}{\mathrm{CPI}} \times 100$$

with CPI determined by multiplying DMI by the CP concentration in the diet.

A complete N balance is required to examine the partition of total N intake towards N in faeces, urine, milk and N retained in body tissues and the foetus (Spanghero and Kowalski 1997), but these types of studies are expensive and cannot be undertaken on a large number of cows in grazing conditions. However, CPB can be calculated on a daily basis as the difference between CPI and PY (Zamani 2012), where the most inefficient cow has the higher CPB.

All the excess of dietary CP in the cow would be excreted except a minor portion that would be retained by cows with positive energy balance. Each kg of LW change was assumed to contain 160 g of CP (Huhtanen et al. 2015). A back-calculation for N excreta estimation was undertaken, considering the retention of N in body tissues as constant. Total N excreta comprises N contained in faeces and urine during a given period. Compared to N excreted in urine (UN), N excreted in faeces (FN) is constant relative to DMI in lactating cows (Peyraud et al. 1995). Faeces are the main fate of undigested feed N, undigested microbial N and endogenous N (Tamminga 1992). Considering this, FN (g N excreted/cow per day) was estimated employing the formula of Reed et al. (2015) ensuring an appropriate suitability for the specific conditions of this study as:

$$\mathrm{FN} = 72.7 - 11.8 \times \mathrm{ME} - 0.4 \times \mathrm{NDF} + 3.5 \times \mathrm{CP} + 0.2 \times \mathrm{ForR} + 9.3 \times \mathrm{DMI} - 0.1 \times \mathrm{DIM}$$

where ForR is the proportion of pasture in the diet. Subsequently, UN (g N urine excreted/cow per day) was estimated as:

$$UN = IN - FN - MN - RetN$$

where IN is intake of N (g of N intake per day), MN is milk N (g of N in milk per day) and RetN corresponds to N retained in body tissues according to LW variation (g N retained/cow per day). Partition of N excreta was not predicted following the Legendre polynomials' functions but estimated according to cow performance and dietary characteristics in each case. Measurements of CPI, PY, and CP retained were converted into N by dividing each variable by 6.25 beforehand (as the average N content of protein is 160 g/kg LW) in order to account for the N partition fractions.

6.3.6 Statistical analyses

The approach of this study is to examine how the N use efficiency and N partition of pastured dairy cows is altered on different management practices (MF and supplementary feed inclusion) considering that these are representative situations of commercial farms with contrasting intensification level in New Zealand conditions. Macciotta et al. (2005) identified that the mathematical properties of the Legendre polynomials functions were able to recognize a large number of curve shapes enabling the lactation curves of large groups of animals in contrasting productive conditions to be modelled. In turn, least-squares means including estimates, standard errors and statistical significances of alphas corresponding to the third order Legendre polynomial of each cow for lactation measures of milk, fat, protein, SCS, MU, MUY, LW and BCS along with lactation curves for milk production traits, efficiencies and cow performance were analysed using the MIXED procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC). The model included the fixed effects of farm production system, lactation number and covariables deviation from median calving date, proportion of F and heterosis effect among F and J, the interactions between lactation number and farm production system, between farm production system and proportion of F and between farm production system and F×J heterosis, and the random effect of cow to account for repeated measures on the same cow.

The proportion of genetic contribution of F on each cow was estimated as:

$$\sigma_i^F = \frac{\sigma_i^{Fs} + \sigma_i^{Fd}}{2}$$

where σ_i^F is the proportion of F genes of cow $_i$ according to the proportion of F of the sire and the dam, correspondingly.

The heterosis effect ($h_{F\times J}$) of the progeny was calculated according to the following equation by Dickerson (1973):

$$h_{F\times J}= \sigma_F^s\sigma_J^d + \sigma_J^s\sigma_F^d$$

where σ_F^s and σ_F^d are the proportions of F of the sire and the dam, respectively. The σ_J^s and σ_J^d are the proportions of J of the sire and the dam, correspondingly.

Estimated Pearson linear correlations and standard errors for actual and predicted daily milk, fat and protein yield, somatic cell score, MU, MUY, BW, and BCS modelled were obtained with the CORR procedure of SAS.

6.4 Results

Descriptive statistics of herd test records containing yields of milk, fat, lactose and protein along with SCS, MU, and MUY are in Table 2. Mean MY of LIPS was 26% lower than HIPS but that gap was reduced to 15% and 20%, respectively when comparing FY and PY between the two herds. There were higher mean, minimum and maximum MU concentrations in LIPS cows (Table 6.2 and Figure 6.2 c), and standard deviations for MU almost doubled in LIPS cows, reflecting larger variations between cows and during the lactation. Results for MUY were similar among herds.

Table 6.2 Descriptive statistics of the lactation length records and herd test records of yield of milk (MY), fat (FY), protein (PY) and lactose (LY), along with somatic cell scores (SCS), milk urea (MU), MU yield, live weight and body condition score (BCS) of grazing cows in two grazing dairy systems during season 2016–17; Low-intensity (LIPS) and High-intensity (HIPS) production system.

	Production system									
	LIPS					HIPS				
Variable	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Days in milk	258	269	33	127	319	210	272	36	110	321
MY, kg/day	2,284	15.7	6.0	0.9	36.6	1,217	21.2	5.5	3.0	37.7
FY, kg/day	2,284	0.8	0.3	0.1	2.5	1,217	1.0	0.2	0.2	1.5
PY, kg/day	2,284	0.6	0.2	0.1	1.3	1,217	0.8	0.2	0.2	1.4
LY, kg/day	726	0.8	0.3	0.1	1.9	558	1.1	0.3	0.5	1.9
SCS[1]	2,276	5.76	1.59	0.01	12.43	1,217	5.13	1.45	1.58	12.02
MU, mg/dL day	726	28.06	10.70	9.10	61.70	557	20.80	5.52	6.08	39.41
MUY, g/day	726	4.17	1.65	0.67	10.02	557	4.40	1.29	0.77	8.28
Live weight, kg	2,359	487	70	320	684	1,999	502	62	352	770
BCS	2,060	4.6	0.4	3.0	6.5	1,405	4.2	0.4	3.0	5.5

[1] The somatic cell count records were log2-transformed to SCS. BCS on a 1-10 scale.

Irrespective of the group of cows of this study, Pearson linear correlations between predicted and actual values for all traits examined were near unity (Table 6.3), which depicts the suitability of the Legendre orthogonal polynomials to model the cow performance during lactation. The accuracy of this methodology to model lactation curves was superior for the milk production traits with correlations greater than 0.992 when compared to other cow performance parameters such as LW or BCS with values of 0.988 and 0.868, respectively. Correlations of actual MU and MUY with their corresponding predictive values were equal to 0.898 in HIPS and to 0.961 in LIPS.

Table 6.3 Estimated Pearson linear correlation and standard error for actual and predicted daily milk production traits, live weight, and body condition score modelled with a third-order orthogonal polynomial fitted to two grazing dairy systems during season 2016–17; Low-intensity (LIPS) and High-intensity (HIPS) production system.

		Production system	
Trait	Overall	LIPS	HIPS
Milk yield, kg	0.997 ± 0.003	0.996 ± 0.004	0.995 ± 0.005
Fat yield, kg	0.992 ± 0.004	0.992 ± 0.006	0.990 ± 0.007
Protein yield, kg	0.994 ± 0.004	0.995 ± 0.005	0.991 ± 0.007
Somatic cell score	0.923 ± 0.005	0.922 ± 0.006	0.916 ± 0.008
Milk urea, mg/dL	0.989 ± 0.003	0.991 ± 0.004	0.968 ± 0.008
Milk urea yield, g/day	0.941 ± 0.007	0.960 ± 0.007	0.898 ± 0.014
Live weight, kg	0.988 ± 0.002	0.995 ± 0.001	0.976 ± 0.003
Body condition score	0.868 ± 0.006	0.846 ± 0.009	0.804 ± 0.012

[1] The somatic cell count records were log2-transformed to SCS. BCS on a 1-10 scale.

Table 6.4 has least squares means of the regression coefficients estimates employed to obtain predicted values for the MY traits and cow performance throughout the lactation. Differences in alphas ($P < 0.001$) are consistent with milk production performance depicted in the descriptive statistics sown in Table 6.2, with higher α_0 (intercept) in all traits of milk production and lower α_0 for SCS in the HIPS. A similar trend was observed and confirmed with the descriptive statistics with regard to LW and BCS in both herds (Table 6.2). Likewise, α_0 of MU was higher in the LIPS cows, corroborating results previously described.

Table 6.4 Least squares means and standard errors of the estimates of regression coefficients of the lactation curves for milk, fat, protein and lactose yields, somatic cell score, milk urea (MU) and MU yield, live weight and body condition score modelled with a third-order orthogonal polynomial fitted to grazing cows in two grazing dairy systems during season 2016–17; Low-intensity (LIPS) and High-intensity (HIPS) production system.

Trait	Production system	α_0	α_1	α_2	α_3
Milk yield, kg/day	LIPS	15.20^{b} ± 0.161	-6.94^{b} ± 0.123	-1.13^{b} ± 0.063	0.21^{b} ± 0.018
	HIPS	19.33^{a} ± 0.221	-5.83^{a} ± 0.168	-1.90^{a} ± 0.086	0.10^{a} ± 0.025
Fat yield, kg/day	LIPS	0.78^{b} ± 0.007	-0.29^{b} ± 0.006	-0.03^{b} ± 0.003	-0.04^{b} ± 0.002
	HIPS	0.89^{a} ± 0.009	-0.13^{a} ± 0.009	-0.02^{a} ± 0.005	-0.03^{a} ± 0.002
Protein yield, kg/day	LIPS	0.62^{b} ± 0.005	-0.21^{b} ± 0.005	-0.04 ± 0.003	-0.01^{b} ± 0.002
	HIPS	0.73^{a} ± 0.007	-0.08^{a} ± 0.007	-0.05 ± 0.004	0.02^{a} ± 0.002
Lactose yield, kg/day	LIPS	0.77^{b} ± 0.009	-0.37 ± 0.006	0.01^{b} ± 0.001	0.05^{a} ± 0.003
	HIPS	1.07^{a} ± 0.012	-0.39 ± 0.009	0.02^{a} ± 0.001	-0.05^{b} ± 0.004
Somatic cell score[1]	LIPS	5.80^{a} ± 0.070	1.12^{a} ± 0.052	0.04^{b} ± 0.039	0.08 ± 0.021
	HIPS	5.02^{b} ± 0.096	0.71^{b} ± 0.072	0.66^{a} ± 0.054	0.03 ± 0.029
Milk urea, mg/dL day	LIPS	31.00^{a} ± 0.305	16.34^{a} ± 0.303	12.84^{a} ± 0.323	-1.27 ± 0.117
	HIPS	23.40^{b} ± 0.419	8.36^{b} ± 0.416	6.98^{b} ± 0.443	-1.05 ± 0.161
Milk urea yield, g/day	LIPS	4.25^{b} ± 0.063	-0.37 ± 0.041	1.02^{b} ± 0.016	-0.70 ± 0.028
	HIPS	4.49^{a} ± 0.086	-0.30 ± 0.056	1.08^{a} ± 0.022	-0.71 ± 0.039
Live weight, kg	LIPS	488.06^{a} ± 2.712	18.35^{b} ± 0.941	13.48^{b} ± 0.714	-6.15^{a} ± 0.913
	HIPS	477.34^{b} ± 3.720	23.81^{a} ± 1.291	20.61^{a} ± 0.979	-13.66^{b} ± 1.252
Body condition score	LIPS	4.59^{a} ± 0.018	-0.13 ± 0.005	0.23^{b} ± 0.006	0.05^{a} ± 0.004
	HIPS	4.25^{b} ± 0.025	-0.12 ± 0.007	0.27^{a} ± 0.008	-0.01^{b} ± 0.006

^{ab}means with different superscripts within trait indicates they were significantly different ($P < 0.05$). [1]The somatic cell count records were log2-transformed to SCS. BCS on a 1-10 scale.

There was a significant effect of production system management on total milk production in the present study, with considerably higher MY in HIPS (Figure 6.1 and Table 6.5). After adjusting cow performance for heterosis effects between F and J, proportion of F, lactation number and deviation of median calving date; LIPS cows had 13% lower MSY during the lactation and this was associated with lower DMI ($P < 0.001$) (Table 6.5 and Figure 6.3 d). Cows in HIPS had significantly higher DMI (Table 6.4) with a higher proportion of non-pasture supplements of lower CP (compared to fresh grazed pasture) included throughout the lactation, which produced a diet lower in CP, and this led to lower CPI ($P < 0.001$) (Table 6.5 and Figure 6.3 d) with associated higher values of ECPU (Figure 6.2 a). Compared to the HIPS herd, values for CPB were significantly higher in LIPS (Table 6.5 and Figure 6.2 b), demonstrating an excess of CP for that group of cows. Values for MU were significantly lower in HIPS but MUY was not different between LIPS and HIPS cows ($P = 0.058$) (Table 6.5 and Figure 6.2 c and d).

Table 6.5 Least squares means (± standard errors) of lactation length, total yield of milk, milk solids, fat, protein and lactose, somatic cell score, live weight and body condition score, dry matter intake (DMI), crude protein (CP) intake (CPI), milk urea (MU) and MU yield (MUY), efficiency of CP utilisation (ECPU) and CP balance (CPB) of grazing cows during season 2016–17 in two grazing dairy systems; Low-intensity (LIPS) and (HIPS) High-intensity production system (HIPS).

	Production system		
Item (per cow)	LIPS	HIPS	P-value[1]
N	257	207	
Lactation length, days	272 ± 2	271 ± 3	0.719
Milk yield, kg	4,232.40 ± 55.3	5,332.10 ± 75.9	<0.001
Milk solids yield, kg	387.6 ± 4.4	443.7 ± 6.1	<0.001
Fat yield, kg	217.4 ± 2.5	243.9 ± 3.5	<0.001
Protein yield, kg	170.5 ± 2	199.7 ± 2.8	<0.001
Lactose yield, kg	214.7 ± 3	296.3 ± 4.1	<0.001
Somatic cell score[2]	5.73 ± 0.07	4.95 ± 0.1	<0.001
Live weight, kg	487 ± 3	475 ± 4	0.012
Body condition score	4.6 ± 0.02	4.26 ± 0.02	<0.001
DMI, kg/day	16.21 ± 0.07	18.49 ± 0.13	<0.001
CPI, kg/day	3.13 ± 0.01	2.8 ± 0.03	<0.001
MU, mg/dL	28.24 ± 0.34	21.38 ± 0.49	<0.001
MUY, g	1,143.40 ± 19.6	1,207.00 ± 26.9	0.058
ECPU, %	20.13 ± 0.13	27.65 ± 0.33	<0.001
CPB, kg CP/day	2.51 ± 0.01	2.03 ± 0.03	<0.001

[1]Differences between treatment were considered significant at $P < 0.05$. [2]The somatic cell count records were log-transformed to SCS. Body condition score on a 1-10 scale.

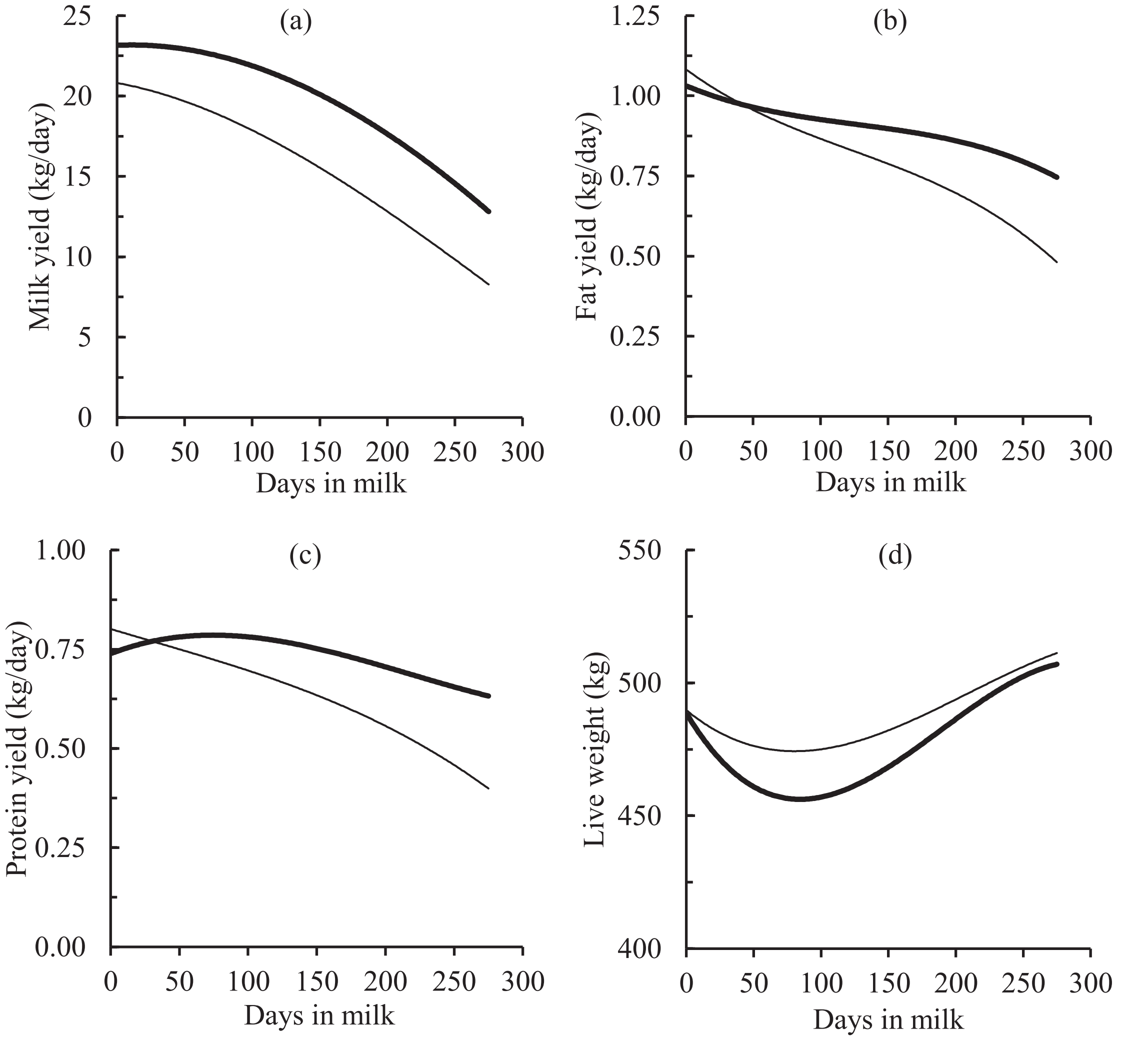

Figure 6.1 Predicted lactation curves of yields of (a) milk, (b) fat and (c) protein; and live weight in two contrasting pasture-based dairy production systems during season 2016-17: Low-intensity (—) and High-intensity (▬) production system.

Estimates of mean N excreta during the lactation (g N per day) were higher in the LIPS cows when compared to the HIPS cows ($P < 0.001$). Figure 6.3 b confirms this gap in N excreted between LIPS and HIPS cows, associated with a higher proportion of UN ($P < 0.001$). Mean FN per day was higher in HIPS cows ($P = 0.0018$) (Figure 6.3 c).

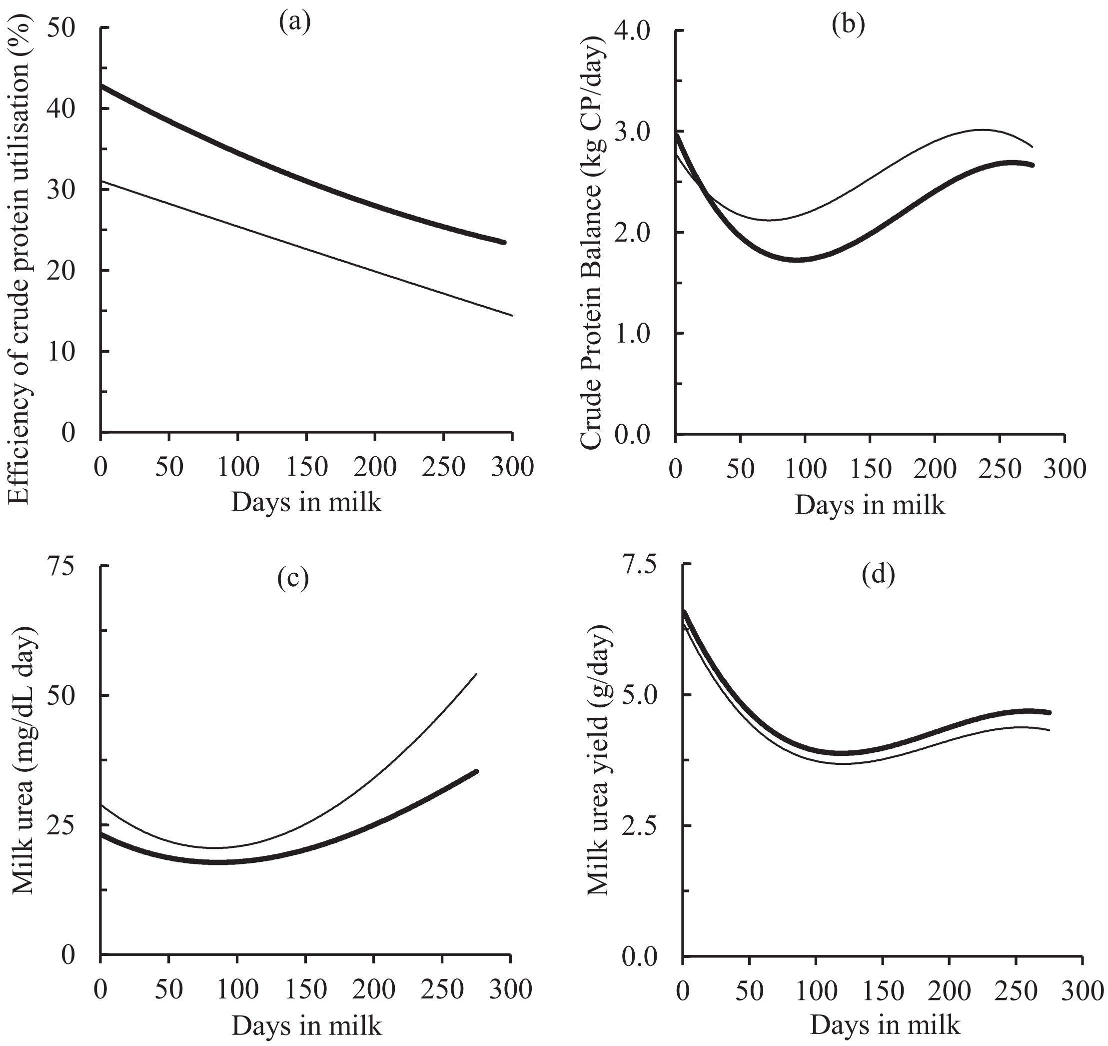

Figure 6.2 Predicted lactation curves of nitrogen use efficiency calculated as (a) the efficiency of crude protein (CP) utilisation and (b) the CP balance, and (c) milk urea (MU) (mg/dL) and (d) MU yield (g/day) on grazing cows in two contrasting pasture-based dairy production systems during season 2016-17: Low-intensity (—) and High-intensity (▬) production system.

6.5 Discussion

In the present study, lactation curves of two measures of N use efficiency, along with MU and MUY of cows milked in two contrasting dairy production systems of dissimilar intensification levels were described. In agreement with the present study, Edwards (2018) reported a significant reduction in milk production when high-producing pastured cows transitioned from twice- to once-daily milking. Moreover, that study showed that the reduction was greater milk yield rather than for milk solids composition. Increasing the interval between milking events results in a reduction of nutrients partitioned towards the mammary gland (McNamara et al. 2008) and a decline of mammary gland cell numbers, accompanied by decreased secretory activity of these cells (Stockdale 2006), leading to a reduction in MY. The reduction in MY in

LIPS cows is accompanied by a reduction in PY, which, in turn, results in a lower ECPU for LIPS cows relative to HIPS cows. However, the energy balance of LIPS cows was greater throughout the lactation in the present study, and this was reflected in higher BCS and lower LW mobilisation in the early lactation stage (Figure 6.1 d).

There was a substantial difference in the intercept between regressions of ECPU of LIPS and HIPS herds (Figure 6.2 a) due to differences in CP and CPI (Figure 6.3 d). Diets high in CP involve an extra nutritional 'cost' to eliminate the surplus N from the animal (Lapierre et al. 2005). For example, 250 g additional ammonia absorption per day as a result of feeding CP above requirements would require an extra 7 MJ per day, reducing energy destined for milk production and reducing ECPU. The better BCS of the LIPS cows demonstrated that the higher CPI of this group of cows did not impact the energy balance, and this was due to the lower MY observed in this group of cows. A higher CPB was observed throughout the lactation in the LIPS cows compared to HIPS cows, reflecting more N than could be allocated to PY (by limiting the MY) resulting in an increase in N concentration in excreta. Determination of N losses in skin, scurf, hair, and excreta in the lactating cow is difficult and can lead to sources of errors when studying the kinetics of N (Spanghero and Kowalski 1997). Nevertheless, the substantial gap in ECPU (and CPB) between LIPS and HIPS is undeniable and overcomes such potential measurement errors (Figure 6.2 a and b).

Contrary to the intercepts for ECPU regressions, the intercepts for CPB tended to be similar for both herds (Figure 6.2 b). This is due to a counterbalance between the differences in CPI and PY of both herds in early lactation. The negative slope in CPB of both LIPS and HIPS herds demonstrated that the body tissue mobilisation in early lactation contributed not only energy but also protein towards the intense metabolic demand that a transition cow (from dry to lactating stage) faces in its first days of lactation (Daniel et al. 2017). By feeding diets with higher supplementation and milking cows twice-daily, HIPS cows produced more milk, and this indicated that more CP was partitioned towards PY and this resulted in less CPB when compared to LIPS cows. Attention should be paid to management practices that reduce milk production, because otherwise all the CP not allocated to milk would escape in excreta. Irrespective of management practices in each herd, all cows had positive CPB, indicating that there was a surplus of CP offered during the lactation, but the greater inclusion of pasture to LIPS cows resulted in a higher CPB (and lower ECPU) when compared to HIPS cows.

The liver along with the portal-drained viscera are tissues of high internal N metabolic activity and while they represent less than 10% of LW, they are responsible for the major N metabolic exchange in ruminants (Lapierre et al. 2005) including ureagenesis, a vital mechanism to overcome poisoning from the excess of ammonia present in the systemic circulation. That labile N pool is highly influenced by feeding management (Spek et al. 2013), among other factors. In turn, urea is transported from the plasma to other fluids such as saliva in order to be recycled, and excreted mainly in urine, but is also present in milk. The relationship between urine urea N and MU was recognised by a number of authors (Jonker et al. 1998; Nousiainen et al. 2004). In contrast to the higher MU in the LIPS herd when compared to the HIPS herd in the present study, earlier studies of Friggens and Rasmussen (2001) and Nielsen et al. (2005) reported increases in MU with decreases in milking intervals, but the explanations were speculative, with authors suggesting that there might be an interaction with time of feed intake and moment of milk sampling resulting in disturbances in MU determinations. Irrespective of management practices in each herd, the results of the present study confirmed a positive relationship of MU with CPI (Mutsvangwa et al. 2016; Barros et al. 2017). Compared to the HIPS herd, CPI of the LIPS herd was always higher and was accompanied by higher MU throughout the lactation (Figure 6.2 c), with the exception of the period around day 90 of lactation when values of CPI of the HIPS herd were similar to the LIPS herd, resulting in similar MU. Cows milked in the LIPS herd were fed mainly ryegrass pastures of high quality and high CP concentration, with minor inclusion of supplements in the diet; and this represents an imbalance of energy:protein ratio (Kolver and Muller 1998) leading to increases in N excreta and MU. On the contrary, De Campeneere et al. (2006) reported higher urine N levels along with lower plasma urea N and MU for cows fed pasture silage compared to cows fed maize silage diets and attributed this to the high consumption of potassium and sodium from pasture silage diets. However, there might be a confounding factor considering the differences in DMI of the pastured-dairy cows with this present study, and that De Campeneere et al. (2006) studied cows in housed production systems. The ensiling process can considerably alter the nutritive value of forage, leading to increases in non-protein N at the expense of true protein, the rate of proteolysis, and concentrations of volatile fatty acids, as well as reductions in carbohydrate content (Hynes et al. 2016). While finding substantial differences in N use efficiency between these two herds, MUY was similar for both herds (Table 6.5). This equity was in response to higher MY along with lower MU in the HIPS herd and the opposite in the LIPS herd. Because of this compensation between MU and MY, an erratic relationship of MU with both ECPU and CPB resulted in this study. At day 90 of lactation, cows had the same MU and equal CPI, but the ECPU was higher and CPB was lower in the HIPS cows. Similarly, Barros et al. (2017) reported some inconsistencies in the relationship of ECPU and MU, with a positive relationship between

MU and feed efficiency of 0.71, leading to higher MY and PY. On the contrary, Nousiainen et al. (2004) improved the estimates of UN excretion and N use efficiency with back-calculations, by including MUY. However, Nousiainen et al. (2004) used housed cows fed total mixed rations with lower dietary CP compared to the grazing conditions of the present study. Several authors, and the results from the present study, suggest that the relationship between MU and N use efficiency is governed by several factors including MY, LW, lactation stage, between-animal variation and nutritional management (Spek et al. 2013; Huhtanen et al. 2015).

This study indicated that irrespective of the lower DMI of the LIPS cows, CPI was increased through ingestion of a larger proportion of fresh pasture with higher digestible N. Compared to the HIPS cows, the greater CPI along with lower PY of the LIPS cows (Table 6.5 and Figure 6.3 d) resulted in a lower ECPU and a greater CPB with inevitable increases in N excreta. Moreover, in the period around day 90 of lactation, similar CPI for cows of both herds resulted in higher UN in LIPS cows, and this was confirmed by the disparity in N use efficiencies at this particular time. Probably, a dietary effect altered the performance of these herds, where LIPS cows with a lower DMI are not having a balanced energy:protein ratio to enhance the uptake of CP towards microbial protein synthesis (Kolver and Muller 1998; Mulligan et al. 2004; Hristov et al. 2005). A number of authors also reported the same strong negative relationship between CP in the diet and N use efficiency, and the increase in N excreta of lactating cows (Hristov et al. 2005; Mutsvangwa et al. 2016; Barros et al. 2017).

Results from the present study confirmed on a daily basis that feeding concentrates to supplement grass-based diets could shift N excretion from urine to faeces (Mulligan et al. 2004; Hristov et al. 2005). While LIPS cows had mean daily UN of 199 g N per day compared to 134 g N per day in HIPS cows, HIPS cows had 139 g N per day in FN compared to 134 g N per day in LIPS cows. It was detected that HIPS cows partitioned more N towards faeces, in which N is less volatile than N in urine, and may be converted to ammonia and nitrous oxide at a slower rate (Hristov et al. 2005; Mutsvangwa et al. 2016). This aspect of the alteration in N excreta partition towards faeces could be interesting from an environmental perspective considering that reducing the rate of N loss may result in less N leached from the system (Ledgard et al. 2009).

In the first 100 days of lactation, HIPS cows had greater mobilisation of body tissue (Figure 6.1 d) which contributed to the CP requirements of those cows (considering that 1 kg of LW mobilisation equates to 160 g of CP; Huhtanen et al. 2015) facing a high demand for nutrients for milk production and other metabolic processes including the uterine involution post-partum.

If not for this mobilisation of LW, it would have been difficult for HIPS cows to achieve the recorded high MY (mean peak milk production of 25 kg), with a diet comprising 14.5% CP in early and mid-lactation. Trevaskis and Fulkerson (1999) suggested that the lower level of MU aligned with peak milk yield was attributed to nutrient mobilisation in early lactation as more N available would be potentially allocated to milk protein synthesis. A recent study by Daniel et al. (2017) recommended subdividing the lactation into stages when analysing protein and energy requirements of lactation.

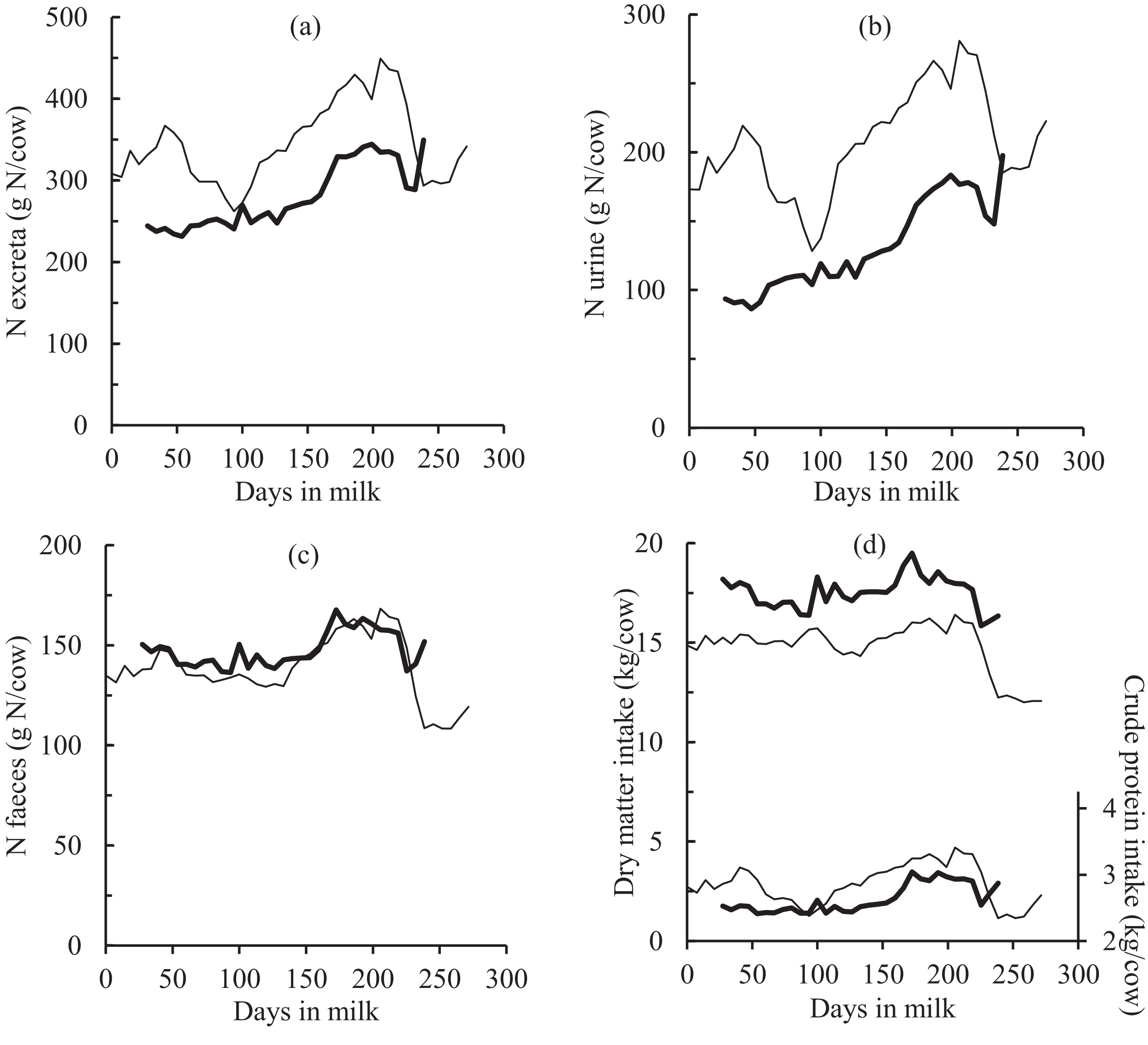

Figure 6.3 Estimations of (a) total nitrogen (N) excreta per cow (g N/day) and partitioned into (b) urine (g N urine/day) and (c) faeces (g N faeces/day) along with (d) dry matter intake (DMI) per cow (kg DMI/day) and crude protein intake (CPI) per cow (kg CPI/day) in two contrasting pasture-based dairy production systems during season 2016-17: Low-intensity (—) and High-intensity (▬) production system.

Additional mitigation techniques must be studied in order to alleviate the N loss to the environment of grass-based systems, specifically in low input once-daily systems. For example, the present study indicates that feeding low CP concentrates to dairy cows grazing good-quality pasture, would reduce their CPI with no negative effect on feed intake or milk production, and at the same time, some shifting of N excreta from urine towards faeces can be achieved. Moreover, this strategic supplementation would need to be carefully considered in order to avoid substitution of pasture eaten and maintain acceptable levels of pasture utilisation (Kolver and Muller 1998).

6.6 Conclusions

Lactation curves of CP use efficiency for both LIPS and HIPS were driven by the CPI and by the levels of milk production. The combined effect of extra supplementary feed and MF employed in each production system affected the overall milk production performance, and consequently, the ECPU was higher in HIPS cows. Moreover, the ECPU of LIPS cows was reduced by feeding diets comprising mainly fresh pasture high in CP. The CPB demonstrated that, irrespective of herd management, all cows were fed CP at levels greater than requirements during the lactation, and LIPS cows had a higher CPB as a result of lower milk protein synthesis and higher dietary CP when compared to HIPS cows.

Lactation curves of MU for LIPS and HIPS cows were in line with levels of CP fed, but no association was found with N use efficiency using the approaches proposed in the present study. The compensation observed between MY and MU levels in both herds resulted in similar MUY and this explained the similarities in MU levels at some stages of the lactation. Thus, an erratic relationship of MU with both ECPU and CPB was observed in this study.

Due to an excess of dietary CP in LIPS cows, UN was elevated, and as this is the most sensitive fraction of excreta, mitigating strategies must be studied and evaluated in regard to alleviating N loss to the environment in lower-input dairy production systems. It is noteworthy to highlight that this paper demonstrated that some management practices considered as part of the de-intensification of pasture-based dairy production systems, such as the reduction of supplementary feed, are worthy of consideration since a detrimental effect on N use efficiency with more N partitioned towards urine was observed. Moreover, this analysis was focused at the cow level (i.e. daily N excreta per cow). Under grazing conditions, it would be essential to extend the analysis to the farm level scale, aiming to measure the N losses per ha.

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Chapter 7

Efficiency of nitrogen utilisation and farm profitability comparison of two pasture-based systems of two contrasting milk production systems

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7.1 Abstract

The aim of the present study was to model and compare the productivity, profitability and the nitrogen (N) utilisation efficiency (NUE) of two contrasting spring-calving pasture-based milk production systems differing in intensification levels in New Zealand. From June 2016 through May 2017; in the low-intensity production system (LIPS) cows were milked once-daily with a stocking rate (SR) of 2.1 cows/ha and fed diets with low supplementation (304 kg pasture silage/cow) with 134 kg N fertiliser/ha and in the high-intensity production system (HIPS) cows were milked twice-daily with a SR of 2.8 cows/ha and fed diets of higher supplementation (429 kg pasture silage and 1,695 kg concentrate/cow) with 87 kg N fertiliser/ha. The cows of LIPS had 23% lower milk production (1,384 kg milk/cow less) than the cows of HIPS. On a farm-scale this milk yield was 41% higher in favour of the HIPS due to the higher SR (16,510 vs 9,693 kg milk/ha). The total costs per ha of LIPS were 39% lower than in HIPS reflecting the low input arrangement of LIPS. The higher revenue of HIPS was a consequence of milking more cows of higher milk production when compared to the cows of LIPS. The increased revenue in HIPS exceeded the higher costs of milk production of the HIPS (when compared to LIPS) resulting in higher net profit in HIPS (2,456NZ$/ha vs 2,058NZ$/ha). At the cow level, the NUE was higher in HIPS (30% vs 27%) reflecting a better-balanced diet for energy and crude protein. While assuming both concentrate and fertilisation N entrances in each modelling scenario of this analysis, at the farm-scale the difference in NUE was higher (38% vs 26%) in favour of the HIPS due to less N fertiliser imported along with higher N captured in milk. If consider the N utilised to produce the concentrate fed on HIPS, the NUE of this scenario would have been diminished but it is out of scope of this paper.

Keywords: milk production, intensification, profitability, nitrogen use efficiency, sustainability.

7.2 Introduction

Milk production from grasslands takes advantage of the high efficiency of the rumen to convert low-quality forage into dairy products of high-value protein for human consumption (Waghorn and Clark 2004). Grazing systems are socially well perceived because they are associated with better animal welfare when compared to housed systems (Macdonald et al. 2008). Pastoral livestock production makes extensive use of ecosystem services and simplifies many of the issues related to handling and disposal of wastes emitted by animals when compared to confinement production systems (Tilman et al. 2002).

The intensification process of grazing dairy systems of New Zealand and other temperate regions relies on the increase of imported bought-in feeds to extend lactation length and N fertiliser to boost pasture production, which are usually associated with increased cows per farm (stocking rate, SR) (Macdonald et al. 2017). These management practices along with the implementation of a well-defined genetic programs consisting of selecting cows based on greater milk production responses to additional feed, have increased the productivity of the New Zealand dairy industry increased since the 1990's (Macdonald et al. 2017). However the poor nitrogen utilisation efficiency (NUE), defined as N captured in saleable products such as milk and meat as a percentage of the total N input, in agricultural systems has been described as one of the main reasons for increased N losses to the environment (Whitehead 1995; Peyraud and Delaby 2006). Dietary crude protein (CP) in excess of animal requirements, frequently encountered under grazing conditions of New Zealand (Waghorn and Clark 2004), results in a decrease in NUE at the cow level defined in this case as N captured in milk and meat as a proportion of total N intake. Excess of CP in the rumen results in more N in excreta (mainly in urine) rather than allocated to N in saleable products (milk and meat) (Bargo et al. 2002; Totty et al. 2013). This N excretion is regarded as an important environmental problem, as well as being wasteful in terms of utilisation of plant nutrients (Peyraud and Delaby 2006). The NUE of grass-based dairy cows is low compared to systems where dietary CP levels are adjusted through inclusion of energy-dense concentrate feeds (Mulligan et al. 2004) when expressed at the cow level.

Driven by fluctuations in milk price, there is a trend in the New Zealand dairy sector to return to traditional grazing systems with lower inclusion of supplements (Wales and Kolver 2017). Whereas a typical modern dairy system mostly operates twice-a-day (TAD) milking, an increasing number of farmers in New Zealand have chosen once-a-day (OAD) milking for the entire lactation despite the well-documented yield loss (Stelwagen et al. 2013; Edwards 2018). Once-a-day milking systems offer the opportunity for substantial change in overall farm operation by reducing costs associated with milk harvesting and by decreasing feed costs (Clark et al. 2006; Stelwagen et al. 2013) and can also have impacts on some of the unsociable labour issues associated with dairying. Usually, OAD are predominantly pasture-based with low supplementary feed inclusion, and are regarded as low intensity (Stelwagen et al. 2013). Considering that the New Zealand dairy industry is strongly focused on increasing productivity (Bewsell et al. 2008), the principal constraint to adopt OAD as a strategic long-term option is the associated reduction in milk production per cow.

The complex interactions amongst components at the production system level makes it difficult to determine costs and benefits of implementing different management or technological decisions (Shalloo et al. 2004). The impractical and expensive realisation of large experimental designs to study complex interrelations, such as the N cycle of grazing dairy systems, drives the use of models in system research (Ryan et al. 2011). The aim of the present study was to simulate and compare the economic performance and NUE along with N balance and losses of two spring-calving pasture-based milk production systems differing in intensification level. The production and economic performances were generated by the Moorepark Dairy System Model (MDSM, Shalloo et al. 2004) and the N balance, along with efficiencies and losses of N, were generated on the N balance model developed by Ryan et al. (2011).

7.3 Materials and methods

The present study was carried out on two dairy research farms in Palmerston North, in the lower North Island of New Zealand from June 2016 to May of 2017. In response to a different management approach a different feeding plan was implemented in each research farm. The Massey University No. 1 dairy farm is managed as a low-intensity production system (LIPS) with cows milked OAD throughout the season, with low SR (2.1 cows/ha) and feed strategy includes restricted supplementation and grazing crops are utilised in summer while fresh ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture is the main diet component throughout the year. On the other hand, Massey University No. 4 dairy farm is managed as a high-intensity production system (HIPS) with cows milked TAD throughout the season, with higher SR (2.8 cows/ha) and also fed pasture but with a higher supplementation level included throughout the year.

7.3.1 Description of farm systems

7.3.1.1 Low-intensity production system

The herd was comprised of 66 Holstein-Friesian (F), 55 Jersey (J) and 136 crossbred (F×J) cows. During June, 58% of the herd was wintered on the dry-stock unit prior to calving. Calving commenced on July 11th and continued up to October 3rd. Cows were milked daily at 06:30 throughout the season.

From June to calving date, pregnant dry cows on-farm were feed-restrained and had access to daily strips of pasture at an allowance of approximately 5.5 kg dry matter (DM) and 2 kg DM of pasture hay per day were offered on the paddock. After calving, milking cows had access as a single group to a new strip of pasture after each milking and were contained in their allocated forage area through the use of temporary electric fences. From December to March and in April, a herb crop [mix of plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*) and red clover (*Trifolium pratense*)] was grazed at an allowance of 3.5 kg DM per cow per day. In March and May, lucerne (*Medicago sativa*) was grazed at an allowance of 3 kg DM per cow per day. Turnips (*Brassica campestris* ssp. *rapifera*) were grazed at an allowance of 2.6 kg DM per cow per day only in February. Pasture silage was fed directly on the paddock in August and from March to May at a rate of 3.5 kg DM per cow per day.

7.3.1.2 High-intensity production system

The herd was comprised of 52 F and 156 F×J cows. During June, 42% of the total cows were allocated off-farm. Calving commenced on July 1st and continued up to September 26th. Cows were milked daily at 05:30 and 14:30 throughout the season.

From June to calving date, pregnant dry cows on-farm had access as a single group to daily strips of pasture at an allowance of approximately 6 kg DM per cow and 2 kg DM of pasture hay per day were offered on the paddock. After calving, milking cows had access as a herd to pasture after each milking. During the lactation, maize (*Zea mays*) silage was fed before the afternoon milking on the feed-pad at an average rate of 2.4 kg DM per cow per day and grain-based concentrate was fed during the morning milking inside the parlour at an average rate of 2 kg DM per cow per day. Pasture silage was fed directly in the paddock from July to September and from November to February at a rate of 1 kg DM per cow per day. In February and from April to May, pasture baleage was fed directly on the paddock at a daily allowance of 0.5 kg DM per cow and tapioca (*Manihot esculenta*) pellets were fed at a daily allowance of 1 kg DM per cow. Molasses was fed inside the parlour at an allowance of 0.25 kg per cow per day during the lactation. From February to May dried distillers grain was fed inside the parlour at an allowance of 0.6 kg per cow per day. Turnips were grazed at an allowance of 2.6 kg DM per cow in February and March.

7.3.2 Animal Measurements

After milking, all cows passed through an automatic race walkover scale (WoW xR-3000 Tru-Test Ltd. Auckland, New Zealand) in order to generate daily live weight (LW) individual records. Yields of milk (MY), fat (FY), protein (PY) and milk solids (MSY; FY+PY), along with somatic cell count, were determined in each herd test using a Fossomatic FT120 (Foss Electric, Hillerød, Denmark) on composite afternoon and morning aliquots where two milking events occurred on a sampling date, and from a unique sample when one milking event occurred on a sampling date.

7.3.3 Feed Quality Measurements

Estimated pasture eaten (kg DM per cow per day) was calculated from pasture disappearance by measuring pre-grazing DM minus post-grazing DM on the grazing area assigned per day divided by the total number of cows. Grazing area was measured using a global positioning system. Pre- and post-grazing pasture heights were measured with a rising-plate meter (Jenquip, New Zealand) following a 'W' pattern across the grazing area on a basis of 3 sets of 50 readings on each occasion. Pasture mass was subsequently estimated using the New Zealand calibration equation for perennial ryegrass-white clover (L'Huillier and Thomson 1988):

$$\text{kg DM/ha} = 140 \times \text{CH} + 500$$

where CH corresponds to the compressed height measured in units of 0.5 cm. Estimated crop eaten was calculated as crop cover pre-grazing minus crop cover post-grazing, measured by harvesting three 0.1 m^2 quadrats to ground level within the area allocated to cows on a daily basis. These measurements enabled calculation of apparent pasture and crop utilisation, and also the proportion of herbage allocated to cows before each herd-test.

Fresh pasture and crop samples (approximately 1,500 g of wet weight) were harvested using the hand-plucking method (Baker 2004) from about 50 sites along the same transect that pre-grazing pasture height was measured, to mimic herbage grazed by cows. Samples of maize and pasture silage were taken from the bunker and samples of grain-based concentrate, tapioca pellets and dried distillers grain were taken directly from the feeders during milking time. Samples of pasture hay and baleage were collected directly from the paddock. All feed samplings were undertaken 24 hours prior to the milk sampling at 09:00. All the samples were freeze-dried and ground (Wiley mill) to pass through a 1.0 mm screen. The levels of ash, CP, lipid, neutral detergent fibre, acid detergent fibre, organic matter digestibility, metabolisable energy (ME) and starch and soluble sugars were estimated by near infrared reflectance spectrometry (Corson et al. 1999) using a Bruker MPA near infrared reflectance spectrophotometer (Ettlingen, Germany). Calibrations for each component had been previously developed (Massey University Nutrition Laboratory, Palmerston North, New Zealand). Based on the proportions of each forage allowed and each individual feed ME content, the dietary ME content [megajoules (MJ) of ME per kg DM] was calculated with a similar approach used for CP. Table 7.1 resumes the annually diet composition of each production system with its chemical composition.

Table 7.1 Proportions of feed ingredients of each feeding system and dietary chemical composition utilised for two contrasting pasture-based dairy production systems during season 2016-17; Low-intensity (LIPS) and High-intensity (HIPS) production system.

	Production system	
Item	LIPS	HIPS
Diet ingredient, % of total feed offered		
Ryegrass-white clover pasture	89.2	60.2
Pasture hay	3.3	2.7
Pasture silage	2.8	6.3
Pasture baleage	-	1.3
Brassica crop	0.6	1.1
Herb-mix crop	3.2	-
Lucerne crop	0.9	-
Maize Silage	-	13.1
Concentrate	-	11.6
Tapioca pellets	-	1.5
Molasses	-	1.2
Dried distillers grain	-	1.0
Dietary chemical composition		
ME, MJ ME/kg DM	10.87	10.66
CP, % of DM	19.54	15.12
ADF, % of DM	22.88	22.49
NDF, % of DM	44.58	41.66
OMD, % of DM	74.25	74.62

ME = metabolisable energy; CP = crude protein; ADF = acid detergent fibre; NDF = neutral detergent fibre; OMD = organic matter digestibility.

7.3.4 Weather measurements

Meteorological data were obtained from the land-based station (21963) (observing authority AgResearch). Daily values of mean maximum temperature, mean minimum temperature, rainfall, radiation and mean windspeed were obtained in order to calculate potential and actual evapotranspiration. Effective drainage was calculated according to the soil moisture deficit model described by Schulte et al. (2005).

7.3.5 Economic analysis

The MDSM (Shalloo et al. 2004) allows the analysis of the effects of the interaction of biological, technical and physical processes on farm profitability. This whole-farm budgetary simulation model runs on an annually or monthly basis and integrates animal inventory, valuation and sales, milk production and sales, labour utilisation and feed requirements. In this model, values of net energy requirements for maintenance, pregnancy, production and daily LW variation were based on the French net energy system where 1 unité fourragère lait is the net energy requirement for lactation equivalent to 1 kg of standard air-dried barley (Jarrige et al. 1986), equivalent to 7.11 MJ of net energy or 11.85 MJ of ME. In turn, apparent dry matter intake (DMI) (kg DM/cow) was estimated based on total net energy requirements for maintenance, pregnancy, production, and daily LW variation, divided by the NE/ME content of any feed offered. Grass utilisation is calculated considering pasture grazed and harvested for silage making from total pasture production throughout the period considered in this study. Feed requirements for maintenance and milk production achieved on specific supplementary feed and crop allowance, LW and LW variation from each herd was considered to estimate total pasture eaten. Farm net profitability was determined by sales of milk and meat less fixed and variable costs using the MDSM applied to the biophysical and economic data collected from information provided by Massey University Agricultural Services for the time of the experiment. Where inputs could not be determined separately for each farm (i.e. overheads, value of change in dairy livestock depreciation), average values were utilised based on an economic survey by DairyNZ (2018) according to each production system. Herd size was scaled to 257 cows in order to permit direct comparisons among production systems.

The MDSM calculates the economic performance subtracting the fixed costs (car use, electricity, labour, machinery maintenance and running costs, telephone and insurance), and the variable costs (concentrate supplementation, fertiliser, contractor expenses, veterinary costs and purchases of livestock) from total sales of both milk and meat, with all values expressed in NZ$. Pasture growth rates and production of each farm utilised in the MDSM were calculated from assessing individual DM yield of paddocks. Table 7.2 and 7.3 summarises the farm parameters and pricing utilised in the MDSM. It was assumed a workload for a single worker of 2,466 hours in LIPS and of 3,147 hours in HIPS with 1.3 and 1.44 farm staff for LIPS and HIPS, respectively.

Table 7.2 Data used on the Moorepark Dairy Systems Model to generate biophysical and financial information for two contrasting pasture-based dairy production systems during season 2016–17; Low-intensity (LIPS) and High-intensity (HIPS) production system.

	Production system	
Item	LIPS	HIPS
Farm size, ha	120	92
Milking cows	257	257
Stocking rate, milking cows/ha	2.1	2.8
Milk yield per cow, kg/cow	4,526	5,910
Milksolids yield per cow, kg/cow	384	422
Milk fat, %	5.54	4.54
Milk protein, %	4.22	3.68
Milk lactose, %	5.15	5.64
Length of lactation, days	272	271
Replacement rate, %	18.3	20.0
Grazed pasture intake, kg DM/cow per year	3,427	3,115
Pasture silage intake, kg DM/cow per year	304	429
Concentrate intake, kg DM/cow per year	-	1,695
Crops intake, kg DM/cow per year	234	20
Average live weight, kg	486	507

Table 7.3 Default financial parameters used in the Moorepark Dairy Systems Model.

Item	Amount[1]
Milk price, NZ$/kg MS	
NZ$/kg Fat	5.05
NZ$/kg Protein	9.19
NZ$/L milk	-0.03
Calves price, NZ$/kg	53.00
Culled cow price, NZ$	874.00
Labour costs, NZ$/hour	20.00
Concentrate cost, NZ$/t	355.00
Fertiliser: urea, NZ$/t	495.00

[1] Information provided by Massey University Agricultural Services.

7.3.6 Nitrogen utilisation efficiency model description

The N balance model developed by Ryan et al. (2011) was used to assess the NUE, N surplus and N losses on both farms at both the cow and the whole-farm level. At the cow level, the N balance model accounted for the partition of N excreta by back-calculating from the total N intake per cow, the proportions of N allocated into milk, maintenance and LW variation. The model estimates partition of N into urine by subtracting N in faeces from total excreta N calculated using the equation described by del Prado et al. (2006):

$$\text{N in dairy cow dung (kg N/cow year)} = 0.15 \times N_{\text{animal intake}} + 28.47$$

where $N_{\text{animal intake}}$ corresponds to the total intake of N during the year. In turn, these N sinks at the cow level were scaled up to the farm level considering total cows farmed per month in order to implement the whole-farm N balance as well as the overall balance on a per hectare basis.

The whole-farm N balance considers all N imported and exported from the milking platform. Imports and exports of N are attained to temporary movement within diverse sinks of N (fertilisers, soil N, pasture, supplements imported, cow, milk and meat, excreta) and it can be expressed per kg of N per hectare or per cow. In the present study, legume N fixation was not considered in the N balance analysis considering that the model was developed for ryegrass pastures with no clover content (Ryan et al. 2011) and slurry was exported from both farms. Nitrogen fertiliser was applied as urea (46% N) to the ryegrass-white clover swards after grazing. In LIPS, N was applied 9 times at a rate of 18 kg N per ha to sustain high demand of pasture which was the main component in the ration. In HIPS, N was applied 6 times at a rate of 15 kg N per ha, the lower rate reflecting lower pasture required in the diet due to higher supplementation. Values of N contained in different feed sources were calculated using the CP collected from the feed quality analysis divided by 6.25 to estimate N imports in each farm. Nitrogen output on whole-farm level was comprised of two categories: N included in saleable products (livestock sales and milk) and N losses from the farm. Nitrogen lost through volatilisation was estimated using the equation modified by Ryan et al. (2011):

$$NH_3\text{-N emission (g/cow per day)} = -0.51 + 0.0742\, N_{\text{fert}} \times SR$$

where N_{fert} corresponds to the input of fertiliser N (kg N/ha per year). The proportion of N attributed to denitrification loss was derived according to soil type and a drainage category as described by Scholefield et al. (1991). For this analysis it was considered the same for both scenarios with a factor of 0.15. The proportion of N leachable was estimated as the remaining proportion of N inputs (e.g. fertiliser, excreta, mineralisation) (Scholefield et al. 1991). In turn, the N leachable was converted into N leaching (kg N/ha year) using the equation provided by Ryan et al. (2011):

$$\text{N leaching (kg N/ha)} = \frac{N_{\text{surplus}} \times 0.24}{\text{effective rainfall (mm)}} \times \text{drainage (mm)} \times 0.01$$

where N_{surplus} corresponds to the remaining monthly N available after subtracting the proportions of N involved in volatilisation and denitrification, and the effective rainfall was calculated using the equation provided by Schulte et al. (2005):

$$\text{effective rainfall (mm)} = \text{rainfall} - \text{evapotranspiration}$$

Nitrogen utilisation efficiency was calculated as the proportion of N recovered in milk and meat products as a proportion of total imported N.

7.4 Results

7.4.1 Climate and soil drainage

Evapotranspiration and effective rainfall varied between production systems, with 470 and 1,007 mm in LIPS and 479 and 1,008 mm in HIPS. Also, autumn and winter together represented 46% and 47% of total evapotranspiration for LIPS and HIPS, respectively. Effective drainage was 557 and 520 mm for LIPS and HIPS, respectively. The lowest drainage detected in both production systems was in summer, with 51 mm in LIPS and 33 mm in HIPS.

7.4.2 Moorepark Dairy Systems Model outputs for the farm systems

In order to run the comparison between PS, the farming area of both scenarios was unchanged, but HIPS herd size was increased to 257 milking cows, resulting in 257 cows in each herd with 120 and 92 ha in LIPS and HIPS, respectively. Subsequently, SR was 24% lower in LIPS compared to HIPS (Table 7.2). This represents one cow less every 1.3 ha of farming area in LIPS, which is in line with the low input approach of this PS. The productive performance of each production system is summarised in Table 7.4. Cows within LIPS had 23% lower milk production than cows in HIPS, representing 1,384 kg of milk less per cow. Considering the different SR, milk production per ha was 41% higher in HIPS when compared to LIPS, representing 6,817 kg of milk extra per ha in HIPS. The increase in MS percentage of cows in LIPS (Table 7.2 and 7.4) shortened the gap between production systems in milk production but was not sufficient to offset the reduction in milk volume. Compared to HIPS, MSY was 9% less per cow and 30% less per ha in LIPS.

The cows of HIPS had 23% higher DMI than the cows of LIPS, representing an extra 1,173 kg of feed per cow annually (feed intake of replacements included) (Table 7.4). Due to the increased SR in HIPS, this gap increased to an additional 41% of feed per ha (5,790 kg of feed extra per ha). Only cows of HIPS had grain-based concentrate, which comprised 34% of the diet. The 0.7% of concentrate intake per cow in LIPS was allocated to calves and heifers. While cows of LIPS received 6% of their total diet as grazing crops, cows of HIPS only received 0.4% of crops.

Table 7.4 Physical performance generated by the Moorepark Dairy Systems Model for two contrasting pasture-based dairy production systems during season 2016-17; Low-intensity (LIPS) and High-intensity (HIPS) production system.

	Production system					
	LIPS			HIPS		
Item	per cow	per ha	per farm	per cow	per ha	per farm
Milk yield, kg	4,526	9,693	1,163,175	5,910	16,510	1,518,890
Milk solids yield, kg	384	822	98,628	422	1,179	108,491
Concentrate intake, kg DM	27	58	7,018	1,723	4,813	442,758
Crops intake, kg DM	234	500	60,034	20	55	5,023
Grazed pasture intake, kg DM	3,594	7,698	923,737	3,286	9,179	844,478
Fertiliser, kg N	62	134	16,050	31	87	8,014
Pasture production, kg DM	5,675	14,584	1,458,405	4,811	13,572	1,236,441
Silage harvested, kg DM	347	891	89,100	157	443	40,300
Pasture utilised, kg DM	3,941	8,589	1,012,837	3,443	9,622	884,778
Pasture utilisation efficiency, %		69			72	

Notwithstanding the low input approach of LIPS, the application of N fertiliser was 54% higher than in HIPS. This represented an extra of 46.6 kg N per ha (Table 7.4). Compared to HIPS, mean pasture yield per ha of LIPS had an additional 1,012 kg of DM. According to the different management approach, grazed pasture intake represented 86% and 59% of the total feed allowance throughout the year for LIPS and HIPS cows, respectively (Table 7.1). Considering the differences in SR, the grazed pasture per ha was 16% higher in HIPS. Silage harvested in LIPS was 2-fold greater than in HIPS. Based on the management strategy and the MY observed in each system, the MDSM predicted 8,589 kg DM of pasture per ha utilised in LIPS (grazed and harvested) and 9,622 kg DM of pasture per ha utilised in HIPS. This represented a 69% and 72% of accumulated pasture utilisation efficiency in LIPS and HIPS, respectively (Table 7.4).

Milk sales represented approximately 93% of total income in both production systems (Table 7.5). Since HIPS had both a higher milk production per cow and a higher SR, an additional NZ$2,776 per ha was received in income when compared to LIPS. Total costs were considerably higher in HIPS, with an additional NZ$2,379 per ha and NZ$454 per cow compared to LIPS. Fertiliser costs represented 13% of total costs in LIPS and 3% in HIPS, signifying an additional of NZ$275 per ha in LIPS. On the other hand, purchased feed costs represented 28% of total costs in HIPS and only 1% in LIPS, signifying an additional NZ$1,689 per ha and NZ$602 per cow in HIPS. Including more crops in LIPS increased cropping costs by NZ$217 per ha, compared to HIPS. Total costs relative to total milksolids production were NZ$4.44 per kg MS and NZ$5.11 per kg MS in LIPS and HIPS, respectively reflecting the lower inputs included in LIPS. Moreover, these costs represented a higher net profit per kg MS in LIPS (extra 0.42NZ$/kg MS) but considering the higher SR and the superior milk yield of HIPS cows, the net profit per ha was NZ$398 higher in HIPS.

Table 7.5 Financial performance generated by the Moorepark Dairy Systems Model for two contrasting pasture-based dairy production systems during season 2016-17; Low-intensity (LIPS) and High-intensity (HIPS) production system.

	Production system					
	LIPS			HIPS		
Item	per cow	per ha	per farm	per cow	per ha	per farm
Milk sales, NZ$	2,476	5,303	636,357	2,843	7,943	730,711
Livestock sales, NZ$	188	402	48,296	193	539	49,618
Fertiliser costs, NZ$	226	483	57,979	75	208	19,154
Purchased feed costs[1], NZ$	10	21	2,493	612	1,710	157,289
Cropping and silage costs, NZ$	166	356	42,751	50	139	12,795
Labour costs[2], NZ$	250	534	64,123	379	1,060	97,493
Total costs[3], NZ$	1,703	3,647	437,648	2,157	6,026	554,357
Net profit, NZ$	961	2,058	247,004	879	2,456	225,972

[1]Excluding feed costs of replacement animals. [2]Based on the workload per cow (hours/cow), labour costs per hour and total cows. [3]Only main costs are reported in this table.

7.4.3 Effect of farm systems on cow N balance

The annual N balance and N utilisation efficiency of the two production systems on cow level are summarised in Table 7.6. From the total N intake, while the grazed pasture N intake represented 90% and 73% in LIPS and HIPS, respectively, the crops N intake accounted for 7% and 0.2% in LIPS and HIPS, respectively. Nitrogen intake included in concentrate only applied to the HIPS cows, and represented 19% of total N intake during the season. Despite the large difference between diets and DMI of the two production systems (Table 7.1 and 7.2), total N intake per cow was similar, with a small difference of 3.5 kg N per cow, representing less than 0.06 kg of CP intake per cow per day throughout the year (Table 7.6). Milk N was the main component of total N output, with a difference of 12% in favour of the HIPS cows (4 kg extra milk N) and this was followed by N in culled animals, with a minor difference between production systems.

Nitrogen surplus was calculated by subtracting N output, including N contained in calf and cull cows plus milk N, from N intake (which includes N intake of replacement cows). Results indicated a slightly greater N surplus in LIPS cows relative to HIPS cows (approximately 0.6 kg N more). The lower N surplus observed in the HIPS cows was a consequence of having a slightly greater total N intake but with a larger proportion of a low protein supplementation and, at the same time, with a substantial N output captured in milk and this was reflected in a NUE of 3 percentage points higher when compared to the LIPS cows.

Table 7.6 Annual nitrogen (N) balance per cow (kg N/cow) and N utilisation efficiency for two contrasting pasture-based dairy production systems during season 2016–17; Low-intensity (LIPS) and High-intensity (HIPS) production system.

	Production system	
Item	LIPS	HIPS
Grazed pasture N intake	107.9	90.6
Silage kg N intake	2.4	7.1
Concentrate N intake	-	23.9
Crops N intake	8.2	0.3
Dairy cow replacement N	1.9	1.9
Total N intake	120.4	123.9
Milk N output	29.0	33.0
Live weight change N	0.06	0.06
Calf kg N output	1.2	1.2
Cull cow N output	2.8	2.9
Total N output	32.6	36.7
N surplus	87.8	87.2
N utilisation efficiency, %	27	30

7.4.4 Effect of farm system on whole-farm N balance

The main sources of N input at the whole-farm level were feeds and fertiliser. In LIPS, fertiliser N represented 81%, while N in feeds (only crops) represented 11%, of total N inputs (Table 7.7). In contrast, N inputs in HIPS was comprised of 53% in fertilisers and 41% in concentrates. The higher reliance of directly-grazed pasture to feed LIPS cows is underpinned by higher N fertilisation levels, and this explains the greater contribution that fertiliser N made to N inputs in the LIPS. In the same manner, the feeding management strategy of HIPS explained the greater contribution that concentrate N made to N inputs.

Table 7.7 Annual whole-farm nitrogen (N) balance (kg of N/ha) and N utilisation efficiency for two contrasting pasture-based dairy production systems during season 2016–17; Low-intensity (LIPS) and High-intensity (HIPS) production system.

	Production system	
Item	LIPS	HIPS
Concentrate N consumed	-	67.5
Crops N consumed	17.6	0.8
Fertiliser N	133.8	87.1
N input in the replacement cows	4.0	5.4
N atmospheric deposition	9.0	9.0
Total N inputs	164.4	169.8
Milk N	56.3	83.6
Live weight change N	0.12	0.16
Calf N	2.2	2.9
Cull cow N	4.7	6.3
Total N output	63.3	93.0
Soil N Mineralisation	81.7	78.1
N surplus	101.0	76.8
N utilisation efficiency, %	26	38

Total N input of HIPS was 3% higher than LIPS. This equated to an additional 5.4 kg N per ha more in HIPS, but this was offset by an even larger N output, which was 29.7 kg N per ha higher than LIPS. Whole-farm N output of both production systems reflected the N output at the cow level. In the case of LIPS, N surplus and NUE at the whole-farm scale were largely affected by the N input, specifically, fertiliser N.

The difference between the concentrate N in HIPS and the fertiliser N in LIPS was not sufficient to offset the difference between N outputs, particularly milk N, and this resulted in a larger N surplus in LIPS and in a greater NUE in HIPS. Compared to the N surplus and NUE at the cow level, in the whole-farm N balance the differences were increased by including the fraction of N fertiliser.

Environmental N losses are summarised in Table 7.8. Total N excreta per ha was 24% lower in LIPS due to the lower SR. There was not much difference between production systems in faecal N per ha, however urinary N per ha was 28% higher in HIPS, essentially following the increase in DMI of HIPS cows along with the higher SR (Table 7.2). In the LIPS, 50% more N was lost through denitrification when compared to HIPS. As the N surplus increased from HIPS to LIPS, so too did the quantity of N available for leaching and the N content in groundwater and this represented 20 and 13 kg of N per ha leached in LIPS and HIPS, respectively.

Table 7.8 Estimated annual nitrogen (N) losses (kg of N/ha) for two contrasting pasture-based dairy production systems during season 2016–17; Low-intensity (LIPS) and High-intensity (HIPS) production system.

	Production system	
Item	LIPS	HIPS
N excreta in dung	31.4	32.4
N excreta in urine	121.5	168.2
Ammonia emissions	13.3	14.7
N lost through denitrification	14.4	9.6
N available for leaching	81.4	54.1
N content in groundwater, mg of N/L	3.51	2.50
N leaching	19.5	13.0

7.5 Discussion

The present study reports the efficiency of N utilisation along with the physical and economic performance of two contrasting production systems in New Zealand differing in intensification. The LIPS farm was based on feeding management consisting of pasture grazed directly with low levels of supplementation in combination with lower SR and cows milked OAD. In comparison, the HIPS system had a 25% higher SR with cows milked TAD along with higher supplementation and lower reliance on pasture. Consequently, this offers a unique opportunity to investigate different aspects of both biological and economic performance along with NUE and N losses of different intensification of pasture-based production systems on farm system scale. Caution is required when interpreting these modelled N leaching results, given that no validation was undertaken and the levels of inputs employed in the HIPS system were higher than average values encountered within the Manawatu region (DairyNZ 2018).

7.5.1 Efficiency of nitrogen utilisation at the cow level

In LIPS, NUE at a cow level was lower than HIPS and this was caused by less N captured in milk due to lower MY, with a correspondent reduction in PY. This was expected because of the reduced milking frequency (MF) in LIPS. By reducing the MF from TAD to OAD, Delamaire and Guinard-Flament (2006) reported a drop of nutrient uptake in the mammary gland which negatively affected MY of cows in peak lactation. Other studies have reported lower NUE at a cow level in New Zealand under grazing conditions with different levels of concentrate inclusion. For example, Totty et al. (2013) observed NUE at a cow level of 17, 16, and 19% in mid-lactation cows grazing solely ryegrass/white clover pasture, high-sugar ryegrass/white clover pasture and high-sugar ryegrass/white clover pasture with chicory and plantain, respectively. In addition, Al-Marashdeh et al. (2016) observed NUE of 20 and 23% in late-lactation cows fed ryegrass/white clover pasture and ryegrass/white clover pasture with 3 kg DM per cow of maize silage supplementation, respectively. The NUE reported in this study was higher than the NUE figures reported by Totty et al. (2013) and by Al-Marashdeh et al. (2016), because cows of HIPS were fed lower protein supplements in the diet that are affecting the balance. Additionally, our measurements of NUE were calculated including total N in milk and other outputs such as LW change, calf N output, and cull cow N output (Table 7.6).

Lower crude protein content and higher intake of the HIPS compared to the LIPS system (Table 7.1), resulted in 3% higher N intake in HIPS (124 kg N intake/cow) compared to LIPS (120 kg N intake/cow). Bargo et al. (2002) reported a similar outcome on cows grazing pastures at different allowance levels with and without concentrate supplementation. They showed that the supplemented cows with concentrate (of lower CP) increased the DMI and substituted a portion of offered pasture, and this resulted in similar CP intake levels among treatments. In this study, the closeness in N intake between production systems was explained by the higher intake of a diet lower in CP in HIPS when compared to LIPS.

Diluting the often-high N contained in directly-grazed pastures with low-N energy-enriched supplement is described as a strategy to provide more energy for microbes to increase microbial protein synthesis (Mulligan et al. 2004). Reed et al. (2017) reported that there is an extra energetic cost spent in eliminating the excess of N from the organs of cows fed with diets exceeding the CP requirements for milk production. In the case of LIPS, milk production was supressed and diet was higher in CP throughout the season. By diverting more N to milk as a consequence of higher metabolisable protein synthesis rather than ruminal ammonia for subsequent recycling or elimination, this nutrition strategy increased NUE in HIPS at a cow level (Bargo et al. 2002) and a herd level (de Klein et al. 2016). Consequently, the higher NUE observed in HIPS cows in the present study was explained by the increased MY due to the higher MF and by feeding a more balanced ration in terms of energy:protein ratio (Bargo et al. 2002; Al-Marashdeh et al. 2016). However, one must be cognisant that there will be N losses associated with production of the extra feed and that the total N losses would be higher if the system boundary was expanded to the inclusion of the crop growth. It is also worth noting that there is significant potential to increase the NUE within each system with higher utilisation of the pasture grown which was extremely low within this study (Table 7.4). It is also worth noting that this study was not designed as a control/treatment type study and therefore the overall conclusions from the production data need to be interpreted within that context.

7.5.2 Efficiency of nitrogen utilisation at the whole-farm level

An Irish study of pastured TAD cows comparing performance of high producing, high durability, and New Zealand strains with diverse levels of supplementation and SR, reported a mean NUE of 31% (Ryan et al. 2011). Roche et al. (2016), in New Zealand, observed a mean NUE of 35% on TAD cows with SR ranging from 2.2 to 4.3 cows per ha. The efficiencies observed by Roche et al. (2016), along with those observed by Ryan et al. (2011) were lower compared to NUE results from the present study, because of the lower N inputs employed in the present study. The N fertiliser rates were 200 kg of N per ha (Roche et al. 2016), 275 kg of N per ha (Ryan et al. 2011), and 87 kg of N per ha (present study). In the same manner, by applying an additional 35% of N fertiliser in LIPS, which was the principal input of N per ha of this system, the N surplus was increased by 24 kg N per ha and the NUE was reduced by 31% (Table 7.7). Based on the grass growth and grass utilisation from this study it could be strongly argued that the nitrogen was surplus to requirements.

7.5.3 Nitrogen losses from the farm systems

The N leaching results from HIPS were slightly higher than the N leaching reported by Christensen et al. (2018) under standard grazing management with similar soil conditions and similar N fertiliser applications (77.5 kg N/ha). Nitrogen leaching results reported by Christensen et al. (2018) had substatial climatic variation between seasons which had a direct effect on soil drainage and N uptaken by pastures. The N leaching results from LIPS were 12.5 kg N per ha per year lower than those reported for a low-input system by Chapman et al. (2017). It needs to be clarified that in the present study, N input due to fixation by legumes was not measured, and that the low-input system described by Chapman et al. (2017) had a SR of 3.5 cows per ha with 154 kg N per ha of fertiliser applied. To run valid comparisons of N losses from one production system to another, N leached as a proportion of total N surplus (i.e. total inputs minus total outputs) is a more appropriate measure, considering the dramatic changes from one scenario to another but agreement is required on which items should be included in the input and output terms and a number of site-specific factors (e.g. soil, climate) will also affect the N cycle and the N captures and losses from the system (de Klein et al. 2016). The N surplus is a key indicator that can be directly linked to N losses from the system, but caution must be taken when comparing production systems with different characteristics, considering that the relationship between N surplus and N leaching can change from one scenario to another. On a whole-farm level, N surplus indicates potential losses of N to the environment, but the internal flows including N produced by legumes, grass harvested by cows and N disappearing from herbage to plant litter are not taken into account in the calculation of the N surplus at the paddock level (Peyraud and Delaby 2006). For example, the N surplus does not account for some internal N flows such as the denitrification potential under some conditions including soil texture and drainage class, and the aquifer material rock type (Rivas et al. 2017). Rivas et al. (2017) explained that some of these land characteristics could be identified in terms of denitrification vulnerability, and nutrient management interventions could be implemented in order to alleviate N losses.

In the current study, the proportion of N leached from N surplus was 17% and 19% for LIPS and HIPS, respectively. Consequently, it is not easy to compare the N surplus from one study to another (Peyraud and Delaby 2006; de Klein et al. 2016). While Ryan et al. (2011) reported a relationship of 15% of N leached from total N surplus, de Klein et al. (2016) observed that this relationship ranged from 15% to 72% by including results from a diverse range of New Zealand basins. In the same manner, this relationship varied from 12% under high SR with high supplementation to 24% under low SR with low supplementation, in a study conducted by Roche et al. (2016). Roche et al. (2016) observed that in the higher SR scenario, more pasture was harvested with appropriate strategic supplementation, leading to higher milk production, thus higher NUE, and at the same time the shorter lactation resulted in less grazing activity in the autumn months which are considered sensitive for N leaching. In the current study, the proportion of N leached from N surplus was between 17% and 19% for LIPS and HIPS, respectively.

The main losses of N from a dairy grazing system occur through denitrification, volatilisation and leaching (Whitehead 1995). Ammonia volatilisation losses originate from excreta (mainly urine) and from N fertilisation (Ledgard et al. 1999; Saggar et al. 2013). Contrary to the positive relationship between volatilisation and N fertiliser applications observed by Ledgard et al. (1999), both LIPS and HIPS reported similar losses of ammonia regardless of differences between the systems (i.e. SR, fertilisation, feeding system). The positive relationship between volatilisation and fertilisation reported by Ledgard et al. (1999) was more evident considering the contrasting rates of N fertilisers of their study. While Ledgard et al. (1999) utilised from nil to 225, 360 and 430 kg N per ha per annum, in this study the fertiliser rates went from 87 in HIPS to 135 kg N per ha in LIPS. Both production systems analysed were within the safety boundaries of N fertiliser levels proposed by Parsons et al. (2016) which were below the 150 kg N per ha per year.

The losses of nitrous oxide and dinitrogen originate as a result of the denitrification process which, in turn, depends on complex interactions between soil properties, soil microorganisms, climatic factors, and management practices (Saggar et al. 2013). The denitrification losses of both scenarios were equivalent to 10% of the N fertiliser applied and were higher than those reported by Ledgard et al. (1999). This was probably due to different fertilisers rates, edaphic conditions and climatic characteristics between studies. Modelling the denitrification process and emissions of nitrous oxide and dinitrogen is complex and despite the progress made in understanding the multiple factors that regulates this process in pastoral soils, there is limited ability to integrate this knowledge to construct and validate robust and predictive process-based models of denitrification (Ledgard et al. 1999; Saggar et al. 2013).

The increase in imported bought-in feeds and N fertiliser usage are usually associated with increased SR to improve productivity, but are likely to increase N losses to the environment (Parsons et al. 2016). Nitrogen fertilisation has a large impact on N losses from both the animal and the farm as it is involved in many processes within the N cycle (Ledgard et al. 1999; Peyraud and Delaby 2006). Despite the positive effect of its use on pasture production, the efficiency with which it is used is variable (Whitehead 1995) and, similar to feed supplementation, depends on the response of the extra milk produced in relation to the extra kg pasture grown. A study conducted by Shepherd et al. (2017) found that a 20% reduction in SR along with less N fertiliser applied resulted in 14% less N excreted per ha per day, due to a decrease in N consumed per ha, hence a decrease in urinary N excreted. In contrast, on a whole-farm level study in Ireland undertaken by McCarthy et al. (2015), there was an increase in measured N losses (including nitrites, nitrates and ammonia) from free-draining soils where lower SR resulted in less utilisation of grazed pasture. The increase in N fertiliser applied in LIPS resulted in 1,260 kg DM per ha of additional pasture production, but because there were less cows available to utilise this extra feed grown, this resulted in a lower response in milk per kg of N applied and in an increase in N leaching in 6.6 kg N per ha. In hindsight, this system should have been run with a lower fertiliser N level.

7.5.4 Physical and economic performance

Despite the relatively low operating cost of running temperate grass-based dairy systems, the land is the main capital component and is becoming a limiting resource for the dairy farming sector (Macdonald et al., 2017). The optimum production system is that which returns the maximum income per unit of limiting resource. Consequently, a prudent strategy would be to dilute the cost of the land by increasing milk production per area (Macdonald et al., 2017) which has occurred in New Zealand through intensifying the dairy systems since the 1990's (Shadbolt, 2012; Macdonald et al., 2017). On the other hand, it is still debated which grade of inclusion of inputs (fertilisers, bought-in feeds) should be included as these would have a great impact on farming costs (Macdonald et al., 2017). Research from Ireland (Hanrahan et al., 2018) has shown that for each additional 10% increase in bought in feed that net profit per hectare reduced by €97 with similar results reported from the UK, New Zealand and Australia.

Compared to other studies within New Zealand, a larger reduction of MY (23%) due to reduced MF was observed (14% reduction; Lembeye et al. 2016; Edwards 2018). The lower reduction in MY due to reduced MF reported by Lembeye et al. (2016) was explained because of the low yield of the TAD cows used for comparison: TAD cows produced 3,420 kg MS per cow (Lembeye et al. 2016) compared to 5,910 kg MS per cow in HIPS (present study) albeit with similar milking frequencies but vastly different feeding systems. In the same manner, Edwards (2018) called for caution when interpreting his results because TAD cows used in his comparison were not chosen randomly. On the other hand, the reduction in MY of LIPS was equivalent to results reported by Clark et al. (2006), who reported a reduction of 30% and 22% in F and J cows, respectively. While Clark et al. (2006) observed a MY loss per ha of 18% when comparing OAD vs TAD, the current study found a difference of 41% between scenarios (Table 7.2 and 7.4) when the milking frequency and feeding system effects were included together. In the study reported by Clark et al. (2006), the SR for the OAD herd was set 16.7% greater than their TAD counterpart herd, aiming to compensate for a loss in MY, whereas the present study the LIPS farm had a 23% lower SR, aiming to comply with environmental regulations imposed by the regional council.

The study conducted by Edwards (2018) to explore profitability of milking herds milked OAD vs TAD within New Zealand, reported an additional 25% in total farming costs per ha from stabilised herds milked TAD. The proportion of total costs from total revenue represented 64% in LIPS which was lower when compared to the OAD farms of Edwards (2018), due to the lower MY observed in that study. Feed costs per ha of HIPS were 44% higher (extra $766 per ha) than feed costs from farms representing a typical system in the Waikato region (‘current’) from 2000 to 2010 (Clark et al. 2019). In the same manner, Clark et al. (2019) calculated farm revenue of ‘current’ farms using $6.11 per kg MS, which was slightly different to the milk price used in the present analyses ($6.31 per kg MS for HIPS). The proportion of total costs from total revenue represented 71% in HIPS, which was similar to those proportions observed by Clark et al. (2019), reflecting the higher input inclusion in both HIPS and the ‘current’ farms of the Waikato region. Procedures in which costs are calculated (or estimated) are not always consistent, and farm management and operation are not always equal, and this might lead to biased comparisons (Shadbolt 2012). The operating profit would be maximised when the marginal revenue equals the marginal costs and the economic result of adding more inputs (i.e.

fertiliser, supplements) would depend on the marginal cost of the additional milk produced and this will vary from system to system considering the level of intensification of each system (Macdonald et al. 2017).

With an additional 5% kg MS per ha from LIPS compared to the stabilised full season OAD milking herd reported by Edwards (2018), operating (net) profit was 19% greater in LIPS compared to Edwards (2018). The net profit from HIPS was 15% higher than the profit from 'current' farms reported by Clark et al. (2019). Interestingly, the net profit from the 'current' farms of the Waikato region reported by Clark et al. (2019) was similar to the LIPS farm. This might be relevant for farmers who are considering adopting full season OAD milking. In agreement with Edwards (2018), profitability can be achieved by adopting full season OAD milking, but in order to improve the net profit of the business, the farm operation must be restructured to reduce costs if reductions in milk production are expected. Higher input systems can provide more consistent MY, but they are more complex to manage, and risk may be higher if variability in feed and milk prices is not controlled (Shadbolt 2012).

Reducing the MF in LIPS resulted in a drop in MY and DMI per cow and per ha (Stelwagen et al. 2013). The reduced SR of LIPS resulted in a lower feed demand per ha (Macdonald et al. 2008), and an increase in N fertiliser usage increased pasture production (Whitehead 1995) and this led to a decline in pasture utilised. In reality it is clear that without environmental restrictions that OAD systems should operate at a higher stocking rate due to reduced feed demand. The decline in pasture utilised per hectare with a low SR and/or increased use of purchased supplements was found the primary reasons for the low input response (fertilisers, supplements, irrigation) along with an increase of associated costs of growing unutilised pasture in conjunction with increased fixed costs. These settings were associated with reductions of the net profitability of pastured-dairy systems (Macdonald et al. 2017; Wales and Kolver 2017). In order to improve the farm performance of pasture-based dairy systems, it is essential to identify the key system components. On a large dataset from the Irish National Farm Survey including a selection of 257 dairy farms of contrasting productive scenarios over a period of 8 consecutive years, Hanrahan et al. (2018) demonstrated that pasture utilisation per ha is a crucial measurement of farm efficiency. Hanrahan et al. (2018) recognised that by determining appropriate SR, grazing seasonal length, and proportion of purchased feeds among other factors, the overall farm performance would be maximised. This study demonstrated that inappropriate (lax) SR reduced the net profit in the LIPS farm. In the same manner, the high level of bought-in supplements in HIPS had a negative impact on farm costs. The low pasture utilisation of both LIPS and HIPS when compared with other studies (Macdonald et al. 2008;

Clark et al. 2019) is linked to the management decisions described in this study and at the same time, environmental consequences were observed. Chapman et al. (2017) observed that by reducing inputs of N fertiliser and supplementation, there is margin to maximise profitability and reduce the environmental footprint of systems, but the SR must be related to overall feed demand and feed offered on farm.

7.8 Conclusions

At a cow level, a similar gap between N inputs and outputs of both systems explained the equal N surplus, but the NUE which resulted was better in the HIPS production system reflecting a more balanced diet in terms of CP and energy. The whole-farm simulation showed a larger N surplus in LIPS as a result of similar N inputs but with reduced N output captured in milk. This represented a lower NUE in LIPS and increased the N losses. The higher revenue from the HIPS system was a consequence of milking more cows producing higher MY compared to LIPS cows, and despite higher costs of milk production, resulted in greater net profit in the HIPS system.

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Chapter 8

General discussion

8.1 Introduction

The main objective of this thesis was to examine and identify key drivers of the nitrogen (N) utilisation efficiency (NUE) of cows on two divergent pasture-based dairy systems. Subsequently, the relationship of milk urea (MU), NUE and N partitioning to excreta, along with milk production and cow performance from herds of contrasting intensification level, were explored. Lastly, the impact of intensification of the pasture-based dairy systems on the financial performance and some environmental aspects at the whole-farm level were assessed.

This chapter presents the main findings of this thesis and offers a general discussion integrating concepts relative to the factors determining the NUE at both a cow and a whole-farm level. This chapter introduces management implications to influence the NUE, aiming to lessen the environmental impact, and presents limitations that arose as a result of the research undertaken throughout this thesis to recommend the direction of future research. Lastly, general conclusions from this collection of research are presented.

8.2 Main findings of this thesis

In Chapter 2 a literature review of the main aspects of the intensification process and its consequences on the N cycle of temperate pasture-based dairy systems was addressed. This chapter identified that the New Zealand dairy industry has steadily increased its presence in the global trade of dairy products since the 1990's through increasing the productivity of dairy farm systems. A reduction in whole-farm NUE and an increase in N losses from farm are associated with this intensification. The increase of both fertiliser N use and stocking rate (SR), and the inclusion of more land for farming, are increasing the pressure on ecosystems and jeopardising the long-term sustainability of the New Zealand dairy industry. Considering that there are no price subsidies or other protectionist market policies in the New Zealand dairy industry, there is no margin for reductions in profitability in order to engage with farmers. Thus, it is clear that any further intensification of the sector needs to consider the environmental footprint while maintaining the profitability. At the same time, there is an increasing number of farmers adopting once-daily milking (OAD) throughout the season, which are generally associated with lower farming intensity (i.e. de-intensification), would face some environmental implications as well.

In Chapter 3, the first experimental chapter, analyses were presented of the phenotypic correlations between cow performance along with MU and efficiency of crude protein (CP) utilisation (ECPU) in two contrasting spring-calving pasture-based milk production systems differing in intensification levels in New Zealand. In the low-intensity production system (LIPS), cows were milked OAD and fed diets with low supplementary feed inclusion during the lactation and in the high-intensity production system (HIPS), cows were milked twice-daily (TAD) with higher supplementary feed inclusion. The reduced supplementation in LIPS led to a diet significantly higher in CPI and imbalanced in energy:protein ratio when compared to the HIPS herd. By reducing the milking frequency (MF) and by limiting the energy in the diet of the LIPS herd, milk yield (MY) was lower and this led to a lower ECPU in this group of cows. Notwithstanding the significantly higher MU levels in LIPS compared to HIPS as a consequence of higher CPI, MU correlation with ECPU was nil and not significant. At some stages of the lactation MU was similar, and in some cases in both herds cows of higher ECPU also had higher MU. This was corroborated by seeing similar MU yield (MUY) in both LIPS and HIPS herds.

In Chapter 4, a prediction model for ECPU was developed, and found that the main factors regulating the ECPU in lactating cows is the increased protein yield as a direct consequence of more milk production and the CPI. These two main factors can be controlled by a range of farming characteristics including cow characteristics (e.g. age, breed), MF, feeding system, climatic conditions, and others (e.g. stage of lactation). Although a positive relationship was observed between CP and MU, and a negative relationship occurred between CP and ECPU, in the machine learning process, MU was rejected as a predictive variable from the ECPU prediction model.

In Chapter 5 the milk production and the ECPU of cows with low vs high MU breeding value (MUBV) were compared in the LIPS and HIPS herds. Irrespective of system, low-MUBV cows had lower MY. Additionally, milksolids yield (MSY) was also lower in low-MUBV cows, but this was only significant in LIPS. In agreement with previous chapters, reductions of MU were not associated with improvements in the ECPU. On the contrary, cows that had higher ECPU also had higher mean MU throughout their lactation. The relationships between MU with metabolisable protein (MP) balance and UN predictions were positive, but these relationships became less responsive when MU increased and, considering that higher MU levels would be observed in grazing conditions as more CP is offered to cows, this might be part of the explanation why no improvements in the ECPU resulted from selecting cows of low MUBV.

Chapter 6 described and analysed the lactation curves of two measures of N use efficiency; ECPU and CP balance (CPB), along with lactation curves of MU and MUY in LIPS and HIPS cows. Nitrogen excreta partition estimations were also explored. In agreement with previous chapters, lactation curves of ECPU from LIPS and HIPS cows were closely related to levels of milk production and CPI. The addition of CPB into the analysis showed that cows of both production systems were fed dietary CP in excess of their protein requirements, although the diet of HIPS cows was more balanced in terms of energy:protein. The CPB also showed that mobilisation of animal body reserves throughout lactation is not only a source of energy, but also a source of protein. Lactation curves of MU for LIPS and HIPS cows increased at the same time as dietary CPI, and there was no association found between MU and NUE throughout the lactation. In early lactation, MU decreased while NUE increased until peak MY, and as lactation progressed, NUE tended to decrease with concomitant reductions in MY, while MU increased regardless of MF and feeding system. The more balanced diet in terms of energy:protein fed to HIPS cows led to more N diverted to the faecal fraction of excreta. The excess dietary CP in LIPS cows led to greater urinary N relative to HIPS cows, which is the fraction of excreta most directly related to environmental impact.

The economic performance and NUE along with N balance and N losses of LIPS and HIPS were modelled and compared in Chapter 7. In this chapter the analysis was extended from a cow level to a whole-farm perspective. In contrast to the findings from previous chapters, the different diets fed in both LIPS and HIPS systems resulted in similar N intake at a cow level, because of a compensation of lower dry matter intake (DMI) of a higher CP diet in LIPS, and higher DMI of a lower CP diet in HIPS throughout the lactation. At the cow level, a similar N surplus was observed for both systems, but the NUE was higher in HIPS as a consequence of a more energy-balanced diet and by milking cows TAD which led to a higher MY. At the whole-farm level, the N surplus was higher in the LIPS system, due to a lower MY and higher fertiliser level compared with HIPS. This resulted in lower NUE and higher N losses in LIPS. The higher revenue from the HIPS system was a consequence of higher MY compared to LIPS cows, and despite higher costs of milk production, resulted in greater net profit.

8.3 Intensification of dairy systems and its relationship with nitrogen utilisation efficiency

The increase in milk production by the New Zealand dairy industry since 1990 has been achieved through uninterrupted intensification, with the principal objective to improve productivity (Macdonald et al. 2017). This increase was accomplished by both intensification (40%) and genetic improvement (60%), which involves selection and crossbreeding of the main New Zealand dairy breeds through the implementation of a national breeding program that selects cows based on greater milk production responses to additional feed (López-Villalobos et al. 1999; Montgomerie 2004; Johnson et al. 2018). As a consequence of this, the contribution of this farming sector to the New Zealand economy increased from NZ$3 billion in 1990 to NZ$16.7 billion in 2016 (Ministry for Primary Industries 2018).

Compared with indoor systems, pasture-based dairy systems of Ireland and New Zealand have some advantages associated with perceived animal welfare, increased product quality and higher social acceptance (Dillon et al. 2005; Macdonald et al. 2008), but grazing systems also face several challenges. For these systems to function optimally, the cow must be able to walk long distances, be robust to changes in feed supply, have good grazing behaviour characteristics and be highly fertile (Roche et al. 2017; Roche et al. 2018). Furthermore, the farmer must ensure high pasture utilisation by matching feed requirements of the herd with pasture growth and feed availability (Macdonald and Penno 1998; Holmes et al. 2002). This involves a compact calving period along with cows being able to become pregnant within 42 days after the start of the breeding period, in order to align the nutritional, productive, and reproductive status at the herd level, aiming to optimise farm management (Macdonald et al. 2008). Additionally, the calving period would need to be adjusted according to the seasonality of the pasture growth (Macdonald and Penno 1998; Holmes et al. 2002). The minimal use of mechanisation will reduce the costs of the business but the base forage is fresh and perishable so it must be directly grazed by cows in time and surplus must be ensiled to be allocated in times of lower pasture growth (Ramsbottom et al. 2015). Despite the low operating cost of pasture-based systems, the land is the main capital component and is becoming a limiting resource. A key focus of pasture-based systems, then, is to 'dilute' the cost of the land by increasing milk production per area (Macdonald et al. 2017).

Temperate pastures in New Zealand usually contain levels of CP that exceed the nutritional requirements of cows (Waghorn and Clark 2004). The elevated levels of dietary CP result in a decrease in NUE with more N excreted in faeces and urine (Ledgard et al. 1999; Castillo et al. 2000; Kebreab et al. 2001). While pastoral farmers generally do less to regulate dietary CP, total mixed rations of housed systems are designed to match nutritional requirements of cows according to the production level targeted (Mulligan et al. 2004; Hills et al. 2015). Therefore, feeding total mixed rations results in cows with higher NUE than pasture-based cows (Castillo et al. 2000; Powell and Rotz 2015; de Klein et al. 2016).

The intensification described in Chapter 2 mainly comprised an increase of imported feeds to extend lactation length, along with N fertiliser to boost pasture production, both of which are usually associated with increases in SR. In general, the poor NUE of N fertiliser within agricultural systems is one of the main causes of increased N losses to the environment

(Whitehead 1995; Ledgard et al. 1999; Peyraud and Delaby 2006; Oenema et al. 2010). In this chapter, it was found that both imported feed and N fertiliser influence N losses, but fertiliser rates appears to have a larger impact. On the one hand, imported feeds contain low to moderate amounts of N, so increasing supplementary feeds increased N in the system by a minor amount and at the same time, diluted the high levels of pasture CP, which increased the NUE of milking cows (Mulligan et al. 2004; Totty et al. 2013). On the other hand, while some of the N fertiliser would be either directly leached from soil or volatilised to the atmosphere, the rest increases the already-high N in plants, and so its overall usage results in higher losses to the environment (Peyraud and Delaby, 2006; Shepherd and Lucci 2013). In this chapter it was observed that SR increases are not always associated with increases in N leaching. For example, by increasing the number of cows per ha, Roche et al. (2016) demonstrated that less pasture available for each cow increased the NUE per cow via improving the pasture utilisation efficiency. A shorter lactation length also meant that there were fewer cows urinating on paddocks in late summer-early autumn. A study conducted by Christensen et al. (2018) demonstrated that late summer-early autumn is the sensitive period for urine depositions in soils, where all urine N accumulates in soil prior to be leached in winter.

Due to the fall in prices for dairy products in the Global Dairy Trade after 2013, there is a trend in the New Zealand dairy sector to return to traditional grazing systems with lower inclusion of supplements (DairyNZ 2018; Wales and Kolver 2017). Moreover, new environmental regulations are introducing limits for intensification of dairy systems (Horizons 2016; Ministry for the Environment and Stats NZ 2019). With modern dairy systems mostly operating TAD, an increasing number of farmers have chosen OAD for the entire lactation despite the well-documented yield loss (Clark et al. 2006; Stelwagen et al. 2013; Lembeye et al. 2016; Edwards 2018). Since the 1990's the adoption of OAD is increasing. While Davis et al. (1998) reported that approximately 3% to 5% of New Zealand dairy farmers had chosen OAD for the entire lactation in 1998, Edwards (2018) reported that approximately 9% of dairy farmers in New Zealand operated their farms in OAD full-season regime in 2018.

Once-daily milking systems should be viewed favourably by society. There are well-documented results of increased animal welfare and immune status of OAD cows (Clark et al. 2006; O'Driscoll et al. 2012; Hemming et al. 2018) along with reductions in cow culling associated with infertility and lameness (O'Driscoll et al. 2010). Moreover, the obvious changes to the working day of a farmer, by reducing time spent in milk harvesting, has been associated with staff lifestyle improvements (Stelwagen et al. 2013) and this could represent advantages to attract and retain farm staff (Tipples 2008; Edwards 2018). Another positive effect of OAD is the increase in lactoferrin in the milk (Farr et al. 2002; Stelwagen et al. 2013; Davis and South 2015). Lactoferrin is a bioactive compound, an iron-binding glycoprotein with bacteriostatic and bactericidal effects on gram-positive and gram-negative bacteria. Lactoferrin is associated with the prevention of many illnesses and diseases, such as ear infections, gastrointestinal infections, severe lower respiratory tract infections, atopic diseases (allergies, hay fever, asthma, and dermatitis), obesity, cardiovascular diseases, childhood leukaemia, and sudden infant death syndrome (Guerra et al. 2018). The increase in the main milksolids constituents (fat and protein) in OAD with respect to TAD cows is well documented (Davis et al. 1998; Stockdale 2006; Lembeye et al. 2016). While the increase in milk fat concentration might be an effect of lower milk volume, the increase in milk protein is due to an influx of serum protein (Stockdale 2006; Stelwagen et al. 2013). Considering that New Zealand milk processing companies calculate the milk price accounting for fat and protein content with deductions based on milk volume, there might be a slight benefit in terms of milk price for OAD farmers (Thomson et al. 2005). Moreover, Pomiès et al. (2007) observed lower levels of free fatty acids in milk from OAD cows in mid-lactation, which might benefit butter and cream manufacturing (Stelwagen et al. 2013). On the other hand, Stockdale (2006) reported that the changes in milk composition due to OAD included increases in true protein, caseins, whey components, sodium and calcium amongst others, and this would generally be detrimental to the manufacturing potential of the milk, especially for cheese. The standards and demerits for somatic cell count required by differing milking companies may vary, but they use similar tests to account for white blood cells in the milk and this helps to indicate the health of the mammary gland (DairyNZ 2017). Thus, milk of high somatic cell count is associated with cows with mastitis and is of inferior quality due to a higher incidence of antibiotic residues (Ruegg and Tabone 2000) and is frequently used to determine quality payments to farmers. Frequent milk removal is generally associated with a reduction in somatic cells (Stockdale et al. 2006), but the increase in somatic cells in OAD cows was not associated with clinical or sub-clinical mastitis in a study conducted by Lacy-Hulbert et al. (2005). A study by Lembeye et al. (2016) compared milk production performance along with lactation persistency and somatic cell score between spring-calving cows milked either OAD or TAD for an entire lactation in New Zealand and reported that irrespective of breed, a stabilised OAD cow in its fourth lactation had similar somatic cell count when compared with a TAD cow.

Usually, OAD milking systems are of low intensity by means of higher pasture-based diets with low supplementary feed inclusion (Stelwagen et al. 2013), which is strongly associated with financial performance (Dillon et al. 2005). It is still debated if farmers choosing OAD as a system should increase or reduce their SR and this is founded on different purposes. On the one hand, Clark et al. (2006) observed increases in SR by 16.7% as farmers aimed to minimise the milk production losses per ha associated with OAD, and on the other hand, Lembeye et al. (2016) recorded a drop in SR from 2.7 to 2.1 cows per ha by OAD farmers aiming to comply with environmental regulations. The interaction between the de-intensification process in these particular systems (i.e. pasture-based diets with less supplements) and the reduction in milk yield (milk protein) (Lembeye et al. 2016; Edwards 2018) is relevant in terms of environmental impact. The increased lactation length commonly observed in OAD systems (Lembeye et al. 2016) might represent a risk considering the extra loads of urine N on paddocks in the sensitive periods of the year previously mentioned.

The New Zealand dairy sector is widely criticised due to intensification being associated with the loss of native plants and animals over large areas that are increasing the pressure on soil and water resources, jeopardising its long-term sustainability (Jay 2007; Basset-Mens et al. 2009; Foote et al. 2015). At the same time, less-intensive dairy systems (i.e. lower SR, OAD, less supplements) are not exempt from environmental implications, i.e. the de-intensification does not necessary reduce the environmental footprint. Therefore, any future sustainable intensification or de-intensification needs to focus on the reduction of the environmental footprint, and this varies from region to region and even farm to farm. In order to be attractive to farmers, it is inevitable that these mitigation practices should not be associated with a reduction in profitability (Pretty and Bharucha 2014; Roche et al. 2018).

8.4 Relationship of dietary nitrogen utilisation and milk urea along with milk production

In Chapter 3, the relationships between ECPU, MU, and cow performance variables including milk production traits, LW and BCS throughout lactation in two contrasting herds of different MF and feeding system were investigated. The ECPU was determined by the level of milk production and by the CPI. The LIPS herd, by feeding larger quantities of fresh pasture with elevated CP, and having reduced milk production, had a lower ECPU. On the other hand, the HIPS herd fed higher supplementation had a lower dietary CP and this, along with higher milk production, resulted in a higher ECPU.

Milk urea has been proposed as a non-invasive and inexpensive indicator for detecting excess CP levels of diets (Broderick and Clayton 1997) and as an index to identify N in excreta and inefficiencies of N utilisation in dairy systems (Jonker et al. 1998). Similar to other authors (Nousiainen et al. 2004; Huhtanen et al. 2015; Barros et al. 2017) this research confirmed the positive relationship between the CP and MU, but in this case a link between MU and the ECPU was not established because cows of both herds had similar values of MUY. Aguilar et al. (2012) conducted a study including records of 889 cows from 8 housed herds intensively monitored in terms of individual feeding, cow performance and milk production, to test the usefulness of utilising individual cow MU records as a feed management tool. A large variation between MU records of cows and herds was observed, and this was not explained by N intake, milk yield, or other management factors. These authors pointed out the limitations of MU as a management tool, and concluded that MU might be used as a feeding management tool at a herd level only when the herd has an average milk production between 30 and 40 kg milk per day, diets contained less than 16% CP with adequate energy, and MU was less than 25.68 mg per dL. A study conducted with pastured dairy cows fed concentrates of varying CP levels to determine the relationship between CPI and N partitioned to milk protein, MU and excreta, observed a weak response of MU with increasing levels of dietary CP (Mulligan et al. 2004). These authors observed that the relationship between measurements of MU and N excreta, specifically urine, was also not significant. Similar to results from this research, Mulligan et al. (2004) reported that when cows produce more milk on diets of higher CP degradability (i.e. rumen-degradable protein), more MU was found in milk.

8.5 Factors affecting the efficiency of dietary nitrogen utilisation at a cow level

In Chapter 4, a model to predict the ECPU in grazing dairy cows in different systems of intensity was described and evaluated. The model was developed including animal, nutritional and environmental variables generated on two herds of contrasting supplementation and MF throughout two consecutive seasons. The ECPU changed throughout the lactation due to fluctuations in protein yield, in turn driven by milk production level. Management practices including feeding system and MF reduce the level of milk production, and influence the ECPU. Because the ECPU focuses only on the N captured in milk to calculate the dietary CP utilisation efficiency, the model presents limitations to capture the effect of N retained in body tissues of cows that mobilised less body reserves. While the LIPS cows had a reduced milk yield, this corresponded with a higher body condition score (BCS) and lower live weight (LW) mobilisation (McNamara et al. 2008; Phyn et al. 2010; Khaembah et al. 2013). Considering that 160 g of CP is used to produce 1 kg of LW (Huhtanen et al. 2015), any gain in LW during lactation represents a 'capture' of N in tissues.

The effect of predicting the ECPU in primiparous cows was also captured by this model. Foskolos and Moorby (2018) had previously found that having fewer primiparous cows in the milking herd increased the average milk production per cow and this improved the efficiency of feed and N usage at a herd level. The increased pressure on high-yielding cows under more intensified dairy systems is associated with a shorter productive lifetime and this is related to increased diseases, metabolic problems and reduced fertility performance (Martin et al. 2019). In contrast, in a well-established OAD herd, cows would have a longer lifespan as less pressure is imposed on these animals and this could represent an advantage in terms of N utilisation efficiency across lactations.

The relationship between MU with dietary CP and CPI on a daily basis was confirmed to be the same as other studies under both grazing (Totty et al. 2013) and housed conditions (Nousiainen et al. 2004; Huhtanen et al. 2015; Barros et al. 2017). Considering that the excess CPI would reduce the ECPU and that MU increases with CPI, MU and ECPU should be negatively correlated. In contrast to other studies (Jonker et al. 1998; Hristov et al. 2005), MU was not considered as a predictive variable for the model due to inconsistencies in its relationship with the ECPU during the lactation. Milk urea decreased at the same time as the ECPU in early lactation and tended to increase at the end of the lactation, while ECPU decreased. A review of factors affecting the relationship between MU and urinary urea (Spek et al. 2013) suggested that confounding factors such as differences in feed intake and dietary protein intake make it difficult to draw a solid relationship between ECPU and MU. A study by Brito and Broderick (2006) found no relationship between MU and CPI: by altering the composition of rations but maintaining similar dietary CP, they observed an increase of rumen-degradable protein (RDP) in diets with more lucerne silage in relation to maize silage and this impaired the synchrony with energy for microbes, thereby reducing the ECPU but without changing MU levels. In this research, the different trends of MU and ECPU throughout the lactation (negative for both in early lactation and negative for ECPU and positive for MU in late lactation), led to similar MUY in both LIPS and HIPS herds. In turn, the nil (and non-significant) correlation between ECPU and MU in LIPS and HIPS cows, made MU unsuitable as a predictive variable of ECPU.

All of these concepts mentioned are important to consider in terms of NUE when implementing lower production level systems, such as OAD. Additional mitigation techniques need to be considered in order to lessen the inefficiency of CP utilisation through capturing less N in milk. High-producing cows capture more milk protein compared to low-producing cows, but at the expense of larger feed intakes (Kolver and Muller 1998; Baudracco et al. 2010). The interactions with diet quality (CP and energy), and diet variations throughout lactation would produce different efficiencies and will determine the partition of N towards excreta (Castillo et al. 2000; Kebreab et al. 2001; Daniel et al. 2017). The next step for the analysis is to integrate the NUE at the cow and whole farm level, but the analysis must move from an average daily basis towards full lactation in order to capture a more tangible effect of the changes in ECPU and to explore the potential of diverse mitigation techniques (see later in the general discussion) (Powell and Rotz 2015; de Klein et al. 2016).

8.6 Effect of genetic merit for milk urea on milk production and efficiency of crude protein utilisation in two contrasting dairy herds

Considering that MU has become an important selection trait to monitor nutritional status of dairy cows in Europe (Stoop et al. 2007), it was suggested that selecting cows for low MUBV would reduce the N losses and, at the same time, increase the NUE by diverting more N towards milk protein (Beatson et al. 2019). Thus, in Chapter 5, the analysis was centred on describing cow performance and ECPU of low vs high MUBV cows in the LIPS and HIPS systems. The breeding values of the two herds utilised in previous chapters (LIPS and HIPS) were calculated in a study conducted by López-Villalobos et al. (2018) and ranked within herd, in low, medium and high MUBV categories. The main findings reported in this chapter were that MY was lower in cows of low MUBV irrespective of production system. In line with findings of previous chapters, the lack of response of MU to ECPU was observed in Chapter 5, with no improvements in ECPU when selecting cows of low MUBV. In addition, no improvements in estimations of N partitioned to urine were detected.

The metabolisable protein (MP) balance estimations undertaken using the equations provided by Givens et al. (2004) confirmed that, irrespective of production system, grazing cows of both LIPS and HIPS systems consumed excess CP throughout their lactation and this has detrimental environmental consequences (Di and Cameron 2002). The relationship between MU and MP balance, and between MU and UN predictions, was positive in both cases, but became less responsive when MU increased and, considering the expected higher MU levels in grazing conditions, this might be part of the explanation why there were no improvements in ECPU when selecting cows of low MUBV under the conditions of this study.

Irrespective of herd management, low-MUBV cows had inferior milk production when compared to high-MUBV cows. The higher CP observed in LIPS was also reflected in the RDP and UDP fractions (Amanlou et al. 2017; Tacoma et al. 2017). Fresh grazed pastures in New Zealand may be high in CP in both early and late lactation, containing mainly RDP (Kolver and Muller 1998). This results in increases in N excreta, particularly in urine (Kebreab et al. 2001; Mulligan et al. 2004). Compared to HIPS cows, in this chapter it was found that LIPS cows had higher RDP intake as more pasture was fed and this resulted in higher N excreted in urine. This chapter identified that feeding strategies have proven to be more effective to reduce N losses while improving the ECPU, compared to selecting cows of lower MUBV.

8.7 Nitrogen balance, efficiency and losses at the cow and whole-farm level: economic and environmental implications

Chapter 6 examined the lactation curves of MU and ECPU throughout the entire season in LIPS and HIPS farm systems. A different measure of NUE was introduced into the analysis, the CPB (Zamani 2012) which is calculated on a daily basis as the difference between CPI and protein yield. In line with the MP balance analysed in the previous section, the most inefficient cows had the higher positive CPB. Additionally, the influence of NUE on the partitioning of N towards faeces and urine was also explored by including equations developed by Reed et al. (2015).

In line with the ECPU analysed in Chapters 3, 4, and 5, the inclusion of CPB in Chapter 6 as an additional measure of NUE, confirmed the greater surplus of CP fed to LIPS cows in relation to HIPS cows. The CPB confirmed that pastured dairy cows within temperate grazing conditions are fed CP in excess of animal requirements irrespective of supplementation level (Kolver and Muller 1998; Castillo et al. 2000; Totty et al. 2013). The positive CPB of HIPS and LIPS cows at the beginning of their lactation was explained by the mobilisation of body reserves to meet energy requirements. The LW loss observed at this stage, not only contributed energy to meet the high demand in peak lactation, but also protein was mobilised (Amanlou et al. 2017; Kaufman et al. 2018), increasing the available CP. The similar CPB between LIPS and HIPS was due to less LW mobilisation along with higher CPI in LIPS cows and, at the same time, higher LW mobilisation along with lower CPI in HIPS cows. In agreement with previous chapters, it was demonstrated that LIPS cows had lower ECPU as a result of higher dietary CPI and lower MY. While estimating similar N partitioned to faeces in both herds (Hristov et al. 2005), the elevated CPI of LIPS cows resulted in higher predictions of N apportioned in urine (Castillo et al. 2000; Kebreab et al. 2001; Reed et al. 2015). The relevance of these results on a per cow basis relies on detecting true deficits and surpluses of N in order to gain an understanding of the general NUE at the whole-farm scale.

Chapter 7 studied NUE on a whole-farm scale. Thus, all inputs (e.g. concentrate feeds for both milking cows and rearing categories, fertilisers) were considered. The economic performance of LIPS and HIPS systems were modelled using the Moorepark Dairy System Model (Shalloo et al. 2004) and the N balance, along with efficiencies and losses of N, were generated using the N balance model developed by Ryan et al. (2011). For this analysis, all actual physical performance data obtained from these two research dairy herds at Massey University was employed. Moreover, all biological processes involved (e.g. N response of fertilisers, N leaching) were modelled using local meteorological information.

An important aspect of this chapter was the SR of both systems, but particularly in LIPS. Although in some instances there is a tendency to increase the SR in OAD systems to overcome the milk yield losses on a per cow basis (Beukes et al. 2004; Clark et al. 2006), in other cases SR could be reduced temporarily (Beukes et al. 2008) or during the entire lactation (Lembeye et al. 2016) for different purposes including feed shortages and compliance with environmental regulations. In Chapter 7, the SR of LIPS was 1.7 cows per ha lower that the study by Clark et al. (2006) and 1.1 cows per ha lower than Beukes et al. (2004). Another aspect that deserves consideration is the rate of N fertiliser used. In LIPS, 134 kg N per ha were applied (9 applications each at a rate of 18 kg N per ha) to sustain high supply of pasture which was the main component in the ration, while in HIPS, only 90 kg N per ha were applied (6 applications each at a rate of 15 kg N per ha) due to less pasture in the diet as a consequence of higher supplementary feed. This combination of lower SR and higher N application in LIPS had negative environmental and, to some extent, financial consequences. Comparative SR provides an alternative to the traditional SR measure of cows per ha, and is calculated as kg LW per ha, divided by the amount of total feed supplied to the herd over 12 months. It is a method of assessing the balance between feed demand and supply on farm (Macdonald et al. 2008) that allows farmers to better calculate the optimum SR for any grazing dairy farm. In Chapter 7, comparative SR resulted in 69 and 77 kg LW/t feed available for LIPS and HIPS, respectively. The lower comparative SR of LIPS, compared to HIPS, explained the lower pasture utilisation efficiency and the excess feed offered due to a lower SR coupled with diminished feed demand due to the reduced MF. The higher comparative SR of HIPS was more in line with the optimal value proposed by Macdonald et al. (2011), but the relatively low pasture utilisation efficiency observed would have been due to the substitution of pasture for supplements. In this case, there is still an opportunity to improve the pasture utilisation efficiency by monitoring the grazing residuals and adjusting the supplementation accordingly (Macdonald et al. 2008; Macdonald et al. 2011).

Interestingly, the differences seen in the previous chapters concerning the CPI between both herds disappeared in the whole-system analysis. Presumably, by integrating to a total single value of feed intake (comprising each daily intake along with its correspondent CP), the differences in CPI between LIPS and HIPS reduced. The simulated results predicted a slightly larger N surplus in LIPS than in HIPS on a per cow basis (87 vs 85 kg N per cow). The HIPS cows had estimated higher feed intake when compared to the LIPS cows because of their increased milk production (Holmes et al. 1992; Delamaire and Guinard-Flament 2006). Due to the increased estimated feed intake of a more balanced diet in energy:protein, HIPS cows had greater N excreta (urine plus faeces), but at the same time captured more N in milk due to a higher MY. The additional concentrate in HIPS, although it increased N input (an additional 24 kg N per cow, or 68 kg N per ha compared to LIPS), also increased NUE at both the per cow level (30% vs 27%) and the whole-farm level (38% vs 26%) compared to LIPS, due to an overall higher energy, and lower CP diet. The greater milk production observed in HIPS reduced N surplus (de Klein et al. 2016). Caution must be taken with management practices that reduce the N captured in milk (e.g. OAD, low input systems, reduced SR), because the resulting lower NUE will increase N losses unless all the N inputs are decreased accordingly (Parsons et al. 2016). This concept was introduced in previous sections on a per cow basis and is now confirmed on a whole-farm basis.

The modelling analysis at a whole-farm level confirmed that a OAD strategy employed in LIPS can reduce costs of production (Armstrong and Ho 2009; Edwards 2018; Lazzarini et al. 2018). Moreover, the levels of milk production of LIPS cows in Chapter 7 were higher when compared with those previously reported (Lembeye et al. 2016; Edwards 2018; Lazzarini et al. 2018), otherwise the gap between the LIPS and HIPS scenarios modelled would have been even greater. The higher revenue in HIPS, as a consequence of milking more cows with higher milk production compared to LIPS, surpassed the higher costs of milk production of HIPS, resulting in superior net profit. In LIPS, the higher N fertiliser rate not only increased the variable costs, but also aggravated the N losses.

8.8 Management recommendations focusing on N utilisation efficiency

The findings discussed in previous sections are highly relevant to dairy farmers in terms of improving the NUE towards better environmental outcomes and specially to those farmers considering the implementation of lower-input systems, such as OAD. In OAD systems, farm costs must be constantly monitored in order to reduce the financial impact of the reduced MY (Stelwagen et al. 2013; Edwards 2018). Considering that use of N fertiliser affects not only N losses, but also variable costs, farmers must think carefully about its usage, along with herd feed demand and pasture production requirements, to maintain expected levels of milk production (Parsons et al. 2016). Surplus pasture grown through higher N fertiliser rates would have a negative impact at both the environmental and economic level, similar to what was observed in Chapter 7.

Accurate daily herbage allocation to dairy cows through constant monitoring of paddocks would result in more consistent daily intake of pasture and in improved feed conversion efficiency (e.g. more milk per kg of pasture grown) (Fulkerson et al. 2005; Beukes et al. 2019). By adjusting the SR and fertilisation rate according to the feed demand of the herd, a more consistent grazing pressure should ensure optimum pasture utilisation. Furthermore, 'true' pasture deficits would be detected early and this would improve the milk response to N fertiliser applied (kg milk per kg N fertiliser). At the same time, more consistent and accurate monitoring of post-grazing pasture residuals would allow strategic supplementation by reducing the substitution rate, which will improve the milk response to supplementation, along with improving NUE as discussed in this chapter. One advantage/opportunity of OAD systems is that the reduced time spent in the parlour on milk-harvesting tasks could be replaced by spending more time developing a more robust and consistent grazing management system.

In the previous section, comparative SR was used to discuss an optimal SR and feed offered for the HIPS and LIPS. At the same time, the reduced MY resulting from milking cows OAD and feeding less supplements, was extensively discussed. If pasture is accurately measured, along with the use of comparative SR to better predict feed required, there may be an opportunity to increase the SR in these systems, without negative environmental consequences. Such decision management would increase total milk production and pasture utilisation with more cows grazing. The NUE would be improved with strategic supplementation and the lactation length could be shortened, aiming to avoid grazing with lactating cows in the autumn months. These management decisions could be complemented with the use of high-yielding, low-CP crops (to feed the lactating cows). Williams et al. (2019) demonstrated that allocating part of the dairy platform (15%) to produce a feed source lower in CP, reduced the urinary N of milking cows. This system targets high NUE at the crop level. Such a crop could be followed by a 'catch crop', of oats (*Avena sativa* L.) or annual ryegrass (*Lolium multiflorum* L.), aiming to capture residual soil nitrates from the previous crop, resulting in reduced nitrate leaching, and providing a winter forage for dry cows (Carey et al. 2016). Economic analysis should be undertaken for a range of alternatives, in order to explore the best combination of management practices to enhance the NUE while maintaining the profitability of the dairy operation.

8.9 Limitations of this thesis and future work

The analyses undertaken in this this thesis were all retrospective analysis (post hoc), so it was not possible to design and manage the animals and farm systems for controlled experiments. In these situations, researchers cannot control the research outcome, and instead must rely only on accurate recordkeeping. Some key statistics cannot be measured, and significant biases may affect the selection of controls (Youngberg and DeMuth 2013; Wigboldus et al. 2016). The retrospective aspect may introduce selection bias and mis-classification or information bias. For instance, the analyses undertaken in this thesis were based on two herds that have not been randomly selected.

The impossibility to retrospectively allocate high vs low supplementation level in both OAD and TAD herds introduced a confounding effect, which limited the statistical analysis to separate the effect of MF and supplementation level. In most of the cases (Chapters 3, 5, 6 and 7) the conclusions were drawn based on the analysis of the combined effect of MF along with supplementation level. The justification relies on the identity of each system, where OAD systems are expected to have reduced supplementary feed regimes (Beukes et al. 2004; Stockdale 2006; Armstrong and Ho 2009; Stelwagen et al. 2013; Lazzarini et al. 2018). Caution must be exercised to not overextend conclusions to try and represent a ‘benchmark’ situation for either OAD or TAD systems. On the other hand, benchmarking studies may also lead to biases, and will require further statistical and analytical analyses (e.g. random forests, stepwise logistic regression) to identify ‘true’ categories and characteristics (Parker Gaddis et al. 2016) of a range of farming systems in this case. Nevertheless, the knowledge gained throughout this thesis provides useful insight for general management practices employed (e.g. MF, fertilisation, SR) on both herds throughout the season.

This research was focused on the NUE of milking cows under grazing conditions, with NUE calculated based on daily estimations of CPI along with measured milk production. To calculate the CPI, estimations of DMI based on energy requirement equations were utilised. Notwithstanding the comprehensive cow parameters utilised to estimate the DMI (e.g. milk production and composition, LW and LW variation, BCS), these equations should be validated to the cows milked OAD. Throughout this research, cows milked OAD in the LIPS herd had consistently lower DMI during their lactation, compared to cows milked TAD in the HIPS herd. Recently, Capelesso et al. (2019) observed that cows milked OAD did reduced their MY but maintained their feed intake level. It needs to be considered that in the study by Capelesso (2019), cows reduced their MF only in early lactation and were fed total mixed rations.

Nevertheless, the DMI effect of MF, along with the validation of energy requirement equations for OAD cows, needs further examination.

An ideal study to assess the NUE on a cow basis would need to include a complete N balance, where the partitioning of N input towards faeces, urine and milk and N retained in body tissues and the foetus, are accurately accounted for (Spanghero and Kowalski 1997; Castillo et al. 2000). Throughout this thesis, accurate measures of N captured in milk were achieved and LW variation was recorded with an acceptable grade of reliance to account for the N retained in the animal. As discussed previously, the implementation of accurate and individual DMI measurements would allow more precise measurement of CPI, which is crucial in the NUE determination. Including measures of N partitioned in excreta would give a more complete depiction of the partitioning of N in cows differing in MF and supplementation level. Moreover, these new sets of measurements would allow comparison of excreta N, along with MU and ECPU, permitting a more exhaustive analysis of the interrelations analysed throughout this study and will help in a better understanding of the N cycle at the cow level.

Milk urea was only measured in early, mid-, and late lactation per cow per season; hence, there were fewer measurements when compared to other traits (e.g. milksolids, LW, BCS). It would have been preferable to have more frequent sampling of MU in order to produce better quality modelled lactation curves. This disparity in availability of records to model, resulted in observed inaccuracies at both peripheries (start and end) of the lactation. Berry et al. (2003) reported a larger increase in the genetic variance for BCS at both peripheries of the lactation curve, and reported that these fluctuations may be due to a combination of both a lack of data at those periods of lactation (as in our case) and possibly because of the mathematical properties of a polynomial, which places relatively more weight on observations at each extremity. Moreover, Coffey et al. (2002) had the same inconsistencies when modelling the energy balance of cows in the period between lactations with random regression analysis using Legendre polynomials, and these irregularities were explained by a lack of records in the dry-cow period.

In Chapter 3, it was mentioned that the predictive model of ECPU did not distinguish the genetic merit effect within each breed. Chapter 6 partially studied this genetic effect by selecting cows of different MUBV as a proxy for low vs high ECPU, but no improvements on ECPU were observed by considering cows of different genetic merit (MU in this case). Thus, it would be necessary to formulate a new research question aiming to identify if cows with genetic advantages in utilising the CP in diets exist.

The sampling methodology employed throughout this thesis collated data on cow performance (e.g. BCS, LW, milk production and quality) and other management variables such as feed allowance, feed quality, and estimations of intake, with an acceptable degree of accuracy on a large number of animals during two consecutive lactations. The large and robust dataset produced permitted insights into the complexities of the NUE of pastured dairy systems. In Chapter 7, it was mentioned that the two scenarios proposed for modelling may not represent in full a 'typical' OAD and TAD system. Further research should attempt to replicate this methodology to farms in different regions and at different scales, in order to have a better understanding of the NUE at a national level.

General conclusions

Under the conditions of this research, the hypothesis introduced in Chapter 1 was not supported by the results. It was observed that the NUE resulted detrimental in both cow and farm levels when reducing farming intensity. The main conclusions from this thesis were:

1. At a cow level, the ECPU was driven by the level of milk production and by the feeding system employed. Moreover, feeding diets higher in pasture content and reducing the MF affected overall milk production performance, and consequently, reduced the ECPU in the LIPS cows.
2. In contrast to housed dairy systems where MU is a good indicator of dietary CP and ECPU, in pasture-based dairy systems, cows are fed diets where there is less control of nutrients and this usually causes an excess of dietary CP in relation to the requirements for moderate milk production, resulting in high values of MU. Beyond a threshold of approximately 20 mg of MU per dL of milk, the slope of the relationship between N partitioned to milk (ECPU) and excreta became less responsive. Consequently, MU was not a good indicator of ECPU under the conditions of this research. This was observed in the nil effect of selecting cows of low MUBV on enhancing the ECPU in grazing conditions with diverse levels of supplementation.
3. The whole-farm simulation predicted a larger N surplus in the LIPS, as a result of similar N input but with reduced N output captured in milk. This represented a lower NUE in the LIPS, and increased the N losses. The higher revenue observed in the HIPS due to milking more cows of higher MY when compared to the LIPS, surpassed the higher costs of milk production of the HIPS and resulted in superior net profit. Notwithstanding

the low input approach of the LIPS, the application of N fertiliser was 2-fold higher than the HIPS, and this aggravated the N losses from the LIPS.

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STATEMENT OF CONTRIBUTION
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We, the candidate and the candidate’s Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate’s contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Martin Correa-Luna
Name/title of Primary Supervisor:	Professor Nicolas Lopez-Villalobos
Name of Research Output and full reference:	
Correa-Luna M, López Villalobos N, Almeida Jr GA, Donaghy DJ, Kemp PD 2018. Phenotypic correlations of milk urea and the efficiency of crude protein utilization with milk yield traits and cow performance in two contrasting dairy systems in New Zeala	
In which Chapter is the Manuscript /Published work:	Chapter 3
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90%
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
I have written the full paper and undertaken the entire analysis of the information, interpreted the results generated and conducted the discussion of the paper. The co-authors gave me advice and comments referring writing style and content.	
For manuscripts intended for publication please indicate target journal:	
New Zealand Journal of Animal Science and Production	
Candidate’s Signature:	Martin Digitally signed by Martin Date: 2019.08.09 10:00:31 +12'00'
Date:	9 August, 2019
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We, the candidate and the candidate’s Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate’s contribution as indicated below in the *Statement of Originality*.

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Correa-Luna M, Donaghy DJ, Kemp PD, Schutz MM, López-Villalobos N 2019. Effect of genetic merit for milk urea on milk production and efficiency of crude protein utilization of grazing cows with contrasting supplement inclusion. New Zealand Journal	
In which Chapter is the Manuscript /Published work:	Chapter 5
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90%
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
I have written the full paper and undertaken the entire analysis of the information, interpreted the results generated and conducted the discussion of the paper. The co-authors gave me advice and comments referring writing style and content.	
For manuscripts intended for publication please indicate target journal:	
New Zealand Journal of Animal Science and Production	
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