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Productivity and quality of a perennial ryegrass pasture treated with controlled release

A Dissertation
submitted in partial fulfilment of the requirements for the Degree of Bachelor of Agricultural Science with Honours

at
Lincoln University

by
Alvand Azimi

Lincoln University
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Abstract of a dissertation submitted in partial fulfilment of the requirements for the Degree of Agricultural Science with Honours.

Productivity and quality of a perennial ryegrass pasture treated with controlled release

by

Alvand Azimi

The objective of this study were to assess the productivity and quality of a perennial ryegrass pasture treated with controlled release urea. Maintaining pasture production with conventional urea fertilizer results in high leaching losses to the environment. Alternatives such as controlled release urea have the potential to maintain production and lessen environmental impact. Therefore, two experiments were conducted using perennial ryegrass (*Lolium perenne*) treated with conventional urea (U) against polymer coated urea (CR).

Experiment 1 was conducted as a field trial on a perennial ryegrass pasture, with six harvests from plots treated with split applications of 150kg N/ha⁻¹ yr⁻¹ of (CR150), 150kg N/ha⁻¹ yr⁻¹ (U150) or 200kg N/ha⁻¹ yr⁻¹ of (U200) and 0kg N/ha⁻¹ yr⁻¹ as the control. Experiment 2 was conducted at the glasshouse using pasture trays of perennial ryegrass with a single application at rates of 0 (control), 50, 100, 150, 200, 300 or 400kg N/ha of CR and U, pasture trays were grown outdoors for 6 weeks and were then moved to the glasshouse. Under field conditions, U200 produced the highest DM, CR150, and U150 were intermediated and statistically similar for 4 harvests (Nov, Jan, Mar and Apr), the control always produced the lowest. The water % of perennial ryegrass grown in the field was variable for all harvests. Crude protein (CP) concentrations were similar for U150 and CR150 for 4 harvests (Mar, April, May and July). Neutral detergent fibre (NDF), and dry matter digestibility (DMD) had no consistent effect with N treatments, and metabolisable energy (ME) was not significant throughout all harvests. Experiment 2 outdoors indicated that CR rates were unable to match growth that of U, while growth in the glasshouse resulted in an overlap of the 2 fertilizer types.

It is likely that moisture and temperature conditions limit use of CR fertilizer. The beginning lag-phase of CR was successfully countered by with a 50/50 application of conventional (U) and coated urea (CR). Perennial ryegrass treated with CR required favourable conditions to match productivity and quality of conventional urea, this was indicated by DM production and CP concentrations. Therefore
if CR fertilizer is used as an alternative to conventional urea, lag phase, and climate should be taken into account by the management of the system.

**Keywords:** Fertilizer, Smartfert ™, slow release, nitrogen, leaching, nitrification, denitrification, volatilisation, mineral N, growth, yield and nutritive value
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Agricultural production in New Zealand currently uses 13.9 M ha of land, and more than 50% predominately relies on pasture production (Beef & Lamb NZ, 2017; Quinn et al., 2009). Pasture-based systems rely on pasture production to maintain profitability, through the conversion of pasture biomass to meat or dairy products (Gallacher, 2013; Quinn et al., 2009). Perennial ryegrass (Lolium perenne) is included in New Zealand’s highest producing pastures, mainly due to its ability to have a high yield potential, good forage quality, ease of management, rapid recovery from grazing and adaptation to high fertility soils (Easton et al., 2001; Skerman & Riveros, 1990). A productive perennial ryegrass pasture is nitrogen (N) limited, thus increasing N fertilizer application generally increases dry matter (DM) production (Harris et al., 1996; Monaghan et al., 2005; Andrews et al., 2007). It has been shown that fertilizer N applications can increase ryegrass production by >50% annually (Andrews et al., 2007; Harris et al., 1996; Ball & Field, 1989; Monaghan et al., 2005). Hence, New Zealand’s systems rely on the underlying pattern of pasture growth, with strategic N applications to combat seasonal pasture deficits, thus allowing systems to finish stock and maintain dairy production all year round (White & Hodgson, 1999; Moir et al., 2007). Increasing N availability through fertilizer applications may also increase perennial ryegrass quality (VanVuuren et al., 1991; Jacobs et al., 1999; Fertilizer NZ, 2014; White & Hodgson, 1999). Quality of a perennial ryegrass pasture can be established by measurements of water content (%), metabolisable energy (ME), digestibility (DMD), crude protein (CP) and neutral detergent fibre (NDF). Dairy systems are heavily reliant on optimum pasture growth and quality to maintain profitability by milk production (Gallacher, 2013; DairyNZ, 2015; Quinn et al., 2009). This is commonly achieved through high N inputs of urea fertilizer.

Conventional urea fertilizer is cheap to apply and readily plant available, therefore giving a good production benefit to achieve optimum pasture growth at an economical cost (Fertilizer NZ, 2014; Andrews et al., 2007; Di & Cameron, 2002; Harris et al., 1996; Monaghan et al., 2005; White & Hodgson, 1999). Urea has shown to have low product off-take (Cameron et al., 2013; Andrews et al., 2007; Di & Cameron, 2002). This is mostly due to excessive application rates exceeding ryegrass uptake capability, therefore leaving the remaining N liable to transportation out of the production system through nitrate leaching (Fertilizer NZ, 2014; Cameron et al., 2013). Leaching of fertilizer N as NO₃⁻ reduces the availability of applied N to pasture plants. Therefore decreasing the N use efficiency of the fertilizer application, also threatening the wider environment and to human health through waterway contamination (MfE, 2007; Cameron et al., 2013; Andrews et al., 2007; Quinn et al., 2009;
MAF, 2008; Di & Cameron, 2002). High N concentrations in aquatic environments causes eutrophication of water bodies, triggering a decrease in biodiversity and a loss in ecosystem services (Andrews et al., 2007; Cameron et al., 2013; Quinn et al., 2009; Di & Cameron, 2002; MfE, 2007). Furthermore, high N concentrations in drinking water are deemed to be detrimental to human health (MfE, 2007; Fertilizer NZ, 2014; Cameron et al., 2013; Quinn et al., 2009; Andrews et al., 2007).

Nitrogen leakage from farm systems can vary according to soil type, amount of N applied and stocking class (MfE, 2007; Cameron et al., 2013; MAF, 2008).

Fertilizer NZ, (2014) recommends that N fertilizer applications for a grazed pasture should not exceed 150 to 200 kg N/ha\(^{-1}\) yr\(^{-1}\) (Cameron et al., 2005). By following the recommended guidelines, risks of N leaching and associated environmental problems can be reduced (Fertilizer NZ, 2014; MfE, 2007; Andrews et al., 2007). Further methods in New Zealand to reduce the amount of N leaching from fertilizer applications include the use of synthetic nitrification inhibitors (DCD) or coated urea fertilizer pellets (Cameron et al., 2013; Moir et al., 2007; Bishop et al., 2008; LeMonte et al., 2016).

Dicyandiamide (DCD) extends the residence time of N fertilizers in the soil as ammonium (NH\(_4^+\)), which is less prone to leaching loss, therefore allowing a longer time for plant N uptake. This increased residence time of fertilizer N in the soil can increase DM production by 21% (Moir et al., 2007; Cameron et al., 2013). But its appearance in dairy milk caused the withdrawal of DCD based products.

Coated urea granules reduce the amount of N available to be lost by delaying the amount of N released by urea granules (Edmeades, 2015; Li et al., 2012, Seward, 1984). Bishop et al., (2008) showed polyurethane coated urea has the potential to reduce nitrate leaching losses between 1 and 6.8 kg N/ha compared to conventional urea. Similarly, LeMonte et al., (2016) showed reductions in atmospheric losses for polymer-coated urea, 127–476% for N\(_2\)O and 121–368% for NH\(_3\). However, delayed N release by controlled release (CR) fertilizer can also cause reductions in pasture production by stalling fertilizer N release. Findings from Bishop et al., (2008) showed, the release rate of polyurethane coated urea lagged during dry surface conditions, causing less DM production, compared to conventional urea. Thus, the effectiveness of CR fertilizer applications can be limited by moisture conditions, giving low water permeability, causing variation in the time and rate of N release (Li et al., 2012; Seward, 1980; Bishop et al., 2008). Other limitations have been described by Seward (1980) as being, coating thickness, climate conditions, pH level and distribution of granules.

Controlled release urea fertilizer has the potential to be used as a viable option to maintain pasture productivity while lessening the environmental impact associated with N application (Edmeades, 2015; Bishop et al., 2008). Little research has been conducted in New Zealand which assesses
maintenance of perennial ryegrass with CR urea fertilizer. Therefore further understanding is required to identify factors that may lead to the use of CR urea fertilizer as an alternative to conventional N fertilizer types.

1.1 Objective of study

The objectives of the study were to assess the productivity and quality of a perennial ryegrass pasture treated with controlled release urea (CR). Two experiments were conducted on perennial ryegrass treated with two N fertilizer products, aldehyde-coated urea (CR) and conventional urea (U), applications carried out at variable rates. 1) Field trial with applications at rates of 0, CR150, U150 and U200 kg N/ha$^{-1}$ yr$^{-1}$. 2) Pasture tray trial having a single application of 0, 50, 150, 200, 300 and 400 kg N/ha, for both fertilizer types.
Chapter 2

Literature Review

2.1 Introduction to New Zealand production

2.1.1 Grasslands

Prior to the arrival of the European settlement, 85% of the total land area of New Zealand was covered in forest (Quinn et al., 2009). Having both a reliable average rainfall (between 600 and 1600 mm) and a stable temperate climate (average temperature around 13°C), conditions were ideal for pastoral agriculture (NIWA, 2001; Quinn et al., 2009). Post-European settlement grasslands were created by removing the existing forest vegetation and sowing grass, allowing livestock to graze outside all year-round (Cameron et al., 2013; White & Hodgson, 1999). The change in land use allowed NZ farmers to create productive pasture systems that could be utilized with mowing or cutting for hay and/or silage (White & Hodgson, 1999; Skerman & Riveros, 1990).

2.1.2 Expansion

In 2015, the total area used for agriculture had expanded to 13.9 M ha (Beef & Lamb NZ, 2017). Of this land area, 56% is being used for pastoral agriculture. The primary driver of this land use expansion has been buoyant international commodity prices for agricultural products (Gallacher, 2013; Quinn et al., 2009). Dairy farming was traditionally practiced in areas where annual rainfall is 1000-1500 mm/yr (Quinn et al., 2009). With the recent intensification, irrigation has allowed dairy systems to expand to areas with <600 mm/yr and attain >4000 mm/yr. From 1994 to 2015, the number of dairy cattle increased 68.9%, from 3.84 to 6.49 million (Statistics New Zealand, 2017). Currently, New Zealand stock numbers for dairy cattle, sheep and beef farmed around 6.5, 29.1 and 3.5 million, respectively. The land area predominantly used for sheep and beef production has gradually decreased from 2.2 M ha since 2007, as lowlands are being converted to dairy, pushing sheep and beef systems to steeper/less productive land (Quinn et al., 2009). In 2012, sheep and beef farming became the most extensive commercial agricultural activity, covering 10.8 M ha of land (Statistics New Zealand, 2015). From 2002 to 2012 the land area used for deer, sheep and beef farming decreased by 28.9% (642,715ha), and 10.8% (1,306,774ha), respectively, over the same period the land area used for dairy increased by 28.2% (877,124ha). Consequently, a majority of the expansion and intensification of dairying is done at the expense of land used by other farm systems (MPI, 2008). The shift towards higher profiting systems is justified by the relative economics of land use (Gallacher, 2013). Increasing profit of pastoral agriculture has large implications for water quality, as stocking rates on dairy farms are significantly higher than sheep and beef systems (Cameron et al.,
An unavoidable consequence of increased stocking rates, is the increase in nutrient leakage from farm systems (Cameron et al., 2013; Quinn et al., 2009; Andrews et al., 2007; Moir et al., 2007; Di & Cameron, 2002; White & Hodgson, 1999; MfE, 2007).

### 2.2 Pasture production and nitrogen

#### 2.2.1 Pasture production

New Zealand livestock production systems are primarily based on ruminants grazing grass species year-round, with pasture providing 85–100% of the total livestock diet (Cameron et al., 2013; White & Hodgson, 1999; DairyNZ, 2015). The dominant pasture species grazed is perennial ryegrass (*Lolium perenne* L.) mainly due to its ease of management, rapid recovery from grazing, adaptation to high soil fertility and good forage quality (Easton et al., 2001; Skerman & Riveros, 1990). Ryegrasses are included in the highest producing pastures, and is the major dietary component of livestock grazing systems (Easton et al., 2001). Growth of a ryegrass pasture is generally nitrogen (N) limited. Nitrogen deficient pastures exhibit signs of yellowing and lightening, while having a restricted growth rate (White & Hodgson, 1999; Monaghan et al., 2005).

#### 2.2.2 Pastoral nitrogen

Since pasture-based systems rely on pasture growth for profitability, limited pasture output will cause the system to produce less saleable products. Farmers generally respond to seasonal pasture deficits by increasing farm input in the form of supplements and N fertilizer (White & Hodgson, 1999; Wilman & Fisher, 1996). Therefore, these pasture-based systems are reliant on manipulating the underlying pattern of pasture growth with strategic N applications to combat low seasonal DM outputs (White & Hodgson, 1999; Moir et al., 2007). Perennial ryegrass pastures typically respond well to increasing N fertilizer inputs (Table 1), especially if the soil is N deficient (Monaghan et al., 2005; Moir et al., 2007; Cameron et al., 2013). Studies by Andrews et al., (2007); Harris et al., (1996); Ball & Field, (1989); Monaghan et al., (2005) indicated that high nutrients inputs, especially N, stimulate annual ryegrass pasture production by up to 50% (Figure 1). Field trials conducted by Ball & Field, (1989) showed that total ryegrass pasture yield increased from 9 t DM/ha⁻¹ yr⁻¹ to 14.7 t DM ha⁻¹ yr⁻¹ with (450 kg N/ha⁻¹ yr⁻¹). This is primarily due to N increasing number of tillers. A field trial conducted by Wilman & Fisher, (1996) suggests that applications of N to ryegrass increase the number of tillers, extension rate and weight of new tillers. Additionally, available N allows for increases in ryegrass weight, tiller density and individual leaf blade size, which ultimately allows for more shoot DM (Harris et al., 1996; Wilman et al., 1977). The relationship between N application and DM yield, was shown to be linear (Jacobs et al., 1999).
Figure 2.1. Monthly production of a perennial ryegrass pasture (kg DM ha\(^{-1}\)) in Hamilton from (June 1993 to June 1995) receiving fertilizer at rates of, (0 kg N/ha\(^{-1}\) yr\(^{-1}\) ●), (200 kg N/ha\(^{-1}\) yr\(^{-1}\) ▲) and (400 kg N/ha\(^{-1}\) yr\(^{-1}\) ■). Adapted from Harris et al. (1996).

Table 2.1. Annual pasture production, DM response to applied N and yield increases for perennial ryegrass and white clover from four N fertilizer rates (0, 100, 200, and 400 kg N/ha\(^{-1}\) yr\(^{-1}\)). Adapted from Monaghan et al. (2005).

<table>
<thead>
<tr>
<th>N fertilizer rate (kg N/ha)</th>
<th>Grass (kg/ha)</th>
<th>Clover (kg/ha)</th>
<th>Total (kg/ha)</th>
<th>Pasture response to N (kg DM per kg N applied)</th>
<th>Annual yield increase (%)</th>
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<td></td>
<td></td>
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<td>Spring/early summer</td>
<td>Late summer/autumn</td>
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<tr>
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<td>102</td>
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</tr>
</tbody>
</table>

2.2.3 Pasture quality

The DM (%) component of yield (the ratio of dry leaf mass to fresh mass) reflects a fundamental tradeoff in plants functioning between active and mature growth; divided into cell wall (fibre) and cell contents (sugars, protein and lipids) (Andrews et al., 2001; Drew, 1967; Skerman & Riveros, 1990). Available soil N and water accessible for uptake are the largest influence on growth partitioning (Andrews et al., 2001; White & Hodgson, 1999; Drew, 1967). Furthermore, N uptake from N fertilizer application may enhance the nutritive quality of ryegrass (Skerman & Riveros, 1990; VanVuuren et al., 1991; White & Hodgson, 1999). The quality of grazed pasture can be described by the digestibility value, protein, gross energy and fibre content (White & Hodgson, 1999; Litherland et al., 2002; DairyNZ, 2008).
The digestibility describes the proportion of the forage that can be potentially digested by ruminants (Litherland et al., 2002; VanVuuren et al., 1991; Drew, 1967). The digestible component of forage comprises of a combination of crude protein, carbohydrates, and lipids (Litherland et al., 2002; Skerman & Riveros, 1990). Digestibility is highest during vegetative growth and declines as the plants matures (lignifies) (VanVuuren et al., 1991; Skerman & Riveros, 1990). Maturation leads to a reduction in leaf to stem ratio (Litherland et al., 2002). Therefore, shorter day rotations will result in higher DM digestibility percentage (DMD) (VanVuuren et al., 1991). Additionally, growth at higher temperatures can cause lower digestibility through increases in fibre content (DairyNZ, n2008; Litherland et al., 2002; Fales, 1986).

Nitrogen applications to grasses can increase the level of crude protein (CP), but no consistent effect to DMD (VanVuuren et al., 1991; Tamminga, 1986). Low digestibility is associated with low CP percentages (Litherland et al., 2002). Like DMD, protein levels are linked to grass growth stage and are affected by soil nutrition (VanVuuren et al., 1991; Skerman & Riveros, 1990; Litherland et al., 2002). VanVuuren et al., (1991) explains decreases in CP are due to maturity, creating an increased resistance within plant cell walls, causing a slower release of cell contents.

The metabolisable energy (ME) of grasses is usually associated with differences in the proportion of protein and often declines according to the accumulation of dead plant matter (Litherland et al., 2002). Dead matter accumulates when senescence rate rises at high temperatures. Wheeler, (2016) suggests that ME content and pasture N concentrations correspond.

Neutral detergent fiber (NDF) measures common structural components in plant cells (i.e. lignin, hemicellulose and cellulose) (Litherland et al., 2002; VanVuuren et al., 1991; Skerman & Riveros, 1990). As pastures mature, they accumulate more NDF, which decreases the nutritive quality and therefore, reproductive phases of grasses cause a decline in NDF digestibility. VanVuuren et al., (1991) showed that NDF for perennial ryegrass was lower from week 1 and 3 after harvesting, thereafter NDF increased, indicating an increase in the cell wall content. Like CP and DMD, amount of maturity at harvest has the greatest influence on NDF (Wilman & Fisher, 1996; VanVuuren et al., 1991).

2.3 Nitrogen related environmental problems

2.3.1 Nitrogen cycle

Applied N undergoes a pathway of transformation from fertilizer and organic forms to aqueous (nitrate and ammonia) and gaseous (ammonium and nitrous oxide) states (Andrews et al., 2007;
Nitrogen applications from fertilizer, urine, and dung are transformed via nitrification, denitrification, and volatilization (Figure 2.2). Nitrogen fertilizer inputs to soil are generally in mineral form, contain high amounts of ammonium (Cameron et al., 2013). Urease is an enzyme that hydrolyzes applied N (dung, urine, and fertilizer) to ammonium carbonate (\(\text{NH}_4\text{CO}_3\)), which dissociates quickly to ammonium (\(\text{NH}_4^+\)). Mineral forms of N are rapidly transformed in nitrification to form nitrate (NO\(_3^\text{-}\)), an oxidation reaction carried out by nitrifying bacteria (Cameron et al., 2013). Nitrate (NO\(_3^\text{-}\)) is readily leached, due to its net negative charge repelling against negatively charged soil colloids.

![Figure 2.2. The soil/plant nitrogen cycle. Adapted from (Cameron et al., 2013).](image)

### 2.3.2 Intensification

Livestock production systems have a strong focus on maximising the output of animal products per unit of land area, in order to maximise profit (Andrews et al., 2007). This is achieved through increasing the productivity potential of land, by renewing low productivity pastures with higher producing pasture species (ryegrasses) and increasing fertilizer inputs to economic optimum levels (Andrews et al., 2007; White & Hodgson, 1999; Quinn et al., 2009; Di & Cameron, 2002). For the past 30 years, the drive for improved productivity has increased by intensification of ryegrass based systems through higher inputs of N fertilizer and/or imported feed (de Klein et al., 2010; White & Hodgson, 1999). Fertilizer N inputs at levels of economic optimum give low N use efficiency (Cameron et al., 2013; Andrews et al., 2007). Di & Cameron (2002) explains that the N intake for dairy production exceeds N off-take in dairy products. At optimum pasture growth rates, ruminant intake
of pasture N and DM is high, with excess N being excreted in urine (Cameron et al., 2013; Di & Cameron, 2002). The total urine N excretion can account for between 60 and 90% of total N ingested by dairy cows (Cameron et al., 2013; Di & Cameron, 2002; deKlein et al., 2010). The N excreted by grazing livestock is returned to the pasture soil at N rates between 500 and 1200 kg N/ha (for cattle) or 300 and 500 kg N ha⁻¹ (for sheep) which far surpass pastures uptake capability (Cameron et al., 2013; Di & Cameron, 2002; Moir et al., 2007).

### 2.3.3 Nitrate leaching

If concentrations exceed pastures uptake capacity, N is susceptible to leaching as nitrate (NO₃⁻) during high drainage periods (Cameron et al., 2013). Livestock class contributes to variable amounts of leaching losses, with sheep and beef, deer and dairy leaching an average 8, 12, and 30 kg N/ha⁻¹ yr⁻¹, respectively (MAF, 2008). Furthermore leaching losses can be higher on stony shallow soils, their low capacity to retain water and nutrients makes them particularly susceptible to nitrate leaching (Andrews et al., 2007; Cameron et al., 2013; Di & Cameron, 2002). Nitrate leaching losses represent not only a loss in soil fertility, but also a threat to the wider environment and to human health, because high concentrations of nitrate in drinking water are deemed to be detrimental to human health (MfE, 2007; Cameron et al., 2013; Quinn et al., 2009; Andrews et al., 2007; Monaghan et al., 2005). Nitrate leaching into waterways also causes eutrophication, triggering a decrease in biodiversity (Andrews et al., 2007; Quinn et al., 2009; Di & Cameron, 2002). Nitrogen as a pollutant poses a threat to valued aquatic resources, such as lakes, rivers and streams carrying cultural and spiritual significance for Maori (Quinn et al., 2009). This also threatens valuable water resources used for recreation by the public (Quinn et al., 2009; Andrews et al., 2007; Di & Cameron, 2002). Nutrient leakage from farm systems is the dominant influence on contamination of water quality in NZ (Quinn et al., 2009; MfE, 2007; Cameron et al., 2013). This is due to agriculture’s presence in 43% of streams and river catchments and 40% of lake catchments (MfE, 2007). The expectation that contamination is a consequence of intensified agriculture; has increased concerns on the long-term sustainability of water resources in NZ, for both indigenous Maori and the general public (Quinn et al., 2009; Di & Cameron, 2002). For this reason, Maori and government are working alongside local agencies in order to establish a long-lasting dynamic equilibrium between agricultural and environmental systems (MfE, 2007; Quinn et al., 2009; Di & Cameron, 2002).

### 2.4 Alternatives

#### 2.4.1 Fertilizer practice

The amount of N lost to leaching is dependent on the livestock class, amount of drainage occurring over a given period, the concentration of N present at the time of N application, and the rate of
nitrification and denitrification in soil (Figure 2.2). The average recovery of N fertilizers in grazed pastures is 25–30% lower compared to cropping systems, due to livestock dung and urine transfers (Cameron et al., 2013; Di & Cameron, 2002). Applications of N fertilizer between 30 and 60 kg N/ha$^{-1}$ yr$^{-1}$ can increase nitrate leaching losses (Cameron et al., 2013). Monaghan et al., (2005) showed that in cattle grazed pasture systems leaching losses increased with increasing rates of N fertilizer. An average 30, 34, 46 and 56 kg N/ha$^{-1}$ yr$^{-1}$ was lost to leaching when rates of 0, 100, 200 and 400 kg N/ha$^{-1}$ yr$^{-1}$ were applied, respectively. Therefore, reducing fertilizer application rates will result in a larger DM response to per kg N/ha, shown in (Table 2.1). Fertilizer NZ, (2014) recommends that applications of N fertilizer should not exceed 150 to 200 kg N/ha$^{-1}$ yr$^{-1}$, if more N is required applications should be split to <50kg N/ha (Bishop et al., 2008). Split applications that match plant demand reduce leaching losses (Cameron et al., 2013; Andrews et al., 2007). Ideally efficacy of application is greatest when soil temperature is above 4°C in spring and above 7°C in autumn (not too early in spring or too late in autumn) (Fertilizer NZ, (2014). Nitrate leaching losses are generally greatest in late-autumn, winter to early-spring months (Cameron et al., 2013). This is mostly due to, growth being restricted by low temperatures and high drainage occurring, as a result of rainfall input exceeding potential evapotranspiration (Monaghan et al., 2005; Cameron et al., 2013; Moir et al., 2007). Therefore N fertilizer applied in late-autumn to early-winter is likely to be less efficient compared to spring applications as plant N uptake is limited which may cause remaining N being leached (Monaghan et al., 2005; Cameron et al., 2013; Bishop et al., 2008).

2.4.2 Legumes

Additional N inputs have been seen in NZ pastoral systems choosing to utilize N fixing legumes (Andrews & Lea, 2013; Andrews et al., 2007). Utilization can occur as seed crop, a green manure or as the main N input for a pasture grown in association with grass. Andrews et al., (2007) showed, white clover can produce around 20% of the total DM produced in binary pastures with ryegrass. Moreover, pasture and dairy production is likely to be similar to that of ryegrass monoculture receiving 200kg N/ha or 70% of a monoculture receiving 350–400 kg N/ha$^{-1}$ yr$^{-1}$. Therefore, binary systems including both ryegrass and white clover species can have an increased N efficiency, replacing some of the system’s reliance on N fertilizers (Andrews et al., 2007; Monaghan et al., 2005). However, DM responses for clover yields are consistently reduced with increasing N fertilizer inputs (Table 2.1). Monaghan et al., (2005) showed that average clover yield over 4 years was reduced by 20, 35, and 48% at N rates of 100 kg N/ha$^{-1}$ yr$^{-1}$, 200 kg N/ha$^{-1}$ yr$^{-1}$, and 400 kg N/ha$^{-1}$ yr$^{-1}$, respectively, compared with no fertilizer N application. Upon of high application rates of N, clover growth and fixation activity may be suppressed (Andrews et al., 2007; Monaghan et al., 2005). Harris et al.,(1996) explained that prolonged use of high N rates may also limit clover recovery once N rates are reduced. Furthermore, N stimulated ryegrass growth may cause direct competition between
clover species, resulting in reduced clover content. Andrews et al., (2007) reports white clover stabilisation can occur at around 20% of pasture DM production, with N inputs by fixation likely to be around 100 kg N/ha\(^{-1}\) yr\(^{-1}\). Increased leaf size in white clover cultivars will result in a competitive advantage against ryegrass, allowing for more clover yield and ultimately increasing N input by fixation (Andrews et al., 2007).

**2.4.3 Dicyandiamide: a nitrification inhibitor**

The nitrification inhibitor dicyandiamide (DCD) interferes with the first stage of nitrification and thus reduces the rate that NH\(_4^+\) is converted into NO\(_3^-\) (Figure 2.2) (Cameron et al., 2013; Moir et al., 2007). Soil N is much less susceptible to leaching loss as NH\(_4^+\) rather than NO\(_3^-\) because the positive charge on NH\(_4^+\) is held on more tightly to the negatively charged soil colloid surfaces (Moir, Cameron & Di, 2007). N fertilizers are predominantly applied in the forms of ammonium or urea (Cameron et al., 2013). Upon application, these N forms are rapidly converted to nitrate by nitrifying bacteria. The concomitant effect of the nitrification inhibitor causes larger quantities of N to be retained soils, giving plants a longer opportunity to increase growth. Field trials by Moir et al., (2007) showed a significant pasture DM increases with DCD treatments, with the pasture DM yields averaging 10.3, 12.4, 12.4 and 16.0 t DM/ha\(^{-1}\) yr\(^{-1}\) for the inter-urine, inter-urine + DCD, urine and urine + DCD treatments, respectively (Figure 2.3a). The mean DCD treatment effect over the trial period increased annual DM production from 10.6 to 12.8 t DM ha\(^{-1}\) year\(^{-1}\), or 21% (Figure 2.3b). Reducing the nitrification rate of applied fertilizer N will give pastures a further opportunity to take up N as NH\(_4^+\), therefore increasing N use efficiency, crop productivity, and safeguarding the environment.
2.4.4 Controlled release fertilizer

Environmental problems will lessen if fertilizer products were designed to be released to match plant demand. All conventional N fertilizers are water soluble, therefore N contained is readily converted to NO$_3^-$ (Figure 2), which is readily leached when large amounts of water pass through the soil profile (Li et al., 2012, Seward, 1984). The idea of creating a coated layer around granules to form a barrier to reduce water penetration into urea granules has been explored by Edmeades, (2015); Bishop et al., (2008); Li et al., (2012); and Seward, (1984). Controlled release (CR) fertilizers are designed to allow the release of active nutrients such as N, in a controlled, delayed manner in synchrony with plant demand. Three categories of modified N fertilizers have been described by Edmeades (2015): chemical (e.g. urea-aldehyde polymers), material (e.g. sulphur coated urea) and bio-active chemicals (e.g. urease and nitrification inhibitors). Chemical modifications reduce the water solubility of N in fertilizers, material modifications slow movement of N from the granule into soil solution, and bio-active chemicals (DCD) are added to reduce the transformation rate of N constituents in soil. Proof-of-concept was established for urea coated with an aldehyde polymer (Edmeades, 2015) and polyurethane (Bishop et al., 2008). Edmeades, (2015) showed polymer coated urea increased NUE by between 5–50% depending on the site and rate of N application. Field trials by Bishop et al., (2008) showed polyurethane coated urea offers the potential to increase the conversion of N to DM from between 12–15 kg DM/kg N and reduce the proportion N leached from high drainage. The level of polymer coating in Edmeades, (2015) demonstrated that CR products will have less cumulative N release over a given leaching period. Bishop et al., (2008) showed that polymer and DCD coatings on urea reduced nitrate leaching losses between 1 and 6.8 kg N/ha compared to conventional urea.
LeMonte et al., (2016) showed perennial ryegrass can be maintained by utilizing CR, while also reducing the gaseous loss of N as nitrous oxide (N2O) and ammonia (NH3). Urea resulted in 127–476% more N2O and 121–368% more NH3, compared to polymer coated urea or the control, respectively. Therefore suggesting that the CR fertilizers have the potential to increase NUE, implying that losses of N via nitrification and denitrification are less than that from conventional urea (Bishop et al., 2008; LeMonte et al., 2016; Edmeades, 2015; Seward, 1984).

The DM production of aldehyde polymer and polyurethane coated urea was shown to be similar (Figure 5), compared to conventional urea (Bishop et al., 2008; Edmeades 2015). Bishop et al., (2008) explained that the release rate of the CR fertilizer tested appeared to have stalled in November due to dry surface conditions, giving lower than expected N uptake and DM yield. This is largely due to the permeability of water being a factor that governs release rate, time and pattern (Li et al., 2012), moreover conditions where moisture is limited, there will be a limited amount of N release. Further limitations to CR have been discussed by Seward (1980) as dissolution being variable according to level of coating (thickness), the temperature conditions (<5°C), moisture deficits (<10%), pH levels insufficient for coating breakdown (according to coating type) and applications below soil surface causing low coating exposure to weather (temperature and moisture). Li et al., (2012), showed polyurethane coating takes 40-50 days for nutrients to release. Moreover, using CR urea with a thick coatings may not give enough exposure for complete coating degradation before urea release ends. This will cause reduced soil quality, with remaining coating being liable to causing contamination to the environment, depending on type of coating (Li et al., 2012).
3.1 Experiment 1: Field trial

3.1.1 Site and preparation

Experiment 1 was conducted in Iverson fields (paddock I9), located near the field service centre (FSC) on South drive at Lincoln University, Canterbury, New Zealand (43°38'50.8"S; 172°28'03.2"E). The site has an annual rainfall of 599mm (30-year average) and was supplemented with irrigation until March (NIWA, 2017). Climatic data is shown in (Figure 3.1). The soil type was a Wakanui silt loam (Immature Pallic soil) which is poorly drained in winter due to a rising water table. Soil test data is shown in (Table 3.1). Prior to trial, (22/07/2016) all weeds and clover were sprayed once with (T-Max) herbicide. On 26/08/2014, the trial site was drilled with perennial ryegrass (Arrow) and white clover (Tribute) at rates of 20 kg/ha and 4 kg/ha, respectively. For the duration of the trial persisting clover and weeds were inspected monthly and removed by hand.

![Figure 3.1. Climatic data for Nov 2016 – July 2017. The monthly total rainfall (mm) and average minimum, maximum and mean air temp (°C) was calculated from daily data retrieved from (NIWA Weather Station, Lincoln Broadfield Ews 17603).](image-url)
Table 3.1 Soil test data taken (23/12/17) from a sampling depth of 75mm. Data shows pH, Olsen phosphorus (Olsen P), Potassium (K), Cation exchange capacity (CEC), Total base saturation (BS), Potentially available nitrogen (Pote Av N), Anaerobically mineralisable nitrogen (AN MinN), Ammonium (NH4+), Nitrate (NO3) and Mineral N (sum).

<table>
<thead>
<tr>
<th>pH</th>
<th>Olsen P (mgL)</th>
<th>K (%)</th>
<th>CEC (kg/ha)</th>
<th>Total BS (ug/g)</th>
<th>Pote Av N (mg/kg)</th>
<th>AN MinN (mg/kg)</th>
<th>NH4 (mg/kg)</th>
<th>NO3 (mg/kg)</th>
<th>Min N (sum) (mg/kg)</th>
</tr>
</thead>
<tbody>
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<td>0.39</td>
<td>12</td>
<td>55</td>
<td>74</td>
<td>42</td>
<td>2</td>
<td>7</td>
<td>10</td>
</tr>
</tbody>
</table>

3.1.2 Design

The effective area used was 48 x 144 m, which was split into 2 complete randomised blocks using a statistical software (GenStat 16th edition). Each block was 24 x 72m, and the 2 blocks were split into 24 plots (2 x 6m). The total duration of this experiment was 33 weeks, during this time treatments were split and applied after each of the 6 harvests (Figure 3.2). The three treatments were: an experiment control (0 kg N/ha); a conventional soluble urea (U) (46-0-0-0) (Ravensdown, 2017); and a controlled release urea (CR), a polymer coated fertilizer product from Smartfert ™ (44-0-0-0) (Eko360, 2017). The CR treatment was applied at 150kg N/ha⁻¹ yr⁻¹ (CR150) and the U treatment was applied at 2 levels: 150 kg N ha⁻¹ yr⁻¹ (U150) and 200 kg N/ha⁻¹ yr⁻¹ (U200). All 4 treatments (including control) were replicated 6 times within the 2 blocks, giving a total sample size of 24 units.

![Graph showing harvest frequency from November 2016 to August 2017 for experiment 1 (field trial).]

3.1.3 Treatment application

On (28/10/2016) the trial site was mowed to a height of 70mm and the first N treatments were applied. The first application for CR150 treatment contained 50% urea (75kg N/ha⁻¹ yr⁻¹) and 50% Smartfert (75kg N/ha⁻¹ yr⁻¹), this was to remove the lag phase caused by the polymer coating. Over a period of 33 weeks N fertilizer treatments were broadcast by hand after each of the following dates: 28/10/16, 21/11/16, 12/01/17, 21/03/17, 10/04/17 and 12/05/17. Irrigation was supplied after treatments were applied.
3.1.4 Measurements

Harvest (Figure 3.2) 1, 2, 3, 4, 5 and 6 occurred on 21/11/16, 12/01/17, 21/03/17, 10/04/17, 12/05/17 and 11/07/17, respectively, were determined by optimum plant height and weather conditions, according field service specialist. Harvests were conducted with a mower by cutting a centre strip (80 x 600cm) of each plot at a height of 8cm, to give a bulk-weighted sample. A subsample of 200g was taken from the bulk, and was oven dried at 65°C for >72 hours to determine pasture water content (%). The weight (kg) and harvest dimension (80 x 600cm) of the bulk samples were used to convert fresh weights to a hectare equivalent (kg FW/ha) and water % was used to achieve dry matter (kg DM/ha). A proportion of the dried samples (experiment 1 only) were ground for quality measurements via near-infrared spectroscopy (NIRS) to measure dry matter digestibility (DMD), crude protein (CP), neutral detergent fibre (NDF), dry organic matter digestibility (DOMD) and metabolisable energy (ME), which was a function of DOMD.

3.2 Experiment 2: Pasture tray trial

3.2.1 Site and preparation

Experiment 2 was conducted at Lincoln University nursery on Farm road in the glasshouse facilities at Lincoln University from 18/05/17 to 21/09/17. Pasture trays were prepared using turfs of perennial ryegrass retrieved from the field trial site. Before starting the experiment, all trays were maintained outside for 6 weeks to allow for establishment. During this time, they were cut once to a 5.5cm height. The experiment ran for 12 weeks. In the first 6 weeks (18/05 – 29/06/17), the trays remained outdoors (winter). The monthly average air temperatures and monthly total rainfall experienced outdoors is shown in Figure 3.1 and trays were watered every 2 days if required, according to rainfall frequency. After 6 weeks (29/06 – 10/08/17) trays were moved inside the glasshouse (Aluminx). The mean daily temperature inside the glasshouse was 19.4°C and the watering frequency was (250 – 300ml) once every 2-3 days. On 06/07/17 all pasture trays were sprayed with herbicide (T-Max) for weed and clover regrowth.

3.2.2 Design

The perennial ryegrass was collected as a 10cm deep layer with topsoil and grass intact. The layer was cut and placed into 70 trays sized 29.5 x 42cm. The tray base contained <3cm of potting mix medium consisting of 4:1 bark:pumice. The potting mix was used to fill any gaps in the pasture trays. Potting mix contained a 0% N fertilizer mix (0-9-0-48), trace elements (Ca, Mg, S, B Cu, Fe, Mn, Mo and Zn) and a soil wetting agent (hydraflo). The same urea and CR fertilizer as the field experiment were used in this experiment. The urea fertilizer and CR fertilizer were applied at rates of 0, 50, 100,
150, 200, 300 and 400 kg N/ha equivalent. This resulted in 14 treatments which were replicated 5 times, giving a sample size of 70 units. Treatments were arranged in 5 complete randomised blocks, using a statistical software (GenStat 16 edition).

### 3.2.3 Treatment applications

Before applying treatments (15/05/2017) pasture trays were cut to a height of (5.5cm) with all clippings were removed via leaf blower. Application of N treatments were broadcast by hand once on 18/05/2017.

### 3.2.4 Measurements

Harvests were completed after each 6 week interval. All trays were cut to 5.5cm (clippers) and all non-ryegrass material was removed. Samples were weighed and oven dried at 65°C for >72 hours to determine water content (%). The sample weight (kg) and tray dimension (29.5 x 42cm) were used to convert fresh weights to a hectare equivalent (kg FW/ha) and water % was used to achieve dry matter (kg DM/ha).

### 3.3 Statistical analysis

All data was analysed for N treatment effects using a one way analysis of variance (ANOVA) in GenStat (16th edition). Significant differences in seasonal DM, total DM, water %, CP, ME, DMD and NDF were described in the results section. Regression of 3rd order polynomial was used to analyse experiment 2. All effects discussed have a probability (P= ≤0.05).
Chapter 4

Results

4.1 Experiment 1: Field trial

4.1.1 Perennial ryegrass growth

![Graph showing perennial ryegrass growth from November 2016 to July 2017. The left axis shows dry matter (kg DM ha\(^{-1}\)) and the right shows water content (%). The legend indicates treatments of urea (U) 200kg N/ha\(^{-1}\) yr\(^{-1}\) (×) and 150kg N/ha\(^{-1}\) yr\(^{-1}\) (■), control release fertilizer (CR) 150kg N/ha\(^{-1}\) yr\(^{-1}\) (▲) and experimental control 0kg N/ha (○).]

Figure 4.1. The growth of perennial ryegrass from November (2016) to July (2017). The left axis shows dry matter (kg DM ha\(^{-1}\)) and the right shows water content (%). The legend indicates treatments of urea (U) 200kg N/ha\(^{-1}\) yr\(^{-1}\) (×) and 150kg N/ha\(^{-1}\) yr\(^{-1}\) (■), control release fertilizer (CR) 150kg N/ha\(^{-1}\) yr\(^{-1}\) (▲) and experimental control 0kg N/ha (○).

In the field trial, dry matter (DM) production for perennial ryegrass increased with N treatment for all harvest dates, relative to the control (Figure 4.1.1). Dry matter production was always highest for U200, while CR150 and U150 were statistically similar for 4 harvests (Nov, Jan, Mar and Apr). Perennial ryegrass DM peaked in the first harvest (Nov), afterwards a decreasing trend was observed.

Water content (%) for perennial ryegrass under N treatments gave no consistent effect and was significant for only 3 harvests (Mar, Apr and May). In contrast to DM, water content increased with time, showing the highest water content in May, 2017.
4.1.2 Total DM production

![Bar chart showing total DM production for different N treatments.]

**Figure 4.2**. The total dry matter (kg DM ha\(^{-1}\)) produced between (21/11/16 – 11/07/17) by perennial ryegrass, under urea (U) application at rates of 200kg N/ha\(^{-1}\) yr\(^{-1}\) (U200) and 150kg N/ha\(^{-1}\) yr\(^{-1}\) (U150), controlled release at 150kg N/ha\(^{-1}\) yr\(^{-1}\) (CR150) and control 0kg N/ha\(^{-1}\) yr\(^{-1}\).

Figure 4.1.2 shows that all N treatments significantly increased the total DM production of perennial ryegrass, relative to the control. Treatments of U200 produced the highest DM, while production for CR150 and U150 were intermediate and statistically similar.
4.1.3 Perennial ryegrass quality

![Graphs showing seasonal quality indicators for perennial ryegrass]

**Figure 4.3.** Seasonal quality indicators for perennial ryegrass: (A) crude protein (CP), (B) metabolisable energy (ME), (C) dry matter digestibility (DMD) and (D) neutral detergent fibre (NDF) for treatments of urea (U) 200kg N/ha⁻¹ yr⁻¹ (X) and 150kg N/ha⁻¹ yr⁻¹ (■), control release fertilizer (CR) 150kg N/ha⁻¹ yr⁻¹ (▲) and experimental control 0kg N/ha (●).

Fertilizer N treatments caused no consistent effect on perennial ryegrass quality in relation to CP, ME, DMD and NDF (Figure 4.1.3). Overall, CP concentrations peaked in April (harvest 4). Mean CP concentrations were highest for U200 in April and May harvests, while U200, CR150 and U150 had statistically similar concentrations for all significant harvests (March, April, May and July). Both metabolisable energy (ME) and dry matter digestibility (DMD) followed a similar pattern, with no detectable difference between treatments, while NDF was inversely related to DMD and ME.
4.2 Experiment 2: Pasture tray trial

4.2.1 Perennial ryegrass growth

**Figure 4.4.** The growth of perennial ryegrass in outdoor (A) and glasshouse (B) conditions treated with increasing N fertilizer rate. (A) The left axis shows dry matter (DM) for urea (●) and controlled release (■) fertilizer. The right shows water content (%) for urea (○) and controlled release (□). Trend line (——) denotes DM for urea, (——) controlled release; and (-----) water content for urea and (-----) water content for controlled release.

Outdoor conditions (Figure 4.2.1A) showed dry matter (DM) production and water content (%) consistently increased for perennial ryegrass with increasing N fertilizer rate. The DM and water content seem to follow a similar trend for each of the treatment types (U and CR). The lowest rate of U treatment (U50) produced higher DM and water content in comparison to all rates of CR treatment.

Glasshouse conditions (Figure 4.2.1B) showed dry matter (DM) production increased for perennial ryegrass with increasing N fertilizer rates. At all N applied rates, CR produced similar DM as compared to their counterpart U. Furthermore, the change of water content within this interval was not statistically significant with respect to N rate and fertilizer type.
Chapter 5
Discussion

Maintaining pasture production while meeting environmental N boundaries is a fundamental trade-off between maximising production through excessive N applications and reducing the environmental impact. An experiment was carried out to assess the productivity and quality of a perennial ryegrass pasture treated with controlled release urea (CR). Two experiments were conducted on perennial ryegrass treated with two N fertilizer products, aldehyde-coated urea (CR) and conventional urea (U), applications carried out at variable rates. 1) Field trial with applications at rates of 0, CR150, U150 and U200 kg N/ha⁻¹ yr⁻¹. 2) Pasture tray trial having a single application of 0, 50, 150, 200, 300 and 400 kg N/ha, for both fertilizer types.

5.1.1 Seasonal DM production under N treatment

The perennial ryegrass DM production over time (Figure 4.1.1) revealed similarities for controlled release (CR150) and urea (U150) fertilizer treatments at 4 harvest points (Nov, Jan, Mar and Apr). Dry matter production for perennial ryegrass treated with N fertilizer was significantly higher at all harvest points than plots without fertilizer application. Differences in DM production between the CR150 and U150 treatments increased during the second half of the field trial. In the first harvest (November), it was expected that CR150 would produce less DM relative to urea treatments (U150 and U200), due to the fact that controlled release fertilizers are predicted to have a lag phase upon application (Bishop et al., 2008; Edmeades, 2015). However, this was not the case as an alternative application method used to counter lag in CR. Note that the DM production was similar for CR150 and U150 for a majority of the harvest dates. Similarly, Bishop et al. (2008) showed that polyurethane coated CR had no significant difference in DM production relative to conventional urea until dry conditions occurred limiting N release, causing less DM production relative to urea. The current trial was irrigated during seasonal rainfall deficits, therefore it is likely that moisture deficits did not limit DM production of perennial ryegrass. The similarities in DM production for CR150 and U150 only occurred until April, at this point temperature began to steadily decline (Figure 3.1). The decline in temperature may have affected the release rate of CR, hence DM production for CR150 and U150 treatments became statistically different for harvests 5 and 6 (May and July). Temperature-induced effects on N release of coated urea has been studied by Seward, (1980) who discussed that low N release efficacy for controlled release fertilizers occurring as a result of moisture deficits (<10%) and/or cold temperature conditions (<5°C). Since the rainfall provided adequate water, even so irrigation was not required after March, hence suggesting no moisture limitations likely occurred. The alternative can be suggested, cold temperature conditions (Figure 3.1), there was a consistent
decline in temperature occurring from March onwards and the coldest point (2.3°C) in July. Consequently, controlled release fertilizer may have been limited by cold temperature conditions, as the temperature declined from March onwards, to the coldest point (2.3°C) in July, and it was found that temperatures below 5°C can reduce CR fertilizer efficacy (Seward, 1980). Since fertilizer granules were broadcasted on the soil surface, it is likely that they suffered a wider range of cold conditions. Hence, cold temperatures may have apparently restricted N release for CR150 treatment which ultimately lead to significantly less DM for CR150 (from May to July) relative to U200 and U150.

5.1.2 Seasonal DM production trends

The perennial ryegrass DM production was greatest in November, January and March (harvests 1, 2 and 3). It is common for pasture production to be higher during spring and summer, compared to other seasons (Cameron et al., 2013; White & Hodgson, 1999). Harris et al. (1996) showed that DM production and DM (%) were highest in late-spring to early-summer. Their study also measured tiller numbers and found that the maximum tiller number per perennial ryegrass plant occurred at a similar time (December). Therefore it can be suggested that high DM production occurred as result of new tiller growth in late-spring conditions.

Similarly, between harvest 1 and 3 plant water content was around 10% lower relative to the remaining harvests. It was expected that water content would follow closely with DM production, but between harvest 1 and 3 water content was lower than expected. Low water content in summer is usually associated with a build-up in dead plant material, rising air temperatures and increasing moisture stress, even under irrigation (DairyNZ, 2008). Furthermore, VanVuuren et al. (1991) showed increased perennial ryegrass maturity occurring with increasing weekly intervals. It is likely that the larger harvest intervals and high average summer temperature accelerated growth to maturity causing increased lignification and decreased water content.

In April, there was a considerable drop in DM production despite having reasonable growing temperatures and high rainfall (Figure 3.1). High rainfall in autumn is known leach residual fertilizer left as nitrate after harvest and mineralise soil organic N, which initially creates N deficiencies (Cameron et al., 2013; White & Hodgson, 1999). It is likely that the high rainfall occurring after March led to nitrate leaching. Also, the consistent drop in air temperature likely negatively influenced perennial ryegrass growth, and therefore reduced plant N uptake. After fertilizer N was applied in April, a positive DM response was seen for all N treatments in May, interestingly the DM for the control treatment dropped to <80 kg DM/ha in July, while all N treatments produced >305 kg DM/ha. Thus it can be suggested that the increasing rainfall increased N leaching and the decline in temperature limited N uptake (Cameron et al., 2013).
5.1.3 Total DM production under field conditions

As indicated by the total DM production (Figure 4.1.2), perennial ryegrass treated with CR150 was statistically similar to that of U150. Increased rate of urea application (U200) significantly increased total perennial ryegrass DM production, hence indicating a potential for greater growth with increasing N supply. Similarly, the DM response of perennial ryegrass to CR150 gave similar results to Edmeades, (2015), where the same rate of N applied as urea or controlled release produced similar DM across three New Zealand trial sites. Notably, their experiment used a single application for a duration of 31 weeks as compared to the current trial in the field which applied fertilizer once every 1 to 2 month over a duration of 33 weeks.

5.1.4 Seasonal quality under N treatment

There was very little variation in crude protein (CP) content of perennial ryegrass caused by N treatment, except from April onwards, where CP content for N treatments were significantly greater than the control (Figure 4.1.3A). Van Vuuren et al., (1991) found that N fertilizer applications to grasses increase the concentration of CP. Therefore it is likely the growth of the control was N limited, indicated by its low CP concentration in comparison to all N treatments.

Figure 4.1.3 shows that N applications increased the concentration of CP, but no consistent effect was seen in ME, DMD and NDF. No significant change in ME content was observed according to N treatment. It was expected that N application would allow for more new growth and less accumulation of dead material, therefore having higher proportions of DMD and NDF (Litherland et al., 2002; DairyNZ, 2008). On the contrary, this was not the case in the current trial, N treatments applied to perennial ryegrass did not cause any consistent effect to digestibility (DMD) percentage and fibre content (NDF).

5.1.5 Seasonal quality trends

The CP content of perennial ryegrass (Figure 4.1.3A) rapidly increased from January (7–8%) to April (19–21%). According to DairyNZ, (2008) CP concentrations <16% will limit summer milk production. Hence, the CP concentration in January (<10 %DM) is likely to limit summer milk production. It is well established that higher growing temperatures cause grass growth to be more lignified, which will cause lower CP concentrations (Wilman et al., 1977; Fales, 1986). Also, Van Vuuren et al. (1991) showed a decrease in CP concentration could be seen due to increasing time between harvests, which was caused by increased plant maturity. Therefore, the low summer CP may be associated with an increase in plant maturity, and higher temperatures causing lignification (Van Vuuren et al., 1991; Wilman et al., 1977; Fales, 1986).
The peak temperature during January decreased towards April. Also between January to March (harvest 3) there was a harvest interval of 10 weeks, however between March to April (harvest 4) the harvest interval was 3 weeks. Therefore it is likely that peak in CP for April (harvest 4) was due to lower temperatures and a shorter growth period before harvest, causing less lignification relative to other harvests. Similarly, Litherland et al., (2002) showed New Zealand pastures CP concentration increased from January to May and peaked around July.

Figure 4.1.3B shows that ME reached its lowest point (10.5 MJ ME/kg DM) in March. Overall, the seasonal difference in ME was marginal, except for in July where the average ME for all treatments was 2.2 MJ ME/kg DM greater relative to March. Compared to a study by Litherland et al., (2002) the average seasonal ME content produced in this experiment is higher than the typical values found in most South Island sheep and beef pastures.

The digestible (DMD) component of perennial ryegrass had an average seasonal range of 70-81%. DairyNZ, (2014) describes high quality pastures (70-85% DMD) as being characteristic of green leafy pasture that is highly digestible and degrades relatively quickly in the rumen, which relates to high ME values. The results in Figure 4.1.3 (B and C), suggest ME and DMD have a similar seasonal trend, with both peaks occurring in July. This was expected as ME is calculated as a function of DM digestibility.

Figure 4.1.3D shows that NDF reached its highest point (58% DM) in March, overall the seasonal range was between 42 and 58% DM. Harvest 4 (March) can indicate relatively high levels of cellulose, hemicellulose, and lignin, as a result of high maturity occurring due to high temperature and a long growth period (Litherland et al., 2002; VanVuuren et al., 1991). Compared to a study by Litherland et al., (2002), the average seasonal NDF of perennial ryegrass produced in this experiment is higher than the typical values found in most South Island sheep and beef pastures. DairyNZ, (2014) describes high NDF concentrations being >45% which are more than required and may limit pasture intake by livestock while having low digestibility in the rumen.

5.2 Experiment 2: Lag phase

Figure 4.2.1A showed that after a 6 week growing period outdoors, CR fertilizer was unable to match growth relative to all U rates (including U50). This is largely due to urea being water soluble making it readily available upon dissolution, while CR has a coating which prevents water from penetrating the urea granules (Li et al., 2012; Seward, 1984; Edmeades, 2015). Li et al., (2012) showed that conventional urea rapidly dissolves when added to water, within 5-10 minutes 100% was dissolved. When urea coated with polyurethane was placed in water it took 10 days for 70-80% of urea contained in coating to be released. Similarly, Bishop et al. (2008) showed at 150 kg N/ha of urea
coated with 5% and 7% polyurethane released 90 and 72 kg N/ha, respectively over the initial 3 months. The increasing N rate (Figure 4.2.1A) for CR fertilizer shows that a marginal amount of growth occurred relative to U rates, within 6 weeks. Therefore suggesting that interval length limited N release for CR treatments. Furthermore, the mean minimum temperature outdoors was 3°C, therefore it possible that the cold weather may of also restricted the rate of N release for CR treatments (Seward, 1980).

Growth in the glasshouse (Figure 4.2.1B) showed statistically similar DM production for both CR and U fertilizer rates after a 12 week growth period. The controlled environment in the glasshouse was likely to favour growth of perennial ryegrass treated with CR fertilizer (Seward, 1984; Edmeades, 2015). The mean temperature was warmer relative to the winter temperature experienced outdoors (Figure 3.1) and the watering frequency was increased. Since DM production and water content for CR did not exceed that of U fertilizer, it is likely that N remained in soil, was not taken up by perennial ryegrass and/or N was still enclosed in coating. Edmeades, (2015) suggests that aldehyde polymer coated urea has the potential to resist N losses via leaching, volatilisation or denitrification, relative to conventional urea. Li et al., (2012), showed urea coated with polyurethane took 40-50 days for nutrient release. The current trial uses an aldehyde polymer coating over a growing period of 84 days, which according to Eko360 (2017) Smartfert requires 90 days for 85% N release, depending on the soil and climatic conditions. Therefore it is likely that release period, soil and climatic conditions played a role in N release for CR fertilizer.

5.3 Conclusion

Experiment 1 in the field showed the seasonal productivity of perennial ryegrass under controlled release urea fertilizer is to similar to conventional urea, when applied at the same rate. However, controlled release is likely to be limited under cold temperature conditions, such as in late-autumn and winter, which may result in reductions in DM production, relative to urea. The overall difference in DM production was marginal and is likely to vary according to environmental conditions. The quality of perennial ryegrass showed no difference according to N fertilizer type. Overall seasonal perennial ryegrass quality was high, although low CP concentrations in summer may limit dairy production and high NDF in early autumn may give a marginal decrease in digestibility, but is likely to cause no major limitations to agricultural production. Experiment 2 demonstrated the lag phase shown by CR treatments. Experimentation showed that use of controlled release urea fertilizer can be restricted due to soil and climatic conditions. To insure effective fertilizer application of coated urea, release rate and plant demand must be taken into consideration.
References


https://www.dairynz.co.nz/media/253690/1-34_Summer_Nutrition.pdf


