MASSEY UNIVERSITY

Master of Philosophy in Animal Science

Nutrient Leaching Under Intensive Sheep and Beef Grazing

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Abstract

The sheep and beef industry plays a vital role in the New Zealand economy, but there is growing concern about water quality in the pastoral farming systems. To address this issue, regional councils are implementing restrictions on nitrate leaching rates to improve water quality. Nitrate leaching is influenced by factors such as plant uptake rate, rainfall, soil type, and texture, as well as the stocking rate of grazing animals. However, there is a lack of information on nitrate leaching from sheep and beef farms, particularly in the context of winter cropping options like kale (*Brassica oleracea*) and Turnips (*Brassica rapa subsp. rapa*). Additionally, the potential of planting Italian ryegrass as a cover crop mixed with brassica to reduce nitrate leaching has not been thoroughly explored.

This study aims to compare nitrate leaching under sheep and beef cattle which are grazing perennial ryegrass/white clover, as well as investigate whether mixing Italian ryegrass with brassica can mitigate nitrate leaching. Furthermore, the study will compare the measured rates of nitrate leaching with predicted values using Overseer and a model that simulates N dynamics in urine patches.

An experiment has been established in twenty hydrologically isolated plots at Massey University's Keeble farm for the year 2022. Each plot contains an isolated mole and pipe drainage system to monitor drainage water and assess nitrate leaching. There were five replicates of four treatments: sheep grazing perennial ryegrass/white clover, sheep grazing turnips/Italian ryegrass, sheep grazing kale, and cattle grazing perennial ryegrass/white clover. Measured leaching losses under all treatments were small and there was no significant difference between the nitrate leaching flux of any of the treatments. While Overseer estimates of nitrate leaching were greater than the observed values, they also suggested that there should be no significant difference in leaching rates from the plots Overseer was used to explore likely leaching rates at greater stocking rates. These results suggested that under more intensive farm systems (18 SU/ha), leaching rates under cattle are likely to be greater than under sheep. This difference can be explained by reference to the distribution pattern of urine-N of sheep verse cattle: sheep spread the urine-N load over a greater area. The findings of this study are evidence of the advantages of dry stock farming, particularly sheep, to water quality.

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1.1 Background to the Study

New Zealand is the world's largest exporter of sheep meat and an important exporter of beef (Mazzetto, Falconer, & Ledgard, 2023). Currently, 94% of New Zealand's sheep meat and 87% of beef production is exported with the highest export value to the Chinese market (beef+lambNZ, 2023). Intensifying production by increasing fertilizer use or animal stocking rate is associated with increasing nitrate leaching (Rawnsley, Smith, Christie, Harrison, & Eckard, 2019).

Winter grazing is a common practice in New Zealand, particularly on the South Island (B. J. Malcolm et al., 2018). In the Canterbury region, dairy winter forage grazing of forages such as kale (*Brassica oleracea var. acephala L*), swedes (*Brassica napus ssp. napobrassica*), and fodder beet (*Beta vulgaris L. ssp. vulgaris*), is a common practice because it produces high yields per hectare. When combined with high stocking density, it causes large deposits of urine nitrogen (N) deposited on bare, wet soil, which in turn causes significant nitrate leaching losses (P. Carey, K. Cameron, H. Di, G. Edwards, & D. Chapman, 2016). It also reduces the amount of farmland that has significant treading damage causing soil compaction and loss of pasture (J. Edwards, Mashlan, Dalley, & Pinxterhuis, 2016; A.-M. Hill, Di, Cameron, & Podolyan, 2015; Smith & Monaghan, 2020). However, the risk of N leaching from large numbers of urine patches deposited during intensive winter grazing is higher in the winter and early spring seasons and is a contributing factor to increase nitrate leaching (Al-Marashdeh, Cameron, Hodge, Gregorini, & Edwards, 2021).

Many studies have quantified nitrate leaching from dairy grazing pasture systems in New Zealand (Betteridge et al., 2022; Matse, Jeyakumar, Bishop, & Anderson, 2022; Smith & Monaghan, 2020; Welten et al., 2019). However, few studies are looking at the mitigation of nitrate leaching in winter crop paddocks (Beare, Gillespie, Maley, Harrison-Kirk, & de Ruiter, 2010; PL Carey et al., 2016; Monaghan, Smith, & De Klein, 2013). For example, sowing a catch crop sooner after grazing a winter crop will reduce nitrate leaching over the winter-spring period (Brendon Malcolm et al., 2021). But sowing the catch crop mixed with winter crop at the same time can lower the cost of sowing, grazed later, and mitigate nitrate leaching. In addition, no studies are comparing nitrate leaching between sheep and beef cattle grazing systems.

1.2 Research Aims

The research aims to accomplish two primary objectives. Firstly, to conduct a comparative analysis of nitrate leaching when sheep or beef cattle graze on perennial ryegrass/white clover swards. Secondly, to evaluate the potential reduction of nitrate leaching when sheep graze on a winter brassica mixed with Italian ryegrass in comparison to grazing the winter brassica alone.

1.3 General objective of this study:

To gather quantitative data on nitrate leaching under both sheep and beef cattle grazing.

1.4 Research questions

1. How does nitrate leaching differ between sheep and beef cattle grazing on Perennial ryegrass/white clover swards? Does this relationship vary with stocking rate i.e. farm intensity.

2. Can growing Italian ryegrass significantly reduce the large nitrate leaching under turnips.?.

3. How do the observed nitrate leaching values compare to the predicted values from Overseer for the same conditions?

4. Can a standing of the distribution pattern of urine-N explain the differences in nitrate leaching rates under intensively stocked sheep and cattle systems?

1.5 Proposed thesis format

Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: Methodology

Chapter 4: Results

Chapter 5: General discussion

Chapter 6: Conclusion

Chapter 2 : LITERATURE REVIEW

2.1 Introduction

Intensive grazing systems in New Zealand (NZ) have the potential to increase nitrate leaching, due to an excess of nitrate($NO3^-$) in the soil (Ledgard & Luo, 2020; Selbie, Buckthought, & Shepherd, 2015). Nitrate leaching reduces the quality of receiving water bodies (Stout, Fales, Muller, Schnabel, & Weaver, 2000). Excess amounts of nitrate leaching can occur through animal urine patches (Scholefield et al., 1993) and to a lesser extent, excess N fertilizer use (Hong J Di & Cameron, 2007). Nitrate leaching risk is highest in the winter when heavy rainfall causes excess soil moisture which in turn, results in drainage and runoff (Liu et al., 2016). Therefore, understanding mitigation strategies to reduce nitrate leaching is important for the sustainability of pastoral systems in NZ (Moir, Edwards, & Berry, 2013). The majority of the research examining N or nitrate leaching mitigation strategies has been undertaken in dairy cattle systems in NZ (Lisa A Box, Edwards, & Bryant, 2017; Marshall et al., 2020), while relatively few studies have examined sheep and beef systems (J. Bryant, Snow, Cichota, & Jolly, 2011; Sarmini Maheswaran et al., 2022).

Brassicas are widely used in NZ to cover periods of feed shortage (A. L. Fletcher, Chakwizira, Maley, & George, 2012). Brassicas provide high-quality feed (De Ruiter et al., 2009; McGrath, Behrendt, Friend, & Moore, 2021; Nichol, Westwood, Dumbleton, & Amyes, 2003) and when they are well-managed, brassica crops normally provide excellent fodder for livestock, and also provide excellent soil coverage because of their fast growth, resulting in a higher-producing herbage system and providing shade for the soil to prevent weed growth (Brust, Claupein, & Gerhards, 2014; Kafle, 2020; Ma et al., 2019; Omokanye et al., 2021). In addition, brassica decreases pest levels and reduces weed problems by reapplying glyphosate three to four days in soil and also due to the residue-mediated (brassica extracts and isolated compounds contained in seed germination, seedling emergence, and establishment) effects which may result from the change of the soil characteristics i.e., physical, biological, or chemical (Breitenmoser, Steinger, Baux, & Hiltpold, 2022; De Ruiter et al., 2009; Dubey, 2011; Haramoto & Gallandt, 2004; Valentine & Kemp, 2007). However, using brassica crops can increase stocking rate and livestock productivity, therefore resulting in nitrate leaching increase. A high potential for nitrate leaching under intensive pastoral grazing systems can increase with a high stocking rate and fertilizer N use (P. Carey, K. C. Cameron, H. J. Di, G. Edwards, & D. Chapman, 2016). Unfortunately, limited information is available on nitrate leaching under winter grazing crops (Hunt & Alexander, 1961; BJ Malcolm, Cameron, Edwards, & Di, 2015; B. J. Malcolm et al., 2018).

Italian Ryegrass has greater N uptake during winter due to its faster growth rate and, therefore, could reduce nitrate leaching (Beare et al., 2010; BJ Malcolm, Cameron, Di, Edwards, & Moir, 2014; BJ Malcolm, Cameron, et al., 2015; Moir, Malcolm, Cameron, & Di, 2012). Studies with dairy cattle and sheep reported that the N uptake by Italian ryegrass in winter was 1.4 to 1.9 times greater than that of perennial ryegrass (BJ Malcolm et al., 2014; Moir et al., 2013). Therefore, understanding how the Italian ryegrass can uptake nitrogen from the soil and reduce nitrate leaching, and also the benefits for the farmers to be grazed again when mixed with brassicas, would benefit improving the research data and findings. This information can be used by the government to make important decisions for legislation and policies and to control and organize farmers for better practices to protect the environment.

This literature review will briefly overview sheep and beef farming systems in NZ and provide details on nitrate leaching through the soil, mitigation options, and evaluate the potential of incorporating different forage crops and different cattle to sheep ratios on-farm economic and nitrate leaching by using Overseer. It reviews three pasture types i.e., perennial ryegrass/white clover, mixed sward, Italian ryegrass, and brassicas species (kale, and turnips) in terms of their nutritional characteristics, their growth profile, and potential to mitigate against nitrate leaching. Finally, the literature review will outline the focus of the thesis, the research objectives, and the experiments.

2.2 Present Status for Beef and Sheep Farming in New Zealand

Sheep and beef cattle are traditionally farmed together in NZ, predominantly on hill country and at a stocking rate that aims to match pasture growth with animal demand (Beef+lambNewzealand, 2017; Charteris, Morris, & Matthews, 1999; Hodgson et al., 2019; Verdugo et al., 2014). The total number of sheep in NZ decreased from 55.2 million in 1991/1992 to 25.7 million in 2021/2022 but the production level of lamb meat was maintained over this period (beef+lambNZ, 2022) (Table 2-1). On the other hand, Table 1 shows beef cattle numbers increased from 3.8 million in 2011 to 4.0 million in 2021. There are several farm class systems to categorize farm types, these all classes distributions are weighted averages of individual farm class data e.g., South Island hill country, South Island high country, North Island hard hill country, North Island hill country, North Island finishing farms, South Island finishing-breeding farms, South Island finishing farms, and South Island mixed cropping and finishing farms (Beef+Lamb New Zealand, 2023).

The number of cattle varies according to several factors such as rainfall, as beef cattle prefer heavier rainfall areas which are accompanied by more feed availability (pasture growth) that available in the North Island (Charteris et al., 1999; Ward, 1962). The sheep to cattle ratio on the farm significantly influences the timing of labor requirements, with higher sheep numbers often necessitating more frequent and specific tasks related to their husbandry and management (Moloney, 2022). Although not currently implemented, in the future, the ratio of cattle to sheep could be adjusted strategically to optimize labor requirements on the farm. Moreover, this ratio also holds relevance for addressing environmental concerns, including water quality and supply, climate change, and greenhouse gas emissions. By varying the ratio of sheep to cattle, the potential exists for achieving improved profitability while simultaneously mitigating environmental impacts (S. T. Morris, 2013).

Table 2.1: Livestock numbers (No) and stock units (SU) at 30 June 2021 (millions).

Livestock No.	2011		2021		CHANGE	
	No	SU	No	SU	No	SU
Sheep	31.1	27.9	25.7	22.9	-17%	-18%
Beef Cattle	3.8	18.6	4.0	19.1	+5%	+3%
Dairy Cattle	6.2	39.4	6.2	39.4	0%	0%
Deer	1.1	1.9	0.8	1.5	-17%	-18%
Total Stock Unit[1]	-	87.9	-	82.9	-	-6%

1Includes goats.

Source: Beef + Lamb New Zealand Economic Service, Statistics New Zealand.

New Zealand is the largest exporter of sheep meat in the world and the sixth-largest beef exporter (FAO, 2018; Mazzetto et al., 2023). In 2021- 2022, the total lamb export value was $3.36 billion free on board (FOB). Beef and veal exports were $3.9 billion FOB in the same year, with China being the main market for sheep/beef, and strong demand from the United States for beef meat (Beef+lambNZ, 2021). New Zealand's sheep and beef farms have maintained this competitive advantage and are generally economically viable due to pasture compromising 95% of the livestock diet (S. Morris, 2008; S. Morris & Kenyon, 2014). Interestingly, the meat and wool sectors have maintained their financial returns despite the decline in both livestock numbers and stock units (Farrell, 2020; Mackay, Rhodes, Power, & Wedderburn, 2012).

The pasture growth curve varies within seasons and between years in New Zealand (Chapman, Cullen, Johnson, & Beca, 2009). The maximum growth rate for ryegrass generally occurs in spring from (September to November) (Roberts & Thomson, 1984) (see Figure 2-1 as an example for the Taranaki region). However, the demand for herbage can exceed supply in critical periods of the year (Verkerk, 2003). Farmers try to meet the deficiency by break-feeding crops such as brassicas and applying N fertilizer.

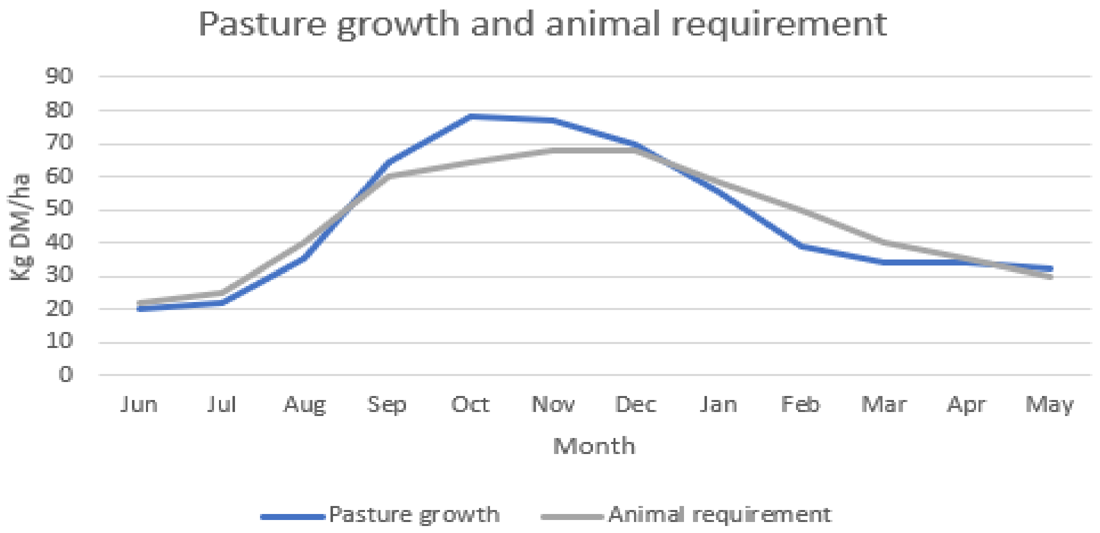

Figure 2.1: Description of pasture growth and animal requirement curves in the Taranaki region (Roberts and Thomson 1984).

2.3 Grazed Forage Systems

New Zealand's intensive farming practices are based on feeding pasture i.e., perennial ryegrass and it is the most widely sown in NZ (Waghorn & Clark, 2004). In spring, pastures have a high growth rate (pasture surplus) in comparison with other seasons where these pastures can lack the ability to provide a sufficient yield (Figure 2-1).

According to Kemp, Kenyon, and Morris (2010) the lack of pasture production in winter made sheep and cattle farmers need more productive and environmentally sustainable pastoral systems, and alternative forage species such as winter crops (brassicas) to fill the shortage in feed during winter and summer (Avery, Avery, Ogle, Wills, & Moot, 2008). This section of the literature review covers subjects related to the other forage species i.e., perennial ryegrass (*Lolium perenne),* Italian ryegrass (*Lolium multiflorum Lam.*), and brassicas such as turnips (*Brassica rapa ssp. rapa*), and kale (*Brassica oleracea spp. acephala*) about use in sheep and beef farming systems in New Zealand.

2.3.1 Perennial ryegrass (*Lolium perenne* L)

2.3.1.1 Morphology

Perennial Ryegrass (Figure 2-2) is native to Europe, temperate Asia, and North Africa (Hannaway et al., 1999). Perennial ryegrass is important as forage in many countries including New Zealand, Australia, and Japan (Thorogood, 2003).

Figure 2.2: Description of the Plant (Perennial Ryegrass) (Modified from source: iStock 2023).

It was introduced to NZ originally by British immigrants from seeds that came from the United Kingdom during the 1800s (Alan Stewart, 2006).

2.3.1.2 Description of the Plant

Perennial ryegrass has a high yield potential, germinates fast, and provides quick levels of feed (Gilliland, Ball, & Hennessy, 2021; Mutwedu, Manyawu, Lukuyu, & Bacigale, 2020; Shayanfar, Sharifiamina, Moot, Moltchanova, & Bloomberg, 2020). In addition, its high palatability and digestibility make it important for livestock forage systems (Hannaway et al., 1999). Also, it is a leafy grass with high palatability, often exceeding 70% digestible dry matter and 20% crude protein (Dennis Hancock, 2011).

2.3.1.3 Management of Perennial Ryegrass

Perennial ryegrass can be sown from February to early April and September till November, in a firm and well-prepared seedbed because the seed size is small (Brown et al., 1998). The persistence of perennial ryegrass-based pastures depends on several factors e.g., the summer moisture, soil fertility, insect feeding, endophyte, cultivar, and animal grazing (D. Clark, 2011). In all regions in New Zealand, grazing management and insect pests are the two main factors for ryegrass persistence. However, poor persistence happens when the desirable species are replaced by undesirable species (Tozer, Cameron, & Thom, 2011).

Perennial ryegrass is frequently interspersed with forage legumes and other grasses, including red and white clover (Nölke, Tonn, Komainda, Heshmati, & Isselstein, 2022; Šidlauskaitė, Kemešytė, & Kadžiulienė, 2022). It also blends very well with white clover and persists well (McDonagh, Gilliland, McEvoy, Delaby, & O'DONOVAN, 2017; Valentine & Kemp, 2007). Nonetheless, ryegrass grows 20 Kg/ha/day faster than white clover does in the winter, and it can grow up to 100 Kg/ha/day in the spring (Valentine & Kemp, 2007). Thus, white clover complements seasonal growth patterns for the perennial ryegrass in the winter and can improve the sward quality in spring (J. Caradus, Woodfield, & Stewart, 1995).

2.3.1.4 Cultivar Types

Perennial ryegrasses are usually classified according to flowering time and chromosome number (Charlton & Stewart, 1999). Since each cell of perennial ryegrass has two sets of seven chromosomes, it is a naturally occurring diploid species (Charlton & Stewart, 1999). The majority of cultivars that are currently on the market are diploid, but plant breeders have also created tetraploid cultivars, which have two sets of 14 chromosomes and a varied ratio of characteristics (Dairy NZ, 2023).

2.3.1.5 Mycotoxin Poisoning

The endophyte, a fungus living within perennial ryegrass (Charlton & Stewart, 1999), produces protective alkaloids but can lead to issues like mycotoxin poisoning in animals (C. Morris, 2006). In a symbiotic relationship, endophytes inhabit plants' spaces, guarding against overgrazing and pests while consuming nutrients (J. R. Caradus, 2023). Major metabolites include peramine, ergovaline, and ryegrass staggers-causing lolitrem B (Finch, Webb, Munday, Sprosen, & Cave, 2022; López-García, 2022). Livestock exposed to these fungi show nervous disturbances and decreased weight gain (Croy et al., 2022; Trieu et al., 2022a, 2022b).

Perennial ryegrass in New Zealand contains two endophyte forms: the widely used Standard and novel types like AR1, AR37, NEA, NEA2, and NEA4, offering diverse benefits depending on factors like region, climate, and management (Walmsley & Turf, 2010). The choice of endophyte can impact animal productivity and health (L. Fletcher, Sutherland, & Fletcher, 1999; L. R. Fletcher & Easton, 1997).

2.3.1.6. Nutrient composition

The nutrient value of pasture differs due to plant phenology, growing conditions, management practices, and constituent species (Waghorn & Clark, 2004). Crude protein percentage ranges between 15.0 and 22.5 %, NDF percentage ranges between 44.6 and 53.6 %, ADF percentage ranges between 20.2 and 27.7%, WSC percentage ranges between 6.7% and 22.3%, and ME ranges between 9.0 and 11.8 MJ per kg DM (Table 2.2). Grace, (1983) reported that ryegrass provides sufficient minerals during ad-libitum feeding, however, Mg and Na are at a marginal level for livestock feeding. In contrast, Potassium was deficient in 5 and 37% of dairy and beef/sheep pastures respectively (Reed, Walsh, Cross, McFarlane, & Sprague, 2005).

The nutritional value of the perennial ryegrass differs depending on the management practices, season, and stage of maturity (J. Burke, Waghorn, & Brookes, 2002; Leddin, Giri, & Smith, 2022). In the studies conducted in New Zealand, crude protein is typically highest in Autumn (22.5%) and lowest in spring and winter (15.0%) (Table 2.2). NDF in (Table 2.2) was (44.6%) the lowest and, (53.6%) the highest. However, the nutritive value for perennial ryegrass drops when temperature increases especially in summer due to changes in leaf: stem ratio and increase cell wall: cell content ratio, and this is associated with lignin increase of the cell wall (Chaves, Burke, Waghorn, & Brookes, 2006; Walsh & Birrell, 1987). However, NDF was reported higher in summer and lower in spring in different studies (Douglas et al., 2019; Thi Truong Nguyen, Navarrete, Horne, Donaghy, & Kemp, 2022; Rivero et al., 2019). ADF in (Table 2.2) was (20.2%) the lowest and, (27.7%) the highest.

Table 2.2: Crude protein (CP), neutral detergent fiber (NDF), water-soluble carbohydrate (WSC), acid detergent fiber (ADF), and metabolizable energy (ME) contents of perennial ryegrass

	Herbage quality (g/kg DM)				
	CP	NDF	ADF	WSC	ME (MJ/Kg DM)
New Zealand					
Summer					
Sun et al. (2012)	217	446	246	67	9.7
T. Fraser and Rowarth (1996)	201	447	202	-	-
Autumn					
J. L. Burke, Waghorn, Brookes, Attwood, and Kolver (2000)	155	487	-	91	
Golding et al. (2011)	196	481	-	-	9.0
Barrell, Burke, Waghorn, Attwood, and Brookes (2000)	225	483	229	81	11.8
Spring					
Sun et al. (2012)	150	536	277	106	9.4
A. Chen, Bryant, and Edwards (2019)1	155	482	249	223	-
Winter					
Sun et al. (2012)	150	536	277	106	9.4

1Perennial ryegrass base/pre-vegetative stage

2.3.2 Italian Ryegrass (*Lolium multiflorum Lam*)

2.3.2.1 Morphology and Cultivars

Italian ryegrass (*Lolium multiflorum Lam*) is a high-quality forage that is cultivated in temperate regions of the world (Choi et al., 2011). It is best adapted to areas with long periods of cool and wet weather and well-drained soils, and also well adapted to the New Zealand climate (Abraha, Truter, Annandale, & Fessehazion, 2015; Chapman, Edwards, & Nie, 2011). Italian ryegrasses have a high winter growth rate and root metabolic activity (BJ Malcolm et al., 2014) in comparison to perennial ryegrass (*Lolium perenne*) (Charlton & Stewart, 1999; Lancashire, 1982).

Figure 2.3: Description of the plant (Italian ryegrass) and individual spikelet (Modified from source: Lizzie Harper 2023).

Italian ryegrass is established quickly and can be ready for grazing 4-6 weeks after sowing, up to 2 weeks sooner than perennial ryegrass, and it produces 10.5 ton DM/ha over 6-8 months (B. J. Malcolm et al., 2020). Although, on dairy farms in New Zealand, the average annual dry matter production of perennial ryegrass-based pastures stands at 14 t DM/ha, while irrigation has enabled yields to exceed 20 t DM/ha/year (Agricom, 2023). Italian ryegrass contains a fungus endophyte AR37 which can help to persist a year longer than those without endophyte (J. R. Caradus, 2023; DairyNZ, 2022a; C. Young, Hume, & McCulley, 2013).

Also, Italian ryegrass are well known for their higher winter/early spring production compared to perennial ryegrass (McCahon, McCahon, & Ussher, 2021). In addition, Italian ryegrass was reported to have higher levels of water-soluble carbohydrates and lower levels of neutral detergent fiber than perennial ryegrass (King, McEniry, Richardson, & O'kiely, 2012). Yields can vary depending on seeding dates, rainfall, temperature, and fertility (Joel Bagg, 2014). However, the total yield for Italian ryegrass in all New Zealand regions for different cultivar types ranges from 12 t DM/ha to 16 t DM/ha (NZPBRA, 2022).

2.3.2.3 Management of Italian ryegrass

The success of the Italian ryegrass establishment was related to the fast germination in low temperatures with a seeding rate of 20-25 Kg/ha (M. Hill & Pearson, 1985; Seeds & Sereals, 2016; Wynn, Hodgson, & Andrewes, 2011). Italian ryegrass can germinate between 20 and 25^{o}C (Hampton & Scott, 1986; M.

Hill, Pearson, & Kirby, 1985). It could be planted at a depth of 10-20 mm and with nitrogen and phosphate fertilizer resulting in increased dry matter (Brown et al., 1998).

2.3.2.4 Nutrient Composition

The crude protein (CP) content of Italian ryegrass is influenced by variety, date of cutting, and nitrogen fertilizer (Bennett, 2016; Lv et al., 2017). Different studies in New Zealand showed different CP content in Italian ryegrass between 5.5% to 28.7% (Table 2.3). Ryan-Salter and Black, (2012) reported that Italian ryegrass varies significantly in the CP content at different times of the year and is at its minimum in summer (5.5%) and increases considerably during winter and autumn (24.3% and 14.3% respectively) (Table 2.3). CP content in Italian ryegrass was higher during late winter (19.9%) than crude protein content in mid (19.6%) and late winter (18.2%) (Table 2.3). Also, increasing N fertilizer will increase CP content in Italian ryegrass (Ertekin, Atis, Aygun, Yilmaz, & Kizilsimsek, 2022; Lv et al., 2022).

The ME value of Italian ryegrass is relatively high during the early, mid, and late winter seasons, ranging between 12.2 and 13.3 MJME/kg DM (De Ruiter, Dalley, Hughes, Fraser, & Dewhurst, 2007) (Table 2.3). However, the ME in Italian ryegrass is higher than in perennial ryegrass (Table 2.2) (Table 2.3). NDF and ADF content ranges between 22.6% and 46.2%, and 14.2% and 23.3%, respectively (Table 2.3). (Table 2.3) shows that the average, NDF, and ADF were 357 and 193 g/Kg DM, respectively.

The water-soluble carbohydrate (WSC) content displayed a range of 11% to 19%, with Italian ryegrass showing a higher average percentage (15%) than perennial ryegrass (11%) (Table 2.2) (Table 2.3). This variation in WSC content across different seasons in ryegrass is significantly influenced by temperature (Kobayashi, Takahashi, Matsumoto, & Nishiguchi, 2008). In cooler climates characterized by lower average temperatures, the WSC ranges were observed between 11% and 19%. However, in warmer climates (tropics) characterized by higher average temperatures, the WSC content notably reduced to 6.5%, as reported by Hopkins (2003). Furthermore, other studies have also indicated that the WSC content tends to be higher during colder weather typical of cool climates compared to warmer conditions typical of warm climates (DairyNZ, 2023).

Table 2.3: Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), water-soluble carbohydrate (WSC), and metabolizable energy (ME), contents of Italian ryegrass.

Author	**Herbage Quality (g/Kg DM)**				
	CP	**NDF**	**ADF**	**WSC**	**ME (MJ/Kg DM)**
New Zealand					
De Ruiter et al, 2007					
Early Winter	182	226	142	115	13.3
Mid-Winter	196	383	206	183	12.6
Late-Winter	199	462	233	194	12.2
Ryan-Salter and Black, 2012	243	-	-	-	-
Summer					
Ryan-Salter and Black, 2012	55.0[1]	-	-	-	11.3[1]
	96.0[2]	-	-	-	9.5[2]
Autumn					
Ryan-Salter and Black, 2012	143[3]	-	-	-	11.7[3]
	287[4]	-	-	-	12.7[4]
Spring					
Ulyatt et al., 1974				153[5]	
				190[6]	
				78[7]	

1 Early Summer; 2 Late Summer; 3 Early Autumn; 4 Late Autumn, 5 Early Spring, 6 Mid Spring, 7 Later springs

2.3.3 White Clover (*Trifolium repens*)

White clover is a legume commonly sown in a mixed pasture sward with grass, herbs, or other legume species. Ideally, white clover should be sown in 3-5 kg/ha in a mix of seeds (Charlton & Stewart, 1999). It is most active in summer with growing temperatures ranging between 15°C and 25°C, 5°C higher than perennial ryegrass (Brock, Caradus, & Hay, 1989; Chu et al., 2022; Dairy NZ, 2022). However, it has high productivity during cool weather conditions and can tolerate grazing, but productivity and quality can be limited during severe dry summer conditions (Anderson, Ochoa, Sahin, & Ates, 2022; Brock & Kim, 1994; J. Caradus et al., 1995; Z. Li et al., 2022). It can grow well in moderate to highly fertile soils; and therefore, can be successfully established in a range of soil types throughout New Zealand (T. D. Nguyen et al., 2020).

White clover can improve the nutritional quality of the grazed pasture (J. Caradus et al., 1995; J. R. Caradus et al., 2022). However, it has a higher feed value than perennial Ryegrass (Egan, Galvin, & Hennessy, 2018). In a mix of white clover and pastures, white clover improves the pasture quality, intake, utilization rates, and performance of animals providing N by N fixation, and reduces N input through fertilization (Cranston, Kenyon, Morris, & Kemp, 2015; Hennessy, Ruelle, & Burchill, 2022).Therefore, these characteristics made white clover an ideal companion species to pasture plants.

2.3.3.1 Nutrient composition

Across several studies conducted in New Zealand, the average CP, and ME contents of white clover were higher than the average of perennial ryegrass, whilst NDF and ADF were lower in white clover (Egan et al., 2018; Francis, Chapman, Doyle, & Leury, 2006; Rattray & Joyce, 1974; Schreurs et al., 2003; Ulyatt, 1981) (Table 2.2, Table 2.4). The ME ranges between 11-12 MJ ME/Kg DM in the previous studies (Table 2.4), hence it is important in New Zealand pastoral systems. The WSC content in white clover ranges between 102-175 g/kg DM (Table 2.4).

Table 2.4: Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), water-soluble carbohydrate (WSC), and metabolizable energy (ME) contents of white clover `

Citation	**Herbage Quality (g/kg DM)**				
	CP	**NDF**	**ADF**	**WSC**	**ME (MJ/kg DM).**
Summer					
C. Lindsay, Kemp, Kenyon, and Morris (2007)	276	263	-	-	11.7
Harrington, Thatcher, and Kemp (2006)	270	-	228	-	-
Autumn					
Barrell et al. (2000)	298	266	201	102	12.2
Winter					
Maxwell et al. (2016)	196	234	202	175	11.6

2.3.4 Perennial Ryegrass and White Clover Sward

White clover and perennial ryegrass are commonly sown in a mix. perennial ryegrass including white clover produced 1205 Kg DM/ha/year more than perennial ryegrass only (McClearn et al., 2019). However, nutrient intake increases when including white clover to perennial ryegrass (Hammond et al., 2013).

In white clover, there is a bacterium *Rhizobium trifolii* that lives in the root nodules and can fix atmospheric nitrogen (N) and increase soil fertility (S. D. Young, van Koten, Gray, Cavanagh, &

Wakelin, 2020). In a pasture of perennial ryegrass-white clover, around 100 Kg N/ha/annum can be fixed from the atmosphere (Carlsson & Huss-Danell, 2003). Therefore, including white clover in the swards reduces the cost by reducing N fertilization use (fixed nitrogen) and increases forage yield (Annicchiarico, Barrett, Brummer, Julier, & Marshall, 2015; J. Caradus et al., 1995; Doyle, Tubritt, O'Donovan, & Crosson, 2022). The dry matter yield of white clover in mixes varies with a yield of 1 t DM per ha to 7 t DM per ha depending on the pasture management, rainfall, and soil fertility (Lee et al., 2018).

2.3.4.1 Nutrient Composition of the Ryegrass/White Clover Sward

Several studies conducted in New Zealand showed a wide variation in nutrient content for perennial ryegrass/white clover (Table 2.5). The crude protein was higher in winter than in other seasons (Table 2.5). The average crude protein was 23.5% which was higher than the average crude protein of perennial ryegrass (Thi Truong Nguyen et al., 2022). Elevated crude protein levels in white clover indicate that the N levels will be high in the pasture, and when the N concentration is higher than the ruminant requirement, then it is vulnerable to loss. The average ME content (10.7 MJ/Kg DM) of perennial ryegrass / white clover sward was higher than the ME content (9 MJ/Kg DM) of perennial ryegrass over various New Zealand studies (Fulkerson, Fennell, & Slack, 2000). The average content of NDF and ADF (48% and 24%, respectively) was higher in perennial ryegrass compared to perennial ryegrass / white clover (43% and 24%, respectively) (Thi Truong Nguyen et al., 2022).

Table 2.5: Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), organic matter digestibility (OMD), and metabolizable energy (ME) contents of perennial ryegrass/white clover sward (DM basis)

Author	**Herbage quality (g/kg DM)**					
Autumn	**CP**	**NDF**	**ADF**	**WSC**	**ME (MJ/kg DM)**	**Clover % in the mix**
Lisa Anne Box, Welten, Coles, Minnee, and Shorten (2019)	201	405	241	-	11.6	
Somasiri (2014)						
Experiment 1	198	485	239	-	9.90	7.5
Experiment 2	293	395	193	-	10.8	1.0
Lisa A Box et al. (2017)	234	419	276	-	11.1	25.7
Winter						
Somasiri (2014)						
Experiment 1	263	432	233	-	10.2	4.5

Experiment 2	320	394	212	-	10.4	2.5
Late spring						
Lisa A Box et al. (2017)	186	460	265	-	11.7	7.28
Summer						
Thi Truong Nguyen et al. (2022)	186	465	269	-	10.0	-

2.3.5 Brassicas

Forage brassicas have historically been used in irrigated temperate livestock systems (Umami, Prasojo, & Haq, 2022; Watt et al., 2021; Watt, Bell, & Pembleton, 2022). However, in recent years, NZ pastoral systems have seen an increase in the importance of forage brassicas (Watt et al., 2022), i.e., Kale and Turnips are some of the most common forage brassicas in New Zealand (AV Stewart, 2002).

In this section of the review, turnips, and kale, will be discussed because it is used in the New Zealand farming systems (AV Stewart, 2002), and the characteristics of these brassicas (turnips, kale) are more suitable for this system, also it is a cheaper option than purchasing supplementary feed (Bell, Watt, & Stutz, 2020), and it can produce high quality and high yields at times of the year when the performance of ryegrass based pasture is limited (John de Ruiter, 2009).

Brassica crops (kale) can be sown from October till December, and some can be sown till February i.e., turnips. Yield can vary between them i.e., kale can yield up to 20 t DM/ha, and turnips can be with different yields depending on crop management and growth environment (De Ruiter et al., 2009). However, bulb turnips (*Brassica campestris var. rapa L.*) have above and below ground (bulb) biomass. While kale (*B. oleracea var. acephala L.*) provides only above ground biomass (Watt et al., 2021).

Forage brassicas (Kale, and bulb turnip) can be fed to ruminants because they have high dry matter (DM) digestibility (0.81-0.89) and metabolizable energy (ME) (12.1-14.1 MJ/Kg DM) (Barry, 2013). Several studies showed that crude protein ranges in brassicas (kale and bulb turnip) (13%-19%) (D. Clark et al., 1997; Moate, Dalley, Martin, & Grainger, 1998; Sun et al., 2012). Barry, 2013 reported that brassica plants have a higher ratio of fermentable CHO (i.e., water-soluble sugars and pectins) and structural CHO (i.e., cellulose and hemicellulose) than what grass has.

2.3.5.1 Turnips (Brassica rapa L; syn. B. Campestris)

Turnips are one of the main brassicas that can be used as a fast-maturing single-graze crop to help in the feed shortage and provide high-quality feed (Collett, 2014; AV Stewart & Moorhead, 2004). Turnip leaves are light green, thin, and sparsely pubescent with white-fleshed, large global developed at the base of the leaf petioles (Fernandes et al., 2007).

The sowing period for turnips can be in February for winter production and yield can be 2-12 t DM/ha (De Ruiter et al., 2009; Sneddon, 2022; Thomson, Hammond, & Muir, 2016). Turnips are more favored in areas where a cool, short growing season limits the use of slower maturing crops (Moot, Matthew, Kemp, & Scott, 2007).

Table 2.6: Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), water-soluble carbohydrate (WSC), and metabolizable energy (ME) contents of turnips

Author	**Herbage Quality (g/kg DM)**				
	CP	**NDF**	**ADF**	**WSC**	**ME (MJ/kg DM)**
New Zealand					
Summer					
Westwood (2012)[1]	142	225	189	270	11.7
Barry (2013)[2]	130	240	180	238	-
Moate et al. (1998)[3] **Leaf**	191	164	**-**	**-**	**-**
C. Lindsay et al. (2007)[4]	165	210	-	-	13.5
Winter					
De Ruiter et al. (2007)[5]	158	177	278	27	12.3
Dalley, Malcolm, Chakwizira, and de Ruiter (2017)[6]	126	417	328	233	-

1,2,4,5 Whole plant; 3 Leaf

2.3.5.1.1 Nutrient composition

Across several studies conducted in New Zealand, the average CP and ME contents of turnips were (15% and 12.5 MJ per kg DM, respectively) (Table 2.6). In addition, leaves in Brassica forages (turnips) have higher CP concentration and less digestibility than bulbs (McCartney, Fraser, & Ohama, 2009; Westwood, 2012).

The nutritional content of brassicas varies with environmental conditions and the degree of maturity of the plant at the time of harvest (Winkler, 2017). The average WSC content is (19.2%) (Table 2.6). NDF and ADF (average percentage) contents were lowest in turnips in comparison with perennial ryegrass and Italian ryegrass (Table 2.2, Table 2.3, Table 2.6) whilst ME for turnips (average percentage) contents were highest in turnips. Therefore, turnips are a good complement to diets based on feeds that have the characteristics of high NDF, low ME, and low CP (Dairy Australia, 2020; Jacobs, Ward, McDowell, & Kearney, 2001).

2.3.5.2 Kale

Kale is normally used as a winter crop; it has a deep root system to tolerate drought (Lob, 2014). In addition, kale is good at tolerating insect pests and can be used as a second winter crop, especially after Swedes because it can tolerate club root and dry rot (De Ruiter et al., 2009; Hejna, Havlickova, He, Bancroft, & Curn, 2019). Kale (Brassica oleracea L. var. acephala) belongs to the Brassicaceae family (CECÍLIO, Bianco, Tardivo, & Pugina, 2017; Satheesh & Workneh Fanta, 2020). It has ruffled leaves and fibrous stalks, and they are deep green in color (Pellicer et al., 2020). The yield varies depending on soil type, soil fertility, and available moisture (Wilson et al., 2006). However, yield for winter kale reaches 8 to 20 t DM/ha (De Ruiter et al., 2009; Smith & Monaghan, 2020).

Table 2.7: Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), water-soluble carbohydrate (WSC), and metabolizable energy (ME) contents of kale.

Author	**Herbage Quality (g/kg DM)**				
	CP	**NDF**	**ADF**	**WSC**	**ME (MJ/Kg DM)**
New Zealand					
Dalley et al. (2017)	135	342	252	-	-
Neave, Schütz, and Dalley (2022)	165	214	170	-	11.5
R. Bryant, DI, MALCOLM, and CHAPMAN (2013)					
Early sown kale, 2013	126	262	-	467	12.7
Late sown kale, 2013	126	275	-	441	12.8
Early sown kale, 2012	125	264	-	462	12.8
Late sown kale, 2012	124	272	-	448	12.9
PGG Wrightson seed (2022)					
Stem	57	-	-	-	10.8
Leaf	173	-	-	-	12.0
Summer					
Rugoho et al. (2014)	175	300	236	319	122
Winter					

Walker (2017)	100	280	240	330	110

Nutrient composition

Across several studies conducted in New Zealand, the average CP in kale is 13%, whilst it is higher for the other winter crops and ryegrass (Table 2.2, Table 2.3, Table 2.6, and Table 2.7). In addition, CP in kale leaf is higher than the stem (Table 2.7). The average percentage of NDF in kale is 27.6% (Table 2.7). The average percentage for NDF and ADF in kale is 27 % and 22 %, whilst higher in perennial ryegrass 48% and 24% (Table 2.2 and Table 2.7). The average ME was higher in kale 12% than the average ME in perennial ryegrass 9.9% as measured in New Zealand studies (Table 2.2 and Table 2.7).

2.4 Nitrogen Leaching Under Intensive Sheep and Beef Grazing

Nitrogen (N) leaching losses in drainage and runoff are major causes of the deterioration in water quality in many parts of the world (Leng et al., 2021; Sarmini Maheswaran et al., 2022; Opoku-Kwanowaa, Furaha, Yan, & Wei, 2020). Nitrate contamination of groundwater is a major threat to ground water because it cannot be captured by plant's roots then it will leach to groundwater (Selvarajah, Maggs, Crush, & Ledgard, 1994). However, nitrate is a negatively charged ion that can move and leach in soil to waterways (Kanthle, Tedia, & Lenka, 2019; Nortjé & Laker, 2021; Quinn, 2021).

Livestock urine is the primary source of nitrate leaching in soil, which varies around the country depending on land uses, climate, and soils (Hong Jie Di & Cameron, 2016; Hansen & Djurhuus, 1997). However, nitrate leaching is higher in cattle than sheep (Betteridge et al., 2022; Williams & Haynes, 1994), while it is 3 times higher in dairy cattle in comparison to beef cattle (Ausseil & Manderson, 2018).

2.4.1 Nitrogen Losses

The amount of nitrate leaching in cattle and sheep grazing systems is dependent on the animal's diet and pasture being ingested (Ledgard & Luo, 2020; Mahmud, Panday, Mergoum, & Missaoui, 2021; Williams & Haynes, 1994). Livestock utilizes a proportion of N and the excess is excreted in urine and feces (Ledgard & Luo, 2020; Min, Lee, Jung, Miller, & Chen, 2022). Ruminants excrete as much as 70–95% of the nitrogen (N) they consume (Selbie et al., 2015). Approximately 20% of the nitrogen consumed is used for producing meat and milk, while 60% is excreted as urine and the remaining 20% as dung (Figure 2.4).

After urination, urea N hydrolysis to ammonium within 24 hours of deposition, and some of the ammonium recovered by the plants, is lost as ammonia, or immobilised in soil organic matter, but most are nitrified within two weeks of deposition (Ball & Keeney, 2019; Thomas, Logan, Ironside, & Bolton, 1988).

Understanding the N cycle and how nutrients can move from the farm to the waterways, is essential to manage these nutrients efficiently in the farm and to know where these nutrients can be lost (Figure 2.4). Cows utilize 30 % of N eaten for milk and meat, while the remaining is lost in the atmosphere as gas or leach in the soil (soil pool) as a plant residue or as dung or urine. A large proportion is lost beyond the root zone to water via a process called "leaching" (Figure 2.4). Urine patches are a significant source of N leaching (Menneer, Ledgard, McLay, & Silvester, 2003).

Sheep, like cows, also utilize a portion of the nitrogen (N) they consume for milk and meat production (Beltran et al., 2021). Similar to cows, sheep's urine patches can be a significant source of N leaching (Sarmini Maheswaran et al., 2022). Despite this knowledge, there are still gaps in the research regarding the specific magnitude of N losses from sheep farming systems and the factors that influence these losses. Additionally, the impact of different forage types, such as winter brassica mixed with Italian ryegrass, on N leaching in sheep farming systems requires further investigation.

Understanding the N loss dynamics in sheep farming systems, particularly in comparison to cattle, is essential to develop sustainable and efficient agricultural practices (Silva et al., 2022). By evaluating the potential reduction of nitrate levels when sheep graze on specific forages, like winter brassica mixed with Italian ryegrass, relative to other forage types, we can gain valuable insights into the environmental implications and profitability of such practices. Consequently, the results of this study will aid in formulating informed decisions and management strategies to minimize environmental impacts while optimizing productivity in sheep and beef cattle farming systems.

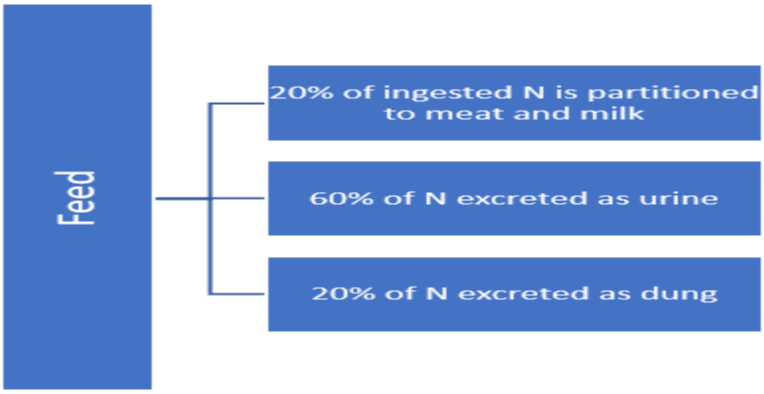

Figure 2.4: A flow chart describing nitrogen partitioned in ruminant.

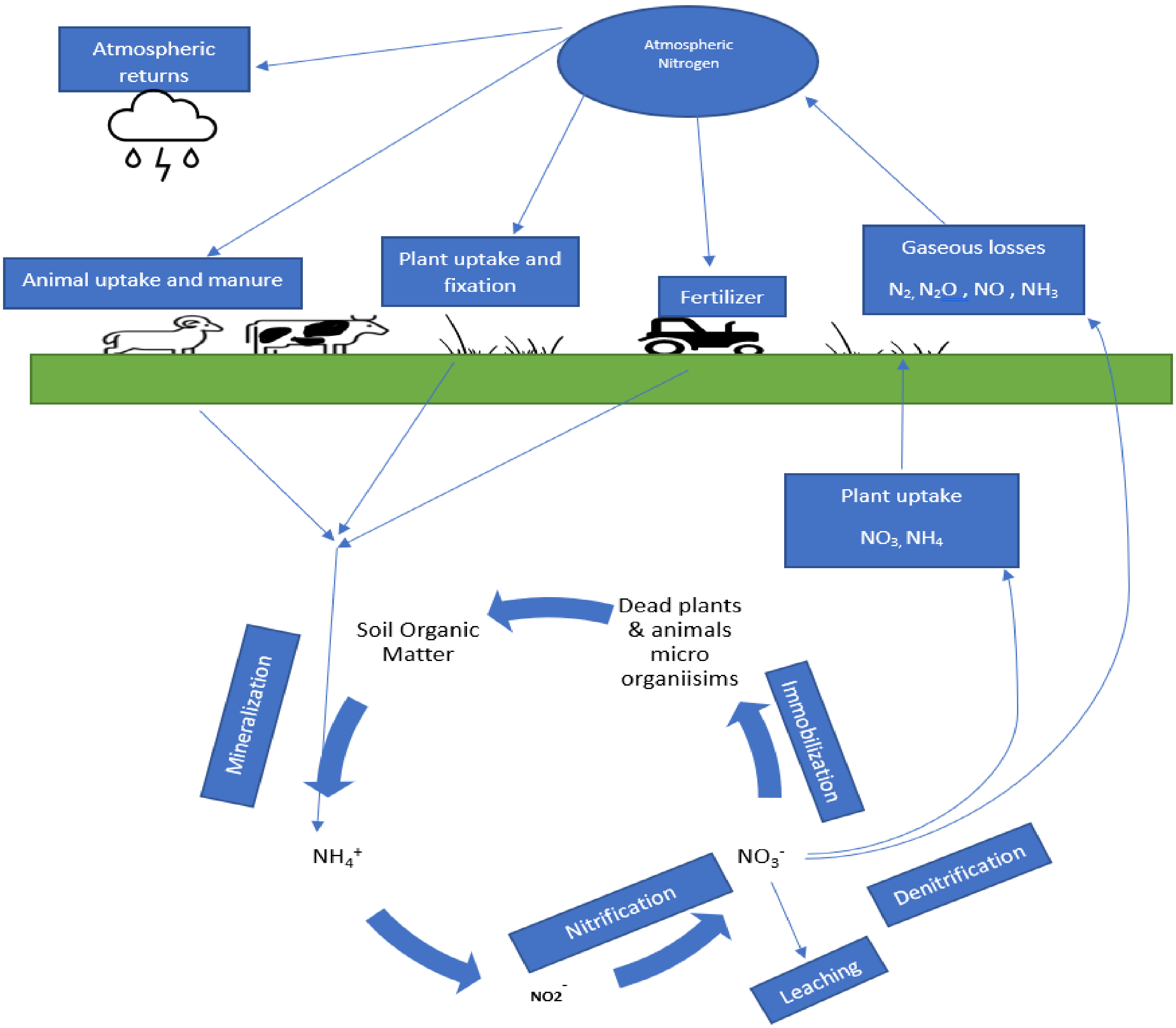

Figure 2.5: The soil/plant nitrogen cycle(N losses) and the process of nitrogen transformation from (Modified from source: Cameron, Di, and Moir (2013).

2.4.2 How Nitrogen is Converted to Nitrate

The nitrogen cycle is the fundamental biochemical process of composting with five main steps, including mineralization, nitrification, denitrification, nitrate leaching, and immobilization (Figure 2.4 and Figure 2.5). Mineralisation (organic nitrogen to ammonium) is the nitrogen contained in the organic matter i.e., animals, plants, urine, and dung, which can be broken to ammonium by a microbe (Figure 2.4). mineralization varies with soil temperature, moisture, pH, salinity, the amount of oxygen in the soil (aeration) (X. Chen et al., 2021; Grzyb, Wolna-Maruwka, & Niewiadomska, 2020; Xue, Clinton, Sands,

& Payn, 2022). A higher rate of mineralization occurs between 20^0C – 35^0C, in well-aerated and moist soils (Curtin, Beare, Qiu, & Tregurtha, 2019; Johnson, Albrecht, Ketterings, Beckman, & Stockin, 2005). A simple mineralization reaction proceeds as:

$R\text{-}NH_2 \rightarrow NH_3 \rightarrow NH_4^+$

Nitrification (ammonium to nitrate) is the transformation of ammonium to nitrate via a bacterium by adding oxygen (oxidation). Nitrification of ammonium in the soil to nitrate depends on substrate supply, environmental conditions (soil moisture, temperature, pH, and aeration), organismal population of nitrifiers and competitors, and the presence of nitrification inhibitors (Norton & Ouyang, 2019; Xue et al., 2022). Thus, nitrification is most rapid when soil is warm (19- 30°C), moist, and well-aerated, but is virtually halted below 5°C and above 50°C (Johnson et al., 2005). In addition, plants can affect the soil process, such as nitrification (de Klein, van der Weerden, Luo, Cameron, & Di, 2020). A simple denitrification reaction proceeds as:

$NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$

Nitrate leaching is the process of downward movement of soluble nitrate through the soil with water (drainage) (Padilla, Gallardo, & Manzano-Agugliaro, 2018). Nitrate leaching can occur when soil water content becomes greater than the maximum soil water holding capacity, resulting in water draining into soil carrying with it the nitrate (D J Houlbrooke, 2009). The nitrate leaching in the soil varies around the country depending on land uses, climates, and soils (Hong Jie Di & Cameron, 2016; Hansen & Djurhuus, 1997). The rate of nitrate leaching depends on soil drainage, rainfall, the amount of nitrate present in the soil, and crop uptake (Johnson et al., 2005).

Volatilization and denitrification are the processes by which N is lost to the atmosphere as a gas (ammonia, nitrous oxide, and nitrogen gas). Volatilization mostly happens in warmer conditions (summer, spring, and autumn) (Vangeli et al., 2022) (Figure 2.4). While denitrification play a major role in reducing nitrate leaching in the colder and wet conditions (winter) (Bu, Fry, & Burford, 2022). Denitrification is a process carried out by aerobic denitrifying bacteria (ADB) (Hao, Ali, Ren, Su, & Wang, 2022). A simple denitrification reaction proceeds as:

$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$

2.4.3 Review of Literature Related to N Leaching from Sheep and Cattle Grazed Pastures

Most of the research examines N leaching mitigation strategies in dairy cattle systems in New Zealand, while relatively few have examined sheep and beef systems. Thus, the lack of information on nitrate leaching from sheep and beef cattle farms will be covered by different studies on nitrate leaching from dairy farms. Across a number of studies, the amount of N leached from sheep pastures has been shown to vary from 6 to 80 Kg N/ha (Brock, Ball, & Carran, 1990; Haynes & Williams, 1993; Heng, White, Bolan, & Scotter, 1991; Hoogendoorn, Betteridge, Costall, & Ledgard, 2010; G. Lindsay, 2016; S Maheswaran et al., 2021; Sarmini Maheswaran et al., 2022; Monaghan, Cameron, & McLay, 1989; Steele, Judd, & Shannon, 1984). Whilst, in dairy cattle, it has varied from 37 to 620 Kg N/ha (Cabrera, Jagtap, & Hildebrand, 2007; Joy et al., 2022; Tan et al., 2022; Wang, 2008; Williamson, Taylor, Torrens, & Vojvodic-Vukovic, 1998). In general, nitrate leaching varies and depends on several factors (forage systems, amount of manure applied, timing of grazing, stocking rate, seasonal rainfall amounts, and soil characters) (Cabrera et al., 2007; Field, Ball, & Theobald, 1985; Haynes & Williams, 1993; Sarmini Maheswaran et al., 2022).

Leaching loss of nitrate from sheep and dairy farming systems has been studied in New Zealand and other countries (Beatson, Meier, Cullen, & Eding, 2019; Betteridge, Costall, Balladur, Upsdell, & Umemura, 2010; D. A. Clark et al., 2020; Field et al., 1985; Hoogendoorn et al., 2010; Joy et al., 2022; G. Lindsay, 2016; Tan et al., 2022; R. R. Woods, Cameron, Edwards, Di, & Clough, 2018). However, there is very little knowledge of methods to mitigate this loss in sheep and beef farms. Also, there is no information on mixing Italian ryegrass with brassicas.

Nitrate loss has been measured on free-drainage soils under sheep and dairy grazing systems in Manawatu (Betteridge et al., 2010; Bishop & Jeyakumar, 2021; Field et al., 1985; Matse et al., 2022; Parminter et al., 2019) and Taupo catchment (J. Bryant et al., 2011; Hoogendoorn et al., 2010; Spicer, Swaffield, & Moore, 2021), as well as in fine-textured soils in Canterbury in South Island (Joy et al., 2022; G. Lindsay, 2016; Matse et al., 2022; Monaghan et al., 1989; Monaghan, Paton, & Drewry, 2002; Williams & Haynes, 1994).

In the South Island, nitrates leaching were found 34% less than average (range:19-49%) when planting oat catch crop in a lysimeter study on Balmoral stony silt loam soil after winter forage grazing (PL Carey et al., 2016). However, Carey; 2017 reported that sowing oat catch crops in mid of August two months after the first urine application, reduced nitrate leaching by 25% over the (winter-spring drainage) in comparison with Italian ryegrass as a catch crop in a lysimeter study. This suggests that the catch crop helps in reducing nitrate leaching. In the North Island, the average annual losses of mineral N from 600 mm below the soil surface were 40 to 29 Kg mineral N/ha/year for cattle and sheep, respectively

(Hoogendoorn et al., 2011). While, 37 Kg N/ha and 1 Kg N/ha were leached from cattle and sheep pastures, in South Island (Williams & Haynes, 1994). However, in both cases, sheep were lower in nitrate leaching than cattle.

In Waikato studies, when cows urine was applied, nitrate leaching loss was highest with the addition of N fertilizer to the perennial ryegrass/white clover at the rate of 400 Kg N/ha in autumn and spring and can leach up to 58 Kg/ha, while there is no leaching increase when 200 Kg N/ha applied (Buckthought, Clough, Cameron, Di, & Shepherd, 2015). Also applying 220 Kg N/ha to perennial ryegrass/white clover can maximize the nitrate leaching up to 61 Kg N/ha with low pasture growth and high rainfall following fertilizer application (Buckthought et al., 2015; PL Carey et al., 2016; Vogeler, Shepherd, & Lucci, 2014). The variation in these studies can be explained by factors such as soil type, climate conditions, and management practices. Understanding these factors is essential for optimizing Italian ryegrass production and implementing targeted management strategies to enhance yields.

The pattern of N loss from sheep and beef farms in different places in New Zealand has also been investigated by Hutchinson et al; (2019) and Monaghan et al; (2021), for hill country typology in Marlborough-Canterbury, a hill country typology in Northland-Waikato-Bay of Plenty, a high-country typology in Otago-Southland, and a finishing and breeding typology in Marlborough-Canterbury, and it was 8, 17, 5 and 16 ppm, respectively. The time of nitrate leaching has also been investigated (Houlbrooke, 2005; Monaghan et al., 2002). In South Island studies, the concentration of nitrate was highest at the beginning of the drainage season, then decreased to 2ppm after 300 mm of drainage. Similarly, Houlbrooke (2005) reported decreasing levels in nitrate to approximately 2ppm after 200 mm drainage from pallic soil. This may be due to different soil types in the different areas of study. However, in the study of Houlbrooke, the nitrate concentration increased in the grazing dairy cows up to approximately 5ppm and then decreased back to the previous levels. The reason for increasing nitrate concentration in the winter more than in spring is due to greater plant uptake of N in spring which is more than the uptake in the winter (Houlbrooke, 2005).

Several studies on nitrate leaching have also been conducted internationally to determine the influence of fertiliser and time of fertilising and to quantify plant uptake and nitrate leaching (Anzai et al., 2022; Aspel, Murphy, McLaughlin, & Forrestal, 2022; Cuttle, Scurlock, & Davies, 1998; Mo, Peng, Xin, & Wang, 2022; Zhao et al., 2022). In a UK study, Aspel et al. (2022) reported that applying of S fertiliser has the advantage on calcium ammonium nitrate fertiliser (measured using a free-draining sandy loam grassland lysimeter facility) by increasing the yield and fertiliser nitrogen recovery. In another UK study, plant (ryegrass) uptake of urine-N deposition was greater in summer (July) than later autumn

(November) (Cuttle & Bourne, 1993) when uptake gradually decreased from 40% of the N applied (equivalent to 300 kg N/ ha) in the first deposition, to 1% of the N applied (equivalent to 300 kg N/ ha) in the final deposition in late autumn. Therefore, much of the urine that was deposited closer to winter remained in the soil ready for leaching when drainage occurred.

In a study conducted in South Africa, after applying different rates of N fertiliser (0, 20, 40, and 80 Kg N/ha after grazing), showed that pasture production was highest for the N80 treatment and there was no difference in the herbage production from treatment N60. At the same time, nitrogen is used inefficiently at rates above 40 kg N/ha (Viljoen, Van der Colf, & Swanepoel, 2020). Similarly, (J. Bryant et al., 2011; Monaghan, Paton, Smith, Drewry, & Littlejohn, 2005; Yang, Lu, Ding, Yin, & Raza, 2017) found that nitrate leaching was higher with high amounts of N fertiliser, and (Granlund, Rekolainen, Grönroos, Nikander, & Laine, 2000) who recommended reductions in fertilisation (particularly manure spread because of their higher nitrogen contents compared to N fertiliser) to adjust nitrogen requirements thereby reducing nitrate leaching.

Furthermore, a French study showed a decrease in urinary N recovery by pasture with different deposition dates. When urine deposition happens later, the nitrate leaching will increase (i.e., between 43% and 77% of the autumn-deposited urine N was leached, compared with between 4% and 34% of the spring-deposited urine N (M.-L. Decau, Simon, & Jacquet, 2004; M. Decau, Simon, & Jacquet, 2003). In New Zealand, the loss of nitrate from different types of animals has been well documented. Bryant et al (2011) investigated nitrate leaching from the effects of soil type, climate, animal type, and nitrogen fertilisation in Taupo catchment. However, Bryant et al (2011) found that nitrate leaching was higher in beef cattle followed by dairy and sheep, and it was higher with increased rainfall for sheep and beef. In addition, nitrate leaching was higher with a higher fertiliser N rate, but it can be reduced in sheep farming with limited fertiliser N inputs and feeding winter crops mixed with Italian ryegrass.

2.4.4 Management Options to Reduce the N Loss to the Environment.

Different mitigation options have been investigated for reducing the amount of nitrate leaching while maintaining production and farm profitability (D. A. Clark et al., 2020; Grant Edwards, Pinxterhuis, Edwards, & Beare, 2015; McCarthy, Hutchinson, & Bowler, 2007). These include improving N fertiliser management, using the recommended stocking rate for sheep and beef, grazing pasture species with high ability to use N in soil efficiently, nitrification inhibitors, and changes by farmers. Most of these strategies have been assessed for use on dairy farms and currently, there are few options available to mitigate nitrate leaching from sheep and beef farming systems. Some of the practices used to reduce nitrate leaching in dairy systems, for example, stand-off pads are not practical or cost-effective options for sheep and beef farming (Anastasiadis, Kerr, MacKay, Roygard, & Shepherd, 2012; S. Morris & Kenyon, 2014).

The use of alternative forage species, to mitigate nitrate leaching from pastoral systems, is gaining more attention in the current research. Therefore, this part of the review summarises the use of alternative forages including Italian ryegrass and brassicas (kale, turnips), for reducing nitrate leaching from grazing systems.

2.4.5 Alternative Forages and Pasture Species

There has been increased interest in alternative forages to manipulate the excretion of urinary-N of livestock. Therefore, the potential of alternative forage species (i.e., brassicas) becomes a suitable strategy for reducing nitrate leaching in New Zealand. In addition, researchers suggested that alternative forage species alone have the potential to reduce nitrate leaching by up to 20% (R. H. Bryant, Snow, Shorten, & Welten, 2020). This review summarises research on some alternative forages (i.e., Italian ryegrass, turnips, and kale) that affect the pattern of nitrate leaching.

Italian Ryegrass

Italian ryegrass can reduce soil N effectively more than perennial ryegrass because it has faster growth rate during cooler seasons and more root activity (BJ Malcolm, Moir, Cameron, Di, & Edwards, 2015; Maxwell, McLenaghen, Edwards, Di, & Cameron, 2019; Poudel et al., 2022; Valkama, Lemola, Känkänen, & Turtola, 2015). As a result, Italian ryegrass have lower nitrate leaching loss (143 Kg N /ha), drainage, and greater N uptake (463 Kg N/ha), than perennial ryegrass (Maxwell et al., 2019; R. Woods, Cameron, Edwards, Di, & Clough, 2016). However, Italian ryegrass has a short-lived life cycle which limits the ability to mitigate nitrate leaching over the long term within a farming system (Lambert, Clark, & Litherland, 2004; Maxwell et al., 2019).

Nitrogen uptake in Italian ryegrass has been investigated in New Zealand and different countries (Table 2.8). Woods et al, (2016) reported less drainage and nitrate leaching loss of Italian ryegrass than perennial ryegrass (75 mm and 64.8 %) with the application of 700 kg N/ha cow urine (Table 2.8). Similarly, Wood et al; 2018 found less drainage volume and less nitrate leaching loss when applied cow urine for Italian ryegrass, plantain, and white clover mixture compared with perennial ryegrass and white clover mixture (Table 2.8). In a 12-month lysimeter study, Italian ryegrass receiving 700 kg N/ha from cow urine had 1.4 times greater N uptake than perennial ryegrass receiving the same amount of N (Maxwell et al., 2019) (Table 2.8).

Maxwell et al, (2019) obtained a 37.6 % higher DM yield over 12 months period of Italian ryegrass in comparison with perennial ryegrass (Table 2.8). Maxwell et al. (2019) found less cumulative drainage volume of Italian ryegrass than what is been found with R. Woods et al. (2016) and R. R. Woods et al. (2018). Therefore, less drainage volume, and more uptake from Italian ryegrass led to lower nitrate leaching (Table 2.8). In contrast to the previous studies, Poudel et al; 2022 reported no significant difference in nitrate leaching between species (Italian ryegrass, perennial ryegrass, and meadow fescue), but there is a significant difference in nitrate leaching loss when using a cover crop in compared to non-using cover crop.

Table 2.8: Nitrogen uptake, N leaching, drainage volume, and dry matter yield of Italian ryegrass compared to perennial ryegrass.

Author New Zealand	**Pasture species**	**N source**	**N loading rate Kg/ha**	**N leaching loss (Kg N/ha)**	**N uptake (Kg N/ha)**	**leachate nitrate C mg NO3$^-$ N-1 /L**	**Cumulative drainage V (mm)**	**DM yield t DM/ha**
R. Woods et al. (2016) (Lysimeter study)	P and WC M	Cow urine	Urine 700	205	811		275	24.3
	I		Urine 700	133	629		200	20.0
R. R. Woods et al. (2018) (Lysimeter study)	P and WC M	Cow urine	No Urine		542		332.5	18.7
			Urine 700	112.7	744			25.0
				113.4	744			24.5
R. R. Woods et al. (2018) (Lysimeter study)	I, Pl and WC M	Cow urine	No Urine		561		256.4	20.6
			Urine 700	12.5	679			24.0
				61.8	656			23.6
Maxwell et al. (2019) (Lysimeter study)	P		Urine 700	214-267	331	146-228	308	12.5
	I		Urine 700	143	463	119	165	17.2
Poudel et al. (2022) (Soil samples)	P					No difference between P and I		3.6-6.7
	I							3.5-5.7

P: Perennial ryegrass; I: Italian ryegrass; PL: Plantain; WC M: White clover mixture; C: Concentration; V: Volume; RC: Red clover.

Brassicas (Turnips and Kale)

Few studies related to nitrate leaching loss in sheep and beef farms grazing brassicas (Kale, turnips). Intensive grazing of brassicas during winter may lead to greater loss of nitrate in drainage (BJ Malcolm et al., 2016). Also, the application of fertilizer nitrogen (N) can lead to an accumulation of nitrate nitrogen ($NO3^{-}$-N) in brassicas when exceeding the requirement (A. Fletcher & Chakwizira, 2012). However, brassicas can capture soil nitrogen remaining after crop harvest, due to their deep tap root (Quintarelli et al., 2022).

Smith et al. (2020) carried out a 2-year leaching study (2018 to 2020) in northern Southland (NZ) using porous ceramic cup samplers under winter-grazed (dairy cow stock grazed) forage crops using fodder beet and kale (year 1 and year 2), on a free draining Edendale typic firm brown soil. Annual nitrate leaching losses were variable for kale for different soil depths, ranging from 5 to 280 kg N/ha over the 2-year study and averaged 80 kg N/ha over the entire study period. A two-year nitrate concentration study (GR Edwards et al., 2014) in a free-draining Balmoral soil to measure nitrate concentration from dairy cows winter grazing a fodder beet (FB); early-sown kale (EK); and late-sown kale with oats grown in sequence (LK) conducted in Canterbury, NZ. The study showed that urinary N concentration was low, and similar for cows offered EK, LK, and FB (2.3, 2.7, and 2.1 g N/L, respectively). In Canterbury, (Grant Edwards et al., 2015) reported that kale produced pre-grazing yields of 11.9–15.5 t DM/ha, with a protein content of 12.5%, equivalent to 240–300 kg N/ha.

Several studies have been conducted on nitrate loss from different brassicas, and the amounts of nitrate loss varied considerably: (6 - 173 kg N/ha) (Table 2.9). The majority of studies used modelled outputs or were measured with soil solution samplers for a short–term duration i.e., one year (Table 2.9). In (Table 2.9) there is a 33 % reduction in the nitrogen applied in more recent years as compared to the amounts applied 10+ years ago. Beare et al, (2010) investigated nitrate leached from kale, kale/wheat, and kale/triticale+ beans, and he found that kale with wheat was the highest nitrate leaching (79 kg N/ha) and the lowest with kale alone (10 kg N/ha) (Table 2.9). Shepherd et al, (2012) found nitrate leaching under kale (173 kg N/ha), and it was higher than the average nitrate leaching with what (Beare et al., 2010) found in his study (43 Kg N/ha) when using soil solution samplers/drainage calculations. Nitrate leaching was higher under kale in comparison with swede in the same study which was conducted in the central plateau (M Shepherd, Stafford, & Smeaton, 2012) whereas Maheswaran et al. (2021) reported greater cumulative nitrate leaching under brassica than perennial ryegrass/white clover in a mole drains drainage water losses study in Manawatu from sheep urine study.

These findings indicate that the choice of crops and their interactions play a significant role in nitrate leaching dynamics. While yield might be a contributing factor, the nature of the cropping system, including the presence of specific companion crops like wheat, can also influence nitrate leaching. Moreover, the variation in nitrate leaching under different crops, such as kale and swede, suggests that grazing days and urine deposition patterns, influenced by factors like livestock management and crop type, can contribute to nitrate leaching variations within farming systems.

Summer turnips registered low nitrate leaching (12-25.3 kg N/ha) when applying 95 kg N/ha (Hanly, Hedley, & Horne, 2017). In general, grazing of brassica returns large amount of N to the soil in the winter when the risk of drainage is high (M Shepherd et al., 2012). In conclusion, after reviewing the nitrate leaching under intensive sheep and beef farming in New Zealand and how is the nitrate lost in the soil after grazing different swards, the aim would be to compare the nitrate leaching values from the field trial with predicted nitrate leaching values from Overseer to calibrate nitrate leaching on Overseer from different forage species for the beef and sheep farms.

Table 2.9: Amounts of Nitrogen Leaching and Applied Under Different Brassica (Kale, Turnips, and Swede).

Author	Brassica	Region	Nitrogen applied (Kg N/ha/yr.	Nitrate leached (Kg N/ha/yr.	Measurement method
Beare et al. (2010)	Kale	Canterbury	282.0	10.0[1]	Soil solution samplers and drainage calculations
	Kale/wheat	Canterbury	321.0	79.0[1]	Soil solution samplers and drainage calculations
	Kale/Triticale + bean	Canterbury	321.0	40.0[1]	Soil solution samplers and drainage calculations
M Shepherd et al. (2012)	Swedes	Central plateau	200(+ grazed)	132.0	Soil solution samplers/drainage calculations

	Kale	Central plateau	200(+ grazed)	173.0	Soil solution samplers/drainage calculations
Hanly et al. (2017)	Summer turnips[2]	Manawatu	95.0	12.0-25.3	Mole drains drainage water losses
Smith and Monaghan (2020)	Kale	Southland		80	Ceramic cup samplers
S Maheswaran et al. (2021)	Swede	Manawatu		6.36	Mole drains drainage water losses

1: 60 cm depth, 2: followed by autumn grass.

2.4.6 Overseer and Nutrient Management Plans for Sheep and Beef Farms in New Zealand

Nutrient management plans include descriptions of the nutrient resources and current practices that may affect nutrient use, nutrient flows within a farm, description of production and environmental objectives that may affect nutrient use or nutrient flows in the farm by using Overseer (DairyNZ, 2013; Foundation for Arable Research, 2012; D. Wheeler, Ledgard, & Monaghan, 2007). Nutrient management plans are the primary tool recommended to reduce nutrient losses in a farm (Osmond, Hoag, Luloff, Meals, & Neas, 2015). In addition, it includes selecting the right fertilizer, amount, time, and place to match plant needs and reduce nutrient loss (USDA, 2020). Overseer is widely used in New Zealand (Muller, 2017), to evaluate feed flow, nutrient balance, and nitrate leaching (Vogeler, Vibart, & Cichota, 2017).

Overseer, a software program utilized to model on-farm nutrient cycling and estimate nitrate losses (in Kg nitrogen/hectare/year) into waterways, serves as a decision support tool for farmers and consultants in developing nutrient plans (DairyNZ, 2022b; Meinke, 2019; MA Shepherd & Wheeler, 2010). Developed by AgResearch Ltd, Overseer is owned by the Ministry of Primary Industries, Fertiliser Association of New Zealand, and AgResearch Ltd. Initially designed as an on-farm reporting tool, it is now used extensively for regulatory compliance and modeling potential mitigation strategies.

The program generates both production and environmental insights, aiding in assessing whether current management practices align with desired outcomes (D. Wheeler, Ledgard, & DeKlein, 2008; D. Wheeler et al., 2007). Users input farm productivity and inputs into Overseer, which assumes adherence to regional council guidelines and effluent regulations (MPI, 2021; Muller, 2017). This modeling tool encompasses a variety of farm systems, including pastoral, horticultural, arable, and vegetable, while calculating an annual nutrient budget representing the long-term average and edge-of-farm losses (D. Wheeler, 2016).

Input data is pivotal for Overseer's assessment of nutrient flows within farms or paddocks, with specific considerations for variables like effluent blocks (D. Wheeler et al., 2007). The program's output indices, such as nitrate leaching (Kg N/ha/year), aid in evaluating environmental impacts (Wheeler et al., 2007). Nevertheless, uncertainties exist within Overseer estimates due to inconsistent data input practices, farmer measurement accuracy, and variability in biophysical relationships (MPI, 2018).

While Overseer functions within the farm's physical boundaries, it accounts for catchment areas, wetland and riparian strips, nitrous oxide (N_2O) emissions, and the greenhouse footprint (CO_2) in farm inputs (Watkins, Wheeler, Brown, Smith, & Yoswara, 2015; D. Wheeler, 2016). Despite its advantages, Vogeler et al. (2017) noted that Overseer does not fully account for the higher nitrogen uptake of diverse pastures compared to simple ones, and it can be time-consuming to input data for complex systems (D. M. Wheeler, 2013).

Chapter 3 : General Methodology

The experiment was undertaken in 2022 between January and December.

3.1 Experimental Site and Treatments

The experiment took place at Massey University's Keeble farm, situated 5 km southeast of Palmerston North, Manawatu, New Zealand (40°24'02.0"S 175°35'52.8" E) on the Tokomaru silt loam, a Fragic Perch-gley Pallic Soil (Hewitt, 1998). Twenty drainage plots, each covering 800 m^2(40m x 20m), were established. Each plot had an isolated mole drainage system to capture drainage (Figure 3.1). The mole drainage from each plot was collected by a pipe drain installed at the plot boundary which conveyed this water to tipping bucket devices where the quantity and quality of drainage was monitored.

The experiment consisted of three forage treatments: sheep perennial ryegrass/white clover, sheep kale, sheep Italian ryegrass/turnips, and cattle perennial ryegrass/white clover (refer to Figure 3.1 and Table 3.1). The plots with Perennial ryegrass/white clover were sown in the spring of 2021 (as mentioned in Table 3.1). However, the brassica treatments, which were initially implemented in the spring of 2021, failed to grow. As a result, they were re-established in the autumn of 2022 using a roller drill and chain harrows.

Manawatu is classified as a class 5 finishing country where a high proportion of stock is sent to slaughter and replacements are often bought in, mostly carrying between 8 and 15 stock units per hectare (Beef+Lamb NZ, 2023). Therefore, the stocking rate in the experiment was selected to simulate an intensive sheep/cattle farming operation appropriate for this farm class and area (Table 3.2). The stocking density used in this study varied depending on the treatment groups and the specific requirements of each grazing plot. For the ewe lambs grazing the drainage plots for both brassica and grass treatments, a total of fifteen groups were formed to ensure simultaneous grazing of all fifteen plots, with 13 ewe lamb per plot.

Each plot was grazed by the same number of ewe lambs or heifers at the same time. However, the number of animals and grazing days differed between treatments. Specifically, the ewe lambs were divided into groups, while the heifers were separated into five groups, with two heifers per plot. Overall, the stocking density was adjusted to ensure uniform grazing across all plots while accommodating the specific requirements of each treatment.

3.2 Soil Fertility and Fertiliser Application

In May 2019, individual soil testing was conducted across all the drainage plots, with samples taken to a depth of 7.5 cm. The mean values for this analysis were; pH (5.7), Olsen P (mg/L soil) (24.0), sulphate sulphur (S) (mg/kg soil) (18.0), potassium (K) (me/100 g) (0.2), calcium (Ca) (me/100 g) (6.7), magnesium (me/100 g) (0.79), and cation exchange capacity (me/100 g) (12). The analysis was conducted at Hills Laboratory in Hamilton, New Zealand. The soil fertility data obtained from this analysis were then used to determine the annual fertilizer requirement.

3.3 Animal Management

The study and all animal handling procedures were approved by the Massey University Animal Ethics Committee (MUAEC 22/23).

Sheep management: Set-up for study

At the beginning of the study (mid-January 2022), a total of 195 ewe lambs (1 year of age, average of 37 Kg) and 10 heifers (1 year of age, average of 270 Kg) were selected. These animals were stratified based on their live weight and then allocated to different pasture treatment groups.

The duration of grazing and interval between the grazing of plots was based on plant growth rates and covers, which were assessed visually. The target post-grazing residuals were 1200 kg/ha for the sheep perennial ryegrass/white clover treatments and 1500 kg/ha for the cattle perennial ryegrass/white clover treatments. While kale and turnips were grazed only once during the winter season, the practice of mixing Italian ryegrass with turnips aims to extend the grazing availability into the spring season, ensuring a more consistent forage resource throughout the year. Therefore, grazing of perennial ryegrass and Italian ryegrass swards occurred in all seasons, thereby enhancing overall grazing sustainability, while the kale and turnip plots were only grazed during winter.

When the ewe lambs grazed the drainage plots for both brassica and grass treatments, they were divided into fifteen groups to ensure that all fifteen plots were grazed simultaneously. All plots were grazed at the same time with the same number of ewe lambs/heifers. However, this number of animals and grazing days differed between treatments.

The heifers were separated into five groups of two heifers per plot. Each plot within a forage treatment was consistently grazed for the same number of days. The number of grazing days and the specific dates when the drainage plots were grazed depended on the herbage mass and growth (Table 3.2).

Ewe lambs in the kale and turnips were gradually adapted to this treatment forage in a different paddock off-site, using on-off grazing with increasing grazing duration of brassica (Kale) each day (2, 4, 6, 8 hours on days one through four) before continuous grazing of brassica on the drainage plots.

3.3.1.1 Pasture Measurements

To measure the perennial ryegrass/white clover mass for within each plot, a rising plate meter (RPM, Filip's Manual Folding Plate Meter, Development and Prototype Engineering, 170 Railway Road, Palmerston North, New Zealand) was used. At least 20 compressed pasture height measurements were taken within each plot. The formula to calculate pasture mass (kg DM/ha) was as follows (Cárdenas, Balocchi, & Calvache, 2020):

average compressed pasture height (readings from RPM) x 158 (the multiplier) + 200.

The pre and post-grazing masses of all plots were measured before animals began grazing and after grazing. For each drainage plot and grazing event, five random quadrats (0.1 m^2 each) were cut to ground level using an electric shearing handpiece. These samples were then placed in plastic bags and taken to the lab, where they were oven-dried at a constant temperature (60°C to 70°C) to estimate the pre and post-grazing herbage mass in kilograms of dry matter per hectare (Kg DM/ha).

Additionally, the pre and post-grazing herbage mass (kg DM/ha) of the brassica plants were also determined by cutting all plants from a 1-meter length of row (1 cm above the ground). 5 plants were randomly chosen from each experimental plot (rows were 0.15 m apart, so each 1 m length of row represented 0.15 m^2), and a sub-sample was selected from these five random samples. The samples were then washed to remove soil contamination and separated into leaves and stems. The stem portions were cut into small pieces and then oven-dried at a constant temperature (60°C to 70°C) until they reached a stable weight.

3.4 Drainage and Runoff Measurements and Water Analysis

Water drainage from the plots was directed through drainage pipes into individual tipping-bucket flow meters placed in nearby sampling pits (Figure 3.2). Each tipping bucket was equipped with a data logger to continuously record the number of tips. The number of tips was converted to flow volume. A small proportion (approximately 0.1%) of the drainage water from every second tip of the tipping bucket flow meter was collected to create a mixed subsample for analysis at the end of each rainfall or drainage event (Christensen, Hedley, Hanly, & Horne, 2019). These samples were filtered through a 0.45-micrometer filter within 12 hours of collection and then frozen until a group of samples was ready for analysis.

The filtered samples were subject to analysis for NO_3^- - N using colorimetric methods on a Technicon Auto Analyser (Blakemore, Searle, & Daly, 1987).

3.5 Calculations

Urine patch measurement

$$Urine\ patch\ area\ (m^2/ha/day) = Urination\ frequency \times area \times number\ of\ animals$$

$$N\ excrete\ (g) = urine\ concentration \times urine\ volume \times urination\ frequency \times number\ of\ animals$$

$$Equivalent\ N\ application\ rate\ (KgN/ha) = \frac{N\ excreted / Urine\ patch\ area}{1000} \times 10000$$

3.6 Statistical Analysis

In our statistical analysis methodology, all data were analysed using SAS 9.13 (SAS Institute Inc, USA), and a predetermined significance level (α) was set at P=0.05. All data were subjected to proc mixed, and means were separated using LSD procedure. Cumulative drainage (mm), $NO3^-$- N concentrations, and cumulative NO_3^--N were analyzed using a model containing the fixed effects of treatment (sheep perennial ryegrass/white clover, sheep kale, sheep Italian ryegrass/turnips, and cattle perennial ryegrass/white clover) and sampling date and their two-way interaction. The models also included replicates (plots) nested within treatment as a random effect.

Drainage (mm) from one of the sheep perennial ryegrasses/white clover plots was greater than the average of the other plots and was deemed to be an outlier caused by a leak in a water pipe. Therefore, in the calculation of cumulative drainage and nitrate losses, the data collected from this particular plot were omitted.

3.7 Overseer inputs

Data were entered into OverseerFM (Version 6). Many of the input parameters for the intensive grazing system were based on field trials, including 10 heifers and 195 ewe lambs, covering 1.6 hectares, with four different treatments: sheep on perennial ryegrass/white clover, cattle on perennial ryegrass/white clover, sheep on kale, and sheep on Italian ryegrass/turnips. The site's annual rainfall was 1149 mm, and the soil type was Tokomaro silt loam, drained with mole and pipe drains.

Urea fertilizer was applied at a rate of 50 kg/ha in July 2022. Individual soil testing was conducted across all the drainage plots in May 2019, and the analysis was used in the Overseer inputs (as mentioned in part 3.2).

Figure 3.1: Layout of the drainage plots s (Sheep P/WC: sheep perennial ryegrass/white clover; Cattle P/WC: cattle perennial ryegrass/white clover; Sheep K: sheep kale; Sheep IR/T: sheep Italian ryegrass/Turnips).

Figure 3.2: Layout of the tipping buckets.

Table 3.1: Description of pasture treatment, cultivars, and seed rate for experiment 2022.

Pasture treatment	Species and cultivars	Sowing rate (Kg/ha)
Perennial ryegrass/white clover	Perennial ryegrass: Platform	19
	AR37 WC: Quartz	6
Turnips/ Italian ryegrass	Turnips: Green Globe/	1.25
	Italian ryegrass: Lush AR37	6
Kale	Kestrel	3.5

Table 3.2: Grazing dates for ewes* and heifers* on drainage plots

Grazing period	Grazing date	Grazing plots
Summer 2022	15 January to 21 January	Perennial ryegrass/white clover[1] Perennial ryegrass/white clover[2]
Autumn 2022	13 March to 19 March	Perennial ryegrass/white clover[3]
	5 May to 11 May	Perennial ryegrass/white clover[4] Turnip/Italian ryegrass plots[5]
Winter 2022	1 June to 7 June	
	4 July to 12 July	
	4 July to 30 July	Kale plots[6]
	15 July to 20 July	Perennial ryegrass/white clover[7]
	11 August to 17 August	Perennial ryegrass/white clover[8]
	11 August to 17 August	Italian ryegrass[9]
	1 August to 3 August	Kale[10]
Spring 2022	22 September to 29 September	Perennial ryegrass/white clover[11]
	22 September to 29 September	Italian ryegrass[12]
	19 October to 24 October	
		Italian ryegrass[13]
	19 October to 24 October	
		Perennial ryegrass/white clover and Italian ryegrass[14]

1, 2, 3, 4 (3 heifers/plot and 20 ewe lambs/plot); 5 (13 ewe lambs/plot); 6 (13 ewe lambs/plot); 7 (2 heifers/plot and 13 ewe lambs/plot); 8 (2 heifers/plot, 13 ewe lambs/plot); 9 (13 ewe lambs/ Italian ryegrass plot); 10 (13 ewe lambs/plot); 11 (2 heifers/plot, 13 ewe lambs/plot); 12 (13 ewe lambs); 13 (13 ewe lambs); 14 (2 heifers/plot, and 13 ewe lambs/plot).

Chapter 4 : RESULTS

4.1 Rainfall and Drainage

Figure 4.1 illustrates that the sheep and cattle perennial ryegrass treatments underwent regular rotational grazing throughout the experimental year of 2022. The grazing duration per month in the plots of perennial ryegrass/white clover remained below 7 days each month, with 130 stock units of ewe lambs and 125 stock units of heifers having the same grazing duration each time. The Turnip/Italian ryegrass plots were only grazed for 9 days during mid-winter (July). Additionally, the regrowth from the sheep Italian ryegrass/turnip plots underwent grazing from August to October, for 7 days. In contrast, the kale plots were grazed for 30 days in July/August.

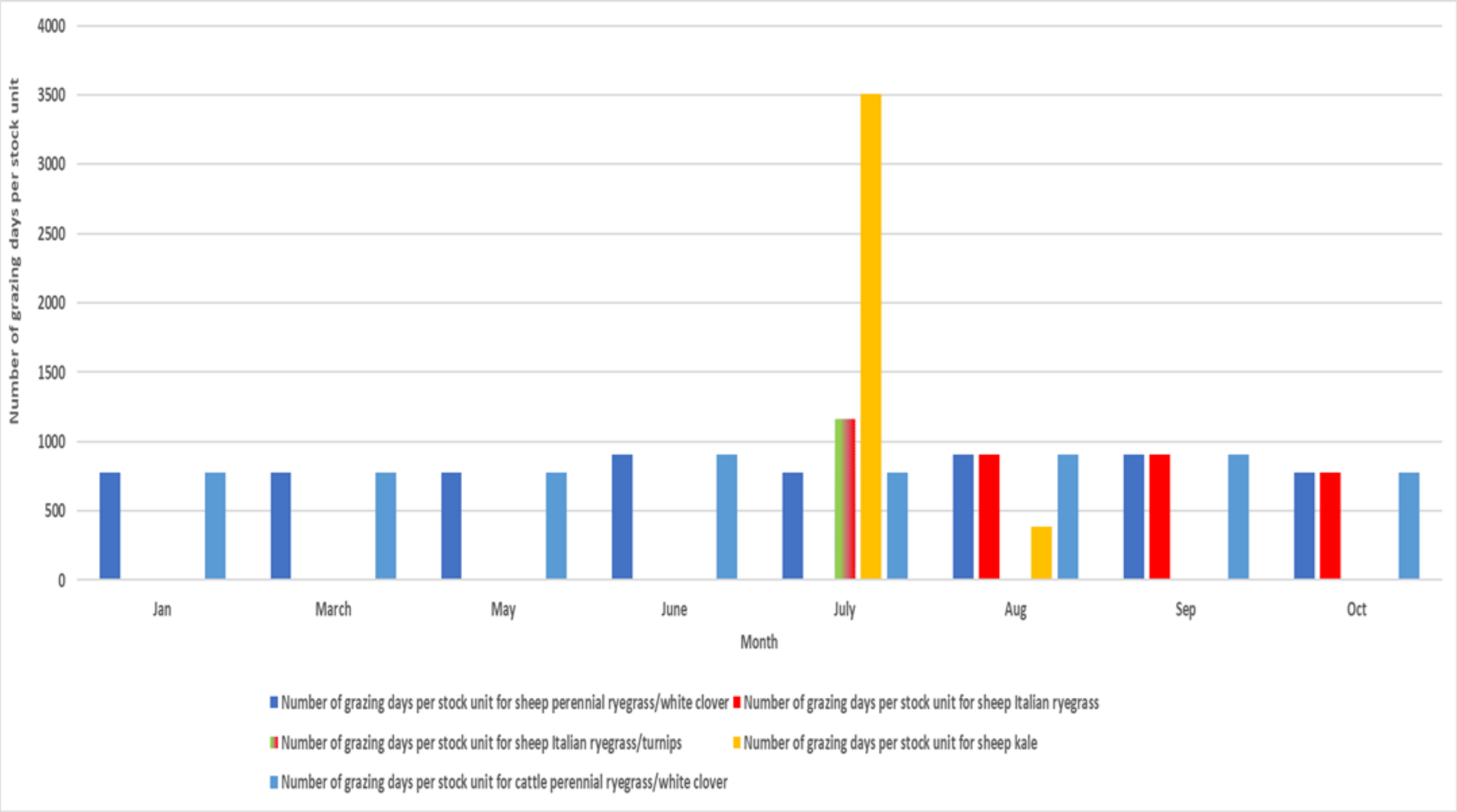

Figure 4.1: Number of grazing days per stock unit for the four treatments sheep Perennial ryegrass/white clover, cattle perennial ryegrass/white clover, sheep kale, sheep Italian ryegrass/turnips, during the experimental year 2022[1]**.**

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[1] Note: There were 13 ewe lambs/plot and 2 heifers/plot. The stock unit for each ewe lamb is 0.8 and 5 for each heifer, so we calculate it as the following.
Ewe lambs = 13/0.08 ha This equals to 162 ewe lambs per hectare.
Number of stock units for the ewe lambs= 162* 0.8= 130 ha
Number of stock units/ha/month = 130 * Number of grazing days each month
Heifers 2/0.08 ha this equal to 25 heifers per hectare.
Number of stock units for heifers = 25*5= 125 ha
Number of stock units/ha/month = 125 * Number of grazing days each month

The annual rainfall for the site was 1149 mm (Figure 4.2). As depicted in Figure 4.2, the peak rainfall was observed during (July) (208 mm). Conversely, the lowest rainfall occurred in (January) (13 mm).

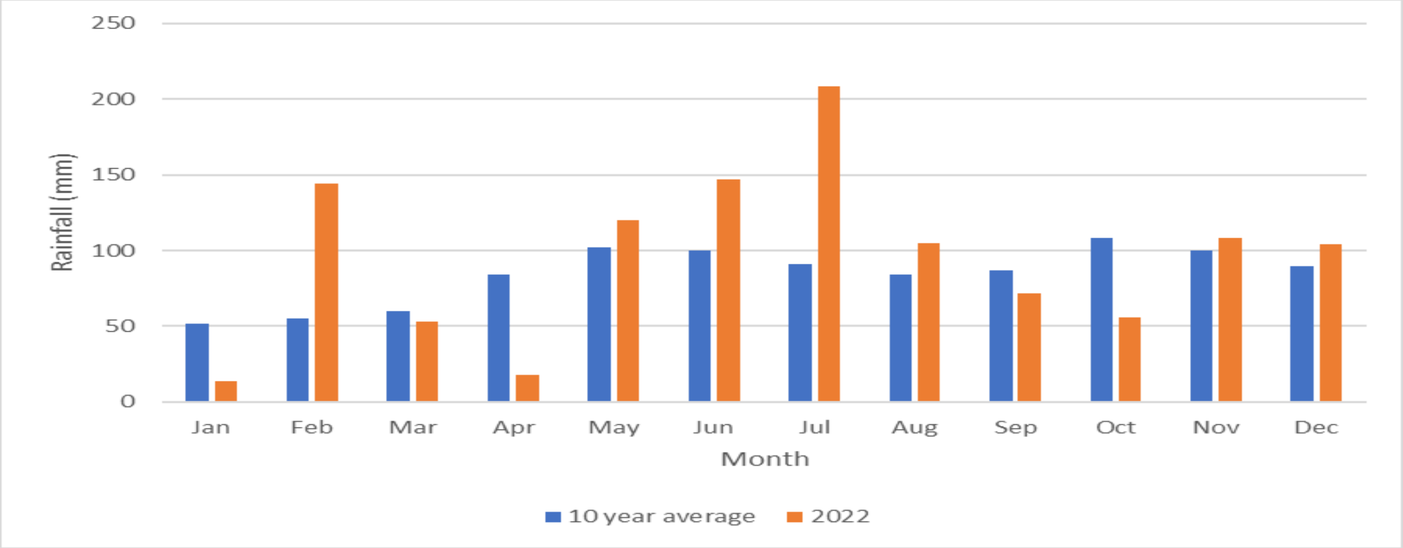

Figure 4.2: Ten-year average monthly rainfall for the experimental site and actual monthly rainfall in 2022, (Sourced from NIWA/AgResearch, Palmerston North meteorological station, 2 km from study site).

The soil temperature at 10 cm ranged between (5 to 23°C) throughout the year (Figure 4.3). The maximum soil water deficit was observed during late summer (February) with a value of around 130 mm. However, throughout the winter into late spring, the deficit was typically less than 7 mm. The measured drainage events generally coincided with periods of soil water surplus, as predicted by the soil water balance of Scotter, Clothier, and Turner (1979).

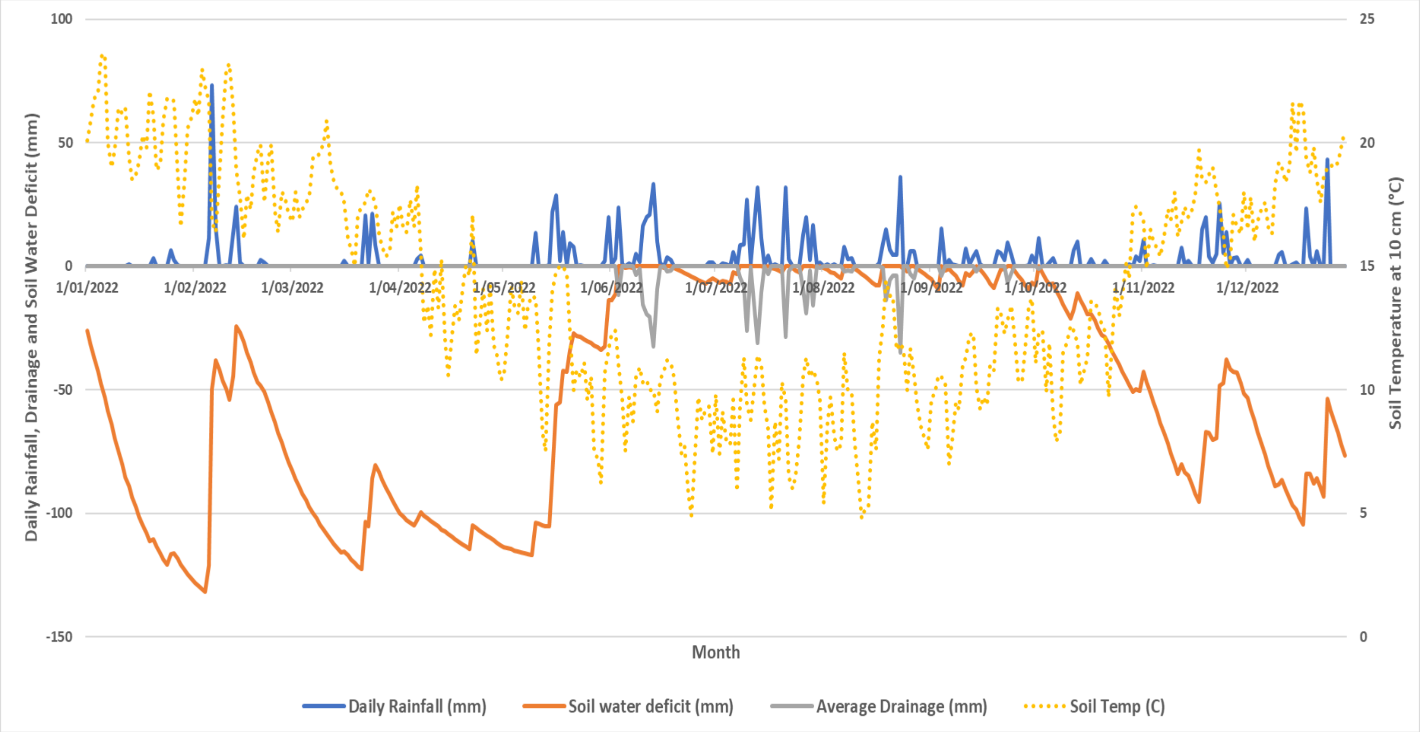

Figure 4.3: Mean daily drainage (mm), rainfall (mm), soil temperature (°C), and modelled soil water deficit (mm) for 2022. Soil water deficit and drainage are absolute values calculated at the weather station located in Palmerston North (Ews) but are displayed as negative values to add clarity to the figure.

The average cumulative drainage measured for the entire drainage season was 270 mm. The cumulative drainage was not significantly different, between treatments ($p > 0.05$; Figure 4.4) (Table 4.1). The drainage season commenced in June and ended in December (Figure 4.4). The size of drainage events from June to August was relatively consistent across the treatments but towards the middle of the season, some differences among treatments developed. Cumulative drainage increased during the initial drainage season before tapering off around the 85th day (September), beyond which there was a minimal increase in cumulative drainage levels (Figure 4.4).

Table 4.1: Effect of treatments, forage dates and their combined effect on cumulative drainage.

Effect	Num DF	Den DF	Standard error	Pr>F
Treat	3	16	24.36	0.1125
Date	11	176	13.22	<0.0001
Treat*Date	33	176	26.43	0.0010

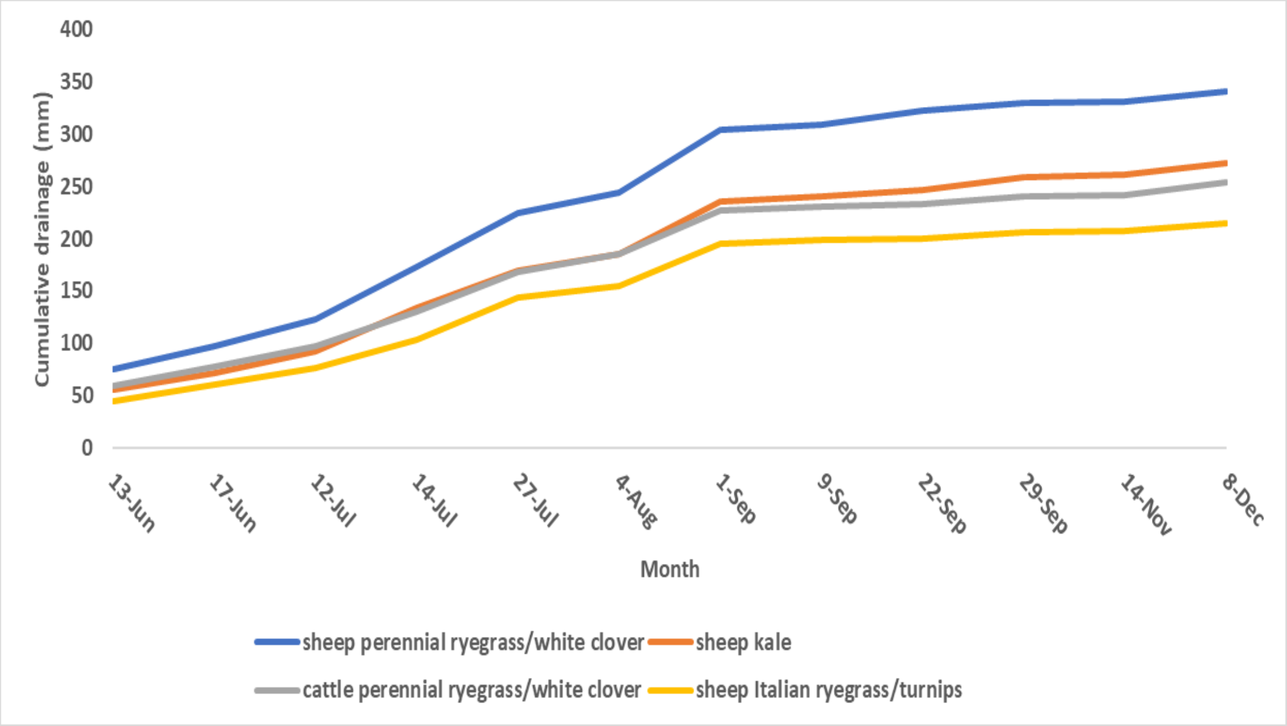

Figure 4.4: Cumulative Drainage (mm) in mole-pipe drainage from June 2022 to December 2022 under the forage treatments (sheep perennial ryegrass/white clover; cattle perennial ryegrass/white clover; sheep kale; and sheep Italian ryegrass/turnips).

4.2 Drainage water nitrogen

Inorganic N concentrations and cumulative losses

The nitrate concentration of drainage fluctuated among treatments over the year (Figure 4.5). The nitrate concentrations for all four treatments were <4 mg /L ($P>0.05$) for drainage events monitored in the earlier part of the year 2022 (June till October) (Figure 4.5) and there was no significant difference ($P>0.05$; Table 4.2) between all treatments. However, drainage under sheep kale had high nitrate (>2 mg N/L) from September till December. The nitrate concentration (Figure 4.5) from drainage under sheep perennial ryegrass/white clover rose from being the lowest from August through October to being the highest in December ($P<0.05$; >12 mg N/L). The peak concentrations of nitrate in sheep perennial ryegrass/white clover, sheep kale, sheep Italian ryegrass/turnips, and cattle perennial ryegrass/white clover were (12.9, 9, 7.6, and 6.7 mg N/L, respectively in December). The NH4+-N concentrations in the drainage events monitored over the study period were very low (<0.1 mg N/L), therefore, the data were not presented.

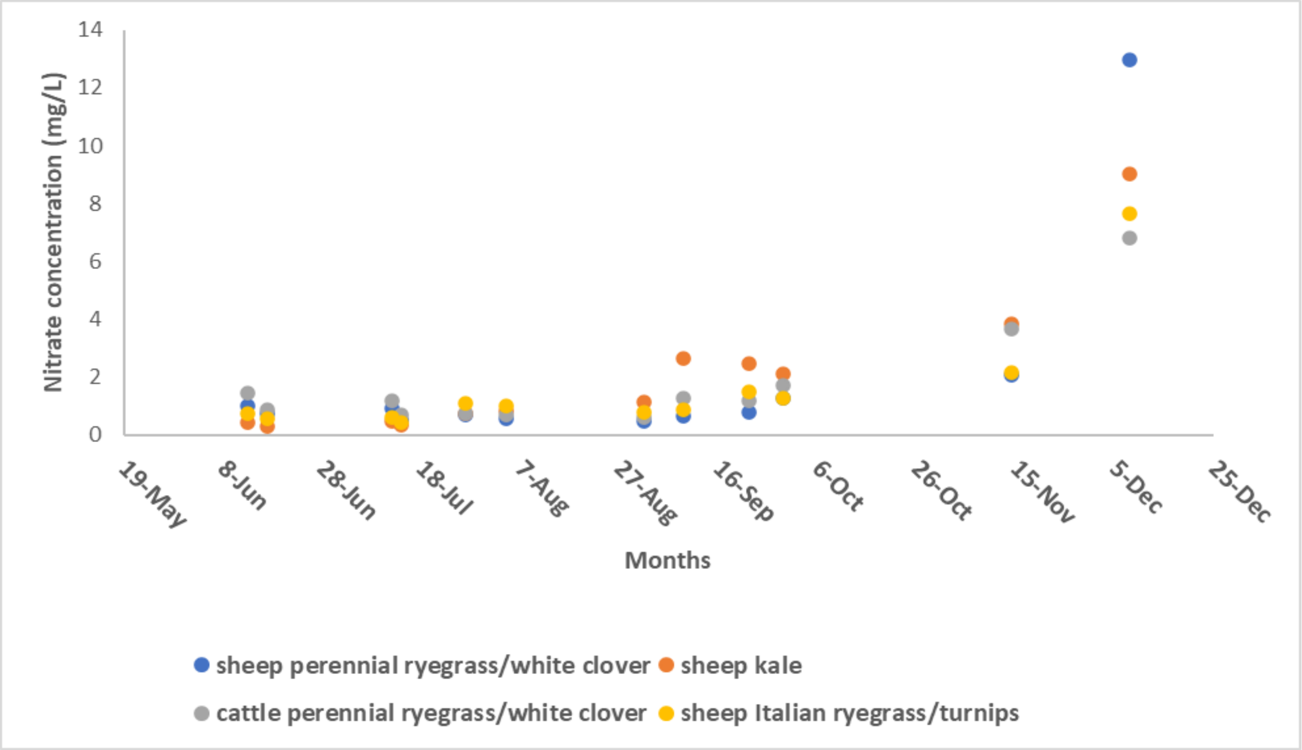

Figure 4.5: Nitrate concentrations (mg/L) in mole-pipe drainage from June 2022 to December 2022 under the forage treatments (sheep perennial ryegrass/white clover; cattle perennial ryegrass/white clover; sheep kale; and sheep Italian ryegrass/turnips).

Table 4.2: Effect of treatments, forage dates and their combined effect on nitrate concentration.

Effect	Num DF	Den DF	Standard error	Pr>F
Treatment	3	16	0.242	0.5767
Date	11	175	0.374	<0.0001
Treatment*Date	33	175	0.748	0.0602

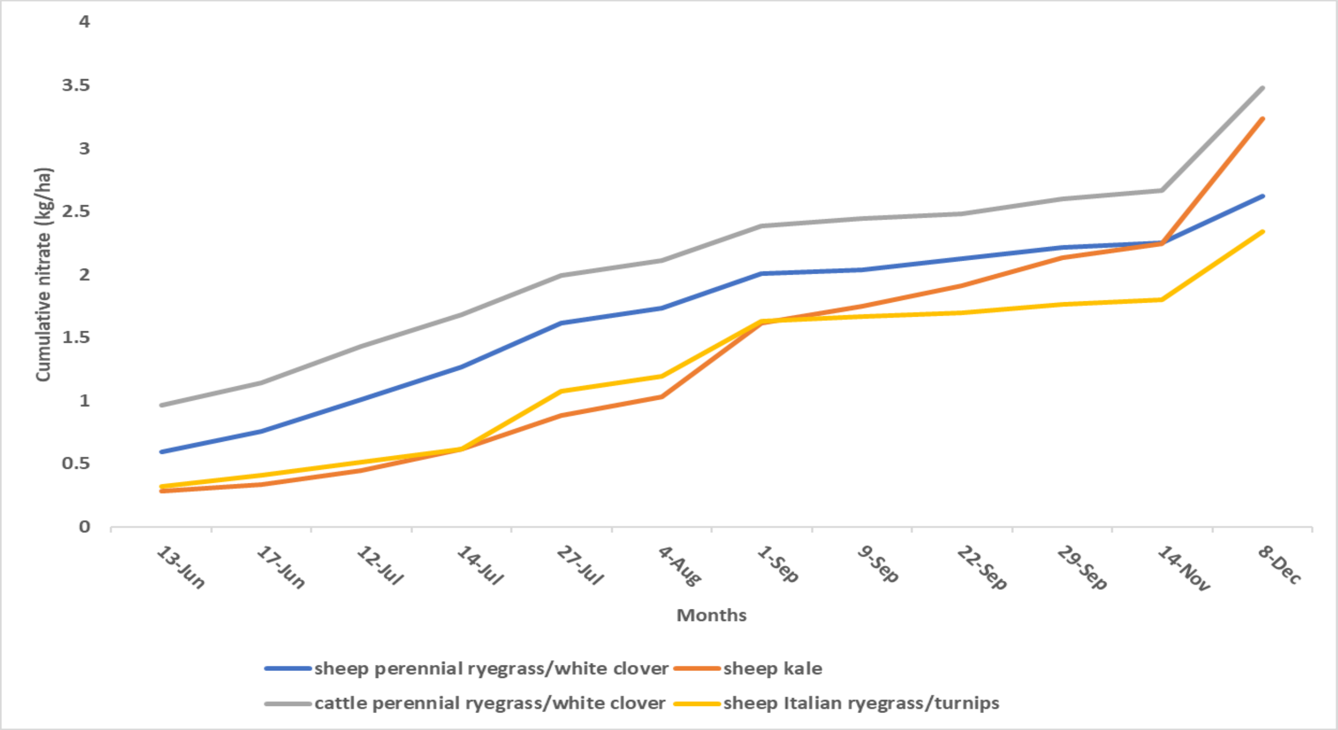

Figure 4.6: Cumulative leaching (kg N/ha) of nitrate-nitrogen (NO_3^--N) in mole-pipe drainage from June 2022 to December 2022 under the forage treatments (sheep perennial ryegrass/white clover; cattle perennial ryegrass/white clover; sheep kale; and sheep Italian ryegrass/turnips).

Cumulative nitrate losses from all treatments were less than 3.5 kg N/ha (Figure 4.6) and there was no significant difference (P>0.05; Table 4.3) between treatments. However, nitrate losses from all treatments remained < 1500 g N/ha (P<0.05) until the beginning of July.

Table 4.3: Effect of treatments, forage dates and their combined effect on cumulative nitrate.

Effect	Num DF	Den DF	Standard error	Pr>F
Treatment	3	16	0.525	0.6801
Date	11	165	0.275	<0.0001
Treatment*Date	33	165	0.549	0.8446

4.3 Overseer simulations

The field experiments carried out in this thesis generated data at the plot scale. The overseer simulation was run for one year. These measured results were compared with values simulated by the nutrient budgeting software Overseer. A series of Overseer files were constructed to predict nitrate-N leaching under the treatment systems. The Overseer files were established so as to represent or correspond to the pasture and animal combinations (treatments) as closely as possible. Overseer does not currently allow for the simulation of crop combinations, so it is not possible to model the turnips/Italian treatment. Results are shown in Table 4.1. The values predicted by Overseer are greater than the measured rates. One possible reason for these discrepancies is that Overseer assumes long-term conditions or steady state whereas the treatments were established on the plots recently. Although the absolute values generated by Overseer may be greater, the differences in leaching losses between sheep and cattle under ryegrass and white clover are very similar to the observed values. As for the measured data, while the Overseer leaching rate under cattle (10 kg N/ha/yr) is slightly larger than under sheep (8 kg N/ha/yr), the difference is within Overseer's margin of error and unlikely to be significant.

Table 4.4: Comparison of the measured cumulative nitrate (Kg N/ha) in the field with predicted results from OVERSEER.

Treatment	Measured values in the field (Kg N/ha)	Expected values from OVERSEER (Kg N/ha)
Sheep perennial ryegrass/white clover	2.6	8
Cattle perennial ryegrass/white clover	3.4	10
Sheep Italian ryegrass/turnips	2.3	-
Sheep kale	3.2	17

Having established Overseer's ability to predict the relative differences in leaching rates under cattle and sheep grazing ryegrass/white clover pasture, the model was used to explore the differences in leaching rates at greater stocking rates i.e., under more intensive systems. The plots were grazed at a rate that corresponded to a farm with a stocking rate of 10 SU/ha. Overseer files were established to model leaching under stocking rates of 14 and 18 SU/ha. It is assumed that each of these systems will produce progressively more grass to sustain these larger stocking rates. Some of this increase in production was achieved through use of nitrogen fertiliser.

As expected, nitrate leaching increases at greater stocking rates (Table 4.2). However, for the more intensive systems, the leaching rates under cattle increases to a greater extent than for sheep. On a farm growing a little more than 14 tonnes of pasture, the leaching rate under cattle might be approximately

36% (11 kg N/ha/yr vs 15 kg N/ha/yr) greater under cattle than for sheep. While these values are not particularly large when compared with leaching rates under dairy farms, they do suggest that there may be advantages to water quality from intensive grazing of sheep compared with cattle.

Table 4.5: Leaching rates under intensive sheep and cattle (heifer) grazing as modelled using Overseer.

SU/ha	Pasture production (Kg DM/ha)	Nitrate leaching under sheep	Nitrate leaching under cattle
10	8300	8	10
14	11283	10	13
18	14275	11	15

As the concentration of N (g/l) in the urine of sheep and cattle is somewhat similar, the differences in leaching rate between sheep and cattle is explained by reference to the distribution pattern of urine deposition. To help explain this point, Table 4.3, which presents some typical characteristics of animal urine, was developed from a review of the most relevant New Zealand literature.

Table 4.6: A comparison of some typical characteristics of sheep and cattle (heifer) urine.

	Urine N concentration (g/l)	Urine volume (l)	Urination frequency (#/day)	Urine patch area (m^2)
Sheep	10	0.2	21	0.04
Cattle	10	2	11	0.2

If these values are applied to the most intensive farm system modelled above (i.e., 18 SU/ha), then the area covered in urine each day on a per ha basis and the equivalent N application rates can be identified (Table 4.4). These calculations demonstrate two important points. Firstly, that the urine-N application rate is very small - cf with equivalent rates under dairy cows which are likely to be greater than 300 Kg N/ha)- and so lends supports to the very small leaching rates measured in this and the Maheswaran et al. (2022) study. Secondly, it makes clear the difference in the urine-N application rates between sheep and cattle at higher stocking rates.

Table 4.7: Area covered by sheep and cattle urine (m^2/ha/day) and the equivalent N application rate from a farm stocked at 18 SU/ha.

	Urine patch area/day (m^2/ha/d)	**Equivalent N application rate (Kg N/ha)**
Sheep	15	33
Cattle	10	101

While the information contained in the Tables above describe the urine-N distribution patterns of sheep and cattle, they do not quantify the effects of these patterns on leaching. To further evaluate the differences in the urine-N distribution pattern between sheep and cattle, a modified version of the model presented in Christensen et al. (2018). The simulation was developed specifically to study urine patch dynamics following grazing events. This model has been further developed to predict leaching under urine patches (D Horne, pers. comm. 2023). The values developed in the above Tables along with other required inputs were placed in the model to identify differences in leaching rates for the urine pattern of sheep and cattle.

The urine patch model suggested that the difference in leaching rates given the urine-N pattern of sheep and cattle identified here should be approximately 40%. This agrees very well with the difference of 36% simulated by Overseer. Again, while the nitrate leaching rates under these dry stock systems are smaller than those commonly associated with dairy farms, it would appear that intensive farming of sheep is a distinct advantage to water quality and warrants further investigation.

Chapter 5 : Discussion

The impact of nitrate leaching under dairy farms and the effectiveness of a range of mitigation options have been studied by several authors in New Zealand (Anastasiadis et al., 2012; Cameron et al., 2013; Christensen et al., 2019; Houlbrooke, 2005; Truong Thi Nguyen, 2023). However, the differences between dairy and sheep/beef farming systems and management practices makes it difficult to apply many of the mitigation options developed for dairy farms to sheep/beef farms (Anastasiadis et al., 2012).

In the current study, the nitrate losses in drainage under sheep grazing perennial ryegrass/white clover were very small (3 kg N/ha) which is similar to values measured at the same site by Maheswaran et al. (2022) who also grazed the plots with sheep. In comparison, the quantities of nitrate leaching (kg per ha) observed in this study were lower than some rates previously reported (8 to 50 kg N/ha) on the same soil type due to differences in stocking rate, grazing time, or the interaction between urine N load, plant uptake, and drainage (mm) (Heng et al., 1991; Magesan, White, & Scotter, 1996; Sarmini Maheswaran et al., 2022; White, Heng, & Magesan, 1998). For example, the studies by White et al. (1998), Maheswaran et al. (2022) and this present investigation can be compared. The sheep stocking rates per hectare on the same soil type with mole and pipe drainage were: 2800, 575, and 812, respectively. The corresponding nitrate losses for two years were recorded as: 35 and 43, <0.5 and 1.5, 0.4 and 1.1 kg N/ha, respectively.

In this study, there was no significant difference in nitrate leaching between plots of perennial ryegrass/white clover grazed by sheep compared with beef cattle (2.6, and 3.4 kg N/ha, respectively). While the large nitrate losses in drainage water from dairy farms have been well documented, and the small rates of N leaching under sheep have also been quantified on a number of occasions, the relative leaching losses under beef animals have received very little attention. As most sheep systems will have a beef component, this lack of measurements of nitrate leaching under beef animals is a gap in our knowledge, and one that the current study set out to address. The results presented here seem to suggest that with the stock class and the stocking rates used in this study, there is little difference between nitrate leaching rates under sheep and beef cattle when they are grazing pasture. Further field studies are required to see if this finding holds for larger and older beef cattle and/or at greater stocking rates.

All of the nitrate leaching losses measured here are small compared with nitrate losses measured under dairy cattle on a neighbouring farm. On a dairy farm located a very short distance from the present site, Nguyen et al. (2022) reported losses of 12 to 23 kg N/ha.

Holten and Urban (1992) found that urine-N output is influenced by dry matter intake (DM) and crude protein content of the diet. Additionally, research suggests that as the live weight of animals increases, the volume of urine excreted also tends to rise (Selbie et al., 2015). In the study reported by Carr (2015), the mean urination volume for 8-9 months old heifers with an average live weight of 215 kg were reported as 839 ml. Selbie et al. (2015) reported that ruminants excrete as much as 70–95% of the nitrogen (N) they consume. Hence, it is likely that animals with greater live weight will have more N in their urine. Therefore, the smaller nitrate leaching losses under cattle reported in this thesis, and perhaps the lack of any difference to leaching rates under sheep, may be attributed to the small live weight (270 kg) of the heifers. Hoogendoorn et al. (2016) reported low nitrate leaching under areas grazed by a combination of sheep and younger store cattle on medium slopes, with a mean range of 5 kg N/ha, respectively. Future research could focus on comparing the nitrate leaching rates under sheep and beef cattle with varying liveweights. Investigating how different classes of beef cattle, such as younger store cattle versus older and larger animals, impact nitrate leaching could provide valuable insights into the relative environmental impacts of different livestock types.

Grazing winter forage grazing such as kale (*Brassica oleracea var. acephala L*), swedes (*Brassica napus ssp. napobrassica*), and fodder beet (*Beta vulgaris L. ssp. vulgaris*) is a common practice in New Zealand, particularly in the South Island (B. J. Malcolm et al., 2018). Winter crops are commonly used to feed both non-lactating pregnant cows and sheep before calving or lambing. However, when coupled with high stocking density, this practice can result in concentrated deposits of urine nitrogen (N) on bare, wet soil. Such conditions, along with the N released as a consequence of tillage, can significantly contribute to nitrate leaching losses (PL Carey et al., 2016). Many studies have quantified nitrate leaching from winter forage grazing with cattle in New Zealand (PL Carey et al., 2016; BJ Malcolm et al., 2022; BJ Malcolm et al., 2016) and found nitrate leaching rates 21% to 66% higher compared to nitrate leaching observed when employing a catch crop or applying no urine. Maheswaran et al. (2022) examined nitrate leaching under sheep grazing brassica and found that cumulative nitrate leaching from brassica was 3.5 kg N/ha greater than cumulative nitrate under perennial ryegrass/white clover. This study aimed to measure nitrate leaching when mixed brassica with Italian ryegrass compared to brassica alone or with perennial ryegrass/white clover.

Catch crops are temporary crops grown between main crop seasons (PL Carey et al., 2016; P. Fraser et al., 2013; BJ Malcolm et al., 2022; B. J. Malcolm et al., 2018), have emerged as effective tools for mitigating nitrate leaching by minimizing nitrate losses from winter grazing with cattle (B. J. Malcolm et al., 2018). For example, Oats, barley, triticale, and Italian ryegrass are all species which can be utilised in a catch crop when sown after a winter feed crop. Indeed, the reason for growing the Italian – turnip treatment was to investigate the potential of the Italian ryegrass to extract some of the surplus nitrate that accumulates in the soil under turnips.

Evidence suggest that catch crops oats (*Avena sativa L.*) can reduce nitrate leaching under dairy cattle by 25-59% (PL Carey et al., 2016; PL Carey, Cameron, Di, & Edwards, 2017; BJ Malcolm et al., 2022; B. J. Malcolm et al., 2018). In a lysimeter study, the introduction of catch crops, specifically oats sown after a brassica crop and between 1 and 63 days after urine deposition in June and July, resulted in a 19-49% reduction in nitrate leaching compared to fallow treatments. A similar lysimeter study by Malcolm et al. (2018) reported a similar reduction in nitrate leaching when oats were sown directly after urine application in early July or early August. In contrast, Carey et al. (2017) found that in the winter-spring drainage period, oats exhibited a 25% reduction in nitrate leaching when sown earlier (in August) and harvested in November, in comparing to Italian ryegrass sown later (in September) and harvested in December. This effect was observed when oats were sown in August and harvested in November after simulated winter forage grazing on kale. Oats exhibited lower nitrate leaching compared to Italian ryegrass under conditions replicating winter forage grazing because Italian ryegrass grew only about half the dry matter and had half the nitrate uptake. This finding emphasizes the potential of distinct crop species to reduce nitrate leaching, especially during critical periods like winter forage grazing, thereby offering insights valuable for sustainable agricultural practices.

It is difficult to draw any conclusions about the effectiveness of the Italian ryegrass/turnips treatment in this study. While leaching losses under this treatment were not significantly smaller than the other treatments, they did have the smallest numerical value. More striking is the difference in leaching rates under turnips grazed by sheep as measured by Maheswaran et al. (2022) and losses under Italian ryegrass/turnips in the current study. Whereas the turnips treatment in the Maheswaran et al. (2022) study had leaching rates that were 2 to 6-fold greater than losses under perennial ryegrass/ white clover, in the current study the incorporation of Italian ryegrass with turnips reduced leaching rates to the point where they matched losses under ryegrass/white clover. This was due, in part, to the regrowth of Italian ryegrass after grazing in July (3070, 3531, and 2008 Kg DM/ha in August, September, and October, respectively). Presumably uptake of nitrate at this time meant that there was less N which was vulnerable to leaching.

Peter Carey, Malcolm, and Maley (2019) discovered that incorporating (sowing) Italian ryegrass after winter crops (early July to early August) significantly diminished nitrate leaching, removing 18 kg N/ha. However, their study noted Italian ryegrass yielding 6 tons in November dry matter per hectare. In contrast to the above studies, the present study offers a different perspective. In this study, kale yielded significantly higher dry matter per hectare (9102 kg DM/ha) compared to Italian ryegrass/turnips (2130 kg DM/ha), and the subsequent regrowth of Italian ryegrass (ranging from 2008 to 3531 kg DM/ha) even though the planting period was similar (early July to early August).

In comparing the nitrate concentration in drainage between this study and the findings of Maheswaran et al. (2022), a similar pattern emerged, mirroring observations made in 2020. The primary nitrate leaching events occurred predominantly in the early part of the drainage season, with subsequent drainage events and sharply increased in July but, in the latter part yielding only marginal increases in leaching. This consistent leaching pattern aligns with alterations in nitrate concentration within the drainage water. The mean nitrate concentration in the collected drainage samples from all four treatments remained relatively within (ranging from <0.5 to 13 mg N/L), gradually intensifying with successive drainage events. Notably, during the initial drainage period, cumulative drainage exhibited a pronounced increase, subsequently tapering around the 85th day, a deviation from the typical drainage trends in the Manawatu region, where post-mid-October drainage is atypical due to accumulating soil water deficit levels (Figure 4.3). Despite the presence of potentially excessive nitrate in the soil, the total leached nitrate remained limited, attributed to the year's low drainage volume, which impeded a substantial nitrate leaching volume (Jabloun, Schelde, Tao, & Olesen, 2015; Thi Truong Nguyen et al., 2022).

Interestingly, cumulative nitrate leaching under the brassica (kale) treatment was not greater than the losses under ryegrass/white clover. Once possible contributing factor to the smaller leaching losses under kale compared to the leaching rates under brassicas observed by Maheswaran et al. (2022), is the preference that the sheep exhibited for kale leaves over stems. As a consequence, they consumed the leaves, leaving the stems largely intact in the plots after mid-August. This selective grazing behaviour potentially contributed to a decrease in urine-N given that nitrate concentrations tend to be higher in the stems of kale (Chakwizira, de Ruiter, & Maley, 2017). Another reason is that the plots have been cultivated for about 3 years as part of Maheswaran et al. (2022) study and so the quantity of N released on cultivation in this study is smaller than the flush of N released when long-term pasture is cultivated.

In September all four treatments were sprayed with glysophate and re-established (September and December). Plots were resown in September 2022 using a direct drill and urea fertilizer (50 kg/ha). However, the observed increase in leaching following the application of glyphosate and plots reestablishment in September and December can be due to a number of factors. For example, glyphosate application reduced plant uptake, and consequently, increased nitrate availability in the soil. In addition, the organic matter and pasture residue mineralization is likely to have contributed to elevated soil N levels (Cookson et al., 2005; X. G. Li et al., 2017). Therefore, for these reasons, there is a risk that late season rains and attendant drainage may result in increased nitrate leaching from areas growing winter brassica crops (Monaghan et al., 2013).

In the current study, the small increase in nitrate leaching observed from September to December could be related to the relative areas covered by urine patches which are considered the primary source of nitrate leaching (H. Di & Cameron, 2002). Although all the treatments exhibited a reduction in nitrate leaching, the sheep grazing on Italian ryegrass/turnips demonstrated numerically lower cumulative nitrate leaching compared to other treatments, specifically sheep grazing on kale, after mid-August. This difference can be attributed to the regrowth of Italian ryegrass in August, September, and October.

The study conducted field experiments at the plot scale to investigate the effects of different treatments on nitrate leaching. These losses were compared with Overseer simulations. Initially Overseer files were established to represent the grazing of the plots as closely as possible. At this lower stocking rate (corresponding to a farm system with 10 SU/ha), Overseer generated values that were greater than the measured values. However, importantly, in terms of a comparison of leaching rates under sheep verse cattle, Overseer yield a similar result i.e., no significant difference in nitrate leaching.

Having established the credibility of Overseer in this context, the model was used to investigate leaching losses under more intensive dry stock farms. When stocking rates were increased to 14 and 18 SU/ha, nitrate leaching increased under both sheep and cattle. However, leaching rates under intensive sheep and beef cattle systems were still less than under intensive dairy farming. Interestingly, the leaching rate under cattle at greater stocking rates is larger than it is under sheep at equivalent stocking rates. Sheep farming would appear to be the form of common pastoral farming with the smallest environmental footprint relative to water quality.

The distribution of the urine-N load deposited by sheep and cattle was explored as an explanation for the differences in leaching rates between sheep and cattle at greater stocking rates. When stocked at similar rates (18 SU/ha), the more numerous sheep which also urinate more frequently, spread the urine-N load over a greater area. The modified urine patch model of Christensen et al. (2019) was used to investigate the implication for nitrate leaching of spreading urine over a greater area. This model suggested that at the greater stocking rate, leaching rates under cattle grazing a ryegrass/white clover pasture would be approximately 40% larger than the corresponding rate under sheep. As noted, this was in close agreement with the Overseer estimate of the difference in leaching between these two systems (36%). This agreement is not surprising as Overseer also has a urine patch model. However, the model of Christensen, (2019) makes the role of the distribution pattern of urine-N deposition more explicit.

The discrepancies between model predictions and field measurements underscore the complexity of nutrient cycling processes and the challenges in accurately capturing them through modeling. Several factors could contribute to these disparities, such as variations in climate, soil types, and animal behaviours that are not fully accounted for in the model.

In conclusion, while the OVERSEER model provides a valuable tool for assessing the potential environmental impacts of different farming practices at the farm scale, the study highlights the importance of validating model predictions with field data. The substantial difference in the predicted and measured values for the 'sheep kale' treatment indicates a need for more comprehensive data in the literature, especially concerning sheep grazing on brassica, to improve the accuracy of future modeling efforts. This study contributes to the ongoing dialogue on the refinement and validation of nutrient budgeting models in agricultural research.

Chapter 6 : Conclusion

At smaller stocking rates, such as the 10 SU/ha studied here, nitrate leaching under sheep and beef cattle is small, and not likely to be very different. Overseer estimates support this conclusion. Overseer simulations suggest that at greater stocking rates nitrate leaching rates under sheep and beef cattle are likely to increase but are still considerably less than losses under dairying. However, for intensive production systems, difference in nitrate leaching under sheep and cattle begin to develop with beef animals leaching greater amounts. A model that simulates N dynamics under urine patches supports this contention and explains this difference in terms of the urine-N distribution pattern. Sheep spread urine-N over a greater area, and this translates into smaller nitrate leaching losses.

It is difficult to draw conclusions about the ability of Italian ryegrass to reduce nitrate leaching losses when sown in combination with turnips. While leaching losses in this study are much smaller than those measured at the same site under turnips in similar conditions, the effect of tillage in recent years on the quantity of mineralised N may have also contributed to much smaller nitrate leaching losses along with Italians ryegrass mopping up surplus nitrate.

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