Effects of alternative forages on nitrate leaching under intensive sheep grazing

S Maheswaran*, LM Cranston, JP Millner, DJ Horne, JA Hanly, PR Kenyon and PD Kemp

School of Agriculture & Environment, Massey University, Palmerston North, New Zealand

**Corresponding author.* Email: *S.Navarathnam@massey.ac.nz; L.Cranston@massey.ac.nz*

Abstract

There is increasing interest in the use of alternative forages to improve animal performance and reduce nitrogen (N) leaching on farms. A system-scale field trial, which included 20 hydrologically isolated drainage plots (800 m^2/plot) was carried out at Massey University's 'Keeble' farm to investigate the effects of forage type on ewe and lamb performance and the quantity of N lost in drainage. Four forage types (treatments) were studied: perennial ryegrass/white clover (RGWC), plantain/WC (PWC), Italian ryegrass/WC (IRWC) and swedes (Brassica). The forage types were included as ~24% area of a self-contained farmlet, with the remaining area (~76%) being RGWC. Ewes were weighed at mating, pre-lambing and weaning, and lambs were weighed at weaning. Drainage (mm) from each plot was measured using a tipping-bucket flow meter and sub-samples of water were analysed for nitrate-N, ammonium-N and total-N losses. The forage types had no effect (P>0.05) on ewe or lamb live weight at any occasion. The average nitrate-N losses for RGWC (0.77 kg N ha^{-1}), PWC (0.45 kg N ha^{-1}) and IRWC (0.56 kg N ha^{-1}) treatments did not differ (P>0.05) and was lower than the brassica treatment (6.36 kg N ha^{-1}).

Keywords: drainage water; forage species; live weight; nitrogen loss; sheep grazing

Introduction

Globally, there is increasing concern about the contamination of waterways with nutrients, in particular, the nitrogen (N) leached from agricultural land (Houlbrooke et al. 2004). Nitrate (NO_3^-) is the most common form of N contaminant in drainage water (Haynes & Williams 1993). Urine N deposited by sheep on the pasture is the main source of NO_3^- leaching in the sheep grazing pasture system (Williams & Haynes 1990). Surplus N (not required for plant growth) in urine patches is susceptible to leaching when drainage occurs (Haynes & Williams 1993). Nitrate leaching is widely believed to be significantly lower from sheep farming systems compared to dairy cow systems (Williams & Haynes 1994). However, in order to remain economically viable, sheep production systems in New Zealand have intensified over time with greater use of N fertiliser and higher stocking rates (Morris & Kenyon 2014). Therefore, it is possible that N leaching losses are greater than historical figures would indicate and should be reassessed under modern intensive practices.

There is increasing interest in the use of alternative forages in pastoral agriculture in New Zealand. Some of these forages are used to reduce N leaching, i.e., improve environmental outcomes (e.g., plantain; *Plantago lanceolata* L. and Italian ryegrass; *Lolium multiflorum* Lam), while others are employed to increase animal performance (e.g., winter crops). There is evidence that the use of plantain on dairy farms can help to mitigate N losses as a result of a decrease in the concentration and amount of urinary N excreted, due to an increase in urine volume and decrease in ammonia production in the rumen (Navarrete et al. 2016). It is known that rapidly growing pasture species, such as Italian ryegrass, display greater N uptake during winter and, therefore, reduce N leaching compared to a perennial ryegrass (*Lolium perenne* L)/ white clover (*Trifolium repens*) sward when grazed by dairy cows (Woods et al. 2016). In contrast, winter crops such as brassicas (e.g., swedes and turnips) produce large quantities of forage (e.g., 8-15 t DM ha^{-1}) and are grazed with high stocking rates during winter when grass growth rate is low (Lucci et al. 2013). Following grazing, the land is left bare until conditions allow for re-sowing in spring. This process of grazing winter brassica species may return large amounts of N to the soil during winter, and subsequently may result in very high rates of N leaching (Monaghan et al. 2013).

Currently, there are no studies of leaching under modern, intensive sheep production systems, particularly when alternative forages are grazed. Further, the limited previous studies carried out estimated N leaching indirectly through animal data (e.g., based on grazing study data) or the use of lysimeters or suction cups. The present study utilises hydrologically isolated plots, which allow for the complete capture of all leached nutrients and drainage water. The aim of this study was to quantify and compare N leaching under sheep grazing on four different forage types (perennial ryegrass (RGWC), plantain/white clover (PWC), Italian ryegrass/white clover (IRWC) and brassica), and to compare the sheep performance in farm systems that incorporated alternative forages. These forages were selected for their ability to reduce N leaching and/or improve animal performance.

Materials and methods

This study was carried out at Massey University's Keeble farm, 5 km southeast of Palmerston North, Manawatu, New Zealand (40°24'02.0"S 175°35'52.8"E) with the approval of the Massey University Animal Ethics Committee (MUAEC 19/20). The site is located in a flat to easy rolling landscape (c. 3% slope) on the Tokomaru silt loam soil, a Fragic Perch-gley Pallic Soil (Hewitt 1998). This paper presents the data collected during 2020.

Experimental design and treatments

The design included four farmlets (each approximately 3.32 ha). Three of the farmlets had 0.81 ha (24% of the area) sown in one of three alternative forages, i.e., IRWC or PWC or brassica (swedes; *Brassica napus* ssp. *Napobrassica*). The remaining area of each farmlet was in RGWC. The fourth farmlet was entirely RGWC (3.31 ha). Each farmlet was stocked at 14 ewes/ha for the entirety of the experiment (46 ewes per farmlet) and was reflective of an intensive sheep-farming operation for this farm class and area (Beef + Lamb New Zealand Economic Service 2021).

The research site included an area with 20 drainage plots (five plots/treatment). Each plot was 40 m x 20 m and contained a hydrologically isolated mole pipe drainage system. The drainage plots were sown with the pasture species reflective of their treatment. These pastures were sown in the autumn of 2019 (21 March 2019) with a roller drill and chain harrows. The plantain/WC and IRWC plots were over-sown in April 2020. The brassica was sown by direct drilling in the spring of 2019. Nitrogen fertiliser, in the form of urea (46% N), was applied to the brassica plots at the rate of 30 kg N ha^{-1}in March. Nitrophoska (12% N) and urea were applied to the other three treatment plots at the rate of 30 kg N ha^{-1} in April and October, respectively. The plots were grazed according to the cumulation of forage and best grazing management practices for these species.

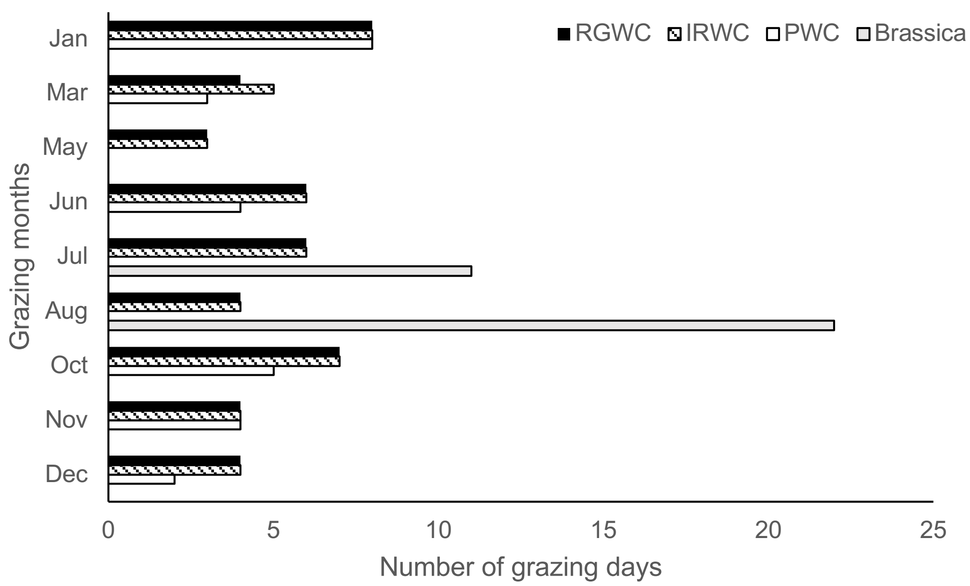
Ewe management and measurements

A total of 184 pregnant mixed-age Romney ewes were selected from Massey University's "Keeble" flock at the start of the study (27 June 2019). The ewes were stratified by live weight (LW) and number of fetuses carried (single/twin/triplet) and allocated to the four forage treatments (n=46 at start) to ensure that treatments did not differ in LW or number of fetuses carried. Ewes that died or were culled were replaced in February 2020, with ewes of a similar LW. Romney rams were introduced on 9 April 2020 for a period of 34 days (two rams per farmlet of 46 ewes). The rams were rotated between mobs on Day 17, to avoid the impact of ram performance on pregnancy rate. All ewes were pregnancy diagnosed using trans-abdominal ultrasound on 1 July 2020 and diagnosed as non-pregnant, single, twin- or triplet-bearing. Three ewes diagnosed as non-pregnant were replaced by pregnant ewes of similar stage of gestation.

Each mob of ewes was rotationally grazed within their farmlet. The duration of grazing and the interval between paddocks was adjusted based on pasture growth rate and cover, which were assessed visually. When the ewes grazed the drainage plots, each mob was separated into five mobs to enable all five replicates to be grazed at the same time (approximately nine ewes/replicate). All replicates within a forage treatment were always grazed for the same number of days and ewes were moved when the target post-grazing residual was reached in any replicate. Where appropriate, treatments on the drainage plots were grazed at once to minimise the effect of differing weather conditions (see Fig. 1). However, the brassica crop was grazed continuously during winter, after the ewes were gradually adjusted to the diet using on-off grazing with increasing grazing durations of brassica each day (2, 4, 6, 8, hours on days one through four) before continuous grazing. Due to mild winter conditions in 2020, the brassica yield was considerably higher than had been estimated, and ewes were unable to graze all the bulb material before set-stocking, with an estimated 5,461 kg DM ha^{-1} remaining.

Approximately one week before the planned start of lambing (26 August 2020), ewes were set stocked on the RGWC area of each farmlet at a stocking rate of 18

Figure 1 Number of days sheep grazed each of the forage treatments (RGWC: perennial ryegrass/white clover; IRWC: Italian ryegrass/ white clover; PWC: plantain/ white clover; brassica) on the hydrologically isolated drainage plots during 2020.



ha[1], until the end of lambing (15 October 2020). Ewes and lambs within each treatment were then rotationally grazed as one mob until weaning (12 December 2020). Ewes were weighed at mating, pre-lambing, and weaning. Lambs were also weighed at weaning.

Drainage water volume measurements and water analysis

Rainfall data were sourced from the National Institute of Water and Atmospheric Research (NIWA) site which was located approximately 2 km from the research area. Drainage water from each isolated plot was channelled through drainage pipes into individual tipping-bucket flow meters located in sampling pits nearby. The flow rate of drainage water was measured with an individual tipping bucket (~5 L) for each plot. Each tipping bucket was calibrated dynamically to account for large tip volumes at high flow rates (Humphrey et al. 1997). All tipping buckets were instrumented with data loggers to provide continuous flow rate measurements. Water from the bucket was tipped over a pipe with small hole on it which passed the sub-sample (~0.5 ml) to a larger container for storage until the completion of the drainage event. After the completion of each drainage event, water samples (~100 ml) were collected manually from the storage container for water quality analysis.

Approximately 50 ml of the subsample was filtered through a 0.45 µm filter. Filtered samples were analysed for NO_3^--N and ammonium-N (NH_4^+-N), using a Technicon Auto Analyser (Blakemore et al. 1987). The unfiltered samples were analysed for total N (TN) content using the persulphate digestion method of Hosomi and Sudo (1986). The amount of NO_3^--N, NH_4^+-N and TN losses (kg ha^{-1}) were calculated as the product of the measured drainage quantity and their concentrations.

Statistical analysis

All data were analysed in SAS 9.4 (Statistical Analysis System, version 9.4; SAS Institute Inc., Cary, NC, USA). Live weight of ewes was subjected to an analysis of variance using the MIXED procedure. The model included the fixed effects of measurement time, forage treatment and the interaction between measurement time and forage treatment. Lamb LW, cumulative drainage (mm), NO_3^--N concentrations and cumulative losses of TN, NO_3^--N and NH_4^+-N were analysed using proc GLM with forage treatment as fixed effect and means were separated using LSD procedure. Drainage (mm) from one of the PWC plots was five times 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 N losses, the data collected from this particular plot were omitted.

Results

Rainfall and drainage

In 2020, the spring was very wet compared to winter, with a particularly high monthly rainfall (136.7 mm) being recorded in September (Fig. 2a). The drainage season in 2020 began in late April and ended in December. The average annual quantity of water that drained across all plots was 83 mm. Throughout the season, there were 13 drainage events from the mole-pipe drainage system, ranging between 0.13 to 19.0 mm (average across all plots). Large drainage events were measured in September and December (Fig. 2a), and the majority of drainage occurred in December (average of 33 mm).

The drainage (mm) of all the treatments remained consistent during autumn (April to June) (average of 1 mm) and winter (July to September) (average of 28 mm), however, during spring (October to December), differences in drainage (mm) was observed between treatments. In the last three months of the year, high (76.2 mm; $P<0.05$) and low (32.9 mm $P<0.05$) drainage (mm) were observed from the brassica and PWC treatments, respectively. Overall, the annual cumulative drainage of the brassica (103 mm) was 7 to 20% greater than that of the other treatments (Fig. 2b).

Nitrate-N concentrations

The average NO_3^--N concentrations of all treatments ranged from 2.7 mg L^{-1} (PWC) to 6.5 mg L^{-1} (brassica) (Fig. 2b). The concentration of NO_3^--N (mgL^{-1}) in drainage water fluctuated between treatments over the year. For RGWC, IRWC and PWC treatments, relatively high NO_3^--N concentrations were observed at the commencement of drainage events in April (RGWC:15.3 mg L^{-1}; IRWC:14.7 mg L^{-1}; PWC 10.5 mg L^{-1}) and, subsequently, when drainage commenced again in June (RGWC:7.3 mg L^{-1}; IRWC:17.3 mg L^{-1}; PWC 6.6 mg L^{-1}). Whereas for the brassica, the highest NO_3^--N concentration of 16.5 mg L^{-1} occurred at the end of the drainage season in December. Overall, compared with the other treatments, the brassica treatment had higher ($P<0.05$) NO_3^--N concentrations in the last six drainage events.

Nitrate-N loss and cumulative NO_3^--N losses

Nitrate-N leached from all treatments remained less than 0.3 kg N ha^{-1} until late July (Fig. 2c). Then, with subsequent drainage events, the losses from the brassica treatment increased ($P<0.05$), while the losses from other treatments remained low. The cumulative leaching load of NO_3^--N kg ha^{-1} from the brassica plots (6.36 kg N ha^{-1}) was higher ($P<0.05$) than that of the other three treatments, with large differences observed particularly in the latter part of the drainage season (Fig. 2c). The annual NO_3^--N leaching loads from IRWC (0.56 kg N ha^{-1}) and PWC (0.45 kg N ha^{-1}) were very low and did not differ ($P>0.05$).

Cumulative NH_4^+-N and total N losses

Ammonium made a minor contribution to the total N leached, and across all treatments represented 7% of inorganic N. Total N losses for RGWC (2.6 kg N ha^{-1}), PWC (1.5 kg N ha^{-1}) and IRWC (2.1 kg N ha^{-1}) treatments were similar ($P>0.05$), but 73 to 84% lower ($P<0.05$) than that of the brassica treatment (16.8 kg N ha^{-1}).

Figure 2 Rainfall (mm) (a) in 2020 (NIWA/Ag Research, Palmerston North meteorological station, 2 km from study site), mean NO_3^--N concentrations (mg L^{-1}) and cumulative drainage (mm) (b), and mean $NO3^-$-N losses (g ha^{-1}) and cumulative NO_3^--N losses (kg ha^{-1}) (c) from perennial ryegrass/white clover, Italian ryegrass/white clover, plantain/white clover and brassica in 2020.

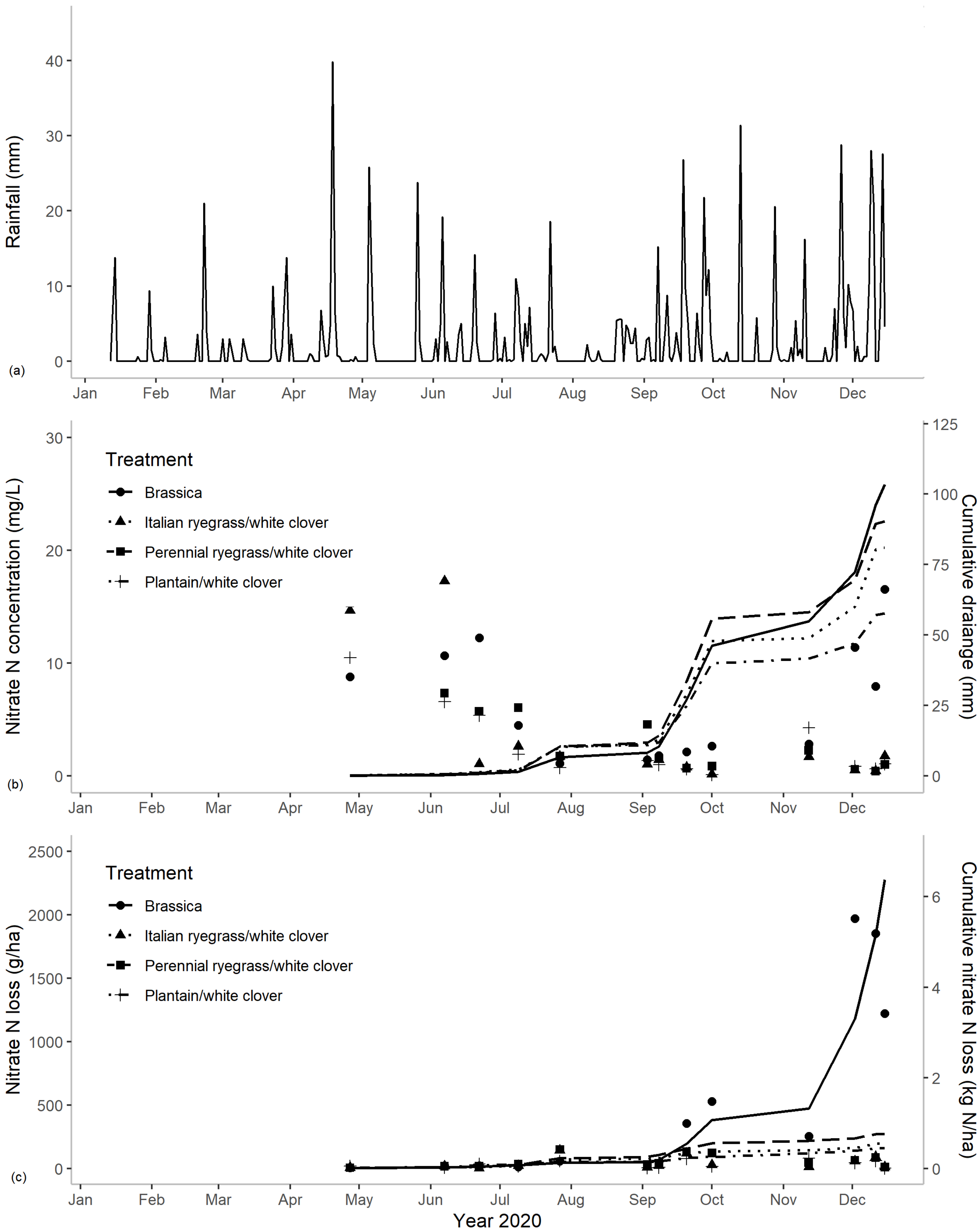


Table 1 Effect of forage treatment (RGWC: perennial ryegrass/white clover; IRWC: Italian ryegrass/ white clover; PWC: plantain/ white clover; brassica) on live weight (LW; kg) of ewes at mating, pre-lambing and weaning, and lambs at weaning.

Treatment	No. of ewes	Ewes LW (kg)			SEM	No. of lambs	Lambs LW (kg)	SEM
		Mating	Pre-lambing	Weaning			Weaning	
RGWC	40	72.3	95.1	75.6	1.40	62	27.3	0.49
IRWC	39	70.5	94.8	76.2	1.44	56	26.6	0.49
PWC	42	74.8	94.2	73.0	1.40	69	25.4	0.45
Brassica	43	69.7	89.3	74.6	1.42	62	26.6	0.46

Sheep performance and number of grazing days on alternative forages

Forage treatments had no effect ($P>0.05$) on ewe or lamb LW on any occasion (Table 1). The RGWC and IRWC plots were grazed nine times throughout the year (Fig. 1) for a total of 46 and 47 days, respectively. The PWC plots were grazed six times and the number of grazing days was relatively low (26 days). The brassica plots were grazed only once continuously during winter (33 days).

Discussion

There was no effect of forage treatment on ewe or lamb LW. Therefore, the impacts of N leaching under different forage types can be directly compared without confounding effects of different animal performance. The lack of an effect of treatment on LW is perhaps unsurprising given that each forage treatment made up 24% of each farmlet system. The brassica treatment had no observed benefit to animal performance, although the crop was not utilised fully. The excess bulb could have been used to stock more sheep or to graze for a longer period, and potentially improve animal performance.

The winter of 2020 was relatively warm with less rainfall, compared with the last five years (NIWA 2021). The length of drainage season was longer than reported in other studies conducted near the current research site (Magesan et al. 1996; Christensen et al. 2019). The drainage (mm) at the end of the season (October to December) was also higher than reported in the previous studies. The higher drainage (mm) measured for the brassica treatment plots was likely due to the lower evapotranspiration rates associated with bare soil during spring (Hanly et al. 2017).

The average NO_3^--N concentrations of drainage water collected from RGWC, IRWC and PWC treatments started high (above 5 mg L^{-1}) for early-drainage events and decreasing with successive drainage events over the winter months (Fig. 2b), as observed by Heng et al. (1991) and Magesan et al. (1996). It is likely that the NO_3^--N that had accumulated in the soil under urine patches, prior to the commencement of drainage events in April and between the drainage events in April and June, contributed to early NO_3^--N leaching for the RGWC, IRWC and PWC treatments (Fig. 2b). This demonstrates that grazing RGWC, IRWC and PWC treatments during late summer and autumn period is an important source of the NO_3^--N that accumulates in soil which, in turn, contributes to NO_3^--N leaching during the early stages of the drainage season. Due to the very low leaching losses observed in the present study, the N accumulation under sheep grazing pastures appears to be much lower than the N accumulation under cattle grazing pastures (Rodriguez et al. 2020). The brassica treatment, however, had higher concentrations of NO_3^--N leached during the initial stage of the drainage season which may have been due to the mineralised N that accumulated as a result of renewing the forage (spraying herbicide and direct drilling) (Fraser et al. 2013).

Grazing of RGWC, IRWC and PWC treatments during spring or late winter did not increase the NO_3^--N concentrations (Fig. 2b). Although drainage continued through into December, NO_3^--N concentrations remained <1.8 mg L^{-1}. This trend of drainage water NO_3^--N concentrations declining over the winter months has been previously reported in dairy cattle studies on the same soil type (Hanly et al. 2017; Christensen et al. 2019). Those studies suggested that lower NO_3^--N concentrations in spring and early summer were likely caused by a combination of factors, such as active pasture growth thereby increased NO_3^--N uptake and insufficient drainage volumes to move significant quantities of NO_3^--N into mole channels before the completion of the drainage season (Christensen et al. 2019).

The brassica treatment had greater NO_3^--N concentrations than other treatments at the end of the drainage season in December. The brassica plots were intensively grazed during winter after which the land was left bare for 17 weeks until re-sowing in late December. The lack of plant uptake likely resulted in higher amounts of NO_3^--N susceptible to N leaching under bare soil in subsequent drainage events. A dairy cow study has also shown that N leaching losses from forage-crop grazing during winter could be more than twice that under grazed RGWC (Monaghan et al. 2013). It is important to note that, in the current study, ewes began grazing the brassica plots in the latter part of the winter and had not completely eaten all the bulbs before set stocking for lambing. As a result, there is a risk of greater total NO_3^--N leaching if the ewes had been able to graze for a longer duration and harvest all the bulb material. It might also be argued that the drainage season in 2020 was protracted, therefore, the losses from the brassica were potentially greater than might have occurred in a more typical year. A daily soil-water balance model analysed using 30 years of data, indicated that only three out of 30 years had greater quantities of drainage after mid-October (Hanly et al. 2017). In addition, resowing of the subsequent forage crop in 2020 was delayed until 27 December 2020 due to prolonged wet soil conditions. To determine the losses that occur when brassica plots are resown more typically in mid spring multiple years of research is required. The amounts of NO_3^--N leached per ha were much lower than those previously reported (8 to 50 kg N ha^{-1}) for sheep grazing RGWC on the same soil type (Heng et al. 1991; Magesan et al. 1996; White et al. 1998). Differences in the stocking rate and grazing time may explain the differences among the sheep studies. For example, White et al. (1998) stocked 40-50 sheep in an area of 0.125 ha for a week in May 1990 and 21 sheep for 5 days in July 1991 and reported losses of 35 and 43 kg N ha^{-1}, respectively, while in the current study, stocking rate was kept constant (46 sheep in an area of 0.4 ha), and the number of grazing days was adjusted according to the amount of forage available. Lower NO_3^--N loss measured in the present study compared to the previous studies could also be due to lower drainage (mm) recorded in 2020 than those reported in the previous studies. The values reported by Heng et al. (1991), Magesan et al. (1996) and White et al. (1998) appear to be very high (~40 kg N ha^{-1}) and more recent measures of leaching under dairy cows (Hanly et al. 2017; Christensen et al. 2019) are more comparable to the present study (2 to 10 kg N ha^{-1}).

The N leaching values observed in the IRWC and PWC treatments were lower than that of RGWC treatment but did not differ significantly. Multiple years of studies with contrasting rainfall patterns are required to determine if differences might occur among forage treatments.

Conclusion

This study suggests N leaching under intensive sheep grazing of pasture-based forages (RGWC, IRWC, PWC) was very low on drained pallic soil. The grazing of a winter crop (brassica) is likely to result in a marked increase in N leaching in years where resowing of subsequent forage is delayed until the end of spring. Further, none of the alternative forages improved animal performance above the levels achieved on RGWC pasture.

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