Does wintering on diverse pastures or kale crop affect N loss risk? Findings from a commercial case study dairy farm near Methven

Racheal H. BRYANT[1*], Jeremy CASEY[2,3], Eva HARRIS[3], Holly WILLIAMSON[1,5] Lisa BOX[4],
Ryan BARLOW[4], Paige BECKETT[1], Claire V. C. PHYN[6] and Stewart F. LEDGARD[4]

[1]*Lincoln University, PO Box 85084, Lincoln 7647*
[2]*BackTrack Dairies, 815 Back Track, Highbank, Methven, 7782*
[3]*Enviro Collective, c/- Barrhill Chertsey Irrigation Limited, 326 Burnett Street, Ashburton 7700*
[4]*BSI - AgResearch Group, Ruakura Research Centre, Private Bag 3123, Hamilton*
[5]*DairyNZ Limited, PO Box 85066, Lincoln 7647*
[6]*DairyNZ Limited, Private Bag 3221, Hamilton 3240*
*Corresponding author: Racheal.Bryant@lincoln.ac.nz

Abstract

This case study describes farmer-led research comparing the practicalities and nitrogen (N) leaching risks from dairy winter grazing on kale or diverse pasture. Two herds of dairy cows grazed either a kale (n=360) or diverse pasture (n=60) paddock on a commercial dairy farm in Methven during June and July 2023. A perennial pasture mix was sown in August following winter grazing on kale. Soil cores were sampled to 15, 30, 60 and 90 cm depth increments in July and November 2023. Herbage yield and N content were measured in November. Following winter grazing in July, soil inorganic N in the 0-90 cm depth under the kale crop areas was two times greater than under pasture (138 vs 67 kg N/ha), and five times greater in November following re-growth of pastures (152 vs 29 kg N/ha). The lower soil inorganic N under pasture could be attributed, at least in part, to a lower stocking density and increased herbage N uptake (98 and 35 kg N/ha under respective pasture and kale paddocks). Pasture wintering demonstrated practical and environmental benefits over kale wintering, but further efforts are likely required to explore cost benefits.

Keywords ammonium, *Brassica oleracea*, crop, nitrate

Background

In the southern regions of New Zealand, grazing non-lactating dairy cows off pasture and on forage crops is commonly practised over the winter months. This cost-effective strategy provides animals with a high-quality feed whilst limiting treading damage to soils and pastures on the milking platform and supports obtaining target pasture covers at calving and through early lactation. However, grazing forage crops through the cool and wet winter months is recognised as an animal husbandry practice that can pose a risk to the environment (Ministry for the Environment 2020) as well as to animal welfare (Neave et al. 2022). High stocking densities on high yielding annual crops, such as brassicas or beets, can be a significant source of nitrogen (N) transfer leading to risk of groundwater degradation through heavy manure loading, treading damage, nutrient leaching and surface run-off into waterways (Monaghan et al. 2007). To manage these risks, changes in government and regional council policy around the criteria for permitted activity may require farmers to alter their management practices to continue intensive winter grazing on crop or adopt an alternative pasture-based system.

Dairy farmers who choose to winter their cows on crops do so for several reasons, with the key drivers typically economics and access to support land or contract grazing. Annual brassica or beet crops provide a resource efficient feed for non-lactating cows in late gestation due to maintaining high quality at high yields. In contrast, lower yielding pastures decline in quality with increasing yield as older leaves become fibrous and senesce. The implications are that, for the same area of land being offered per cow, more supplement is needed to meet cow nutrient requirements with a pasture-based diet compared with a crop diet. To help address this issue and to reduce the risk of muddy conditions and nutrient losses, pasture-based wintering systems typically use more land area per cow wintered. This increase in area corresponds to a reduction in stocking density and reduced risk of urine patch overlap. Furthermore, the pasture acts as a catch crop following grazing and, depending on the species composition of the pasture, the variation in rooting depth and winter activity may provide additional advantages in terms of capturing urine N deposited during grazing (Nichols and Crush 2007). Consequently, under a pasture wintering system the soil N load from urine and nitrate leaching risk is expected to be lower than that under crop. However, the measured environmental impact of wintering dairy

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cows on crop versus pasture has received little attention with few published studies to date (Simon et al. 2024; Smith et al. 2024). Smith et al. (2024) noted that pasture management prior to and during winter grazing played an important role in managing N leaching risk. Previous research comparing different crops has demonstrated that feeding low protein crops and/or supplements can reduce urinary N concentration (Edwards et al. 2014, Smith and Monaghan 2020) and following a winter forage crop with a catch crop can reduce the risk of nitrate leaching (Malcolm et al. 2018). First principles and published studies (Simon et al. 2024; Smith et al. 2024) would support the hypothesis that wintering on pasture could reduce the risk of nitrate leaching via the following mechanisms:

1. Less excretal N per unit area. Pasture wintering typically requires more area per cow, so the risk of urine patch overlap is reduced compared with intensive stocking on crops.
2. Increased plant N uptake. If not severely damaged, pastures begin regrowth after grazing and transfer soil inorganic N to organic forms in leaf tissue. Although good management practices for intensive winter grazing include the re-sowing of affected areas, often this is delayed due to cold, wet conditions and the opportunity for N uptake is reduced.

Information is required to test not just these hypotheses, but the practicality of adoption of alternative pasture wintering systems in the Canterbury region. Previous research identifies uncertainty to be a major challenge for adoption of environmental mitigation strategies (Fleming 2019), and the importance of farmer-to-farmer extension in long-term adoption is also recognised (Kansanga et al 2021). Therefore, the purpose of this research was to use a farmer experience comparing pasture-based and kale crop wintering practices and to provide quantitative data for assessing the nitrate leaching risk using a case study of a commercial dairy farm in Methven, Canterbury. A secondary objective was to use this case study to determine the variation in mineral N, using a deep soil coring method, for the purpose of developing suitable experimental methods for future research.

Approach

A mid Canterbury environmental consultancy group (Enviro Collective), which represents several irrigation schemes in the region (Barhill Chertsey Irrigation, Acton Farmers Irrigation and Rangitata South Irrigation), established a collaboration with a local Methven farmer, who was using two different wintering practices, and scientists from the Low N Systems research programme (https://dairynz.co.nz/low-n). Their goal was to inform local farmers of the practicalities of alternative pasture-based wintering. The two wintering systems compared were: 1. Kale crop plus baleage and 2. Diverse pasture plus baleage.

Site characteristics and baseline management

The study was conducted at Back Track Dairies Ltd, Highbank, Canterbury (43.64355°S, 171.73784°E, 280 m asl). The study areas consisted of 10 ha of kale and 5 ha of pasture on a Templeton moderately deep, well drained, Pallic soil (S-map online, https://smap.landcareresearch.co.nz/; Manaaki Whenua, Hamilton). Prior to establishment, soil pH, Olsen P (mg/ml), sulphate S (mg/kg) and cation exchange capacity (me/100g) was respectively 6.1, 22, 12 and 15 for the kale paddock (July 2022, 7.5 cm depth) and 6.2, 46, 11 and 11 for the pasture paddock (November 2022, 15.0 cm depth). The history of the areas differed in that the kale area was previously permanent pasture under pivot irrigation on the milking platform. The pasture paddock was on adjacent support land without irrigation and had previously been used for winter grazing with successive kale and fallow periods over the previous eight years. The kale area was established by spraying out perennial ryegrass and white clover pasture mid November 2022, followed by direct drilling with kale (cv. Regal) at 4.5 kg seed/ha on 10 December 2022. The diverse pasture area was sown with diverse pasture on 16 December 2022 after full cultivation. The diverse mix, which consisted of Italian ryegrass, triticale, red clover, white clover, Persian and Caucasian clover, chicory and plantain, was sown at a combined rate of 38 kg seed/ha, and was chosen on the expectation that a diverse pasture would be more drought tolerant and help to break up hard soil from years of compaction after wintering on kale. A post-emergence spray was applied at 3 L/ha (Dynamo) to control weeds in January 2023. Following establishment, 2.2 t DM/ha was conserved as baleage from the pasture area in February 2023 before closing the paddock for winter.

From 1 June 2023, the two areas were grazed using 360 mixed-age (pregnant, non-lactating) Holstein Friesian x Jersey cows on the kale area and 61 carry-over (non-pregnant, non-lactating) Holstein Friesian x Jersey cows on the pasture area. The feed allocation area was 7.3 and 20.5 m^2/cow/day for the kale and pasture treatments, respectively, to achieve target forage DM allocations of 9.5 and 7 kg DM/cow/d. Fresh allocations were provided daily for cows on kale and every second day for cows on pasture using electric fencing. Pasture baleage from the same source was offered to both groups by allocating either 2.5 and 6.0 kg DM/cow/d to the respective kale and pasture treatment herds, as well as an additional 2.5 kg DM/cow/d of ryegrass straw to the cows on kale. The kale was 30% leaf and 70% stem containing metabolizable energy (ME) and crude protein (CP) content of 12.5

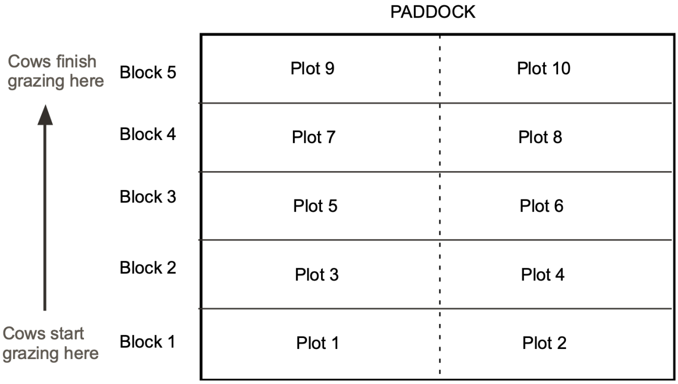

Figure 1 Arrangement of blocks and plots in each paddock in relation to grazing.

MJ/kg DM and 18.2 %. The ME and CP of the pasture was 10.3 MJ/kg DM and 13.8% CP, while the silage was 9.6 MJ/kg DM and 18.9% CP. Both groups of cows had *ad libitum* access to fresh water. Space allocation and back fencing was based on ensuring access to the concrete troughs, with a maximum area of 5 ha for kale cows and 1 ha for pasture cows.

On 30 August 2023, seven weeks after cows finished winter grazing, a perennial seed mix (Cates, Ashburton) containing perennial ryegrass (cv Abergreen AR1, Hustle AR1, Base AR1), white clover (cv. Fiona, Aberlasting), and red clover (cv. Rosi) was direct drilled into the kale area at 27 kg/ha following top work cultivation and was undersown into the pasture area at 10 kg/ha.

Fertiliser applications between establishment in December 2022 and final measurements on 6 November 2023 included 600 kg of Serpentine SuperPlus at sowing in December 2022 (P:S:Mg:Ca minerals at respective percentages of 6.8:8.5:5.0:16.5) and three applications of SustaiN-based fertilisers (Ballance Agri Nutrients, Tauranga) on 16 January, 20 February and 8 August 2023 (69, 46 and 30 kg N/ha, respectively) amounting to 145 kg N/ha in total for the kale area. Over the same period, the pasture area received a total of 60 kg N/ha as split applications on 25 January and 8 August 2023.

Measurements and monitoring

Soil moisture and temperature data under irrigated areas were monitored using nearby (within 300 m) Aqualinc moisture sensors (Aqualinc Research Ltd, Ashburton), which records moisture at 10 and 30 cm depth and soil temperature at 10 cm depth. Rainfall data from June to December 2023 were obtained from the NIWA DataHub (https://data.niwa.co.nz; NIWA) for the Rakaia Greenfields weather station 4720, which was located approximately 4 km north of the dairy farm.

Pre-experimental soil tests to 60 cm depth were carried out immediately prior to winter grazing in June 2023 by collecting and bulking 10 random cores (50 mm diameter) along a transect in each half of each paddock. Prior to bulking, the cores were cut into depths of 0-15, 15-30, and 30-60 cm. Samples were sent to Hill Laboratories Ltd (Hamilton) for inorganic N content (ammonium and nitrite+nitrate-N), which showed a soil N content in kale and pasture areas of 41 ± 4.0 and 26 ± 4.6 kg N/ha (0-60cm), respectively (mean ± SD, Mann-Whitney $U = 0$). Based on yield cuts prior to grazing in June, the kale crop and pasture masses at the start of winter grazing were, respectively, 13.2 ± 0.37 and 5.2 ± 0.75 t DM/ha (mean ± SD).

To ascertain the variation in soil inorganic N concentration at varying depths the soil sampling procedure was altered for the following two sampling dates immediately post winter grazing on 18 July 2023 and prior to the first defoliation event of the resown pasture on 13 November 2023. Five blocks (covering approximately half the total paddock area) were established in each paddock, according to the pattern of winter break-feeding. Within each block, two areas (plots) were sampled (Figure 1). From the pseudo-replicated area, four 25 mm diameter, 90 cm deep cores were collected from each plot (a total of 40 cores per paddock). The cores were laid out on a board and cut into 0-15, 15-30, 30-60 and 60-90 cm depths and the soil from each depth was separately bulked by plot (i.e. from four cores) and placed in a labelled plastic bag. The bags were placed in chilly-bins with frozen pads to keep them below 4 °C until they reached the laboratory (a maximum of 36 hours). Thus, there was a total of 80 soil samples for analysis (i.e., 2 paddocks x 10 plots x 4 depths).

Upon arrival to the soil lab (AgResearch, Ruakura), the samples were extracted for inorganic mineral N within 24 hours using the standard 2 M KCl solution method (Mulvaney, 1996). The extracts were analysed for inorganic N (nitrate-N and ammonium-N) using a SEAL AA3 segmented flow analyser (SEAL

Analytical, Mequon, WI, USA). Nitrite is an intermediate compound produced when ammonium is converted to nitrate in the soil. As nitrite is produced it is usually converted rapidly to nitrate and the amounts typically found in soil are very small. As per common practice, the nitrate-N figures reported herein include any nitrite-N in the sample. Nitrate and ammonium concentrations were converted into quantities (kg/ha) assuming bulk density values for the Templeton silt loam of 1.25 and 1.50 g/cm^3 for the 0-30 and 30-90 cm depths, respectively (Di and Kemp, 1989).

Plant N uptake was determined on 6 November 2023 by harvesting all herbage within one quadrat (0.2 m^2) to soil level per block within each winter treatment area (n=10/paddock). Harvested material was washed and oven-dried at 60°C to a constant weight at the Lincoln University field laboratory to determine herbage mass (kg DM/ha). Additional samples of herbage were cut to soil level at multiple random locations, along a diagonal transect, within each half of the wintering areas. These samples were mixed thoroughly and subsampled (100 g FW) and hand sorted into sown species and dicot and monocot weeds. Each component was oven dried at 60°C and dry weights recorded. The dried sample was then recombined and ground to pass through a 2 mm sieve for determination of N content by NIRS (FOSS NIRSystems, Maryland, USA).

Statistical analysis was undertaken using Genstat Edition 22.1 (VSN International Ltd). Non-normally distributed data (soil nitrate, ammonium and inorganic N) was transformed using a square root or $\log_{10}$ function (July soil ammonium and inorganic N) and analysis of variance within sampling date conducted using the General Linear Model procedure where wintering treatment, sampling depth and their interactions were used as fixed terms and plot was used as a random term. Means were separated using the Bonferroni multiple comparison procedure. Back-transformed means and standard errors are presented. Baseline soil and herbage data were compared using Mann-Whitney U non-parametric tests due to small sample size and descriptive statistics used for means presentation.

Results and Discussion

Soil temperatures at 10 cm depth averaged 7.3°C during June and July and had increased to 14°C in the week preceding the final soil sampling in November (Figure 2). Immediately following post winter soil sampling on 18 July, 155 mm of rain fell between 20 and 25 July, which led to peak moisture content in mid-July. Although the change in soil moisture in Figure 2 cannot be used to determine drainage due to location outside of the experimental areas, the data provide a useful indication of the climate conditions at the time.

There was considerable variability in total soil inorganic N (0-90 cm) between plots within the same paddock at both the July and November sampling dates (Figure 3). This is likely due to the spatial variability of urine patches in the paddock. Despite the variability, there was little overlap between the kale and pasture datasets, with 50 and 81% less soil inorganic N in the pasture compared with the kale paddock in July and November, respectively. In July, total soil inorganic N ranged from 98-175 kg N/ha in the kale paddock plots and from 32-103 kg N/ha in the pasture paddock plots. The mean soil inorganic N content (to 90 cm soil depth) of the kale paddock (138± 28.0 kg N/ha) was twice that of the pasture paddock (67 ± 27.2 kg N/ha, mean±SD, $P<0.01$). In November, total soil inorganic N in the kale paddock was more than five times greater than in the pasture paddock (152±33.2 vs 29±16.6 kg N/ha; $P<0.001$) and ranged from 92-224 kg N/ha compared with 15-69 kg N/ha, respectively.

Although total soil inorganic N within treatment did not change substantially between the two sampling dates, the distribution and form of inorganic N varied considerably across the soil depths (Table 1). Following winter grazing in July, 58% and 46% of the total inorganic N was in the form of ammonium in the top 15 cm of soil for kale and pasture paddocks, respectively (Table 1). The large amounts of soil ammonium reflect N deposition from urine during winter grazing, which has been transformed from urea to ammonium by soil microbes. The elevated ammonium N contents following grazing are consistent with those of Ruz-Jerez et al. (1991) who conducted a similar study using soil cores to monitor changes in soil inorganic N contents below recently grazed pastures. Those authors measured soil ammonium contents of 30 kg N/ha immediately following grazing of ryegrass and clover pastures, which is similar to the observation for pasture in the current study (41 kg N/ha). We hypothesised greater soil inorganic N contents under the kale system due to greater urine patch overlap under the lower area allocation of this system relative to pasture wintering (7.3 vs 20.5 m^2/cow).

By November, ammonium-N contents in the top 15 cm of soil accounted for only 4 and 12% of total soil inorganic N (0 to 90 cm) in respective kale and pasture paddocks (Table 1). Instead, nitrate accounted for 83% and 54% of total soil inorganic N in kale and pasture paddocks. For both treatments, over 50% of the nitrate was in the soil horizon below 30 cm. In the kale paddocks, nitrate concentrations between 30 and 90 cm depth averaged 93 kg N/ha, which was 11.6 times higher than the 8 kg N/ha measured in the pasture soils at the same depth ($P<0.05$; Table 1). The difference in quantity and distribution of ammonium and nitrate between July and November reflect plant uptake of N and soil processes including the transformation of

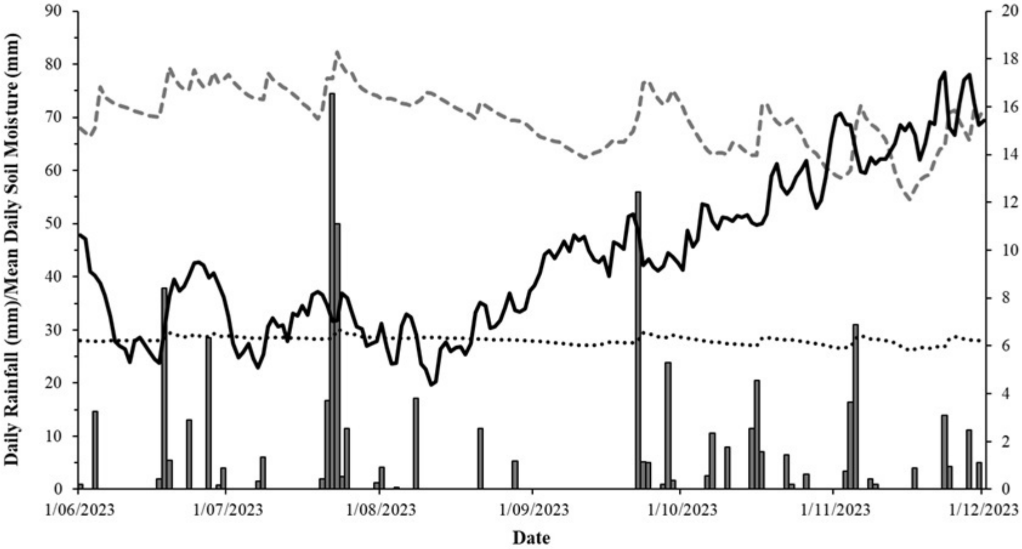

Figure 2 Rainfall (mm; grey bars), soil moisture content (mm) at 100 mm (dashed line) and 300 mm depth (dotted line), and soil temperature (°C) at 100 mm depth (black line). Rainfall data were obtained from the NIWA Rakaia Greenfields weather station (4720), and soil measurements were provided by Aqualinc Research Ltd.

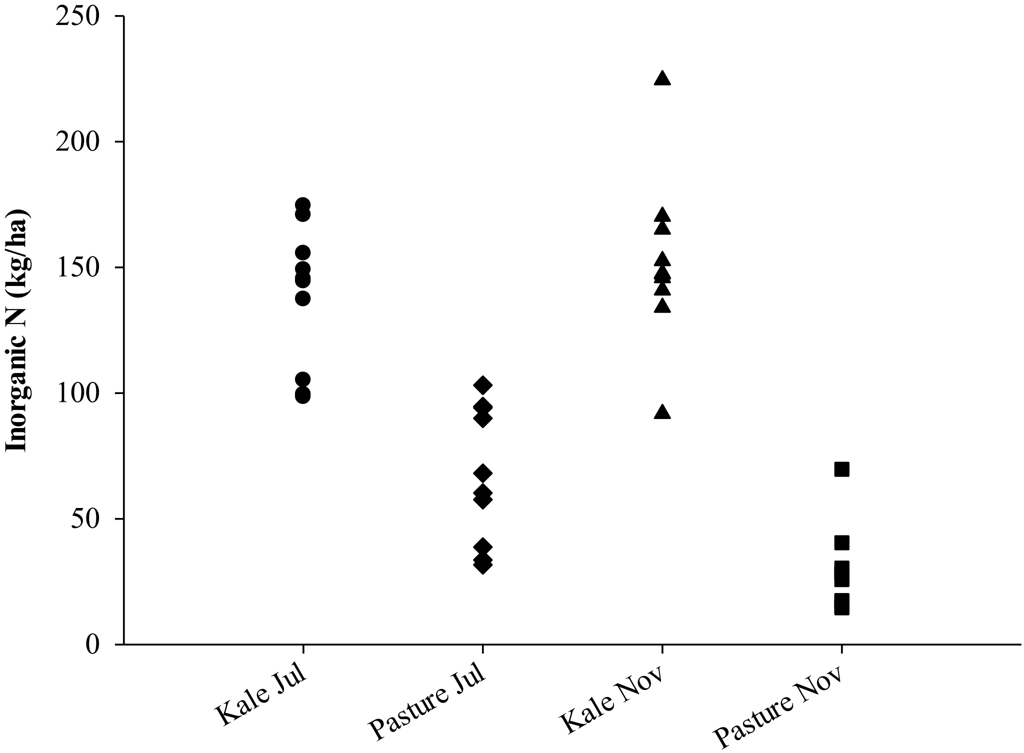

Figure 3 Total soil inorganic N contents (0-90 cm; kg N/ha) in the kale and pasture paddocks for samplings made post-winter grazing (July) and post-pasture regrowth (November).

Table 1 Ammonium, nitrate and total inorganic N in soil (kg N/ha) to 90 cm depth in kale or pasture wintering paddocks post grazing in July and November. Kale and pasture areas were resown and undersown, respectively, with a perennial pasture mix in August. Means have been back-transformed*. SEM is the standard error of means for the interaction between wintering system and depth.

	July			November		
Depth	**Ammonium**	**Nitrate**	**Inorganic N**	**Ammonium**	**Nitrate**	**Inorganic N**
			Kale			
0-15	73.8^{a}	19.1^{a}	95.3^{a}	5.8^{ab}	14.8^{c}	20.8^{c}
15-30	8.7^{b}	9.9^{b}	19.0^{bc}	5.4^{ab}	20.4^{c}	26.1^{c}
30-60	9.0^{b}	6.9^{b}	16.3^{bc}	9.1^{a}	58.4^{a}	68.2^{a}
60-90	0.2^{c}	4.1^{c}	4.6^{d}	3.9^{bc}	34.1^{b}	38.2^{b}
			Pasture			
0-15	23.0^{ab}	14.3^{a}	41.1^{ab}	3.3^{bc}	3.7^{d}	7.1^{d}
15-30	0.6^{c}	6.9^{b}	4.9^{d}	1.8^{c}	2.2^{d}	4.0^{d}
30-60	1.0^{c}	6.6^{b}	7.7^{cd}	3.0^{bc}	4.0^{d}	7.8^{d}
60-90	1.3^{c}	3.6^{c}	5.0^{d}	2.8^{bc}	4.4^{d}	7.6^{d}
SEM	1.28	1.17	1.26	0.80	1.98	2.06
P value						
Wintering system	<.001	<.001	<.001	0.002	<.001	<.001
Depth	<.001	0.006	<.001	<.001	<.001	<.001
C x D	<.001	0.227	0.027	0.014	<.001	<.001

*Means within columns with different superscripts are significantly different between wintering system (P<0.05)

ammonium to nitrate and the movement of that nitrate through the soil profile with drainage. The rainfall events and peaks in soil moisture contents at 10 cm depth (Figure 2) indicate potential drainage events, which could have led to movement of inorganic N down the soil profile (Cameron 1983).

The greater reduction in soil inorganic N of the pasture system between July and November is likely due to pasture regrowth and N uptake, compared with the extended period of fallow under the kale system (Figure 4). Regrowth of pastures following winter grazing enabled greater herbage yields of 4.9 ± 0.34 t DM/ha for the pasture paddock compared with 0.7 ± 0.08 t DM/ha for the kale paddock (P<0.01). The botanical composition of the pasture paddock consisted of predominantly Italian ryegrass and triticale (75%) with the remainder as legumes (10%), plantain (2%), chicory (4%) and dead material (8%). The new pasture in the kale paddock consisted of perennial ryegrass (65%) and weeds (35%). Herbage N contents of 1.99 and 4.96% resulted in estimated N yields of 98 ± 7.6 versus 35 ± 4.1 kg N/ha for pasture and kale systems, respectively (P<0.01).

Under the kale system, lack of plant uptake and large rainfall events are likely responsible for the shift of nitrate to below the root zone of the new pasture. Gibbs (1986) reported that around 80% of root mass is in the top 40 cm of the soil when maximum root input was reached >190 days after sowing ryegrass. In the current study, the pastures were relatively new (75 days since sowing in the case of the paddocks used for winter kale) so root mass and depth were expected to be relatively low. Consequently, nitrate below 30 cm depth is expected to be at much greater risk of leaching than nitrate in soil above this height. Further, the role of diverse pastures containing attributes such as cool season growth and deeper roots (Italian ryegrass and triticale) and reduced urine N load (herbs) have the potential to further mitigate N loss and are worthy of further exploration (Nichols and Crush 2007, Eme and Roche 2025). Assuming that nitrate present below 30 cm depth represents leached nitrogen, (93 v 8 kg N/ha, 30-90 cm, Table 1) then, even after adjusting for the 2.5-fold increase in land area for pasture wintering, nitrogen losses from the kale system remain over 70% higher.

An additional contributor to the relatively high N leaching risk under the kale system may also stem from the higher fertiliser N input (145 vs 60 kg N/ha) and enhanced mineralisation when the kale area was

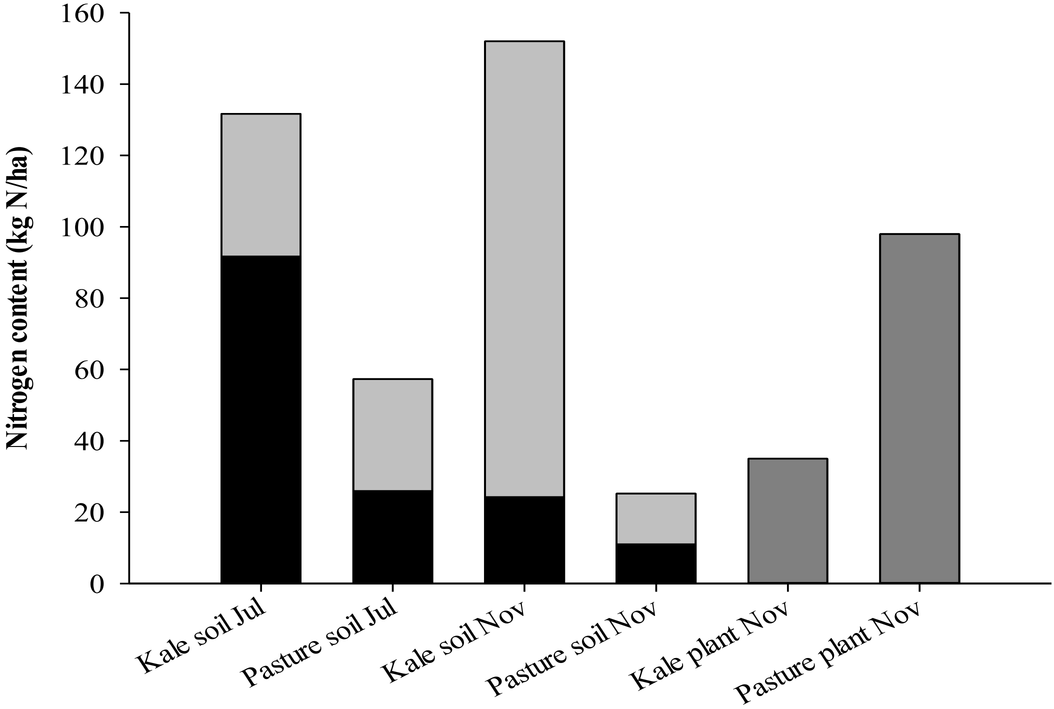

Figure 4 Total inorganic nitrogen (NH_4^+: black bars; NO_3^-: light grey bars) in soil, and organic nitrogen in plant biomass (dark grey bars), measured post-winter grazing of kale and pasture paddocks in July, and again in November following growth of resown pastures and undersown existing pastures in areas previously winter-grazed on kale or pasture, respectively.

cultivated post winter to sow the new pasture in August. Ledgard et al. (2009) reported a positive exponential relationship between N inputs and nitrate leached, and this aspect is also probably reflected in the greater pre-winter soil inorganic N concentrations for the kale compared with pasture areas.

The preferred practice for cultivation prior to sowing is an additional challenge for managing N losses from crop systems where high stocking densities in wet conditions can lead to compaction and further delays in the timing of a catch crop reduce the efficacy of this mitigation practise (Malcolm et al. 2018). Additional benefits of adopting systems that require less tillage or direct drilling include reduced costs and improved soil organic matter retention (Lane and Willoughby 2013). From an economic perspective, feedback from the farmer was positive towards wintering on pasture. The farmer estimated annual costs at $2,170/ha for the kale wintering system, comprising $1,016/ha for crop establishment, $854/ha for post-winter cultivation and regrassing, and $300/ha for additional fertiliser. In comparison, the pasture-based system cost $1,630/ha/year, including $516/ha for establishment, $414/ha for post-winter undersowing, and $700/ha for fertiliser. Given the stocking densities used in this study (8 vs 20 m²/cow/day), pasture wintering would require 2.5 times more land than kale, equating to $11.09/cow/week for kale and $23.40/cow/week for pasture (not including supplement costs). In spite of this, the farmer expressed that they intend to move to a pasture wintering system for all their dairy cows as they see it as an economically viable option with a number of co-benefits including better welfare in terms of animal comfort and ease of management for staff. Supplement required for feeding cows on pasture can be made from the pasture area to reduce costs. For instance, over the 12-month period the pasture area yielded 12.3 t DM/ha compared with 13.9 t DM/ha across the kale area. A list of pros and cons from the farmer experience is provided in Table 2, which highlight areas where risks may need to be managed to aid adoption. The farmer also reflected “in hindsight, we wouldn’t do diverse pasture again. Hard to maintain - diverse pastures and triticale created bulk for the first cut then lost quality later”, suggesting that there may be opportunities to investigate options to reduce seed costs and improve the management and quality of these types of pasture swards. For instance, had the farmer used a permanent pasture system (instead of diverse) and only stitched in additional seed after wintering, then the cost of pasture wintering would be closer to $16/cow/week. In this case study example, the management and soil histories of the two wintering areas differed. Additional

Table 2 Farmer experience of the pros and cons of pasture wintering of dairy cows compared with crop wintering

Pros	Cons
Economic (when all-grass) on basis of whole farm system	Need more area, may be challenging for some farmers
Reduction in nitrate leaching, aids renewal of consents, gained social license	Care with pasture planning, managing quality and quantity
Easy to manage during winter	Needs decision support on when to close paddocks
Reduced labour so more time off for staff through winter	Requires clear liaison with grazier
Improved animal welfare, less mud	Costs increased if a 'buffer' of extra supplement is required
Doesn't require nutritional transition	Allow additional costs for pasture remediation
Flexibility to adjust area and supplement according to conditions	Need good quality silage as pasture can be lower in metabolizable energy content than crop
Enables the extension of good management practice (advanced mitigation) onto support land	Basic infrastructure required for back fencing, needs to happen for regrowth to occur
Reduced machinery costs	Pests can be an issue (Grass grub and porina)

research is required to confirm the observations made in this case study under more controlled conditions and to assess the longer term environmental and economic risks.

Conclusions

These results demonstrate the potential negative impact of high stocking densities and post-winter fallow periods on soil inorganic N load and nitrate leaching risk. We were able to use intensive soil sampling between 0 and 90 cm depths to indicate N transformations and detect statistical differences in soil N contents of over 50% under pasture compared with kale wintering, as well as shifts in nitrate concentrations to lower soil depths. Collectively, our results indicate that there is potential for diverse pasture-based wintering systems to reduce soil N contents and N leaching risks compared with traditional brassica crop wintering systems. The farmer in this study considered pasture wintering to be a feasible option for implementation at a commercial scale from both an economic and management perspective. However, further research is needed to validate the observations from this case study.

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