Evaluating pasture-based dairy cow wintering systems across soil and climatic conditions in southern New Zealand: implications for nutrition, welfare and environmental risk

Anna TAYLOR[1]*, Ross M. MONAGHAN[2], Archie WHITE[2], Chris SMITH[3], Rebecca CUMMING[2], Mark CRAWFORD[4], Federico TOMASETTO[1] and Robyn DYNES[1]

[1]*Bioeconomy Science Institute, Lincoln, New Zealand*
[2]*Bioeconomy Science Institute, Invermay Research Centre, Mosgiel, New Zealand*
[3]*139 Bourke St, Invercargill, New Zealand*
[4]*Otago Regional Council, Dunedin, New Zealand*
*Corresponding author: Anna.Taylor@agresearch.co.nz

Abstract

Autumn-saved pasture offers a potentially attractive alternative for wintering livestock in the South Island, although variability in feed accumulation and uncertainty over suitability on poorly drained or structurally vulnerable soils constrain adoption. We evaluated pasture-based wintering using six case-study farms across Canterbury, Otago and Southland selected to represent a range of soil, landscape and rainfall conditions. Kale and fodder beet paddocks within a wintering system were also assessed on two farms. System performance was evaluated using proxy indicators including assessments of ground cover (drone-derived), soil condition, cow cleanliness, body condition score and diet adequacy. Overall, body condition score (BCS) outcomes from the pasture wintering case studies indicated adequate nutrition despite variation in estimated ME supply. Where soils were suitable, pasture systems delivered improved cow cleanliness and reduced environmental risk compared with forage crops that were monitored on two of the farms. Successful outcomes were associated with permeable, structurally resilient soils and lower grazing pressures (≥15 m^2 cow^{-1} day^{-1}) than typically applied to winter forage cropping systems.

Keywords: cow cleanliness, ground cover, nitrogen leaching risk

Introduction

Over-wintering of cattle in the relatively cool and wet conditions of southern New Zealand remains a complex challenge due to the multiple outcomes that are sought, namely the provision of a nutritious diet and achieving acceptable standards of animal welfare and environmental performance. Research within the past couple of decades has drawn attention to some of the challenges posed by systems that rely on grazed winter forage crops as the main component of winter diets. These studies draw attention to the intensive nature of such grazing activity, outlining how feed demand and crop yield typically result in relatively high instantaneous stocking densities (Smith and Monaghan 2020; Houlbrooke et al. 2009) or "grazing pressures". These grazing pressures can result in considerable soil deformation and damage, particularly when conditions are wet and/or soils are structurally vulnerable to the effects of animal treading (Drewry and Pato 2005; Houlbrooke et al. 2009). One consequence of these grazing impacts is the removal of the growing plant as a potential sink for nutrients such as nitrogen (N) and phosphorus (P) that are mineralised in the soil or returned in concentrated forms via animal excretal deposition. Removal of a (re-) growing plant will thus exacerbate the risks of nutrient transport in surplus rainfall due to the greater accumulation of soil nutrients during winter and spring. Intensive animal treading on wet soils will also reduce rates of soil infiltration, resulting in greater amounts of surface runoff and associated transport of P, sediment and faecal microorganisms. The creation of a wet and muddy soil surface also has implications for reduced animal lying and poorer comfort (Schütz et al. 2024; 2025).

Recent interest in pasture-based wintering systems as alternatives to intensive forage-crop wintering is driven by aims to minimise regulatory exposure, simplify farm management, and/or maintain acceptable levels of soil condition and animal welfare. Yet empirical evidence supporting improvements in soil and welfare outcomes remains limited, with inconsistent results sometimes reported both anecdotally and within the small existing literature (e.g., Simon et al. 2024). These inconsistencies may arise from the substantial effects of landscape vulnerability factors, such as soil permeability and structural vulnerability, on soil condition and function. Additionally, grazing management, particularly the magnitude of grazing pressure, likely exerts a major influence on these outcomes. Simon et al. (2024) reported only modest soil and water quality benefits from shifting to

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pasture-baleage wintering on a structurally vulnerable soil, with overall soil condition remaining poor under both crop- and pasture-based systems. In contrast, improved cow thermal comfort has been observed on well-drained soils, where pasture wintering with hay bales was associated with increased rumination and cleaner coats, indicating a more suitable lying surface (Schütz et al. 2024). Social media accounts further highlight this variability, reporting outcomes ranging from severe soil treading damage comparable to forage crops to lightly impacted soils and pastures that recover rapidly in spring. Accordingly, further research is needed to identify combinations of landscape attributes and management practices that can reliably improve soil and animal-welfare outcomes while maintaining nutritional and profitability objectives.

Here we report findings from a study that assessed a range of outcomes across six farms that undertook some form of a pasture-based approach to wintering pregnant dairy cattle during 2025. Two of these farms also used winter forage crops for some of their herds and thus served as a benchmark for some of the responses that were monitored on paddocks that were used for pasture wintering. Our approach sought to identify any patterns that might be evident in monitored responses in paddocks that were selected to encompass a range of landscape vulnerabilities that ranged from very freely-draining soils on flat terrain to slowly permeable, structurally-vulnerable soils on gently sloping land. Some of the hypotheses that we sought to test were (i) the pasture-based diets provided adequate nutritional value for cows to meet target body condition scores by the end of winter, (ii) winter-grazed pastures delivered better outcomes for vegetation cover and soil condition than winter crops, (iii) animal cleanliness was greater for cows wintered on pastures than on crops, and (iv) some of the responses relating to hypotheses (ii) and (iii) could be related to landscape vulnerability attributes such as soil drainage and/or vulnerabilities to waterlogging and/or structural degradation.

Materials and Methods

Assessments were undertaken on six dairy farms that undertook some form of a pasture-based approach to wintering dairy cattle during 2025. Three farms were located in Canterbury, two in Southland and one in Otago. Brief details of each wintering approach and farm landscape attributes are documented in Table 1. Of note for the Otago farm (O1_MIa and b) is that cows spent the majority of winter on kale (O1_MIa) or fodder beet (O1_MIb) crops before returning to pasture for 2 – 3 weeks ahead of calving in August. For farm S1_Kale, cows also spent most of the winter on kale before transitioning to pasture shortly ahead of calving in August. Pasture was the sole fresh feed offered to herds during winter in all of the other case studies that were assessed. These pasture paddocks were shut at a range of dates during summer and autumn depending on winter grazing date and what type of pasture was to be offered. For example, the "stock-piled" pastures of case study S1_SSP could be shut as early as January to allow for the accumulation of up to 6.5 T DM ha^{-1} prior to winter grazing, whilst the modern cocksfoot pastures of C2 could be shut as late as April for feeding in late winter. Monitoring focused on indicators that serve as proxies for successful wintering, as described below.

Farms were selected for monitoring either because participating farmers reported positive experiences with their pasture-based wintering systems, or because they were interested in exploring innovative alternatives to forage cropping for wintering livestock. However, recruitment was constrained by the limited number of farms using pasture-based approaches designed to preserve pasture viability and allow recovery after winter grazing. In response, the project adopted a pattern-based analytical approach, relating measured outcomes to a range of landscape and management variables as described below.

Assessment of diet allocation

To determine the nutritional adequacy of winter diets offered to dairy cows on each farm, herbage sampling of winter pasture paddocks and supplementary feeds was undertaken during visits to participating farms during early (2-6 June), mid (7-11 July) and late (11-15 August) winter. Herbage clips to targeted post-grazing height were taken from pastures and crops along predetermined transect lines across each paddock or paddock break of interest, taking care to avoid gateways, troughs, fence lines and shaded locations. Supplementary feeds (baleage, hay, whole-crop cereal silage or straw) were also sampled. If the feed was set out in the paddock a grab sample was taken from multiple places. If the supplement was still in a bale form or in a silage stack, then 6 - 8 sample cores were taken per bale or from the face of the silage stack, taking care to ensure that the outside and centre of bales and silage stack faces were equally represented. Fresh herbage and supplementary feeds were dried at 60°C for dry matter determination then sent to R.J. Hill Laboratories Limited for feed quality analysis (Metabolisable energy (ME), N content). Measurements of pre and post grazing mass or apparent daily feed intakes were not directly carried out, instead derived from farmer and researcher visual estimates of feeds offered and their utilisation. These apparent intake estimates were combined with the feed component analysis to calculate overall dietary intakes of ME (MJ ME and kg N cow^{-1} day^{-1}, respectively) and protein contents (%). Cow body condition scores (BCSs) were assessed by qualified veterinarians at the

Table 1 Details of farm wintering approaches and some farm landscape attributes. Soil permeability classes and vulnerability indices (SVI) were sourced from S-map On-line (MW-LR, 2024).

Farm code	Location	Wintering approach	Number of paddocks monitored	Typical grazing pressure, m^2 cow^{-1} day^{-1}	Attributes of dominant soil types	Winter (Jun – Aug) rainfall, mm
C1	Canterbury	Old (20+ years) cocksfoot pasture	7	18	Well-drained, moderate over rapidly permeable soil layers. SVI = 0.51	106
C2	Canterbury	Modern cocksfoot pasture (<5 years old)	6	21	Well-drained, moderate over rapidly permeable soil layers. SVI = 0.51	263
C3	Canterbury	Mixed pastures (incl. cocksfoot).	5	30	Mix of well-drained and moderately well drained soils; moderate over rapidly or slowly permeable soil layers. SVI = 0.53	283
S1_SSP[1]	Southland	Stock-piled pastures containing cocksfoot, prairie grass, plantain, chicory etc.	2	16	Well-drained, moderately permeable soils. SVI = 0.67	135
S1_HBG[2]	Southland	Hay bale grazing on ryegrass/white clover pasture.	5	16	Well-drained, moderately permeable soils. SVI = 0.67	135
S1_Kale	Southland	Kale + baleage + straw	2	8	Well-drained, moderately permeable soils. SVI = 0.67	135
S2_BG[3]	Southland	Bale (hay & baleage) grazing on ryegrass/ white clover pasture.	3	15	Moderately-well drained Brown and Podzol soils; slowly permeable. SVI = 0.47	273
S2_BGD[4]	Southland	Baleage grazing on diverse pasture – diploid, tetraploid, cocksfoot & fescues.	1	15	Poorly-drained Peat soil; high vulnerability to waterlogging. SVI = 0.5	273
O1_MIa[5]	Otago	Kale (June & July), then pasture and baleage (August)	3	11, 25[6]	Poorly-drained, moderate over slowly permeable soil layers. SVI = 0.51	200
O1_MIb	Otago	Fodder beet (June & July), then pasture and baleage (August)	4	12.5, 25[6]	Poorly-drained, moderate over slowly permeable soil layers. SVI = 0.51	200

[1]SSP = stacked summer pasture; [2]HBG = hay bale grazing;
[3]BG = hay and baleage grazing; [4]BGD = hay and baleage grazing of diverse pastures; [5]MI = mix of crop and pasture diet
[6]values for crop, then pasture phases.

beginning and end of winter 2025 and summarised into distributions representing category intervals of 0.5 that ranged from 3.5 to greater than 6.5.

Vegetation cover and soil condition

Monthly assessments of vegetation cover on winter-grazed paddocks on each farm were derived from drone imagery captured before (first assessments made in early June) and after winter grazing, which continued until near-full vegetation cover returned in spring. The latest post-winter drone imaging was attained in November (from one and three paddocks for farms C2 and O1, respectively). No grazing or mechanical disturbance occurred between the end of winter grazing and the final drone assessment. Drone imagery was processed and analysed using a custom Shiny web application (Chang et al. 2023; accessed on 10th April 2026) developed in R (R Core Team, 2024). The application utilized the *terra* package (Hijmans 2024) for raster data manipulation and the *randomForest* package (Liaw and Wiener 2002) for image classification. Vegetation indices, including Excess Red (ExR) and Excess Blue (ExB), were calculated from red–green–blue imagery to improve image classification (Liu et al. 2022) along

with brightness and band ratio metrics. A supervised machine learning algorithm (i.e. Random Forest) classification model, using the "*tuneRF*" function which is essential for balancing model complexity and generalization, was trained using manually selected pixels representative of three distinct cover categories: "bare soil" (exposed soil with no vegetation or residue cover), "vegetation cover" (green, actively growing plant material), and "other" (comprising predominantly uneaten feed residues such as hay and baleage, along with senescent plant material, trampled vegetation, weathered crop stubble, and water troughs). The trained models were then applied to classify each pixel in the imagery, with results validated through visual inspection and ground-truthing during field visits. Classification outputs were visualized using *ggplot2* and *tidyterra* packages (Wickham 2016; Hernangómez 2023), enabling quantification of proportional cover for each category across monitored paddocks throughout the winter period.

Imagery metrics of vegetation cover were used to calculate mean Cover (C) factor estimates for each monitored wintering system over the June–November period. As described by Renard et al. (1997) and Panagos et al. (2015), the C factor is one of five components of the Revised Universal Soil Loss Equation (RUSLE) used to estimate soil erosion risk and represents a factor that farmers can most readily influence to reduce soil loss rates. In this study, C factors were calculated from the combined proportional areas within each monitored paddock that were classified as "green vegetation" and "other" cover, recognising that much of the latter category consisted of feed residues (e.g. uneaten hay and baleage) that nonetheless provided some protection against raindrop splash. Assumed pasture canopy heights, representing the second component of the C-factor calculation, were 0.15, 0.06, 0.10 and 0.15 m for June, July, August and September, respectively. Canopy heights for uneaten kale and fodder beet (or swede) crops were assumed to be 1.4 and 0.5 m, respectively.

Surface conditions in each paddock were scored for soil wetness during monthly visits to monitored paddocks in winter. These measures followed those described by Neave et al. (2022) and were intended as simple and practical methods to assess paddock soil conditions and investigate potential relationships with other indicators such as animal cleanliness (described below) and the extent of vegetation cover or bare ground. Two indices of wetness were assessed at 13 locations along a "W"-shaped transect within a recently-grazed (i.e. within two days of grazing) break. The first involved determining imposed boot imprints as either "dry", "wet", or "sodden" based on the appearances outlined by Neave et al. (2022). The second involved determining if there was any visible liquid (water or urine) pooling in close vicinity of each of the 13 sampling locations within each transect (within a half-boot length). This was scored as a binary outcome where "yes" indicated surface water pooling at least the size of the palm of a hand was present.

Visual Soil Assessments (VSAs), taking a 20cm cube of topsoil and following the method described by Shepherd (2000), were conducted in selected paddocks in late spring 2025 to assess soil physical quality. Anticipated substantial changes in soil condition resulting from cultivation of paddocks used for winter forage cropping in 2025 meant that assessments were restricted to pasture paddocks grazed over the preceding winter. Soil inspection and scoring were undertaken at five locations within representative areas of each selected paddock, with an additional three assessments conducted for paddocks where supplemental hay residues were clearly present and appeared to have influenced soil condition. Soil inspection locations were scored for attributes that included structure, porosity, colour, mottling, earthworm numbers and surface relief and for the extent of bare ground. Due to very dry soil conditions at some VSA inspection locations, relatively few earthworms were found in the inspected topsoils and this component was therefore omitted from an overall VSA score calculation to avoid biassing results. This calculation procedure broadly followed the formula and weightings described by Shepherd (2000) (equation 1):

Overall VSA Score = (Structure x 3) + (Porosity x 3) + (Colour x 2) + (Mottles x 2) + (surface relief x 1) + (bare ground extent x 2)

Equation 1

An overall VSA percentage score was then calculated assuming a maximum possible score of 26 (equation 2):

VSA% = (Overall VSA Score/26) x 100)

Equation 2

Standard Error of Mean (SEM) values were calculated for the overall scores derived from equation 2.

Cow cleanliness

Cow cleanliness was assessed in paddock during monthly winter visits following the method described by PAACO (2022). In brief, two focal areas on the animal, the belly (including udders) and thigh areas, were assessed for the extent of manure or mud coverage. A score was assigned depending on the manure or mud (may be dried) patches in either of these: 1= <25 cm diameter in either focal area; 2 = > 25 cm diameter in either focal area; and 3= >25 cm diameter in both of the focal areas. If both sides of the animal were visible on first encounter, the worst side of the cow was scored. Sample sizes for cleanliness scores at each assessment occasion were determined using the PAACO (2022)

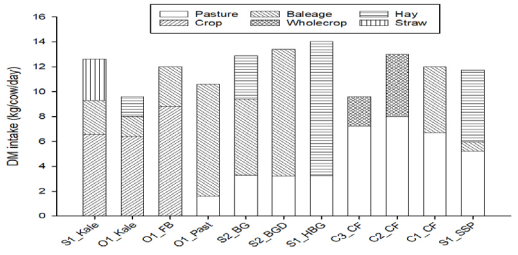


Figure 1 Estimated daily dry matter (kg DM/cow) intakes for cows wintered on the dairy farms monitored during winter 2025 (refer to Table 1 for Farm code descriptions).

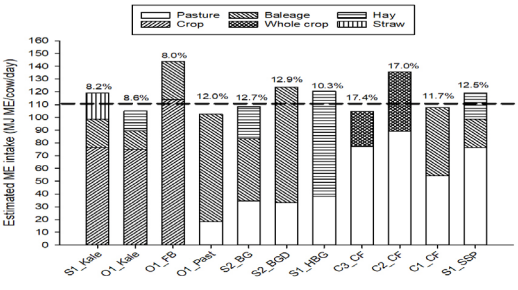


Figure 2 Estimated mean daily metabolizable energy (MJ ME/cow; bars) intakes from feed components analysed for farms monitored through winter 2025. Weighted calculations of dietary crude protein (%CP) levels from the feeds consumed are shown as percentage values above each bar of ME intake. The dashed black line indicates the ME requirements for a 500 kg cow 2 – 3 weeks pre-calving (DairyNZ, 2026).

sample size calculator that considers herd size. The number of cows scored per farm during the three winter visits ranged from 68 to 219. Cow hygiene score was used as a proxy for lying-surface cleanliness and suitability.

For brevity, mean values were calculated from individual monthly assessments of feed intakes and quality, soil wetness and cow cleanliness.

Results

Nutritional assessments of winter diets

Estimated feed dry matter (DM) allocation varies in their proportions of pasture, crop and supplementary feeds (Figure 1). Estimated metabolizable energy (ME; Figure 2) intakes ranged from approximately 102 to 144 MJ ME cow^{-1} day^{-1}. Six of the eleven diets met or exceeded the estimated requirement of 111 MJ ME cow^{-1} day^{-1}. In the pasture-based systems, fresh grazed pasture was estimated to contribute between 1.6 and 8 kg DM/cow per day (Figure 1), accounting for approximately 15–61% of total dietary intake. Baleage, hay, and whole-crop cereal silage were the primary supplemental feeds offered and, in some systems,

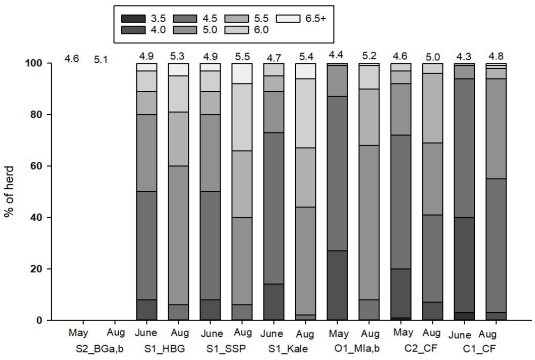


Figure 3 Body Condition Scores (BCSs) for herds monitored through winter 2025. The bars show the distributions of BCSs nominally made for pre- and post-winter grazing assessments. Average herd scores are given on top of the appropriate bar (only mean herd scores were available for farm S2_BG/D).

comprised a substantial proportion of total DM intake e.g. up to 76% (Farm S2_BGD), 75% (S1_HBG), and 38% (C2), respectively. The estimated mean crude protein (CP) concentration of the pasture-based diets was 13.3%, with values ranging from 10.3 to 17% (Figure 2). Mean CP concentrations were unexpectedly low in diets based on kale and fodder beet crops (8 – 9%). The commercial laboratory responsible for feed analyses noted that nitrogen concentrations in many crop samples submitted in 2025 were lower than anticipated, potentially reflecting inadequate N nutrition or reduced leaf-to-stem ratios of crops. The latter observation was consistent with visual assessments of the sampled crops in this study.

Cow body condition scores generally reflected the adequacy of the pasture-based diets offered during winter 2025, with nearly all herds for which data were available achieving a mean BCS of 5 or greater by August (Figure 3). The exception was Farm C1, which recorded a slightly lower mean BCS of 4.8. This may be attributable to (i) relatively modest intakes of protein N from pasture with a low crude protein content (10%) throughout winter, and (ii) the lower pre-winter mean BCS of 4.3 recorded for this herd. Across the pasture-based systems presented in Figure 3, the mean BCS gain over winter was 0.5, with values ranging from 0.4 to 0.6.

Vegetation cover and soil condition

Patterns of vegetation cover varied across the six monitor farms over the April to November period (Figure 4). On the two farms where both crop and pasture paddocks were monitored (S1 and O1), the crop paddocks showed a pronounced decline in cover, falling from near-complete cover (>90%) in April–June to <5% by August and remaining at or near bare-

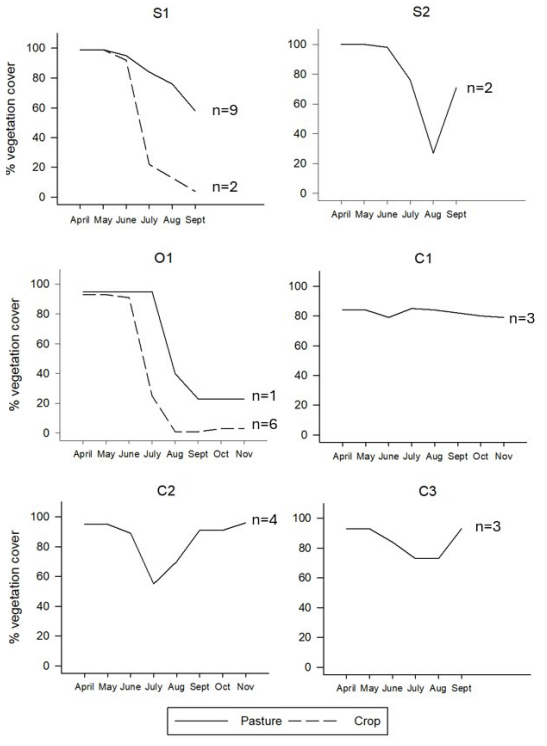


Figure 4 Percentage vegetation cover of winter grazed paddocks on six farms monitored over autumn, winter and spring 2025. Cover was averaged over crop paddocks and pasture paddocks; the number of paddocks assessed (n) is shown in each relevant plot.

ground levels through spring. Pasture paddocks on the same farms also declined through winter, though to differing extents: mean cover on pasture areas of farm S1 remained above 55% throughout, while cover on the pasture area of farm O1 dropped sharply in August and plateaued at around 20% through to November. The remaining pasture-based farms showed cover declining through June–August, during grazing, before recovering through spring. At C2 and C3, the extent of cover decreased to minimums of approximately 55% and 73%, respectively, before rebounding to ≥90% by September–November. Farm S2 reached its lowest cover (~28%) in August before recovering to ~70% by September. Farm C1 was notable for maintaining comparatively stable cover (78–85%) throughout the monitoring period, albeit for this farm it was difficult to distinguish between 'brown' (senescent) vegetation and bare soil.

Assessments of soil wetness reflected the combined influences of soil permeability, wintering system (pasture versus crop), and rainfall (Table 2). Grazed winter pastures on relatively permeable soils (Farms C1, C3 and S1) were generally assessed as "Dry," with little to no surface water pooling observed, particularly during visits following periods of relatively modest rainfall. A notable exception occurred at Farm C2 during the June visit, which followed a rainfall event of 45 mm; under these conditions, all assessment locations were classified as "Wet," and extensive surface water pooling was evident. In contrast, conditions during subsequent visits in July and August were considerably drier, with 77% and 100% of assessments rated as "Dry," respectively.

The combined effects of winter forage cropping and slowly permeable soils were most evident at Farm O1_MIa+b, where "Wet" or "Sodden" conditions were recorded in 59–85% of assessments and surface water pooling was observed at 72% of locations. Similarly, the young pasture paddock grazed during August on this farm was frequently assessed as wet (56% of observations), with surface water pooling recorded in 10% of assessments, likely reflecting the limited permeability and lower structural resilience of the soil. In contrast, predominantly dry conditions were observed at Farm S1_Kale. Although this was a crop-based system, the relatively low winter rainfall combined with a moderately permeable, well-drained soil type likely contributed to these drier conditions. Also of note are the mostly dry conditions observed for farm S2, despite the less permeable soils and relatively high winter rainfall at this location.

Visual Soil Assessments (VSAs) conducted in winter pasture paddocks during late spring generally reflected underlying soil vulnerability characteristics. Overall VSA scores were lower for soils with slow permeability compared to rapidly permeable soils or soils with a low susceptibility to waterlogging (Figure 5). One notable exception was Farm S2_BGD. Although the Organic soil at this site was classified as having a high risk of waterlogging, it has a low Structural Vulnerability Index (Hewitt and Shepherd 1997), likely due to the protective influence of high soil organic matter content. Also of note in Figure 5 are the relatively low scores recorded for Farm S1. While the Selwyn soil at this location is moderately permeable and has a very low waterlogging risk, its comparatively high structural vulnerability likely contributed to the reduced VSA score. The lowest overall VSA score was observed for the pasture area on farm O1, which likely reflects the combined effects of low soil permeability, moderate-to-high structural vulnerability, and a history of relatively intensive land use.

Across the pasture-based systems, calculated vegetation cover (C) factors (Figure 5) ranged from 0.11 (S1_SSP) to 0.24 (C2), all well below the value of 0.63 calculated for the S1_Kale crop paddock but elevated relative to the un-grazed pasture baseline of 0.052. Intermediate values were returned for the two O1

Table 2 Assessments of soil wetness and the presence of surface water pooling in recently-grazed breaks. Percentage scores are the averages of assessments made for visits in June, July and August. Farms listed in order of increasing winter rainfall.

Farm code	Soil permeability[1]	Dry	Wet	Sodden	Pooling[2]	Winter rainfall, mm
C1	M/R	100	0	0	0	106
S1_SSP+ HBG	M	100	0	0	0	135
S1_Kale	M	100	0	0	0	135
O1_MIa[3]	M/S	15,44	77,56	8,0	72,10	200
O1_MIb[3]	M/S	41,44	59,56	0,0	72,10	200
C2	M/R	59	41	0	33	263
S2_BG	S	95	5	0	3	273
S2_BGD	S	100	0	0	0	273
C3	M/R + M/S	100	0	0	0	283

[1]Permeability attributes of: M/R = moderate over rapid; M = moderate; M/S = moderate over slow; S = slow.
[2]presence of pooling not included in the percentage calculations for Dry, Wet or Sodden categories (which sum to 100%).
[3]values for crop (June and July visits), then pasture (August; one paddock only) phases.

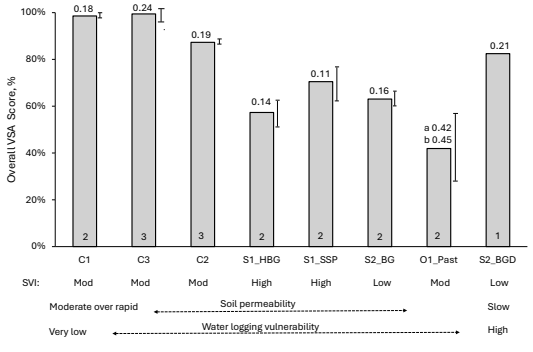


Figure 5 Mean overall VSA scores assessed in late spring for pasture paddocks used for winter grazing. Farms (described in Table 1) are plotted from left to right according to increasing soil vulnerability attributes of impermeability and waterlogging. Soil Structural Vulnerability Index (SVI) categories are listed below bars. The values within the bars are the number of paddocks assessed. The numbers above the bars are the calculated cover (C) factors. O1_Past refers to the pasture paddocks that were used for 2 – 3 weeks ahead of calving in August and are presented as the area-weighted value for (a) kale then pasture and (b) fodder beet/swedes then pasture. Error bars represent +/- SEM values

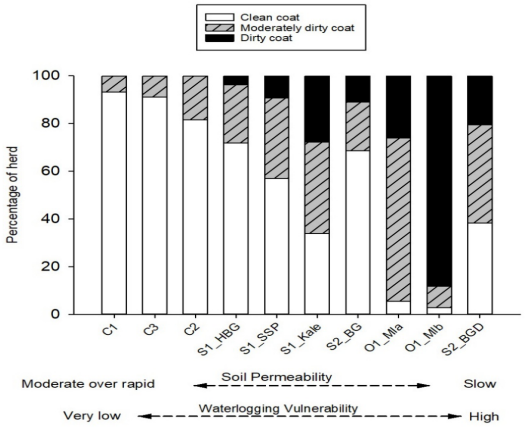


Figure 6 Herd hygiene distribution scores ranked from left to right according to Soil Permeability and Waterlogging Vulnerability attributes. Each bar is coded by farm ID as detailed in Table 1. Scores are the mean values of two to five assessment occasions over the winter grazing period.

mixed-diet systems (0.42 and 0.45 for systems a and b, respectively), reflecting area-weighted combinations of crop and pasture phases. O1_Past (a) combined a kale crop phase (C = 0.65; June – July) with a pasture (C = 0.33; August), while O1_Past (b) combined a fodder beet/swedes crop phase (C = 0.69; June–July) with the same pasture phase (C = 0.33; August).

Cow cleanliness

Patterns observed for cow cleanliness generally reflected observations of soil conditions, with cleaner coats observed for locations where conditions were assessed as "Dry", soil permeability was rapid and waterlogging vulnerability was relatively low (Figure 6). As expected, coats were generally also cleaner for cows that were wintered on pasture compared to those that were, for the most part, wintered on crop (S1_Kale, O1_MIa,b).

Discussion

The key goals of this study were to provide insights as to whether pasture-based wintering approaches provided adequate nutrition, delivered better outcomes for vegetation cover and soil condition than approaches using winter crops, and resulted in better scores for cow cleanliness. A secondary aim was to explore if some

of the observed responses were related to landscape vulnerability attributes such as soil drainage and/or structural vulnerability.

The pasture-based systems monitored in this study appeared to supply adequate nutrition for the pregnant non-lactating dairy cows, with nearly all herds achieving a mean gain of 0.5 BCS units over winter and reaching the industry target of 5.0 or greater by August. Although estimated ME supply was below 110 MJ ME cow^{-1} day^{-1} for five diets, BCS outcomes provide a more direct indication of nutritional adequacy given actual feed intake was not measured.

Dietary protein levels were within the optimal range of 12-16% for pregnant, non-lactating dairy cows sufficient to meet protein requirements without driving excessive N intakes and subsequent urinary excretion (Dalley et al. 2017; de Ruiter et al. 2019; Wheadon et al. 2023; Woods et al. 2023). Nonetheless, several diets sat at the lower end of this range, and operators of such systems should remain mindful of the protein supply when autumn-saved pastures are a principal feed component. The unusually low CP contents recorded for the kale (7.8–11.2%) and fodder beet (6.6–6.8%) crops were unexpected. These values sit below the ranges typically reported for New Zealand winter crops (Dalley et al. 2017; Wheadon et al. 2023; Woods et al. 2023) and likely reflect atypical and season-specific effects on crop N nutrition or altered leaf-to-stem ratios; the latter observation was consistent with visual assessments of the crops sampled in the present study. While low CP in fodder crops can be beneficial from an N excretion perspective, it may compromise desired gains in cow BCS and growth of the calf foetus.

To the authors' knowledge, the vegetation cover (C) factors reported here represent the first quantified estimates documented for winter grazing in southern New Zealand. Although the C values for grazed winter pastures (Figure 5) were higher than those reported for ungrazed pastures, they were lower than values for grazed winter forage crops assumed by Donovan and Monaghan (2021). On the crop paddocks monitored, cover declined rapidly over winter and remained bare, reflecting their management for complete, one-time grazing. In contrast, pasture-based systems exhibited a more typical winter "dip," with cover declining during June–August before recovering in spring. The O1 pasture paddock was a partial exception, with cover falling sharply in July and plateauing at around 20%, likely due to the combined effects of slowly permeable soils and higher grazing pressure than at other pasture sites. Farm C1, by contrast, maintained consistently high cover (78–85%) throughout winter, consistent with an older, lower-quality sward retaining substantial residual biomass under grazing. Overall, the relatively low C values under pasture wintering indicate a lower erosion risk than under conventional forage-crop systems. Residual vegetation and feed residues such as uneaten hay and baleage reduce raindrop impact and surface runoff, protective mechanisms that are largely absent once forage crops are fully grazed. The retention of live pasture cover also maintains an active nitrogen sink into late winter and early spring, functioning similarly to the "catch crop" effect observed for oats following forage crop grazing (Malcolm et al., 2022).

Soil wetness responses reflected the expected interaction between soil permeability, wintering system and rainfall. Visual Soil Assessment (VSA) scores broadly followed this pattern, with the highest scores recorded on rapidly permeable soils and the lowest where permeability was slow and/or inherent structural vulnerability was high. There were, however, notable departures from this trend. At Farm S2_BGD, a low Structural Vulnerability Index, likely associated with high soil organic matter, appeared to moderate the effects of waterlogging on an otherwise vulnerable Organic soil. Conversely, relatively low VSA scores at Farm S1, despite moderate permeability, may be explained by the high SVI (0.67) characteristic of this soil type. These findings align with earlier work by others (Drewry and Paton 2005; Houlbrooke et al. 2009; Monaghan et al. 2017), who showed that intensive winter cattle grazing can reduce macroporosity, saturated hydraulic conductivity and air permeability, particularly when soils are grazed while wet, and that impacts are greatest on soils inherently vulnerable to treading damage.

The hypothesis that cow cleanliness would be greater on pasture than on forage crops was supported, although the magnitude of the effect was clearly mediated by underlying soil properties. Similar improvements in welfare indicators, including cleaner coats, increased rumination and better-insulated lying areas, have been reported for pasture wintering on well-drained soils supplemented with hay bales (Schütz et al. 2024). Importantly, the present study provides a cross-farm perspective: even within pasture-based systems, cow cleanliness declined where soils were less permeable (e.g. S2_BGD), reinforcing the view that the welfare benefits of pasture wintering are not automatic but are contingent on the landscape setting in which the system is placed.

Another overarching theme from the results is the likely role of grazing pressure in mediating outcomes. Space allowances on the pasture-based systems (15–30 m^2 cow^{-1} day^{-1}) were two- to four-fold greater than those typical of conventional winter forage cropping in southern New Zealand (Smith and Monaghan 2020; Houlbrooke et al. 2009), reducing both treading intensity and expected returns of excretal N. This is consistent with Drewry and Paton (2005), who showed that soil physical deterioration under cattle-grazed forage crops

depends strongly on treading intensity, with back-fencing and on-off grazing markedly reducing pugging damage. Lower grazing pressures, combined with maintained vegetation cover, therefore appear to be key drivers of the improvements reported here. Where pasture wintering was deployed on slowly permeable or structurally vulnerable soils, however, these benefits were diminished, consistent with Simon et al. (2024), who found only modest gains from pasture-baleage wintering on vulnerable soils.

Conclusions

The pasture-based wintering systems studied delivered acceptable nutritional, welfare and environmental outcomes, with generally adequate diets, BCS targets largely met, higher vegetation cover than forage crops, and cleaner cows. Results suggest pasture wintering can work well on well-drained, resilient soils under lower grazing pressure, supporting a risk-based approach that accounts for landscape suitability. However, findings are limited by the small, observational study conducted over a single winter, atypical crop CP levels in 2025, likely positive selection bias, and reliance on estimated values of feed intake. Broader multi-year studies across diverse landscapes, including measurements of winter-deposited urinary N, are needed to confirm some of the benefits reported here.

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