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Differences in farm management factors on New Zealand dairy farms with divergent bulk milk urea concentration

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ABSTRACT

In grazing dairy systems, the CP content of perennial ryegrass-white clover pastures often exceeds cows' nutritional requirements. Excess dietary nitrogen (N) is excreted in urine, increasing the risk of N leaching into soil and waterways or being released as nitrous oxide, a greenhouse gas. The relationship between milk urea concentration and excess dietary N may provide an indicator to support managing the risk of higher urinary N losses. The first objective of this observational study was to compare milk urea concentration within and between lactation seasons, in bulk milk collected from dairy herds using pasture-based systems in New Zealand. The second objective was to identify farm management factors that affect bulk milk urea (BMU) concentration by comparing farms with divergent BMU. Milk urea was measured in tank milk (n = approximately 2.2 million collections per lactation season; approximately 230 collections per farm across approximately 9,600 farms, with milk collected daily or every 2 d) over the 2016–2017, 2017–2018, 2018–2019, and 2019–2020 lactation seasons. Divergent BMU farms (n = 50/group), with annual mean BMU consistently low (L50) or high (H50) across New Zealand over 4 seasons, were selected and their farm management metrics (farm-reported, annual) and milk production were compared. Additionally, divergent BMU groups within 7 different New Zealand regions were compared (n = 50/group per region). Bulk milk urea concentration from all farms across all 4 lactation seasons followed a normal distribution (range 0 to 69.5 mg/dL), increased through lactation (25.5, 27.5, and 31.6 mg/dL for spring, summer, and autumn, typically corresponding to early, mid, and late lactation, respectively), and varied between lactation seasons. Monthly BMU ranged from 13 to 26 mg/dL for L50 and from 33.2 to 45.8 mg/dL for H50. Distributions of milking frequency, breed, and geographical region were different for L50 and H50. Farm area, herd size, and milk solids production per cow were similar between the 2 groups, whereas milk production per hectare and stocking rate (cows/ha) were greater for H50. Estimated total DM eaten per hectare, pasture and crops eaten per cow and pasture and crops eaten per hectare were all greater for H50. The H50 group applied substantially more annual N fertilizer. Observations for L50 and H50 groups were mirrored by regional divergent BMU groups, with some exceptions that likely reflect differences in farm management systems between regions. Understanding drivers of BMU concentration may provide tools for farmers to improve N use efficiency and reduce risk of excess urinary N loss from dairy herds.

Key words: urinary nitrogen, farm nitrogen surplus, pasture-based systems, grazed pasture, cow

INTRODUCTION

New Zealand dairy farmers predominantly use pasture-based systems in which grazed forage supplies most of the energy and protein required for milk production. Calving usually begins in July and August (late winter/early spring), enabling the peak lactation and feed demand to align with maximum pasture growth. Lactation continues through to April and May (late autumn) when cows are dried off. These low-cost pasture-based systems enable an internationally competitive dairy export sector but face environmental challenges associated with management of nitrogen (N) losses in some regional catchments. The traditional perennial ryegrass-white clover pastures are characterized by relatively high CP content, which often exceeds the nutritional requirements of grazing livestock (Colmenero and Broderick, 2006; Bryant et al., 2020). When dietary N is in excess of cow requirements,

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The list of standard abbreviations for JDS is available at adsa.org/jds-abbreviations-26. Nonstandard abbreviations are available in the Notes.

or its metabolism is constrained (e.g., due to insufficient energy for rumen microbes to utilize the dietary N), the surplus N is mostly excreted as urea in urine and deposited directly onto pasture in urine patches (Vibart et al., 2009; Selbie et al., 2015), although some is also excreted as urea in milk and to a lesser extent in feces. Urine patches contain approximately 600 kg of N/ha on average (Selbie et al., 2015), and may cover 20% to 30% of a grazed paddock annually (Moir et al., 2011). Of the urinary N deposited, an estimated 41% (range 3%–65%) is used by plants and 26% (range 10%–63%) is immobilized in soil, although these proportions vary with urine patch characteristics and environmental factors (Selbie et al., 2015). The remaining N is at risk of leaching into groundwater and surface waterways (e.g., as nitrate) or being released into the atmosphere as nitrous oxide, a greenhouse gas (Castillo et al., 2000).

Identifying farm management factors that reduce excess N on farm has the potential to decrease N loss from dairy systems. For example, management of synthetic N fertilizer and imported feed varies widely, and depends on factors such as climate and farming intensity. In New Zealand, the use of N fertilizer to support higher pasture productivity has increased substantially since the 1990s, supporting expansion in national dairy cow numbers (Gray, 2024). Initially, N was used to enhance the establishment of new pasture. Practices now extend to application during spring and autumn for increased pasture growth in cooler months, and in many instances, all-year-round application following cow-grazing rotations. In July 2021, a national regulatory cap was introduced in New Zealand to limit synthetic N fertilizer application on grazed land to 190 kg of N/ha per year, aiming to reduce N losses into waterways (New Zealand Government, 2020).

Farmers are increasingly seeking to improve N use efficiency to support productive and environmentally responsible pasture-based systems, while also meeting evolving regulatory requirements aimed at reducing N losses. Tools that can indicate surplus dietary N have the potential to help farmers improve N use efficiency and reduce the risk of environmental N loss. Research in TMR systems has demonstrated that milk urea concentrations may be a useful indicator of urinary N excretion, due to the strong relationship between urea N concentration in milk and urinary N output (Jonker et al., 1998; Kohn et al., 2002). Urea is produced in the liver to detoxify ammonia arising from rumen degradation of dietary CP and from the metabolism of absorbed amino acids and body protein (Tan and Murphy, 2004). Excess ammonia accumulates when rumen-degradable protein exceeds microbial demand relative to available fermentable energy, and this balance is also affected by rumen passage rate. Urea produced from this surplus enters the bloodstream and diffuses into body fluids, including milk. Although some urea is recycled to the rumen, most is excreted in urine. Higher dietary N intake increases circulating urea, resulting in greater urinary N excretion and elevated milk urea concentrations, making milk urea a useful indicator of surplus dietary N. A recent meta-analysis of pasture-based studies evaluated associations between various animal, management, and dietary factors with milk urea N and urinary N (Mangwe et al., 2025). The analysis determined that milk urea N was a moderate indicator of urinary N output under pasture-based diets, and the addition of N and DMI into models improved the robustness of predictions. This association was weaker than that reported in TMR-fed, housed cows (Kauffman and St-Pierre, 2001; Spek et al., 2013; Bougouin et al., 2022), likely due to greater inherent variability of pasture-based diets. Further, another recent study, monitoring 5 pasture-based New Zealand dairy farms in Canterbury over 5 lactations provided evidence to support the use of milk urea as an on-farm indicator, by demonstrating herd-level associations between estimated dietary N surplus and milk urea concentration measured in bulk tank milk (Woods et al., 2024).

Many dairy farmers have routine access to bulk milk urea (**BMU**) concentration data from tank milk collected for processing, providing a readily available indicator of the risk of dietary N surplus or deficit relative to herd requirements. Understanding the farm-level management factors that contribute to variation in BMU may offer insight into strategies for reducing the risk of excess urinary N excretion in pasture-based dairy systems. However, there is limited information on annual and seasonal variation in BMU concentrations, particularly in grazing systems. Therefore, a primary objective of this observational study was to evaluate within and between lactation season variation in BMU across New Zealand dairy farms. A secondary objective was to identify farm management factors potentially associated with BMU by comparing farms with divergent BMU profiles. This study used data from a farmer-shareholder milk processing company, providing the opportunity to assess BMU variation in more than 9,000 dairy farms over multiple lactation seasons. Seasonal data preceding the introduction of the national synthetic N fertilizer cap in 2021 (as described earlier; New Zealand Government, 2020) were used to capture a wider range of total N inputs and help disentangle some of the relationships influencing BMU at herd and farm level.

MATERIALS AND METHODS

Dairy Farms

This large-scale, retrospective observational study used information collected by the Fonterra Co-operative

Ltd. (Auckland, New Zealand) from member dairy farms (n = ~9,600) over 4 lactation seasons (2016–2017, 2017–2018, 2018–2019, and 2019–2020), each defined as running from June 1 to May 31. Information gathered for the study included farmer-reported details about the farm management in addition to milk processing records including milk volume and composition of bulk milk collected from farms.

Farm Dairy Records

Farm management data were self-reported annually by farms. Farm dairy records (**FDR**) are a core requirement for shareholding farmers' Terms of Supply to Fonterra Co-operative Ltd. They are required to be submitted annually to provide evidence of the work done on farm to produce quality, sustainable milk so that Fonterra can advocate on behalf of shareholders with customers, regulators, and the New Zealand community. Farms that supplied milk did not always have FDR reported each season and not all farms had all variables reported. Farmer-reported data contained input errors, and obvious outliers were excluded from the dataset by removing farms with values outside set limits (outlined below), with missing values depicted in the n count. The selected comparators from the FDR were as follows: effective farm area (ha), herd size (peak cow number), stocking rate (cows/ha; upper limit = 10), imported annual supplementary feed (t of DM/ha; upper limit = 10). The estimated total annual N from imported supplementary feed (N imported feed, kg of N/ha) was calculated based on feed type and amount reported by the farmers, and the attributed N content of each feed type was based upon reference values as reported in Overseer (2025). Similarly, the total annual N from fertilizer (N fertilizer, kg of N/ha) was calculated based on farmer-reported fertilizer type, amount applied, and the standard N content attributed to each fertilizer type by the manufacturers. Mean annual milk solids (**MSO**) production per cow (kg of MSO/cow; lower limit = 50, upper limit = 850) and milk solids production per hectare (kg of MSO/ha; lower limit = 100, upper limit = 4,000) were sourced from Fonterra milk production data for each season. For each farm, the annual pasture and total DM eaten (t of DM/cow, t of DM/ha) was estimated by back-calculating the annual ME requirements of the herd (for maintenance, production, walking, pregnancy, and live weight change based on Nicol and Brookes, 2007). The proportion of DMI from pasture and crops was calculated as the difference between the estimated DMI and farm records of imported supplements offered (assuming 85% of supplementary feed offered was eaten) and estimated volumes of feed eaten at grazing when cows were not on the dairy farm effective area. Metabolizable energy contents of pasture, forage crops, and supplements for these calculations were assumed from reference values (Overseer, 2025). Estimated variables included total annual DM eaten (t of DM/cow; t of DM/ha) and pasture and crop DM eaten (t of DM/cow; t of DM/ha). The annual purchased nitrogen surplus (**PNS**; upper limit = 700) for each farm was calculated as PNS (kg of N/ha) = annual N inputs (kg of N/ha from fertilizer plus kg of N/ha imported in supplementary feed) minus annual N outputs (N exported in milk, meat, feed, and effluent as reported in FDR).

Bulk Milk Urea Concentration

Information gathered for the study included details about volume and composition of bulk milk collected from farms at every collection (usually daily or every 2 d) for processing (mean 2.19 million collections per lactation season; mean 228 collections per farm × 9,602 farms per lactation season, milk collections from June 1, 2016, to May 31, 2020). A representative 30-mL aliquot was automatically sampled at each collection as milk was pumped from the bulk tank into the milk tanker. Milk samples were chilled without preservative and transported to a central laboratory for analysis (MilkTestNZ, Horotiu, New Zealand). Bulk milk urea concentration (mg/dL) was determined using mid-infrared spectroscopy on a CombiFOSS instrument (FT 6000 and FT+ until June 2019, then FT+ and FT7 for 2019–2020, Foss Electric, Hillerød, Denmark). Urea concentration was calibrated monthly via the CL-10 reference method (ISO 14637:2004; enzymatic differential pH measurement).

Relationship Between Bulk Milk Urea Concentration and Farm Management

Low and high BMU farms were selected (1) from all Fonterra suppliers and (2) from Fonterra suppliers within geographical regions and were compared over 4 lactation seasons using Fonterra's seasonal milk production data and farm variables self-reported annually by farmers in their FDR. Possible farm management drivers of BMU were identified by using the FDR from farms with divergent BMU. A group size of 50 farms was used (i.e., 50 low and 50 high BMU farms) for the dataset derived from all Fonterra suppliers, and for each region in the regional analyses. These farms were identified by calculating the mean annual BMU concentration for each farm for all 4 lactation seasons. Farms were ranked from lowest to highest annual BMU within each season and an accumulated score calculated across all 4 seasons. The 50 consistently lowest BMU farms (**L50**) and the 50 consistently highest BMU farms (**H50**) across all the 4 seasons, with annual FDR for at least 3 of the 4 seasons, were selected. In addition, regional divergent BMU groups were created for 7 New Zealand regions (Northland, Waikato, Bay of Plenty, Taranaki, Lower North Island, Canterbury, and Otago-Southland) by ranking farms within each region on annual BMU across all 4 seasons and selecting the 50 consistently lowest and 50 consistently highest BMU farms, as described above for L50 and H50. A group size of 50 farms was chosen because this number corresponded to approximately 10% of farms in the smallest region (Bay of Plenty).

Statistical Analysis

Group monthly BMU means were calculated using the monthly mean BMU for individual farms within the group for each lactation season. Group annual BMU means were calculated using the annual mean BMU for individual farms within the group for each lactation season. Data analyses were performed in R (version 4.3.3, R software, R Core Team, 2024). The distributions of variables were explored visually, and descriptive statistics were calculated (median and interquartile range [**IQR**]) by BMU group and lactation season. In addition, combined lactation season medians and IQR were calculated for the 4 lactation seasons for each BMU group using individual farm mean data across 4 seasons. The distributions of farm management variables of interest were compared across low and high BMU groups selected from all farms, and across low and high BMU groups selected from within the 7 regions. Differences between groups were tested using nonparametric Wilcoxon rank tests.

RESULTS

Data in this study were derived from approximately 9,600 Fonterra supplier dairy farms across New Zealand, which collectively produced approximately 80% to 82% of New Zealand's annual milk production. Results reported as "all farms" refer to this full dataset; where indicated, analyses used a subset of 50 consistently low and 50 consistently high BMU farms (L50, H50, and regional analyses). Cows were typically managed in a pasture-based system with seasonally concentrated spring calving. Pastures were predominantly perennial ryegrass and white clover–based pastures, often grazed in situ all year and supplemented with forage crops and conserved pasture (as silage or hay) made on farm and feed imported onto the farm. This was true across all regions, although some regional variation was evident, created by regional climate and farm management practices. For example, the mean percentage of grazed pasture and forage crops in the annual diet of the L50 and H50 BMU divergent herds in each region varied between 82% and 94% (Supplemental Table S2, see Notes). Holstein-Friesian × Jersey cross was the most common breed and twice a day (**TAD**) was the predominant milking frequency for 69% of all farms, with 26% of farms milking once a day (**OAD**; see Table 1). The farms varied in effective farm area (median 125 ha, IQR 84–197), herd size (median 333 cows, IQR 224–530), and milk production (median 361 kg of MSO/cow per year [MSO includes milk fat and milk protein], IQR 312–411).

Table 1. Percentage distributions of breed, milking frequency, and region (sourced from Fonterra farm dairy records reported by farmers in the 2019–2020 lactation season) of farms included in the survey dataset as well as the divergent bulk milk urea (BMU) groups (the consistently lowest 50 BMU farms [L50] and highest 50 BMU farms [H50] across all 4 lactation seasons from 2016–2017 to 2019–2020)

		Divergent BMU group	
Variable (%)	All farms	L50	H50
Breed	(n = 7,563)	(n = 50)	(n = 50)
Holstein-Friesian	30	16	32
Holstein-Friesian or Jersey cross	56	52	58
Jersey	12	26	6
Other	2	6	4
Milking frequency[1]	(n = 7,331)	(n = 50)	(n = 50)
Twice a day	69	44	76
3 in 2 or 10 in 7 d	5	8	8
Once a day	26	48	16
Region	(n = 8,165)	(n = 50)	(n = 50)
Northland	10	32	2
Waikato	35	28	36
Bay of Plenty	7	22	0
Taranaki	17	0	30
Lower North Island	9	8	16
Upper South Island	11	4	12
Lower South Island	11	6	4

[1] Milking frequency reported for the majority of the lactation season, not accounting for practice around calving and dry-off.

New Zealand Dairy Farm Bulk Milk Urea Concentrations

The BMU concentration in tank milk samples collected from all farms across all 4 seasons had a mean of 27.5 mg/dL and ranged from 0 to 69.5 mg/dL, following a normal distribution (Figure 1). Distribution of BMU in samples showed that 17.6% had BMU concentrations of less than 20 mg/dL, 44.9% were between 20 and 30 mg/dL, and 37.5% were greater than 30 mg/dL.

Assigning milk samples to early (late winter and spring: August, September, October), mid (late spring and summer: November, December, January, February), and late (autumn: March, April, May) lactation phases showed the distribution of BMU concentration changed between the 3 phases (Figure 2). Most milk samples (80%) were collected during early and mid lactation (~11% per month), with 20% (~7% per month) collected in late lactation as cows dry-off and tanker pick-up frequency declines due to lower milk volumes. In early lactation, the mean BMU

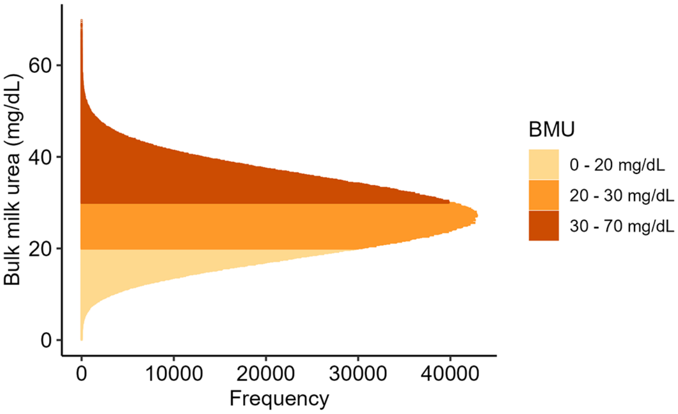

Figure 1. Distribution of bulk milk urea (BMU) concentration (mg/dL) for all tanker milk collections from all farms over 4 lactation seasons from August 2016 to May 2020.

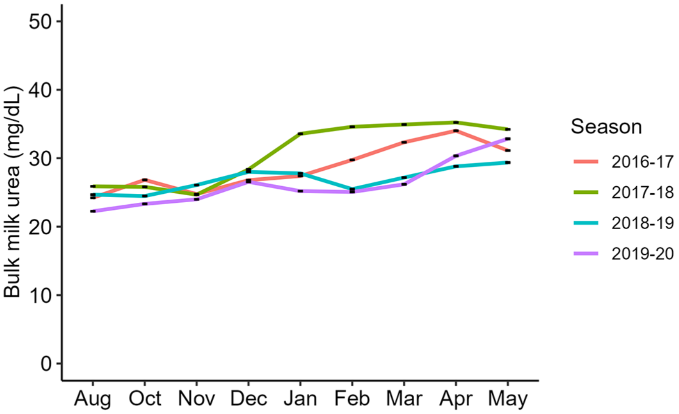

Figure 3. Variation in the monthly bulk milk urea (BMU) concentration (mg/dL) for all farms over 4 lactation seasons from August 2016 to May 2020. Values represent mean ± SEM.

concentration was 25.3 mg/dL; 26% of samples were less than 20 mg/dL, 48% were between 20 and 30 mg/dL, and 27% were greater than 30 mg/dL. In mid lactation, the mean BMU concentration was 27.5 mg/dL; 16% of samples were less than 20 mg/dL, 48% were between 20 and 30 mg/dL, and 36% were greater than 30 mg/dL. In late lactation, the mean BMU concentration was 31.6 mg/dL; 8% of samples were less than 20 mg/dL, 33% were between 20 and 30 mg/dL, and 59% were more than 30 mg/dL.

The monthly mean BMU for all farms across the 4 lactation seasons ranged from 22.3 to 35.2 mg/dL (Figure 3), and variations were observed both within lactation season and across lactation seasons. Within each lactation season, BMU concentrations tended to be below the annualized mean at the start of the lactation season and above the annualized mean by the end of the lactation season. There was greater variation in BMU between the 4 lactation seasons in summer and early autumn (January, February, March) compared with spring (August, September, October) and late autumn (April, May). Bulk milk urea values were highest through January to May in 2017–2018 with monthly mean values over 35 mg/dL in March and April. Although BMU fluctuated for individual farms, there were many farms that maintained either low or high values across a lactation season and across several seasons (data not shown).

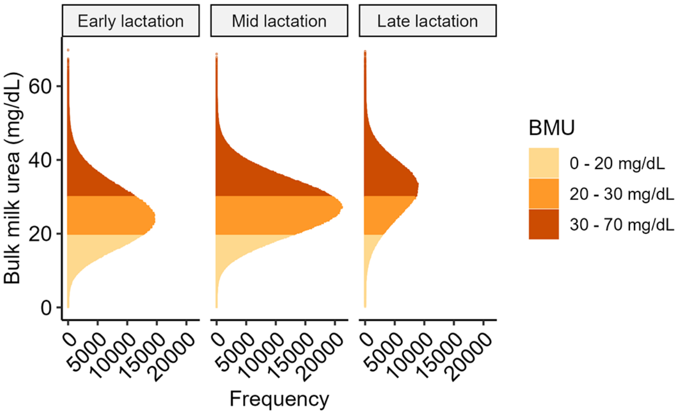

Figure 2. Distribution of bulk milk urea (BMU) concentration (mg/dL) for all tanker milk collections assigned to early (late winter and spring: August, September, October), mid (late spring and summer: November, December, January, February), and late (autumn: March, April, May) lactation phases, from all farms over 4 lactation seasons from August 2016 to May 2020.

Factors Influencing High and Low Bulk Milk Urea

Divergent groups (50 farms per group) were selected from all farms based on their annual BMU being consistently low (L50) or high (H50) over the 4 lactation seasons. Over that time period (2016–2017, 2017–2018, 2018–2019, 2019–2020), the mean monthly BMU ranged from 13.1 to 25.9 mg/dL for L50 and from 33.2 to 45.8 mg/dL for H50. The pattern of variation across individual lactation seasons for both L50 and H50 farms mirrored that for all farms shown in Figure 3, albeit lower or higher in BMU concentration dependent on group (Figure 4). The L50 and H50 groups had very similar fluctuations of BMU across individual seasons, and there was a clear separation between groups that was consistent across all seasons.

Breed distribution was different between BMU divergent groups (Table 1). For L50, there were more Jersey herds and fewer Holstein-Friesian herds compared with all farms. Conversely, for H50, the distribution of breeds was similar to all supplier farms. The BMU divergent groups also had differing milking frequencies, with both groups unlike the distribution observed for all farms

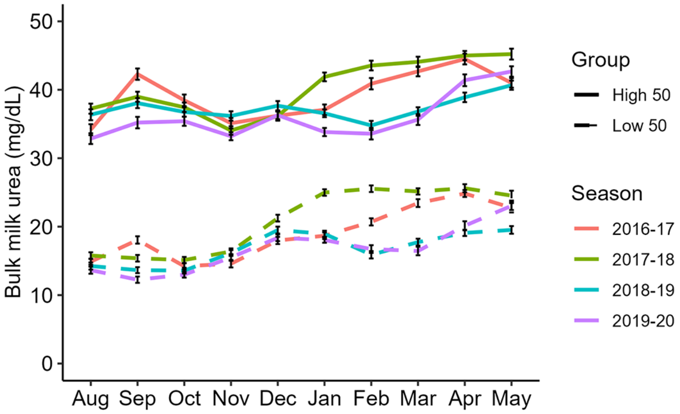

Figure 4. Variation in the monthly bulk milk urea (BMU) concentration (mg/dL) for 50 low BMU farms (L50) and 50 high BMU farms (H50) across 4 lactation seasons, August 2016 to May 2020. Values represent mean ± SEM.

(Table 1); L50 had more farms using OAD milking, and H50 had a predominance of TAD milking, with less OAD milking.

Most New Zealand geographical regions were represented within the divergent BMU groups; however, the distribution was different compared with all farms (Table 1). A total of 82% of L50 farms were from Northland (32%), Waikato (28%), and Bay of Plenty (22%), whereas 82% of H50 farms were from Waikato (36%), Taranaki (30%), and Lower North Island (16%). Many regions were unevenly represented between the divergent BMU groups; for example, Northland numbers were high in L50 and low in H50, Taranaki had no farms in L50 and 30% in H50, and Bay of Plenty had 22% farms in L50 and none in H50.

Additional data for farm characteristics, derived from milk production information and FDR, were combined over 4 seasons, and the group median and IQR are presented in Table 2 (separate 4 lactation season data are presented in Supplemental Table S1, see Notes). Effective farm area and herd size (peak cow number) varied widely for both L50 and H50, with no difference in median values between groups. The L50 had a lower stocking rate expressed as cows per hectare ($P = 0.014$; Table 2) and also expressed as live weight per hectare (median [IQR] 1,103 kg/ha [900–1,311] and 1,303 kg/ha [1,175–1,419] for L50 and H50, respectively; $P = 0.002$). Milk production varied widely in both groups, both per cow and per hectare, as denoted by the IQR. Milk production per cow was similar between groups; however, milk production per hectare was higher for H50 compared with L50 ($P = 0.030$; Table 2).

Estimated total tonnes of DM eaten per cow were similar for the divergent groups; however, estimated tonnes of pasture and crops DM eaten per cow were lower for L50 compared with H50 ($P = 0.009$; Table 2). This resulted in pasture and crops being 84% of the annual diet per cow for L50 and 88% of the annual diet for H50. Estimated total tonnes of DM eaten per hectare and tonnes of pasture and crop DM eaten per hectare were both lower for L50 compared with H50 ($P = 0.021$ and $P < 0.001$, respectively; Table 2). Overall, there was no difference between groups in the annual amount of imported feed DM per hectare or the calculated annual amount of N from imported feed per hectare, although there was a wide range within groups for these variables.

Most notably across all 4 lactation seasons, H50 applied 2 to 3 times more N fertilizer annually compared with L50 ($P < 0.001$; Table 2; Supplemental Table S1), and this was reflected in the PNS being at least 3 to 4 times higher for H50 compared with L50 ($P < 0.001$; Table 2; Supplemental Table S1).

Factors Influencing High and Low Bulk Milk Urea in Individual Regions Across New Zealand

Comparisons of divergent BMU groups selected within 7 New Zealand regions were utilized to further explore how farm management factors affect BMU concentration. Group median and IQR, using individual farm data averaged over 4 lactation seasons, are reported in Supplemental Table S2. The median annual BMU for regional low BMU groups varied from 19.5 mg/dL (IQR 18.8–20.2) in Northland to 23.2 mg/dL (IQR 21.6–23.7) in Canterbury; whereas for high BMU regional groups, the median annual BMU varied from 31.8 mg/dL (IQR 30.9–32.1) in Northland to 36.1 mg/dL (IQR 35.3–37.1) in Waikato. The difference in median BMU between regional divergent groups was largest in Waikato (16.4 mg/dL) and smallest in Canterbury (10.6 mg/dL).

Regional fluctuations in BMU across a season tended to be mirrored by low and high BMU groups (Figure 5). Comparing regions within seasons, the BMU patterns across a lactation were very similar for some seasons, whereas for other seasons the regional patterns were more divergent. For example, a comparison of monthly BMU variation across 2017–2018 and 2018–2019 for the divergent groups from Waikato and Canterbury is shown in Figure 5. In 2017–2018, low and high groups from both regions followed a very similar BMU pattern across the season. In contrast, for 2018–2019, the 2 regions diverged in BMU during February, March, and April, with higher BMU levels for both Canterbury groups (similar to 2017–2018), whereas in Waikato the BMU for both low and high groups declined over these months, with Waikato groups following the 2018–2019 pattern observed for L50 and H50 BMU groups as shown in Figure 4.

Table 2. Farm characteristics of groups divergent in bulk milk urea (BMU; 50 low BMU farms [L50] and 50 high BMU farms [H50] selected from across New Zealand)[1]

	Divergent BMU groups		
Farm characteristic	L50	H50	*P*-value[2]
Bulk milk urea (mg/dL)	18.4 (17.5–19.0)	37.5 (36.7–38.8)	<0.001
Effective farm area (ha)	103 (72–162)	97 (68–173)	0.69
Peak cow number	253 (206–381)	234 (194–515)	0.89
Stocking rate (cows/ha)	2.5 (2.1–3.0)	2.9 (2.6–3.2)	0.014
Milk production per cow (kg of MSO[3]/cow)	337 (304–378)	338 (311–388)	0.64
Milk production per ha (kg of MSO/ha)	759 (661–1,069)	941 (847–1,150)	0.030
Total DM eaten per cow[4] (t of DM/cow)	4.9 (4.4–5.7)	5.0 (4.5–5.4)	0.86
Total DM eaten per ha[4] (t of DM/ha)	12.4 (10.1–15.4)	14.2 (12.2–15.5)	0.021
Pasture and crops eaten per cow[4] (t of DM/cow)	4.1 (3.6–4.6)	4.4 (4.1–4.8)	0.009
Pasture and crops eaten per ha[4] (t of DM/ha)	10.2 (8.8–11.6)	12.5 (11.2–13.5)	<0.001
Imported feed (t of DM/ha)	1.6 (0.9–2.9)	1.4 (0.8–2.1)	0.21
Nitrogen imported feed (kg of N/ha)	26.0 (15.0–47.0)	31.5 (15.8–46.8)	0.99
Nitrogen fertilizer (kg of N/ha)	59.1 (29.3–89.0)	151.9 (101.8–204.0)	<0.001
Purchased N surplus[5] (kg of N/ha)	27.8 (6.0–65.8)	127.6 (89.0–188.3)	<0.001

[1] Data are shown as annual group median and interquartile ranges (in parentheses) averaged across 4 lactation seasons (2016–2017, 2017–2018, 2018–2019, and 2019–2020). Data were sourced from milk production and composition data, and farm dairy records reported by Fonterra suppliers.

[2] Wilcoxon rank sum test; Wilcoxon rank sum exact test.

[3] MSO = milk solids (milk fat and milk protein).

[4] Calculated using the energy model according to Nicol and Brookes (2007).

[5] Purchased N surplus = N inputs (N in fertilizer + imported supplementary feed) − N outputs (milk, meat, exported feed).

At a regional level, there was considerable variation in farm area across the regions with smaller farms in the North Island and larger farms in the South Island with corresponding larger herd sizes on larger farms. For divergent BMU groups, low BMU farms tended to be larger in size, although this difference was only significant in Otago-Southland (median 257 ha vs. 178 ha for low and high BMU groups, respectively, $P < 0.001$; Supplemental Table S2). Divergent BMU groups did not fit any particular trend for herd size; however, Otago-Southland tended to have higher numbers of cows in the low BMU group compared with the high BMU group (median 613 cows vs. 513 cows, respectively, $P = 0.06$; Supplemental Table S2). Conversely, stocking rates were significantly lower in low BMU groups compared with high BMU groups in all regions, except for Northland (median 2.0 cows/ha vs. 2.1 cows/ha, respectively; $P = 0.25$) and Taranaki (median 2.8 cows/ha for both groups; $P = 0.71$), whereas in the Bay of Plenty stocking rates were higher in the low BMU group (median 2.9 cows/ha vs. 2.5 cows/ha, $P < 0.001$). Milk production per cow was not significantly different between divergent groups within different regions. Milk production per hectare followed the pattern of stocking rates (i.e., when stocking rates were numerically or significantly lower in low BMU groups compared with high BMU groups, milk production per hectare was also lower).

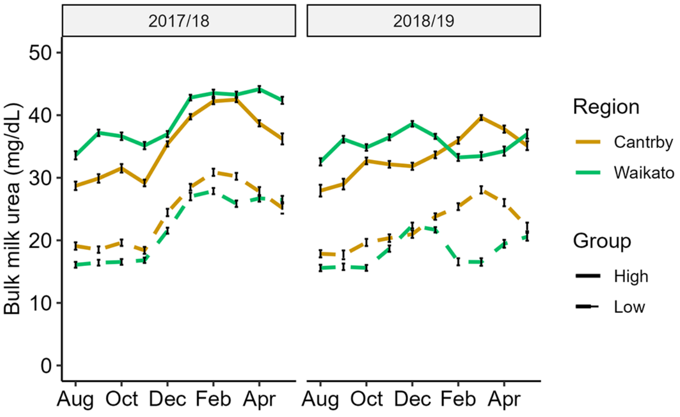

Figure 5. Comparison of the variation in the monthly bulk milk urea (BMU) concentration (mg/dL) for 50 low BMU farms and 50 high BMU farms from Waikato and Canterbury in 2017–2018 and 2018–2019 lactation seasons. Values represent mean ± SEM.

For most regions, there was no difference between divergent groups in the estimated amounts of total DM eaten per cow. However, in South Island groups, the low BMU groups ate more total DM per cow than the high BMU groups (Canterbury: median 5.5 t of DM/cow vs. 5.1 t of DM/cow, respectively, $P = 0.002$; Otago-Southland: median 5.2 t of DM/cow vs. 4.9 t of DM/cow, respectively, $P = 0.024$). Total DM eaten per hectare was lower for low BMU groups in those regions where stocking rates were lower compared with high BMU groups. In most regions, there were no differences between divergent groups for the amounts of pasture and crops DM eaten per cow; however, in the Bay of Plenty and Taranaki, low BMU groups ate less per cow compared with high BMU groups (Bay of Plenty: median 4.1 t of DM/cow vs. 4.6 t of DM/cow, respectively, $P = 0.005$; Taranaki: median 4.4 t of DM/ha vs. 4.6 t of DM/cow, respectively, $P = 0.044$). The amounts of pasture and crops DM eaten per hectare were different between divergent groups when stocking rates were different. Similar to the observations for L50 and H50 BMU groups, regional low BMU groups tended to eat less pasture and crops as a percentage of their annual diet, compared with regional high BMU groups.

Low BMU groups had significantly higher amounts of imported feed compared with high BMU groups in the Bay of Plenty (median 1.8 t of DM/ha vs. 0.7 t of DM/ha, respectively, $P < 0.001$), Taranaki (median 1.6 t of DM/ha vs. 1.0 t of DM/ha, respectively, $P = 0.008$), and Lower North Island (median 1.7 t of DM/ha vs. 1.3 t of DM/ha, respectively, $P = 0.021$), and the amounts of N in imported feed were also higher for the low BMU groups in the Bay of Plenty (median 37.3 kg of N/ha vs. 17.9 kg of N/ha, respectively, $P = 0.012$) and Taranaki (median 36.7 kg of N/ha vs. 22.5 kg of N/ha, respectively, $P = 0.035$). Similar to the findings for L50 and H50 BMU groups, all other regional divergent groups showed no difference between the imported feed and N imported feed variables.

As observed for L50 and H50 BMU groups, N fertilizer usage (kg of N/ha) was 2 to 3 times lower for regional low BMU groups compared with high BMU groups across all regions ($P < 0.001$), except the Bay of Plenty where there was no difference ($P = 0.29$). For low BMU groups from the regions, the median annual fertilizer applied ranged from 35.8 kg of N/ha in Northland to 86.8 kg of N/ha in Canterbury, whereas for high BMU groups the median ranged from 66.5 kg of N/ha in the Bay of Plenty to 221.3 kg of N/ha in Canterbury. Therefore, Canterbury applied the most N fertilizer across all regional low and high BMU groups.

Nitrogen fertilizer was the main influence on PNS, resulting in much higher PNS for high BMU groups compared with low BMU groups in all regions ($P < 0.001$), except the Bay of Plenty where there was no difference between groups ($P = 0.64$), similar to their N fertilizer. Northland scored the lowest PNS (median 22 kg of N/ha) of all regional low BMU groups and the Bay of Plenty scored the lowest PNS (median 41.6 kg of N/ha) of all regional high BMU groups. Across all regions, Canterbury scored the highest PNS for both low (median 57.9 kg of N/ha) and high (median 174.0 kg of N/ha) BMU groups.

DISCUSSION

Bulk milk urea is a useful indicator of herd dietary CP status and therefore urinary N loss risk because it reflects how efficiently cows convert dietary N into milk, providing insight into potential dietary N surplus. In pasture-based systems, where most N losses occur through urine patches, this makes BMU particularly relevant. Studies in both TMR and pasture-based systems show a positive relationship between milk urea concentration and urinary N excretion, with recent meta-analyses and farm-level monitoring confirming its value in pasture-based systems (Woods et al., 2024; Mangwe et al., 2025). In New Zealand, BMU data are available at every milk collection, giving farmers frequent feedback throughout the seasonal lactation cycle. This regular information could help support efforts to reduce the risk of excess urinary N losses through tactical management of herd nutrition and N use, as well as signaling timing for applying non-dietary practices such as standing cows off paddocks at key periods for N leaching.

This article is the first to describe a comprehensive nationwide database of BMU concentration from seasonal, block-calving, pasture-based dairy systems. A recent systematic review investigating associations between milk urea N and urinary N identified over 40 New Zealand studies, with milk urea levels ranging from 12 to 73 mg/dL and a median of 34.8 mg/dL (Mangwe et al., 2025). One of the earliest reports of milk urea concentration in New Zealand grazing dairy cows described levels of 38 to 48 mg/dL in milk samples from 4 to 5 herds in the Lower North Island during spring 1990 and 1991 (Moller et al., 1993). Over the 4 lactation seasons we monitored from farms across New Zealand, we found a wide range of BMU concentrations similar to those described by Mangwe et al. (2025) for cows fed pasture-based diets. Additionally, we observed both within-season and between-season variation in BMU concentration, with over half the values <20 to >30 mg/dL indicating opportunities to improve herd feed management or manage N loss risks from the farm system.

In our dataset, there was an increase in BMU concentration across each lactation, with highest concentrations typically observed in late lactation. In pasture-based dairy systems, higher BMU concentration at this time likely reflects an increase in CP content of autumn pastures and thus an increase in N intake (Pacheco et al., 2009). This means higher dietary N surplus and higher BMU concentration (and likely higher urinary N excretion; Mangwe et al., 2025) coincides with a critical risk period for N leaching from urine deposited onto pastures as cooler temperatures restrict pasture growth and N uptake, whereas higher rainfall increases risk of drainage (Selbie et al., 2015). In pasture-based dairy systems, a larger range in concentration of milk urea is reported compared with systems feeding cows TMR in housed conditions (Tavernier et al., 2023). Similarly, in pasture-fed dairy cows, a wide range of urinary N output has been reported (50 to 438 g/d; median 179 g/d) and it was moderately correlated with milk urea N (Mangwe et al., 2025). They reported a 1.0 mg/dL increase in milk urea N (equivalent to 2.5 mg/dL milk urea) was associated with a 9.6 g/d (95% CI: 6.9–12.3) increase in urinary N output. The relationship between milk urea and urinary N provides a potential for farmers to use BMU to help identify opportunities to optimize N in their systems and reduce urinary N loss risk, particularly at critical times of the year such as autumn.

Milk urea is influenced by dietary CP content and N intake in particular (Kauffman and St-Pierre, 2001; Colmenero and Broderick, 2006; Mangwe et al., 2025). Therefore, identifying management factors that show consistent relationships with BMU concentration could provide opportunities for adjusting practices. We selected farm groups divergent in BMU and determined several differences in their farm management metrics and practices. Farms with consistently high annual BMU (H50) applied 2 to 3 times more N fertilizer annually, had greater estimates of pasture and crops eaten per hectare, and had a higher stocking rate compared with farms with consistently low annual BMU (L50). Similar milk production per cow between the H50 and L50 groups, but higher stocking rate meant that H50 produced more milk per hectare. The higher stocking rates along with greater estimates of pasture and crops eaten per hectare strongly indicate that H50 farms were growing more pasture per hectare compared with L50, and would explain the use of larger amounts of applied N fertilizer to boost pasture growth (Gray, 2024). As well as increased pasture growth, fertilizer could also increase protein levels in pasture (Lambert and Litherland, 2000), a factor known to drive higher concentration of milk urea (Spek et al., 2013; Mangwe et al., 2025). Fertilizer amount was the main factor driving higher PNS for the high BMU group, indicating those farms have a greater amount of excess N at risk of being lost from the farm system (via leaching or nitrous oxide emissions). This highlights an area of opportunity for farmers to improve N use efficiency, for example by reducing total amounts of N fertilizer, matching the timing of applications for greatest pasture growth response, or limiting fertilizer applications during autumn.

Manipulating nutritional composition to maintain a consistent dietary intake for grazing cows is more complex compared with feeding housed cows with TMR (Hoekstra et al., 2007). Along with N fertilizer application rate, other farm management practices that can influence milk urea include length of the pasture regrowth period, grazing allocation, grazing interval, targeted grazing residuals, and herbage variety (Hoekstra et al., 2007). In a recent New Zealand study, Glassey et al. (2023) investigated grazing management practices of dairy herds divergent in BMU and collected data at a more detailed level than the reported annual farm records in our dataset. They observed some differences between groups for grazing management practices and reported that low BMU dairy herds grazed pastures with lower CP compared with high BMU herds, and this varied by season and geographical region (Glassey et al., 2023). A farm's ability to change grazing management practices (e.g., extend grazing interval, pre- and postgrazing pasture mass) is likely to be affected by management factors such as stocking rate and supplement use as these influence demand and flexibility.

Further comparison of the divergent BMU groups in the current study found less than half of L50 farms were milking TAD all season, compared with about 70% of all farms and 76% of H50 farms. Although cows milked OAD are reported to have lower milk production compared with cows milked TAD (Clark et al., 2006), we found no difference in milk production per cow for L50 and H50 groups. Interestingly, dairy cows milked OAD or using extended milking intervals (≥18 h) were observed to have lower concentrations of milk urea (Hall et al., 2023), which is consistent with the higher proportion of OAD farms in the L50 group in our study. A comparison of 6- and 12-h milking intervals likewise demonstrated a lower milk urea with longer milking intervals (Nielsen et al., 2005). Milking frequency and milking interval may be other factors to explain differences in BMU between L50 and H50 groups and, therefore, should be considered by farmers when interpreting their BMU concentrations.

Breed was also different between the groups, with more Jersey and less Friesian herds in L50 compared with H50. A recent meta-analysis investigating the effectiveness of milk urea N as a tool for evaluating protein feeding and N use efficiency selected only studies using Holstein dairy cows to remove the influence of breed (Zhao et al., 2025). Kauffman and St-Pierre (2001) reported a difference between Jersey and Friesian breeds for the linear relationship between urinary N and milk urea N over the range of milk urea N values they observed; however, they concluded that the breed effect was accounted for by BW rather that breed per se. This suggests that a larger proportion of Jersey herds, with lighter animals, is another factor to explain differences in BMU concentration observed between L50 and H50 groups in our dataset. Interestingly, the observation that milk production per cow was similar for divergent groups indicates that the L50 group produced higher amounts of MSO per kilogram of live weight due to their higher proportion of lighter Jersey herds. Similar to milking frequency, breed is another factor that should be considered when interpreting BMU concentrations, although dietary factors such as dietary CP content and the N to ME ratio of the diet, and N intake, are likely to have a stronger influence on BMU (Mangwe et al., 2025).

Several observations for L50 and H50 groups were mirrored by the 50 low and 50 high BMU farms selected within each of the 7 regions. For example, there were no differences in area, cow numbers, or milk production per cow for most geographical regions. Similarly, fertilizer was the most obvious farm management factor identified, with 2 to 3 times higher application for high BMU farms in each region compared with low BMU farms, driving higher PNS in the high BMU farms. However, within the regions, there were exceptions to the general findings that may provide deeper insights into ways to optimize N use efficiency on farm. For example, unlike L50 and H50, there were no differences in stocking rates for divergent groups in Northland and Taranaki. Likewise, there was no difference in milk production per hectare in Northland, Taranaki, and Lower North Island. The low BMU groups in the Bay of Plenty, Taranaki, and Lower North Island imported more feed, which was also higher in N in the Bay of Plenty and Taranaki, compared with high BMU groups in those regions; divergent groups in other regions were similar to L50 and H50 with comparable amounts of imported feed that were not different in N content. In Canterbury, estimated total DM and pasture and crops eaten per cow were higher for low BMU groups. These exceptions may illustrate that each region (or individual farm) across New Zealand may require a customized solution to improve N use efficiency and reduce N loss risk.

The Bay of Plenty was the outlier region for several farm characteristics. Stocking rate in this region was higher for the low BMU group compared with the high BMU group, whereas in other regions it was the reverse or not different. Milk production per cow and per hectare was higher for the low BMU group compared with the high BMU group, along with higher estimated total DM eaten per hectare, the opposite to observations for all other BMU divergent groups that showed significant differences. Furthermore, the Bay of Plenty was the only region where there was no difference between low and high BMU groups for the amounts of fertilizer used and their PNS score. The Bay of Plenty had the smallest number of total farms of all the regions; therefore, sample size may have influenced the results (i.e., the 100 farms [50 low and 50 high] represent a greater proportion of all Bay of Plenty farms). The factors that explain differences in BMU concentration for this region require a more granular dataset and further analysis.

A limitation of this study is that the farm characteristics are based on farmer self-reported data. Although care has been taken to remove obvious outliers by using limits to filter the information, some data may still be inaccurate. However, using 50 farms per group plus using data from 4 consecutive seasons should have reduced any inconsistencies that remain. Another limitation is that BMU values used to select the low and high BMU groups were annualized numbers. For an individual farm, BMU values can fluctuate considerably over a season (data not reported), and in some cases, this means that the annualized number may not correctly reflect the BMU across a season. However, selecting those farms with consistently high or low BMU over 4 consecutive lactation seasons has likely reduced this potential issue. From the regional analysis, it is evident that variations for farm characteristics between divergent BMU groups were dependent on region. The 50 low (L50) and 50 high (H50) farms selected from all suppliers were not balanced for region and this may also be a limitation of our study.

A key limitation of the statistical approach in this study is that comparisons between high and low BMU groups were conducted using nonparametric, univariable tests, without adjustment for potential confounders such as breed, milking frequency, or region. Although this limits the ability to attribute observed differences to specific management factors independently of these variables, the approach was considered appropriate for the current analysis. This was a large-scale, retrospective observational study, designed to characterize patterns in BMU and explore broad associations with farm management practices, rather than to establish causation. The priority was to use a method robust to the skewed distributions and variable completeness of the farmer-reported data, while avoiding overinterpretation of relationships in the absence of detailed, time-matched covariate information. More complex, multivariable analyses, incorporating adjustment for confounding factors, would be a logical next step in prospective or longitudinal studies with richer datasets, where the focus is on quantifying the relative contributions of specific factors to BMU variation.

This was an initial study to determine whether or not divergent BMU farms can be differentiated by their farm characteristics. The most obvious difference identified was the amount of N fertilizer used annually. The data indicate that farms with low BMU use much less N fertilizer but had similar supplement use per hectare, yet milk production per cow was similar to that achieved on high BMU farms likely due to the lower stocking rate. This may reflect appropriate use of N fertilizer relative to potential pasture and crop eaten. However, whereas amounts of fertilizer were known, timing of application was unknown, and practices between low and high BMU farms potentially differed. Identifying fertilizer and grazing management practices between divergent BMU groups (not available in this dataset) could assist farmers to use BMU as a proxy to guide decisions on improving N use efficiency at a farm level. For example, shorter grazing intervals after N fertilizer application may result in higher pasture CP content. Interestingly, feeding N in excess of requirement uses additional energy to metabolize excess protein, and to synthesize and excrete urea, reducing energy available for milk production (Reed et al., 2017). Depending upon pasture supply, feeding of supplements will vary between farms; however, low-cost homegrown pasture and crops are the predominant feed on New Zealand dairy farms representing approximately 80% of feed intake. Overall, this suggests that pasture composition is one of the bigger drivers of divergent BMU in pasture-based systems, mostly but not exclusively through differences in CP content, as demonstrated by Mangwe et al. (2025).

In conclusion, BMU is a practical indicator of herd dietary CP status and potential urinary N loss risk. This large-scale study analyzed BMU concentrations from ~9,600 pastoral dairy farms across 4 seasons and a wide geographical and climate range, highlighting substantial variation both within and between lactation seasons and identifying several farm management metrics and practices that differentiate farms with high and low BMU concentration. Farms with high BMU concentration had a greater purchased N surplus, and practices that typically lead to greater dietary CP such as increased use of N fertilizer and a greater proportion of pasture in the diet. Further, there was a trend of increasing BMU and dietary protein surplus in late lactation, which corresponds with autumn feeding management among spring-calving herds. Understanding factors affecting BMU concentration can support farmers to use BMU as an indicator of surplus or deficit herd dietary N relative to requirements alongside other information to improve farm N use efficiency and reduce risk of urinary N loss from dairy herds. Further work is required to determine the relative importance of the factors identified.

NOTES

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Nonstandard abbreviations used: BMU = bulk milk urea; FDR = farm dairy records; H50 = group of 50 farms with consistently high annual mean bulk milk urea concentration; IQR = interquartile range; L50 = group of 50 farms with consistently low annual mean bulk milk urea concentration; MSO = milk solids (milk fat and milk protein); OAD = once-a-day; PNS = purchased nitrogen surplus; TAD = twice-a-day.

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