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RESEARCH ARTICLE

Farm-level risk factors and treatment protocols for lameness in New Zealand dairy cattle

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ABSTRACT

Aims: To identify farm-level risk factors for dairy cow lameness, and to describe lameness treatment protocols used on New Zealand dairy farms.

Methods: One hundred and nineteen farms from eight veterinary clinics within the major dairying regions of New Zealand were randomly enrolled into a cross-sectional lameness prevalence study. Each farmer completed a questionnaire on lameness risk factors and lameness treatment and management. Trained observers lameness scored cattle on two occasions, between October–December (spring, coinciding with peak lactation for most farms) and between January–March (summer, late lactation for most farms). A four-point (0–3) scoring system was used to assess lameness, with animals with a lameness score (LS) ≥2 defined as lame. At each visit, all lactating animals were scored including animals that had previously been identified lame by the farmer. Associations between the farmer-reported risk factors and lameness were determined using mixed logistic regression models in a Bayesian framework, with farm and score event as random effects.

Results: A lameness prevalence of 3.5% (2,113/59,631) was reported at the first LS event, and 3.3% (1,861/55,929) at the second LS event. There was a median prevalence of 2.8% (min 0, max 17.0%) from the 119 farms. Most farmers (90/117; 77%) relied on informal identification by farm staff to identify lame animals. On 65% (75/116) of farms, there was no external provider of lame cow treatments, with the farmer carrying out all lame cow treatments. Most farmers had no formal training (69/112; 62%). Animals from farms that used concrete stand-off pads during periods of inclement weather had 1.45 times the odds of lameness compared to animals on farms that did not use concrete stand-off pads (95% equal-tailed credible interval 1.07–1.88). Animals from farms that reported peak lameness incidence from January to June or all year-round, had 0.64 times odds of lameness compared to animals from farms that reported peak lameness incidence from July to December (95% equal-tailed credible interval 0.47–0.88).

Conclusions: Lameness prevalence was low amongst the enrolled farms. Use of concrete stand-off pads and timing of peak lameness incidence were associated with odds of lameness.

Clinical relevance: Veterinarians should be encouraging farmers to have formal lameness identification protocols and lameness management plans in place. There is ample opportunity to provide training to farmers for lame cow treatment. Management of cows on stand-off pads should consider the likely impact on lameness.

Abbreviations: ETI: Equal-tailed credible interval; LS: Lameness score; MICE: Multiple imputation chained equation; NSAID: Non-steroidal anti-inflammatory drugs

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Introduction

Worldwide, lameness is one of the most important dairy cattle diseases impacting animal welfare (Whay and Shearer 2017), productivity (Huxley 2013), greenhouse gas emissions (Mostert *et al*. 2018) and the social licence to farm dairy cattle (Hampton *et al*. 2020). We thus need effective evidence-based prevention strategies to reduce the burden of lameness.

For lameness, most of our evidence base is derived from large-scale observational studies (Bran *et al*. 2018; O'Connor *et al*. 2020; Browne *et al*. 2022b). Whilst such studies do not allow temporal causation to be assessed, the complexities and cost of conducting interventional studies for claw-horn lameness (Thomas *et al*. 2015; Wilson *et al*. 2022), compared to the relative ease of collecting data on a large number of farms/cows, means that observational studies have been key to our understanding of the epidemiology of disease.

These observational studies have identified a wide range of risk factors including animal-level risk factors such as age (Mason 2017), previous lameness (Randall *et al*. 2018), and body condition score (Lim *et al*. 2015) as well as farm-level risk factors such as

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housing system (Haskell *et al*. 2006), routine hoof-trimming (Griffiths *et al*. 2018), patience of farm staff (Chesterton *et al*. 1989) and rainfall (Ranjbar *et al*. 2016). However, the multifactorial nature of lameness involving, as it does, animal, environment and management components means that we need system-specific studies that identify risk factors for that system (Ranjbar *et al*. 2016). For example, Barker *et al*. (2010) identified that in the UK, the use of automatic floor scrapers was a key risk factor, while Chesterton *et al*. (1989) identified track maintenance on New Zealand dairy farms as an influential factor. The first of these is not relevant to cows kept permanently at pasture, while the second is irrelevant in zero-grazed cows.

In New Zealand, dairy cows on the vast majority of farms are kept permanently at pasture. This means that they are not regularly exposed to hard surfaces outside milking times and, on an increasing number of farms (Milet *et al*. 2015), when they are fed supplementary feed (usually for a short period of time before or after milking). This system is markedly different from many of the systems used in North America and Europe where much of the research on lameness risk factors has been undertaken (Olechnowicz and Jaśkowski 2010; Oehm *et al*. 2019). Thus, in order to develop evidence-based lameness control programmes for dairy cattle in New Zealand we need research that is relevant to the New Zealand system. However, there is a lack of such data (Ranjbar *et al*. 2016).

This means that the current industry-led lameness programme, Healthy Hoof (https://www.dairynz.co.nz/support/training/healthy-hoof-programme/) has based its guidelines for lameness prevention on a mix of recommendations supported by published evidence and recommendations from expert opinion (including 4/5 authors of this paper). For example, maintaining farm tracks immediately around the milking parlour is emphasised as a crucial risk-reduction strategy. This is consistent with the findings of Chesterton *et al*. (1989) that "average maintenance state of the main track" accounted for 13.7% in the variation in lameness prevalence between farms. However, the focus on tracks near the milking parlour is based on expert opinion that these tracks will be responsible for most of the impact on lameness of poorly maintained tracks. Furthermore, expert opinion is used to decide where there is conflicting published evidence. For example, Healthy Hoof recommends that, for Friesian cows, the size of the collecting yard should be at least 1.5 m^2 per cow. This focus on collecting yard size (though not the specific minimum) is consistent with Ranjbar *et al*. (2016) who reported that an increase in the available space was associated with a reduction in the odds of lameness. However, Chesterton *et al*. (1989) reported that increased space per cow in the collecting yard was associated with an *increase* in the odds of the farm having a high lameness prevalence. This combination of evidence-base and expert opinion stands in stark contrast to the New Zealand-developed SmartSAMM mastitis and milk quality programme (https://www.dairynz.co.nz/animal/cow-health/mastitis/tools-and-resources/about-smartsamm/) which is backed up by 23 evidence-based technotes (https://www.dairynz.co.nz/animal/cow-health/mastitis/tools-and-resources/guidelines-and-technotes/).

We clearly need more data and analysis of the risk factors for lameness in pasture-based cattle in New Zealand, so that we can better guide lameness control programmes. Furthermore, to develop such programmes, we need a better understanding of what is currently happening in regard to lameness treatment and management of New Zealand dairy farms. Thus, the aims of this study were to describe the lameness treatment and management practices carried out on New Zealand pasture-grazing dairy farms and to investigate farm-level risk factors for lameness on those farms.

Materials and methods

The study was designed as a cross-sectional descriptive study, with all procedures approved by Massey University human ethics committee, application number 4000025095 and Massey University animal ethics committee application number Protocol 21/55 and 22/36.

Details on farm enrolment and lameness score methods are described in full in Mason *et al*. (2023b). In brief, a total of 120 dairy farms across New Zealand were enrolled into a cross-sectional study on lameness prevalence and risk factors. Veterinary clinics from eight territorial regions of New Zealand (one clinic per region, henceforward referred to as region), four within the North Island of New Zealand (Northland, Waikato, Taranaki, and Manawatū) and four within the South Island of New Zealand (West Coast, Canterbury, Southland, and Otago), were contracted to each randomly enrol fifteen farms. Veterinary clinics were conveniently selected based on previous experience in providing high-quality research on dairy farms. On each farm, the locomotion of all lactating cows was scored on two occasions during one dairy season (New Zealand dairy seasons are from 1 June to 31 May), using a 0–3 scale, where lameness score (LS) ≥ 2 was considered clinically lame (DairyNZ lameness score; Supplementary Table 1). Lameness scores were collected between October–December and then again in January–March, with a median of 91 (IQR 78–105) days between scores. Animals were scored by trained and calibrated observers (one observer for each vet clinic within region) immediately after milking. Where possible cows were observed whilst walking on a flat concrete surface, or where a concrete surface was not available or appropriate, on a flat compacted race surface immediately adjacent to the

milking shed. Scored cows included animals that had been previously identified as lame by the farmer and had been placed into a separate herd at the time of the lameness scoring visit. Animals with LS $\geq$ 2 and the total number of animals scored on each farm were tallied. Details of the training methods and their validation and the prevalence analysis flowing from this data can be found in Mason *et al*. (2023b). The power of the study, and thus the number of farms enrolled, was selected based on being able to detect lameness prevalence to within 5%, if the true prevalence estimate was 8.3%. It was not powered to detect differences between farm-level risk factors. However, the power calculation of 100 cows from 100 farms used in Browne *et al*. (2022b) would infer that the current study was powered to detect a risk factor with a relative risk of 1.3, with an 80% power.

On each of the farms, the primary decision maker for animal health was asked to respond to a survey after the completion of the first farm visit. The farmers were blind to the results of the lameness score until the completion of the study, and no lameness advice was provided to the farmers by study personnel.

Farmer questionnaire

A questionnaire consisting of four sections was sent to all enrolled farmers (Supplementary Material 1). The first section consisted of farm demographic and descriptive information and included responses on herd size, breed proportion, collecting yard shape and size, milking parlour design, milking frequency, farmer-defined lameness incidence risk for the lactation and month of peak lameness incidence. The second and third sections were on lameness diagnosis and treatment, respectively. This included how lame cows were identified, whether all lame cows had their hooves lifted and examined, if lame cows were treated in a purpose-built lame cow crush, whether lame cows were treated by an external operator (veterinarian and/or hoof-trimmer), if the farmer had had any formal lameness treatment training, the predominant lameness lesion identified, the proportion of lame cows that received non-steroidal anti-inflammatory drugs (NSAID) or a block, and whether any culling decisions were based on lameness or if the farmer prioritised culling based on lameness. Data were also collected on whether lame cows were milked once-a-day, and if lame cows were always managed in a separate herd near the milking parlour. The final section was on lameness and animal handling management on farm, and included the use of a top-gate, whether the backing gate or top-gate was alarmed or electrified, whether dogs were used to move cows, whether the farm had a permanent foot-bath or in-shed feeding, or whether they used a concrete stand off pad (i.e. cows were held on either a feed pad or on the collecting yard during periods of inclement weather to protect pasture from pugging damage). Farmers were also asked to report the maximum one-way distance a cow would walk, and the average distance walked per day across the season, and what percentage of the farm tracks underwent maintenance every year. Questionnaires were completed by the primary decision maker on-farm either in person at the completion of the first LS visit, or within two weeks following the first LS via phone consultation, with farmer responses transcribed by the technician. Study technicians were responsible for transcribing all questionnaire responses into an Excel spreadsheet (Microsoft Corp., Redmond, WA, USA). All responses were from the farmer, with no on-farm validation of farmer responses by study personnel.

Statistical methods

At the completion of the collection period, the raw questionnaire data in a .csv file was imported into R (R Core Team 2023, R Foundation for Statistical Computing, Vienna, Austria), where all data analysis was conducted. Farmer survey data were tabulated and reported descriptively, split by whether they were on the North or South Island.

Scores for individual cows were collapsed into binary lame (LS 2 or LS 3) or non-lame (LS < 2) categories and the unit of interest for all lameness score data was at the cow level. All continuous variables were categorised into either two or three categories, based on discussions between the researchers on the biological relevance and granular reporting of the answers, and each containing an equal number of farms. The proportion of each breed was recategorised as the single breed that made up the greatest amount of the herd. The month of greatest number of lameness cases was categorised into July–December, or January–June, with the latter category including all responses where no defined monthly peak ("all months") was reported as the greatest number of lameness cases. As farmers could select more than one option for lameness detection methods, this variable was collapsed into whether farmers only identified lame animals informally when cows were walking to and from the milking parlour, or if they selected any of the formal lameness identification methods (LS from external providers, farm staff or on-farm technology). Farmers that entered more than one primary lameness lesion were recategorised as reporting multiple lesions.

Missing predictor data was handled using different methods, depending on the analysis. At the univariable level, all missing values were removed from the respective models. At the multivariable level, missing data was handled via two methods, depending on

the proportion of data missing for each variable. If a variable had greater than 10% missing, it was not included in the multivariable model, regardless of its significance at the univariable level. If a variable had less than 10% missing, it was included in the initial multivariable model, and multiple imputation chained equations (MICE; n = 10 chains) were used to simulate and replace missing predictor values, using the mice package in R (as described in Van Buuren and Groothuis-Oudshoorn 2011).

The final data set consisted of a total of 34 farm-level risk factors (described in Tables 1–3). These variables were individually assessed at a single risk factor level, with the individual risk factor as the predictor and the presence/absence of lameness at the cow level being the outcome. These analyses used frequentist mixed logistic regression, implemented using the lme4 package in R (Bates 2010). A simple univariable model was not used for this analysis as there were two areas of lack of independence with cows having two repeated scores, and cows nested with farm. Information on the lameness score associated with each cow was not collected ear tags were not recorded as this is logistically challenging under New Zealand conditions (Werema *et al*. 2021), so repeated scores within cows could not be modelled. Instead, score (spring or summer) nested within farm was included as random intercepts, with a uniform correlation structure as there were only two time points for each study, in all the single-risk factor models. Whilst this will not account for all of the potential clustering within cow, this source of clustering has been reported to be very small in previous cattle lameness research (Browne *et al*. 2022b). The OR, with 95% CI and p-value based on the log-likelihood ratio test, was then reported individually for each of the 34 risk factors. These OR can be interpreted as the odds of a cow being lame in the average farm with the presence of the risk factor, without accounting for any potential confounders. Any variable with a log-likelihood ratio test (between a model with the variable included and an intercept only model) with $p < 0.20$ was then included into an initial multivariable mixed logistic regression model. These variables were first assessed for collinearity, with variables with variance inflation factors > 4 deemed to have high collinearity with other predictors, and not included further in the analysis.

For the subsequent multivariable analyses, Bayesian generalised linear regression models were used, using default priors (weakly informative for intercept and random effect intercepts, and flat priors for the population-level fixed effects), and the same outcome (lame/not lame) and random effect structure as used for the single risk factor models, as per Browne *et al*. (2022a). The primary motivation for using Bayesian methods was to utilise posterior probability interpretation and improved variables selection stability techniques. These were implemented within the brms package in R (Bürkner 2017), using no-u-turn Markov chain Monte Carlo sampling methods. For each of the 10 MICE chains, five chains of 6,000 iterations each, with 500 warm-up iterations, were run (a total of 50 chains). Starting with a full model, variable selection was carried out using leave-one-out cross-validation with Pareto smoothed importance sampling algorithms, the model with the combination of fixed effects with the smallest expected log predictive density defined as the best fit for the data (Vehtari *et al*. 2017). No interactions were investigated. Posterior predictions of the median OR probability were made for each remaining variable, with uncertainty around the OR of these variables reported as 95% equal-tailed credible intervals (ETI). Posterior probabilities were also reported as the percentage of posterior samples that had an OR < 1 or > 1, depending on the direction of central measure. Trace plots of each chain and the rhat statistic (>1.05 was defined as poor convergence) were used to assess convergence of posterior samples. Sensitivity analysis of the priors was carried on the final multivariable model for the fixed and random effects to assess the influence of the default priors on posterior probabilities.

Results

Farm descriptive statistics

A total of 119 of the 120 enrolled farms responded to the farm survey, 14 farms from the West Coast, and 15 farms each from the other seven regions. Farm characteristics, split by island, are presented in Table 1. From the 119 farms, a total of 2,113/59,631 (3.5%) cows had a LS ≥ 2 at the first LS event. During the second LS event, a total of 1,861/55,929 (3.3%) cows had a LS ≥ 2. At the farm level, across both scoring events, median lameness prevalence was 2.8% (min 0, max 17.0%) (more detail available in Mason *et al*. 2023b).

Lameness identification and treatment methods

Descriptive statistics of the methods reported by farmers for lameness identification, treatment and recovery management are presented in Table 2, grouped by island. Due to errors entering survey data, data were missing from farmers from Northland and West Coast for two questions on treatment methods. The majority (90/117; 77%) of farmers relied on informal identification by farm staff to identify lame animals, although this was more pronounced in the North Island (52/60; 87%) than the South Island (38/57; 67%). Of those that reported formal lameness identification methods, 16 (14%) farmers carried out

Table 1. Characteristics of farms (n = 119) enrolled into a lameness prevalence and risk factors study, from the North (n = 60) and South (n = 59) Islands of New Zealand.

Characteristic	Overall (n = 119)	North (n = 60)	South (n = 59)	P-value[a]
Herd size; n (%)				<0.001
110–359	40 (34)	30 (50)	10 (17)	
360–560	39 (33)	19 (32)	20 (34)	
561–1,850	39 (33)	11 (18)	28 (48)	
Missing	1	0	1	
Milk solids (kg/cow/year); n (%)				0.023
240–399	39 (34)	26 (44)	13 (23)	
400–460	39 (34)	20 (34)	19 (34)	
461–600	37 (32)	13 (22)	24 (43)	
Missing	4	1	3	
Number of full-time staff; n (%)				0.006
<2.5	66 (56)	41 (68)	25 (43)	
≥2.5	52 (44)	19 (32)	33 (57)	
Missing	1	0	1	
Milking frequency; n (%)				0.17
Less than twice-a-day	33 (28)	20 (33)	13 (22)	
Twice-a-day all year	86 (72)	40 (67)	46 (78)	
Yard size (m^2); n (%)				<0.001
<300	21 (36)	16 (53)	5 (17)	
300–600	18 (31)	11 (37)	7 (24)	
>600	20 (34)	3 (10)	17 (59)	
Missing	60	30	30	
Predominant breed; n (%)				0.016
Holstein-Friesian	47 (39)	27 (45)	20 (34)	
Jersey	18 (15)	13 (22)	5 (8.5)	
Holstein/Jersey cross	54 (45)	20 (33)	34 (58)	
Milking parlour; n (%)				0.008
Herringbone	59 (50)	37 (62)	22 (37)	
Rotary	60 (50)	23 (38)	37 (63)	
Calving system; n (%)				<0.001
100% spring calving	108 (91)	49 (82)	59 (100)	
Split calving	11 (9.2)	11 (18)	0 (0)	
Yard shape; n (%)				0.052
Circular	81 (70)	46 (78)	35 (61)	
Rectangular	35 (30)	13 (22)	22 (39)	
Missing	3	1	2	
Farmer-reported % lame: n (%)				0.12
<7%	40 (40)	21 (38)	19 (42)	
7–15%	35 (35)	16 (29)	19 (42)	
>15%	25 (25)	18 (33)	7 (16)	
Missing	19	5	14	
Peak lameness; n (%)				<0.001
No peak	4 (3.4)	3 (5.1)	1 (1.8)	
January–March	15 (13)	0 (0)	15 (26)	
April–June	11 (9.5)	2 (3.4)	9 (16)	
July–September	32 (28)	22 (37)	10 (18)	
October–December	54 (47)	32 (54)	22 (39)	
Missing	3	1	2	

[a]Pearson's χ^2 test of proportions comparing responses from farms from the two islands.

lameness scoring of the herd, 13 (11%) used on-farm technology to assist with lameness identification, and two (2%) used external providers to conduct lameness scoring. White line disease was reported as the predominant lameness-inducing lesion (51/118; 43% of farmers), and this was consistent across the two islands. The majority of farmers reportedly undertook all the lame cow treatments themselves with no assistance from external providers (75/116; 65%), with the other 41 (35%) farmers using professional hoof trimmers or veterinarians for at least some of the lame cow treatment. Most (69/112; 62%) had no formal training. Lame cow crushes were present and used on approximately half of the farms. Fifty percent (49/98) of responding farmers reported using blocks for at least 22% of lame animals, and 47% (49/104) used NSAID for at least 30%. Once-a-day milking of the identified lame animals was common (73% (72/99) of all farmers always milked lame animals once-a-day), with the practice more common in the South Island compared to the North Island (80% *vs.* 63%). Lame animals were always managed in a separate herd near the milking parlour on 83% (85/103) of farms. Most farmers considered lameness when making culling decisions (72/110; 65%), however, this decreased to 42% (48/113) when they were asked if they prioritised culling decisions based on lameness.

Farm descriptors of lameness management factors

A small percentage of farmers used dogs to move cows (18/116; 16%), although this practice was almost entirely associated with North Island farmers (Table 3). One third of farmers (37/116; 32%) used a concrete stand-off pad, including 48% (28/58) of North Island

Table 2. Descriptive statistics of lameness treatment and recovery management as reported by 119 farmers enrolled into a lameness prevalence and risk factors study, from the North (n = 60) and South (n = 59) Islands of New Zealand.

Characteristic	Overall (n = 119)	North (n = 60)	South (n = 59)	P-value[c]
Identify lame cows; n (%)				0.010
Dedicated lameness scoring or technology	27 (23)	8 (13)	19 (33)	
Informal, non-dedicated task	90 (77)	52 (87)	38 (67)	
Missing	2	0	2	
Primary lameness; n (%)				0.047
Footrot	18 (15)	13 (22)	5 (8.6)	
Multiple lesions	18 (15)	4 (6.7)	14 (24)	
Other	6 (5.1)	3 (5.0)	3 (5.2)	
Sole lesions	25 (21)	14 (23)	11 (19)	
White line	51 (43)	26 (43)	25 (43)	
Missing	1	0	1	
Lift hoof; n (%)				0.70
Always	75 (91)	40 (93)	35 (90)	
Never or sometimes	7 (8.5)	3 (7.0)	4 (10)	
Missing	37	17[a]	20[b]	
% Treated with hoofblock; n (%)				0.68
≤22	49 (50)	26 (48)	23 (52)	
>22	49 (50)	28 (52)	21 (48)	
Missing	21	6	15[b]	
Where lame cows are treated; n (%)				0.001
Lame cow crush	59 (52)	20 (36)	39 (67)	
Other	54 (48)	35 (64)	19 (33)	
Missing	6	5	1	
External trimmer; n (%)				0.11
No	75 (65)	34 (58)	41 (72)	
Yes	41 (35)	25 (42)	16 (28)	
Missing	3	1	2	
Formal trimming training; n (%)				0.56
No	69 (62)	36 (64)	33 (59)	
Yes	43 (38)	20 (36)	23 (41)	
Missing	7	4	3	
% treated with NSAID; n (%)				>0.99
≤30	55 (53)	27 (53)	28 (53)	
>30	49 (47)	24 (47)	25 (47)	
Missing	15	9	6	
Lame milked once-a-day; n (%)				0.051
No	12 (12)	9 (21)	3 (5.4)	
Sometimes	15 (15)	7 (16)	8 (14)	
Yes	72 (73)	27 (63)	45 (80)	
Missing	20	17	3	
Cull based on lameness; n (%)				0.050
Maybe	13 (12)	5 (8.9)	8 (15)	
No	25 (23)	18 (32)	7 (13)	
Yes	72 (65)	33 (59)	39 (72)	
Missing	9	4	5	
Prioritise culling based on lameness; n (%)				0.062
Maybe	34 (30)	12 (21)	22 (39)	
No	31 (27)	20 (36)	11 (19)	
Yes	48 (42)	24 (43)	24 (42)	
Missing	6	4	2	
Management when lame; n (%)				0.031
Always in separate herd near shed	85 (83)	33 (73)	52 (90)	
Other	18 (17)	12 (27)	6 (10)	
Missing	16	15[a]	1	

[a]Farmers from Northland did not answer this question.
[b]Farmers from West Coast did not answer this question.
[c]Pearson's χ^2 test of proportions comparing responses from farms from the two islands.
NSAID = non-steroidal anti-inflammatory drug.

farmers and 16% (9/58) of South Island farmers. There was a difference between the islands in the use of top-gates to move cattle in the collecting yard, with use on 67% (39/58) of South Island farms compared to 23% (13/57) on North Island farms. The majority of farms (89/116; 71%) had a backing gate with an alarm or hose that turned on when the gate moved. Permanent footbaths were an uncommon finding (9/115; 8% of farms). Undertaking track maintenance on more than 20% of the farm tracks over the preceding 12 months was reported on 35% (40/115) of all sampled farms but was more common on South Island farms than North Island farms (30/57; 53% *vs.* 10/58; 17%, respectively).

Farm risk factors for lameness

Univariable associations between the 34 reported predictor variables identified 11 variables that could be included in the initial multivariable models (Supplementary Table 2). However, region and island were both highly collinear (variance inflation factors

Table 3. Descriptive data of management strategies for lameness as reported by 119 farmers enrolled into a lameness prevalence and risk factors study, from the North (n = 60) and South (n = 59) Islands of New Zealand.

Characteristic	Overall (n = 119)	North (n = 60)	South (n = 59)	P-value[a]
Top gate; n (%)				<0.001
No	63 (55)	44 (77)	19 (33)	
Yes	52 (45)	13 (23)	39 (67)	
Unknown	4	3	1	
Electrified backing/top gate; n (%)				0.12
No	89 (77)	48 (83)	41 (71)	
Yes	27 (23)	10 (17)	17 (29)	
Unknown	3	2	1	
Backing gate alarm/hose; n (%)				<0.001
No	34 (29)	26 (45)	8 (14)	
Yes	82 (71)	32 (55)	50 (86)	
Unknown	3	2	1	
Use dogs to move cows; n (%)				0.010
No	98 (84)	44 (76)	54 (93)	
Yes	18 (16)	14 (24)	4 (6.9)	
Unknown	3	2	1	
Concrete stand-off pad; n (%)				<0.001
No	79 (68)	30 (52)	49 (84)	
Yes	37 (32)	28 (48)	9 (16)	
Unknown	3	2	1	
In-shed feeding; n (%)				<0.001
No	41 (40)	34 (59)	7 (16)	
Yes	62 (60)	24 (41)	38 (84)	
Unknown	16	2	14	
Permanent footbath; n (%)				0.49
No	106 (92)	54 (95)	52 (90)	
Yes	9 (7.8)	3 (5.3)	6 (10)	
Unknown	4	3	1	
Farm policy for managing lameness; n (%)				<0.001
No	25 (22)	21 (36)	4 (7.1)	
Yes	89 (78)	37 (64)	52 (93)	
Unknown	5	2	3	
Maximum one-way distance; n (%)				0.26
≤1.5 km	68 (60)	32 (55)	36 (65)	
>1.5 km	45 (40)	26 (45)	19 (35)	
Unknown	6	2	4	
Track maintenance over past 12 months; n (%)				<0.001
≤20%	75 (65)	48 (83)	27 (47)	
>20%	40 (35)	10 (17)	30 (53)	
Unknown	4	2	2	
Average distance walked per day; n (%)				0.77
≤2 km	55 (50)	28 (49)	27 (52)	
>2 km	54 (50)	29 (51)	25 (48)	
Unknown	10	3	7	

[a]Pearson's χ^2 test of proportions comparing responses from farms from the two islands.

> 10) with other predictors and thus were not included in any multivariable models. The nine remaining variables were farmer-reported lameness incidence risk, calving system, farmer-reported peak lameness incidence period, primary lameness lesion, use of an external trimmer, use of a top-gate to move cattle in the collecting yard, electrified backing gate, backing gate alarm/hose, use of a concrete stand-off pad and track maintenance. All of these nine variables had <10% missing data, and were thus included in the initial multivariable model, using MICE.

Two farm-level predictors were selected for the final multivariable generalised linear mixed model on the association with the odds of lameness (Table 4). After accounting for herd and repeated LS between cow, animals from farms that used concrete stand-off pads

Table 4. Final Bayesian multivariable logistic mixed regression model for the association between farm-level risk factors and the odds of lameness with output as OR and 95% equal-tailed credible intervals (ETI). Data from cows across 119 farms, using multiple imputed chained equation (n = 10) for missing data.

Characteristic	Estimate	Std. error	OR (95% ETI)[a]
Peak lameness incidence			
July – December	Reference		
January – June[b]	−0.44	0.14	0.64 (0.47–0.88)
Concrete stand-off pad			
No	Reference		
Yes	0.37	0.16	1.45 (1.07–1.88)

[a]OR and 95% highest density uncertainty interval.
[b]January–June also includes four farms that stated all months of the year had equal incidence of lameness.

during inclement weather were associated with 1.45 times the odds (95% ETI = 1.07–1.88) of lameness compared to animals on farms that did not use concrete stand-off pads. There was a 100% probability that the OR of lameness was >1 on farms that used concrete stand-off pads during inclement weather compared to those that did not. Animals from farms that reported peak lameness incidence from January–June or all-year-round, had 0.64 (95% ETI = 0.47–0.88) times the odds of lameness than cows from farms that reported peak lameness incidence from July–December. There was a 100% probability that the OR comparing peak lameness from January–June was <1 compared to July–December. No issues with model convergence were identified. Sensitivity analysis of the priors revealed no undue influence on posterior probabilities, with log odds and standard errors of the final fixed effects changing by <5%.

Discussion

This cross-sectional survey of 119 dairy farms across eight regions of New Zealand revealed associations between lameness prevalence and using a concrete stand-off pad and with the timing of peak lameness. A range of lameness treatment procedures and lameness management practices were reported, with potential areas for improvement identified, such as considering lameness identification as a dedicated job on farm.

Lameness identification was not treated as a formal dedicated task on most farms. This is in agreement with the situation in Ireland, where only one of 99 Irish dairy farms carried out lameness scoring and used technology to identify lame animals (Browne *et al*. 2022c). Early identification of lameness is a critical component of lameness management (Groenevelt *et al*. 2014; Pedersen and Wilson 2021). As the low detection of lameness by farmers is as apparent in New Zealand (Alawneh *et al*. 2012; Fabian *et al*. 2014; Mason *et al*. 2023c) as it is worldwide (summarised by Sadiq *et al*. 2019), improving lameness detection is one major area that could see improvement across New Zealand dairy farms (Leach *et al*. 2010).

The use of formal lameness identification, whether via on-farm technology or via lameness scoring, is greater in the South Island, possibly due to larger herd sizes (Gargiulo *et al*. 2018) and greater frequency of rotary milking parlours (Dela Rue *et al*. 2020) on these farms. Automated lameness detection methods, such as cameras with machine-learning technology, have the potential to offer a range of lameness identification benefits, from real-time lameness prevalence and incidence monitoring, through early identification of lame cows along with automated identification and drafting and even assessing the decision making for the recovery of lame animals. All of these are difficult to achieve using manual lameness scoring, However, before widespread adoptions and recommendations of these systems occurs, optimising sensitivity and specificity, and addressing farmer barriers and needs must be addressed (Alsaaod *et al*. 2019; O'Leary *et al*. 2020).

All lame cows were managed in a separate herd near the milking parlour on 83% of farms, and 87% of farms milked lame cows once-a-day at least some of the time. Provided the nutritional needs of the convalescing lame cows can be met (Lim *et al*. 2015), the recovery of treated lame cows on pasture provides an ideal surface to encourage recovery (Mason *et al*. 2023a). It was speculated that the practice of allowing cattle to recover on pasture close to the milking parlour and milking them once-a-day was in part responsible for the rapid time to recovery noted in 241 cattle lame with claw-horn lameness (median time of 19 days for animals to become sound and 7 days to become non-lame) (Mason *et al*. 2023a). Although the recovery of lame cows once identified and treated remains an under-researched area of lameness management, the authors believe this should be considered an integral part of all on-farm lameness management plans globally.

Very few South Island farms used dogs to move cattle (7%), in contrast to almost a quarter of North Island farmers (24%). The use of biting dogs has been strongly associated with the risk of high lameness prevalence on New Zealand dairy farms (Chesterton *et al*. 1989). However, in that same study, whether dogs were used at all was not associated with lameness in the final path analysis, and the current study did not reveal a negative association between the use of dogs and the odds of lameness. A well-behaved dog is likely to be better than a human with poor patience when moving cattle (Chesterton *et al*. 1989), and thus the authors suggest that a blanket recommendation to avoid dogs on dairy farms to minimise lameness is not appropriate. Instead, concentrating on educating farm staff and owners on the importance of cattle handling should be the priority, regardless of the methods used to achieve this.

The use of a concrete stand-off pad was identified as an important risk factor for lameness. As this practice was reported by one-third of farmers, there is substantial room for improvement in this space. The negative impact that concrete has on hoof-health is well documented in housed dairy systems (Adams *et al*. 2017; McLellan *et al*. 2022). Factors associated with concrete surfaces have also been reported previously in pasture-based systems, with the smoothness of the concrete surface associated with the risk of lameness (Ranjbar *et al*. 2016). Although information was not collected on when farmers were using stand-off pads in this current study, anecdotally, this practice is most common around the time of parturition, a period where the hoof is most vulnerable to

damage (Tarlton *et al*. 2002; Knott *et al*. 2007). The issue with the concrete pad is likely not just due to the concrete surface *per se*, but also the lack of choice the cow has for a standing surface. Cattle prefer to stand and ambulate on comfortable softer surfaces when given the choice (Telezhenko and Bergsten 2005; Boyle *et al*. 2007; McLellan *et al*. 2022), and this choice of surfaces has resulted in less time standing on concrete, with an associated reduction in the risk of lameness (Boyle *et al*. 2007; McLellan *et al*. 2022). The practice of using a stand-off pad removes this choice for the cow, thus the surface likely becomes more critical. Collecting data on the timing, frequency, surface, and space available would be of interest in future studies, as would data on pad use. It is possible that farms with a pad are more inclined to use concrete stand-off pads, thus this association may be confounded by the total daily time on concrete. However, this study provides enough evidence that the practice of standing cows off on concrete surfaces during times of inclement weather greatly increases the risk of lameness and should be discouraged, and other methods (e.g. dedicated sand area) need to be investigated on these farms if the practice is to continue. Furthermore, it is likely that any practice that results in prolonged exposure to concrete in pasture-grazing cattle is harmful. On Irish dairy farms, retaining cattle on the concrete collecting yard until all cows were milked, rather than being able to freely walk back to pasture, was associated with 2.26 times odds of lameness (O'Connor *et al*. 2020). Finally, practical alternatives for a concrete stand-off pad should be researched to provide farmers tools to manage both animals and pasture. Information on the prevalence of lameness on farms that use compost barns or sacrifice paddocks would be a useful addition.

The time of peak lameness incidence, as defined by farmers, was associated with the odds of lameness. Farms where lameness peaked between January and June, or which had no defined peak, were associated with a reduction in the odds of lameness compared to farms that had peak lameness between July to December. As 108/119 (91%) farms were 100% spring-calving, this can be extrapolated out to farms that reported peak lameness in the second half of lactation were associated with reduced odds of lameness. A criticism of this association is that it is relying on farmer recall. However, all farmers should have similar recall bias pressure and if anything, this bias should have shifted the result towards no association. As the posterior probabilities reported suggest a large effect (a 95% probability that the true odds of lameness were between 12 and 53% lower on farms that reported a peak lameness prevalence in the second half of lactation), we believe this to be a clinically relevant association. Whilst we do not know why this is the case, one theory is that farms that are reporting a later lameness peak may have a lower overall annual incidence of lameness and a delayed time to first-lameness. As lameness risk increases with age (Newsome *et al*. 2016; Mason 2017) and with previous cases of lameness (Randall *et al*. 2018), this delayed time to first lameness may have prolonged and profound effects on the lameness prevalence. However, the evidence is not clear on this point, with both reduced risk of lameness (Oehm *et al*. 2019), and increased risk of lameness (Thomas *et al*. 2023) reported in animals that are lame later in lactation compared to earlier in lactation. Thus, more research is needed into this area.

Whilst it must be stressed that unconditional associations may be biased, some unadjusted associations identified in this current study warrant further discussion. The presence of an alarm or hose that turned on when the backing gate moved was associated with a 27% reduction in the odds of lameness. This unconditional finding was also reported by Chesterton *et al*. (1989). From a Bayesian perspective, reporting a similar finding across more than one study increases the probability that the effect is real. Thus, these unconditional associations add evidence that placing alarms on backing gates to alert cows and farm staff to the presence of the moving gate assists in reducing lameness risk. This is presumably due to reduced pressure placed on cattle in the collecting yard (Ranjbar *et al*. 2016).

The use of a top-gate was also associated with a reduction in the odds of lameness. We do not know why this is the case but speculate that the use of a top-gate improves cow flow within the collecting yard (Chesterton *et al*. 1989; Ranjbar *et al*. 2016). Milking order and cow behaviours can impact lameness risk (Sauter-Louis *et al*. 2004). Those authors hypothesised that the use of the backing gate mostly affects those cows at the rear of the collecting yard, and also identified that these cows positioned at the rear of the collecting yard had greater risk of lameness compared to those positioned towards the front of the collecting yard. A top-gate likely improves cow flow within the yard, ensuring that the animals placed towards the back of the collecting yard are less likely to have backing gate pressure placed on them, thus lowering the risk of lameness.

The lack of association with some variables is also of interest. Conflicting associations between herd size and risk of lameness have been reported in studies investigating housed or partly-housed cattle. An increased risk of lameness with increasing herd size has been reported in some studies (Sjöström *et al*. 2018; Oehm *et al*. 2019; Browne *et al*., 2022). In contrast, other studies in housed cattle have reported that increased herd size was associated with a reduced risk of lameness (Chapinal *et al*. 2013, 2014; Solano *et al*. 2015). Such evidence for associations between herd size and lameness in either direction is

lacking in pasture-based studies. In this current study, no association between herd size and lameness was identified ($p = 0.70$), consistent with the findings of other pasture-based lameness risk factor studies (Chesterton *et al*. 1989; O'Connor *et al*. 2020). These findings all suggest that herd size *per se* is not a useful predictor of lameness risk across any dairy system, and placing emphasis on this factor is unfounded.

We recognise that with one scorer per clinic and one clinic per region, the hierarchical structure of the data is potentially confounded, and we cannot definitively identify the level at which clustering is occurring: within scorer, clinic, or region. All scorers were trained and followed a standard operating procedure and we believe that the variation between scorers is likely to be small and so the risk of clinic and region being confounded by scorer is minimal. We also believe that with 15 farms scored per clinic and with the limited pool of candidate farms available to each clinic, any variation between clinics is also likely to be small and so the risk that region is confounded by clinic is also small. Thus, we have reported our results with region as the grouping effect but recognise that this term is in fact a proxy for scorer within clinic within region. Given the epidemiological risk factors for lameness in New Zealand, we believe that the differences we have observed are more likely to reflect differences between regions than between clinics and are more intuitive and useful for the reader. However, further work is required to confirm these regional effects and to definitively separate them from the effects of clinic and scorer.

Regional and island differences in lameness prevalence were reported at the univariable level. Region and island were intrinsically linked to certain risk factors, and as a consequence, substantial collinearity and convergence issues arose when region or island were placed into multivariable models. For example, only 2/45 farms from the three most southern regions (Southland, Otago, and Canterbury) used dogs, compared to 16/75 farms from the other regions. Therefore, region can be considered a case of an extreme confounder in this dataset, and it was not possible to separate out the latent effect of region from the reported risk factors. Furthermore, whilst region and island were strongly associated with the odds of lameness, these variables are just proxies for certain latent farm variables, and further investigations should be conducted to identify particular farm factors that may occur in those regions with greater or lower levels of lameness. This is the challenge of interpreting region-specific (veterinary clinic-specific) data on lameness risk factors (Chesterton *et al*. 1989). It is possible that the risk factors reported from Taranaki are not valid to a population of farms outside of Taranaki. The other potential bias was that different trained observers were used for each region; this is covered at length in Mason *et al*. (2023b).

A major limitation of this study design was that all farm-level variables were reported by the farmer; no on-farm validation or recording of potential risk factors were conducted by study personnel. We attempted to minimise this limitation by asking closed-ended questions and splitting the data into two or three categories for analysis. The implications of this likely reduced the power of the analysis for certain variables (e.g. walking distance). We encountered issues with the data when open-ended answers were requested and the question could be skipped; collecting yard size, for example, had a large proportion of missing or improbable entries. The number of biologically relevant associations reported in this current study was far fewer than that reported by Chesterton *et al*. (1989) (although different analytical methods were used), and part of this may be due to these survey data limitations. One positive for this study design, however, is that it removes any potential bias that a technician may have if they are conducting both the lameness scoring and farm data collection (Chesterton *et al*. 1989; Ranjbar *et al*. 2016).

Despite these limitations, due to the nature of the sample, across several regions of New Zealand, we believe that the enrolled farms are representative of the greater New Zealand dairy farming population. Whilst we have identified a few areas that could be improved upon, such as reducing concrete stand-off pads and improving lameness identification, there is still a lot of unexplained variation for between- and within-farm lameness prevalences that urgently need investigating.

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