Animal 19 (2025) 101497

Contents lists available at ScienceDirect

Animal

The international journal of animal biosciences

Died, euthanised, slaughtered or alive? outcomes for 10 023 Ayrshire and Holstein cows and associations between veterinary treatments and mortality

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A R T I C L E I N F O

Article history:
Received 23 December 2023
Revised 17 March 2025
Accepted 18 March 2025
Available online 25 March 2025

Keywords:
Culling
Dairy cow
Herd-specific effects
Mortality
Veterinary treatment

A B S T R A C T

Animal welfare and disease prevention are important considerations for the modern dairy industry that strives for sustainability and responsibility. Diseases negatively impact cow welfare, lifespan, milk yield and lifetime productivity, and through those, farm economy, and resources needed in producing dairy foods for human consumption. Unassisted deaths and euthanasia represent cows that have suffered from an illness or trauma and leave the herd too early and without deliberate planning. The objectives of our study were to describe different ways cows exit the herd and farmer-reported reasons for culling, and to compare characteristics and veterinary treatment history of cows that either died unassisted or were euthanised on-farm. We studied data from the Finnish national Dairy Herd Improvement database and followed 10 023 cows in 76 herds in Finland, for 305 days. Based on a farmer-reported way for a cow exiting the herd, we grouped the cows into four categories based on their status at the end of the follow-up period: died unassisted (**DIED**), were euthanised (**EUT**) on farm, were sent to slaughter, or stayed alive in a herd, which accounted for 2, 4, 17, and 77% of the study population, respectively. We analysed cow characteristics and veterinary treatments (**VET**) the cows had received and explored their associations with on-farm deaths using generalised linear mixed models. Overall, the survival of Ayrshire and Holstein (**HOL**) cows was similar, but HOL cows died on farm more often. The median time from calving to exit was 26 days for DIED and 38 days for EUT cows. Compared to EUT cows, a smaller proportion of DIED cows had been treated by a veterinarian, but for a wider range of diseases. Having a VET for calving difficulty and digestive tract disease increased the odds of being a DIED cow, and VETs for milk fever, digestive tract or claw and leg diseases increased the odds of being an EUT cow, compared to not having the VET recorded. To gain more knowledge which could help to reduce mortality in the future, we suggest (1) separating the groups of DIED and EUT cows in forthcoming studies on culling and mortality, and (2) including the way dairy cows exit a herd into routinely monitored and reported statistics within the dairy industry and more detailed herd specific analyses into farmers' and advisors' tools for benchmarking and problem−solving at individual herd level.

Implications

Diseases impair dairy cow welfare and shorten her productive life. We explored ways cows leave the herd, with special emphasis on comparing the veterinary treatment history of cows that died on farm. Overall, calving difficulty and digestive tract diseases increased the odds of dying unassisted, and milk fever, digestive tract and claw and leg diseases the odds of being euthanised, but with large herd-specific variations. Including the way cows exit herds into statistics routinely recorded and reported within the dairy industry and using them in future research would provide knowledge that may help to reduce on-farm mortality.

Introduction

Animal welfare and disease prevention are important considerations for the modern dairy industry that strives for sustainability and responsibility in all actions potentially impacting nature, animals, people, and societies (IDF, 2023). Consumers expect high

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https://doi.org/10.1016/j.animal.2025.101497

standards in livestock production (De Vries and Marcondes, 2020), but at the same time want inexpensive food produced with minimal environmental and public health impacts (e.g., carbon footprint and antimicrobial resistance). Farmers differ in their tendency to call a veterinarian, whose choice of actions depends on perceptions and motivations affecting their decision-making (Lastein et al., 2009).

Despite advances in feeding and cow comfort in housing, the productive lifespan of cows has not markedly increased, being on average less than 3 years in the United States (De Vries and Marcondes, 2020). The length of productive life of Finnish Ayrshire and Holstein cows has increased by about 240 days in 20 years and shortened by 190 days in 13 years among Holstein (**HOL**) cows in Croatia (ICAR, 2023). Decreasing dairy cow morbidity and mortality would improve both animal welfare and efficiency of milk production, but earlier studies indicate that the structural changes in the dairy industry (e.g. increasing herd sizes and intensifying production) potentially impair dairy cow welfare. Mortality of dairy cows has increased (Thomsen et al., 2006; Alvåsen et al., 2012 and 2014; Compton et al., 2017; Reimus et al., 2018), and a high cow-to-employee ratio has been associated with higher odds of mortality (McConnel et al., 2015).

The terminology describing mortality and culling has been inconsistent in earlier studies (Fetrow et al., 2006; Compton et al, 2017; Thomsen and Houe, 2023). In this paper, we refer to mortality as cows dying unassisted or by euthanasia on farm and to culling as mortality plus cows that have left the herd because of slaughter, whereas cows sold to another farm are not included. Sending a cow to slaughter can be an economically driven part of planned renewal of the herd or biologically ‘‘forced", whereas on-farm deaths clearly represent involuntary culling. They are caused by severe disease or trauma and often occur unexpectedly in early lactation (Fetrow et al., 2006; Alvåsen et al., 2014; Shahid et al., 2015; Thomsen, 2023).

Papers on the culling of dairy cows are numerous; however, previous studies have mostly treated on-farm deaths and slaughtered cows as one cohort. Moreover, they have very seldom distinguished between unassisted deaths and euthanised cows or compared the effects of diseases on different ways a cow exits a herd (Alvåsen et al., 2014; Thomsen, 2023; Thomsen and Houe, 2023). On-farm deaths, however, can comprise approximately 1/4 of the cows that exit herds (Sarjokari et al., 2018); therefore, we suggest that they should be explored separately.

Culling reason "died" has been among the most frequently reported disposal codes (injury or other, reproduction problems, mastitis, low production, or feet and legs) in the large dairy countries like the United States, and culling reasons have remained quite similar (De Vries and Marcondes, 2020). In Finland, 17 codes are in use for reporting culling reasons: not known, accident, mastitis, teat injury or trauma, poor fertility and failure to conceive, poor feet conformations, feet or claw disease, calving difficulty, metabolic and digestive tract diseases, milk fever, some other disease, low milk yield, old age, poor udder structure, poor milk flow, ill temper, and some other reason. Proportions of the most frequently reported culling reasons have not changed in Finland from 2011 to 2020 (unpublished data), and mastitis and fertility disorders have remained the most common during the last decades (Dairy Herd Improvement data presented in result seminars of ProAgria, the organisation gathering the Finnish data. The last five annual reports can be found in Finnish at https://www.proagria.fi/ajankohtaista/maidontuotannon-tulosseminaari-2024, accessed 27.10.2024).

Mortality is one of the animal welfare indicators, but more research is needed before mortality records are fully applicable for the welfare assessment of dairy cows and routine recordings of cow mortality should be made available (Thomsen and Houe, 2018). In the global standard statistics of ICAR (https://my.icar.org/stats/chart, accessed 29.3.2024), trends in culling were only available for Finnish (from the years 2004–2023), Croatian (during 2009–2022), and Norwegian (during 2020–2022) dairy cows, and the data do not allow viewing on-farm deaths separately from slaughtered cows. In Finland, we have good possibilities for studying culling data, because the final status and destination of a cow are reliably known. Our national mandatory and voluntary control programmes include monitoring the locations where animals are moved (Autio et al., 2021). Finnish dairy farmers are required by law to report all births, deaths, and movements of cattle between farms to a register kept by the Finnish Food Authority (https://www.ruokavirasto.fi/en, accessed 29.3.2024). In Finland, no public livestock markets or auctions exist for cows removed for their herd, instead, sold cows are shipped from the farm directly to the buyer farm, slaughter cows straight to a slaughterhouse, and cow carcasses due to on-farm deaths or euthanasia to a rendering plant for destruction (Hagner et al., 2023).

The objectives of our study were to describe different ways cows exit the herd and farmer-reported reasons for the exit, and to compare characteristics and veterinary treatment history of cows that died unassisted or were euthanised on-farm.

Material and methods

The data used in this study were collected as a part of a larger research project, where all conventional Finnish dairy herds with free stall barns and more than 80 cows in 2010 had been invited to participate in the project (Sarjokari et al., 2018 have described the selection of the study population and data collection processes in more detail). We had visited all the herds (n = 82) interested in participating and received permission from the farmers to use their Dairy Herd Improvement data for research. All data retrieved during the earlier project had not been analysed, so in this study, we used a subset of 76 herds with recorded veterinary treatments available (herds with no records for mastitis treatments in the health recording database were excluded). Olsson et al. (2001) and Rintakoski (2014) have described the Nordic health recording databases in more detail.

We followed 10 023 cows' first lactation starting in the year 2011, until their exit from the herd or 305 days in milk. The study period was from 1 January 2011 to 31 October 2012. Cows of other than HOL or Ayrshire (**AY**) breeds were excluded (n = 69). Cow-level data on breed, parity, recorded veterinary treatments (**VET**), dates for calving and removal from herd, as well as the way of exiting from the herd and farmer-recorded culling reason, and lifetime milk yield (sum of a cowś milk yield from all lactations for the cows that have exited the herd), had been obtained from the Dairy Herd Improvement database.

We grouped the cows into four categories based on their status at the end of the follow-up period: cows that had died unassisted (**DIED**), been euthanised (**EUT**) on farm, sent to slaughter (**SLA**), or stayed alive in a herd (**ALIVE**). Descriptive statistics were first run for the entire study population and for the groups of cows with different outcomes using STATA statistic software, release 16.1. (StataCorp, 2019). Age at the time of exit from the herd and lifetime milk yield were compared with two-sample *t*-tests and differences in the frequency of reasons for culling with Pearsońs chi-square tests.

Two different generalised linear mixed models were created, where the status of an individual cow classified as exit/no exit was used as the outcome (Stroup 2013). In the models, the odds of being a DIED or an EUT cow were examined with ALIVE cows as a reference group. The models were fitted using the GLIMMIX procedure of SAS 9.4 (SAS Institute Inc., Cary, NC, USA), with an adaptive Gauss-Hermite quadrature as an integral approximation method (Stroup, 2013), and validated using calibration plots (Wu et al., 2019).

The models included cow and herd–level variables. Clustering of cows within herds was considered by including herd as a random effect, and all the other variables were considered as fixed effects. Cow-level variables were breed (HOL / AY), parity (1 / 2 / 3 or higher), calving season (January to April / May to August / September to December), VET as binary variables (no / yes). Breed composition of the herd was categorised by the proportion of cows in the herd that were of the same breed than the cow herself (0–40 / 41–69 / 70–100%). VETs considered were: (1) calving difficulty, (2) milk fever, (3) clinical mastitis, (4) digestive diseases, including all gastrointestinal diseases and clinical ketosis, (5) claw and leg diseases and trauma, (6) reproductive disorders, including treatments for metritis and all fertility disorders, and (7) other treatments, including all other diagnoses not mentioned before. The reference group for cows with a certain VET was all cows with the same outcome (DIED / EUT) but without the VET. The VETs considered are described in more detail in Supplementary Table S1 (and the codes listed in Finnish in https://www.wordpress.faba.fi, accessed 27.3.2024). The VET for calving difficulty was only considered if it occurred during 3 days prior to 3 days postregistered calving date, and the VET for milk fever between 2 days pre– to 7 days postcalving. Other VETs were considered from 21 days precalving to the end of the follow–up, or 305 days from calving. Herd-level variables considered were herd size (less than 120 / 120 or more cows), annual mean milk yield of the cows, kg (as a continuous variable), and milking system (milking parlour / automatic milking system). Results of the descriptive analyses were used in deciding reasonable cut-points for categorising herd size and breed composition of the herd.

The statistical models (for both DIED / EUT) were built using same main principles. The reason for choosing this approach originated from a long list of potentially interesting and biologically meaningful explanatory and confounding variables. We screened them and eliminated clearly non-significant ones from further modelling, to be sure that the most important variables of interest in this study were included in the final models. This modelling path based on biological relevance and multiple steps allowed us to have a more reasonable number of variables examined in each step and to overcome problems arising from multicollinearity and preventing the risk of overfitting. We used some flexibility in the model constructions by including VET terms with slightly larger *P*-values than 0.05, and presented effect estimates and Confidence Intervals in addition to *P*-values, to avoid excessive emphasis on *P*-values in model construction and interpretation (Greenland et al., 2016).

The modelling path started by introducing all cow and herd level variables (breed, parity, calving season, breed composition, herd mean milk yield, milking system), except the VET variables, into a model in addition to a random herd effect (intercept). Non-significant terms ($P < 0.05$) were dropped one by one, starting from those with the biggest *P*-value. Cow's breed and parity were kept in the models irrespective of their statistical significance. The second step was to add the VET variables one by one into the models resulting from the previous step, to screen out clearly non-significant variables ($P > 0.2$). Next, the VET variables with $P < 0.2$ in the previous step were all added to the model simultaneously and the clearly non-significant variables were removed one by one, leaving the variables with $P < 0.05$ or close to that in the final model. After that, we examined all two-way interactions between herd size, milking type, breed, parity, and different VETs in the model. The potential need to consider herd-specific effects of VET variables was examined by introducing random effect (slope) for each VET variable remaining in the models. They were first introduced into the models one by one, and if found significant, they were included in the model jointly. They were dropped one by one, if found non-significant. Unstructured correlation structure was included in the model to estimate the covariance of the random effects. The need to keep the random effects in the model was examined using the likelihood ratio test. Only the random slope for the VET of other diseases was significant in the model for euthanised cows, but while adding it, the main effect of the VET became non-significant. Therefore, in that case, both the main effect and the random slope were dropped from the model.

In addition to the main models, we ran supplementary models, built separately for 1st, 2nd, or 3+ parity (DIED / EUT) cows. The supplementary models included all variables that were in the main models, plus coẃs previous lactation 305-day milk yield (kg) for second and higher parity cows. In the models for 1st and 2nd parity cows, VET for milk fever was not included. In this phase, we also tested if any of the VET variables which were dropped from the main models would have been significant in the supplementary, parity-specific models.

Results

Study herds and cows

The median herd size of the 76 study herds was 115 cows (ranging from 73 to 326) on the day of the herd visit, and the annual average milk yield per cow was 9 173 kg (SD = 878) in 2011. All study herds were housed in free stall barns, half of which had been in use for more than 4 years and had either a conventional milking parlour or automatic milking system in use (Table 1). Most of the study herds (n = 72) had both AY and HOL cows. The study population included similar proportions of first, second and higher parity cows, whose calvings had occurred evenly throughout the year (Table 2). The overall mean lifetime milk yield of the study cows that exited the herds, 21 979 kg (SD = 16 117), corresponded with an 11.3 kg (SD = 5.68) mean daily milk yield per day of the coẃs entire life when calculated from birth to death. Lifetime milk yield was 21 781 kg (SD = 15 766) for AY, and 22 255 kg (SD = 16 599) for HOL cows. More detailed description of the study herds is presented in Supplementary Table S2.

Survival

Of the 10 023 study cows, 7 726 (77%) stayed alive for 305 days after calving and 2 297 (23%) exited the herd; 176 (1.8%) died unassisted, 416 (4.2%) were euthanised, and 1 705 (17%) were sent to a slaughterhouse. The frequency of cows exiting the herd peaked right after calving (Fig. 1). Most of the unassisted deaths and euthanasia took place during early lactation, whereas sending a cow to slaughter occurred more evenly throughout the lactation. The median time from calving to exit was 26 days for DIED, 38 days for EUT and 157 days for SLA cows. At the time of exit, the study cows were on average 4.6 years old (EUT cows 4.5 yr., DIED and SLA cows 4.7 yr.). AY cows exited the herd on average at the age of 4.7 years and HOL cows when 4.5 years old. AY cows died unassisted 173 d ($P = 0.071$), were euthanised 161 d ($P = 0.006$), and slaughtered 43 ($P = 0.156$) days older compared to HOL cows.

Overall, survival of AY and HOL cows until the end of the study period was very close, the percentages for exiting the herd were 12.8 and 13.2% for first, 19.5 and 18.6% for second, and 34.8 and 37.6% for third and higher parity cows, respectively. However, HOL cows died or were euthanised on farm more often compared to AY cows (6.5 vs 5.5%, respectively, $P = 0.033$) but were less often slaughtered (16.1 vs 17.7%, respectively, $P = 0.045$), the biggest differences found among first parity cows (Fig. 2). The proportion of cows that exited the herd and the proportion of different ways of

Table 1
Descriptive statistics of the herd level variables that we considered in the modelling process, and the number and percentage of study cows within each category (n = 76 herds and 10 023 dairy cows in total).

Variable		Herds		Cows	
		n	%	n	%
Herd size, cows					
	<120	43	57	4 340	43
	≥120	33	43	5 683	57
Barn age, years					
	2 – 4	22	29	3 011	30
	>4	38	50	5 057	50
	multiple[1]	16	21	1 955	20
Milking type					
	Parlour	46	61	5 955	59
	AMS	30	39	4 068	41
Milking type & Herd size					
	Parlour < 120 cows	30	39	2 965	30
	Parlour ≥ 120 cows	16	21	2 990	30
	AMS < 120 cows	13	17	1 375	14
	AMS ≥ 120 cows	17	22	2 693	27

Abbreviations: AMS = Automatic milking system.
[1] Barns that had undergone multiple expansions.

Table 2
Descriptive statistics of the cow level variables considered in the modelling process, and the number of cows within each category, cows died unassisted (n = 176), euthanised (n = 416), sent to slaughter (n = 1 705), or stayed alive (n = 7 726), n = 10 023 dairy cows in total).

Variable		Cows	%	DIED	%	EUT	%	SLA	%	ALIVE	%
Breed											
	Ayrshire	5 789	58	98	56	219	53	1 022	60	4 450	58
	Holstein	4 234	42	78	44	197	47	683	40	3 276	42
Parity											
	1 st	3 488	35	32	18	83	20	338	20	3 035	39
	2 nd	2 932	29	31	18	100	24	429	25	2 372	31
	3 +	3 603	36	113	64	233	56	938	55	2 319	30
Calving season											
	Jan – April	3 188	32	66	38	130	31	541	32	2 451	32
	May – Aug	3 392	34	53	30	161	39	622	36	2 556	33
	Sep – Dec	3 443	34	57	32	125	30	542	32	2 719	35

Abbreviations: DIED = died unassisted, EUT = euthanised, SLA = sent to slaughter, ALIVE = stayed alive.

exit varied considerably between individual farms (Fig. 3). In some herds, almost all exited cows had been sent to slaughter, but in others, nearly half of the removed cows had been euthanised on farm, and in a few herds, a big proportion of cows had died unassisted.

Veterinary treatments and their associations with on-farm deaths

Of all the study cows, 32% (n = 3 244) had been treated by a veterinarian at least once during the follow-up period. The percentage of treated cows was 35% (n = 602) among the SLA cows, 34% (n = 140) among EUT, 32% (n = 2 468) among ALIVE cows, and 19% (n = 34) among DIED cows. Of the treated cows, 80% had codes for only one VET, 17% had recordings for two and 3% for three or more VETs (Table 3). Of the treated DIED, EUT, SLA, and ALIVE cows, 38, 23, 22 and 20%, respectively, had more than one VET code recorded. There were 21 different potential combinations of two VETs, of which 11 had occurred for DIED and 19 for EUT cows (Supplementary Table S3).

Overall, reproductive disorders and mastitis were the most frequently recorded veterinary treatments (Table 4). The number of cows with a VET code for less frequent diseases was small for DIED and EUT cows. Also, the number of specific veterinary treatment codes varied remarkably between individual farms (Supplementary Table S2). VET for calving difficulty, mastitis, and digestive tract diseases was more frequent among DIED than EUT cows, whereas the proportion of cows treated for claw and leg disease was higher for EUT than DIED cows (Fig. 4).

The number of cows that died unassisted was low in most VET categories (Table 4); therefore, the difference in the risks for death between treated and non-treated cows was close to zero in most of the herds (Fig. 5). Overall, cows with VET for calving difficulty or digestive tract disease had greater odds for dying than cows without them, but cows with VET for mastitis or reproductive disease or disorder had lower odds of being a DIED cow, compared to cows that did not have a VET for those disease groups (Table 5). The magnitude of the ORs and CIs in the supplementary models for cows of different parity were like those in the main model with all parities included (Supplementary Table S4). Third–parity and older cows had greater odds to die unassisted than first–parity cows (Table 5). First–parity HOL cows had significantly higher odds of dying unassisted compared to first–parity AY cows (Supplementary Table S4).

The difference in the risks for euthanasia of treated and non-treated cows for milk fever was higher than zero in about one-third of the herds (Fig. 5). For cows with or without a VET for digestive, claw or leg, or other diseases the risk difference was higher than zero in about one-fourth of the herds. Overall, Cows with

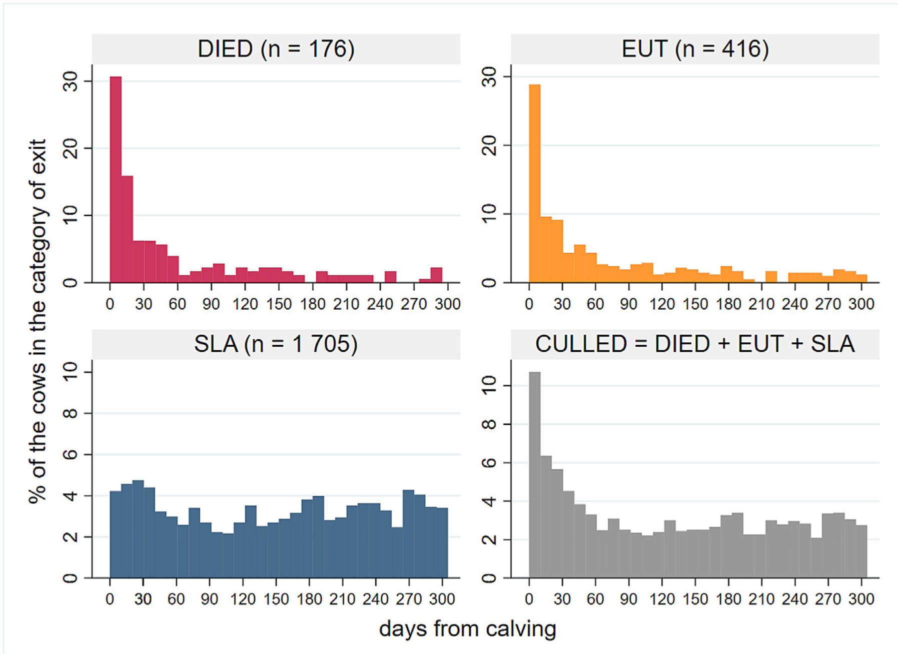

Fig. 1. The percentages of dairy cows that exited their herd on different days of lactation by different ways; died unassisted (DIED), euthanised (EUT) on farm or sent to slaughter (SLA).

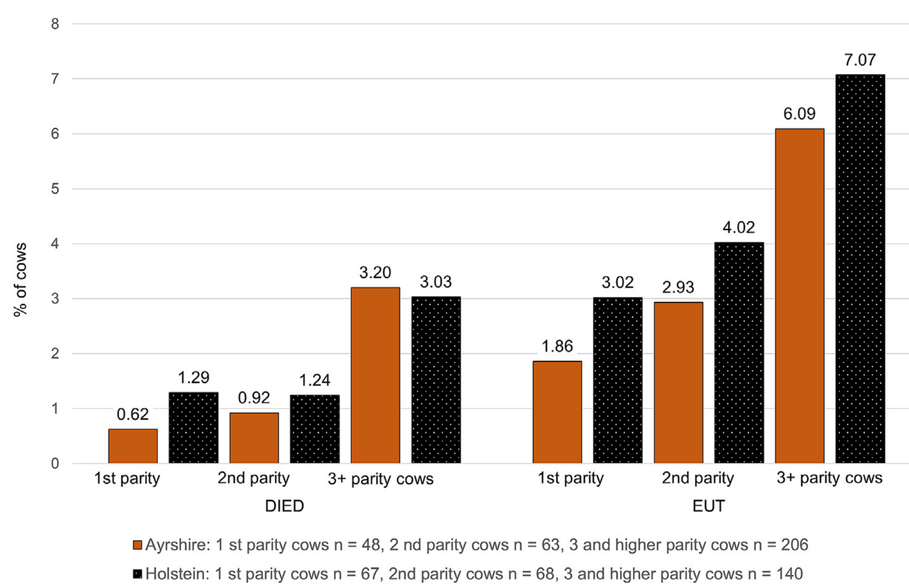

Fig. 2. The percentages of Ayrshire and Holstein cows that died on farm (unassisted deaths = DIED, euthanised cows = EUT), stratified by parity.

VET for milk fever, digestive tract disease, or claw and leg disease had greater odds, and cows with VET for mastitis and reproductive diseases or disorders had lower odds of being euthanised on farm, compared to the cows that had no VET for those diseases (Table 6). The odds of being euthanised on farm tended to be greater for HOL compared to AY cows (Table 6), and it was higher among first–parity HOL cows compared to AY cows of same parity (Supplementary Table S5). First–parity HOL cows with a VET for claw and leg disease had significantly higher odds of euthanasia compared to first–parity AY cows (Supplementary Table S5). Calving during May to August was associated with greater odds of being EUT, compared to calving during September to December (Table 6). The nature of the associations (positive / negative) between VET and the outcome of a cow at the end of the study period are summarised in Table 7.

Reasons for death and culling

Farmer-reported reasons for death or culling of the study cows differed considerably between the ways of exiting the herd (Fig. 6). Overall, for most DIED cows, the farmer had not known the reason for death or had suspected a disease of the digestive tract; for EUT cows, feet and claw problems and mastitis were the most often reported reasons; and mastitis clearly dominated in the reported reasons for culling of SLA cows. For first parity cows that died (n = 12 AY, n = 20 HOL) or were euthanised (n = 36 AY, n = 47 HOL), accidents were the most frequent farmer–reported reason (AY 19%, HOL 25%) for on-farm deaths. Feet and claw diseases appeared to be more common (24 vs 8%) but calving difficulty (6 vs 14%) and mastitis (2 vs 13%) were less frequent reasons for on-farm deaths among AY than HOL cows. For 2nd and higher par-

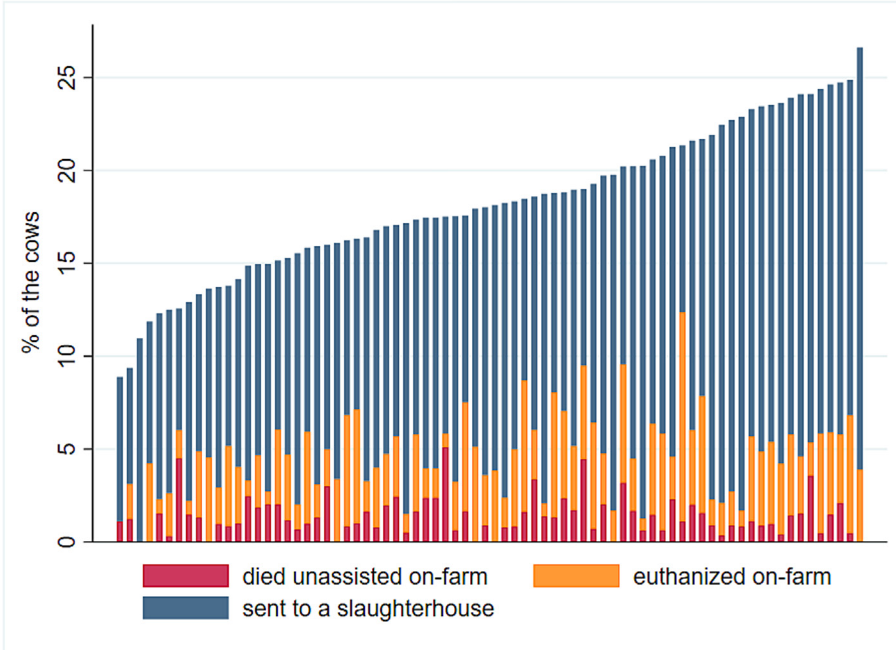

Fig. 3. Herd level percentages of the study dairy cows exiting the herd by different ways.

Table 3
The number of dairy cows that had one or more different veterinary treatment codes recorded.

N VETs	DIED	%	EUT	%	SLA	%	ALIVE	%	Total	%
0	142	81	276	66	1 103	65	5 258	68	6 779	68
1	21	12	108	26	471	28	1 985	26	2 585	26
2	12	7	25	6	107	6	407	5	551	6
3	1	<1	6	1	19	1	70	1	96	1
4	0	0	1	<1	5	<1	3	<1	9	<1
5	0	0	0	0	0	0	3	<1	3	<1

Abbreviations: VET = veterinary treatment, DIED = died unassisted, EUT = euthanised, SLA = sent to slaughter, ALIVE = stayed alive.

Table 4
The number of dairy cows that had veterinary treatments for calving difficulty, milk fever, mastitis, digestive diseases, claw or leg diseases or trauma, reproductive disorders, or other diseases. The columns include the number of cows within each category: cow died (n = 176), euthanised (n = 416), sent to slaughter (n = 1 705), or stayed alive (n = 7 726), n = 10 023 cows in total.

VET for	Total	%	DIED	%	EUT	%	SLA	%	ALIVE	%
Calving difficulty[1]	42	0.42	3	1.70	3	0.72	4	0.23	32	0.41
Milk fever[2]	256	2.55	8	4.55	32	7.69	47	2.76	169	2.19
Mastitis[3]	1 249	12.46	13	7.39	38	9.13	336	19.71	862	11.16
Digestive[4]	213	2.13	8	4.55	22	5.29	33	1.94	150	1.94
Claw and leg[5]	350	3.49	3	1.70	25	6.01	60	3.52	262	3.39
Reproductive[6]	1 590	15.86	9	5.11	35	8.41	218	12.79	1 328	17.19
Other[7]	326	3.25	4	2.27	25	6.01	64	3.75	233	3.02

Abbreviations: VET = veterinary treatment, DIED = died unassisted, EUT = euthanised, SLA = sent to slaughter, ALIVE = stayed alive.
[1] Calving difficulty, including all reasons for veterinary–assisted calvings.
[2] Milk fever, puerperal paresis with clinical symptoms.
[3] Mastitis, subacute and acute cases with clinical symptoms.
[4] All gastrointestinal diseases and clinical ketosis.
[5] All claw and leg diseases and trauma.
[6] Treatments for all fertility disorders and metritis.
[7] All other treatments and diagnosis codes not mentioned before.

ity AY and HOL cows, the reported reasons for on-farm deaths were 5 and 5% for calving difficulty, 11 and 12% for milk fever, 14 and 11% for mastitis, 10 and 15% for digestive tract diseases, 11 and 12% for feet and claw diseases, and 9 and 7% for accidents, respectively.

Discussion

A cow's path from getting ill to receiving veterinary treatment that succeeds or fails, to on-farm death, or to slaughter is very complicated. It involves a lot of decision–making by a

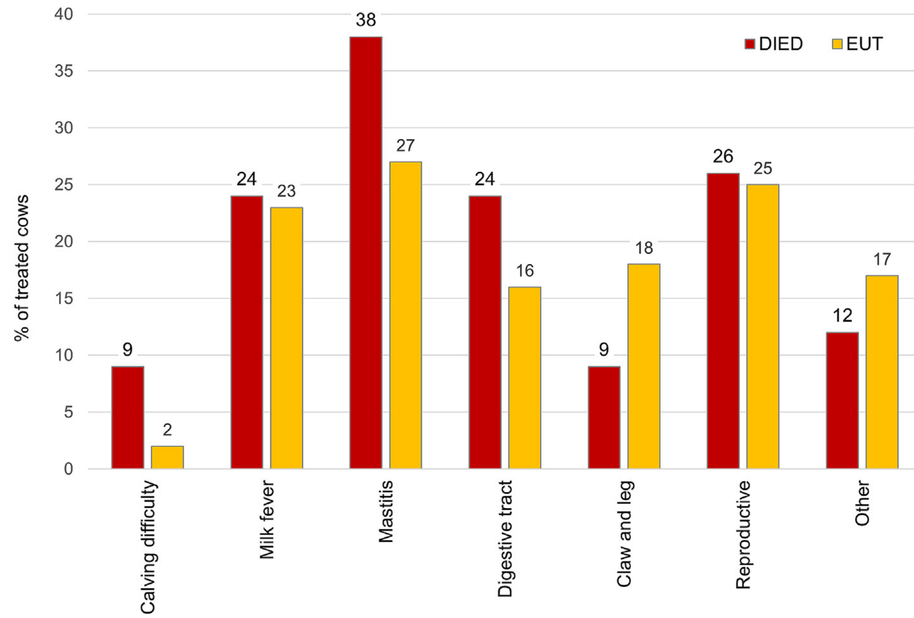

Fig. 4. Frequency of treated dairy cows with certain veterinary treatments (VET), as a percentage of all treated cows that either died unassisted (DIED) or were euthanised (EUT).

farmer and a veterinarian. Sometimes, a cow is simply found dead without a farmer noticing any symptoms. Each farmer uses veterinary assistance differently. Also, a farmer's and veterinarian's preferences for treatment options vary, which may affect the result. In some cases, a farmer decides to euthanise the ill or injured cow, with or without any attempts to treat her. Often, a vet is called, and the cow gets treated with or without success. In some cases, the cowside diagnosis made is incorrect, and the cows dies or gets well, despite or because of the given treatment. Occasionally, an accident or another disease follows the first one, making it hard to know if death was due to the disease that started the path or the last one, or the combination of all the diseases. This common-sense reasoning is supported by the studies of Lastein et al (2009), McConnel and Garry (2017) and Hagner et al. (2023).

We observed that Holstein cows died on-farm with a higher probability than Ayrshire cows, and that the cows that died unassisted had been treated less frequently by a veterinarian, but with a wider range of diagnoses compared to euthanised cows. Overall, cows with veterinary treatment for calving difficulty or digestive tract diseases had higher odds of dying unassisted, and cows with milk fever, digestive tract or claw and leg diseases had higher odds of being euthanised, compared to cows not having the treatment mentioned. Also, we noticed large between-herd differences both in the percentages of the ways cows exited the herd, in the proportions of cows with different veterinary treatments, and in the case-fatality analyses. In most of the herds, for any of the VETs, the risk difference between treated and non-treated cows was close to zero, but different from that in some herds, depending on the VET and the way of exiting the herd (DIED / EUT). However, the low number of VET cases in each category (DIED / EUT) must be considered in interpreting them. Therefore, we suggest detailed herd-specific analyses for problem–solving at individual herd level. Using multiple sources of information (farmer, farm records, autopsy results), with qualitative assessments, seems to be necessary in that work, especially in cases (like milk fever) where autopsy alone could be inconclusive.

Occurrence and timing of death and culling

Our observations that most on-farm deaths occur shortly after calving, but cows are slaughtered more evenly throughout the lactation, as well as the overall mortality and culling risks in this study agree with results from studies conducted in the USA (Dechow and Goodling, 2008; McConnel et al., 2009; Shahid et al., 2015), Sweden (Alvåsen et al., 2012 and 2014), Estonia (Reimus et al., 2018; Rilanto et al., 2020), and Denmark (Thomsen, 2023).

Of our study cows, a greater percentage was euthanised compared to dying unassisted, which agreed with the results of Neary et al. (2022), but was in contrary to some other research (Thomsen et al., 2004; Fusi et al., 2017; Roche et al., 2020). This difference might be explained by different management practices of farmers, and distance from commercial slaughterhouses in the countries. In Finland, euthanasia is seen as the ethically humane option. Sending a cow to slaughter is not always possible, because EU legislation (Council regulation, EC 1/2005) prohibits transporting animals that are not fit for it (e.g., cows that have just calved, are not able to stand up, or are severely lame). Similarly, if the probability of a carcass being condemned in meat inspection is high, and as commercial emergency slaughter is not available, these cows are most often euthanised on farm.

In our study, calving during May to August was associated with higher odds of being euthanised, compared to calving during September to December. Our findings agreed with Alvåsen et al. (2012 and 2014), whose categorisation of calving season our study also followed. This categorisation of calving season was based on local conditions; grazing is quite common during May to August, and the climate is cold and humid during autumn and winter in Finland. Also, Hertl et al. (2011) reported a higher probability for multiparous cows with mastitis to die in spring and summer compared to other seasons. Many diseases are associated with parturition, and the relationship between cow mortality and weather conditions has been shown to depend on temperature, humidity, and age of the cows (Stull et al., 2008; Vitali et al., 2009). In 2011, temperatures fluctuated fast and considerably in Finland,

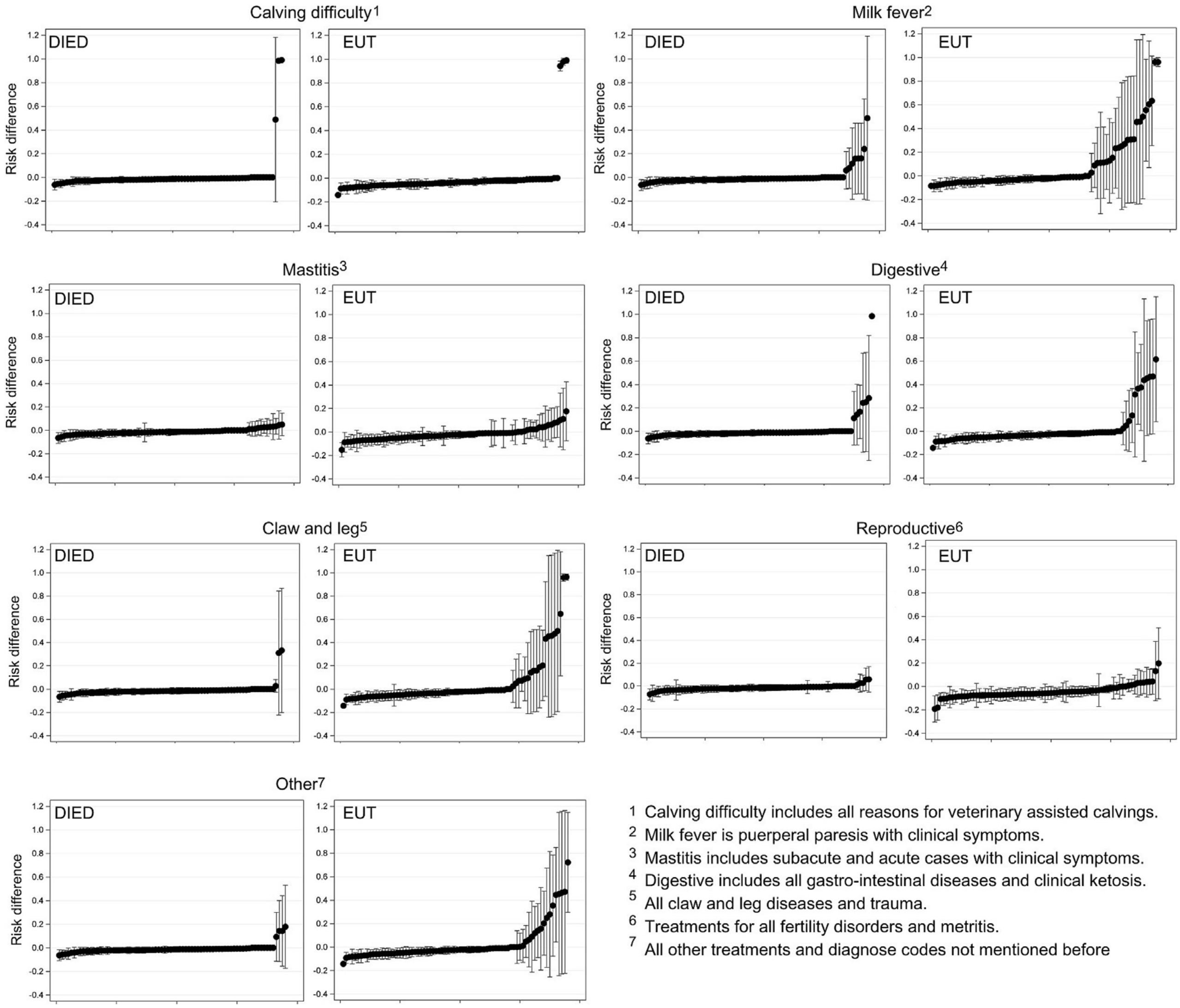

Fig. 5. Herd-specific risk differences for unassisted deaths (DIED) or euthanasia (EUT) on farm between the dairy cows that had or had not been treated by a veterinarian.

which may have affected also cows. As the weather conditions change between study years in different countries, and there is clear evidence of seasonality, they should be considered as a factor in studies for mortality and culling.

Associations between diseases and the outcome for a cow

Similarly to our observations, earlier studies have reported large between-herd differences in the percentages of cows dying or being euthanised on farm or sent to slaughter (Dechow and Goodling, 2008; Shahid et al., 2015; Armengol and Fraile, 2018). Factors predisposing to mortality and culling are complex, and overall disease status, housing, and management in individual herds can explain differences (Alvåsen et al., 2012 and 2014; Pinedo et al., 2014; Sarjokari et al., 2018). Culling of dairy cows also involves a lot of decision–making by a farmer (Jansen et al., 2009; Haine et al., 2017; Roche et al., 2020). A recent study by Owusu-Sekyere et al. (2023) suggested that the role of animal health is less important in culling decisions, instead, they are mostly influenced by farmerś investment decisions and other farm-specific practices. A British study reported that the ability to perform euthanasia varied, and most farms did not have anyone who had been trained to perform it (Neary et al., 2022). Farm-specific factors are reflected in the risk differences between treated and non-treated cows in individual herds also in our study, and by the fact that random herd effect (intercept) was significant in the models.

The cowś overall status impacts the farmeŕs and veterinariańs decision–making (Neary et al., 2022); pregnant cows with good genetic value and high milk yield are treated more commonly than cows that are expected to be less productive (Schneider et al., 2007; Reimus et al., 2018; Gussmann et al., 2019). Also, a farmer calls a veterinarian for a cow that he/she thinks needs medical treatment, and he/she wants to keep in the herd. A veterinarian treats the cow if the diagnosis and cow's condition indicate a reasonable prognosis for recovery.

In Finland, farmers do not have access to medicinal products without a prescription from a veterinarian (Rajala-Schultz et al., 2021), and therefore most diseases, especially those with severe signs and those where antibiotics, hormones, local anaesthesia or painkillers are needed, are treated by veterinarians. Oral substances that are not registered as medicines can be used without prescription from a veterinarian, for example for digestive tract diseases. Finnish farmers have never been allowed to administer intravenous calcium infusions for the treatment of milk fever. During the study period, treatment of clinical mastitis with antibiotics had to be initiated by a veterinarian, after a clinical examination of

Table 5
Results from modelling associations between veterinary treatments and the outcome of a cow dying unassisted on farm (n = 176). The comparison group consisted of dairy cows that were alive in herd at the end of the study period (n = 7 726).

Variable		OR	CI	*P*	Est(p)
Breed					
	Ayrshire	1		0.028	0.019
	Holstein	1.43	1.04–1.97		0.027
Parity					
	1 st	1		< 0.001	0.012
	2 nd	1.32	0.80–2.18		0.016
	3 +	5.33	3.56–7.97		0.061
Calving difficulty					
	no	1		0.016	0.010
	yes	4.94	1.35–18.07		0.049
Mastitis					
	no	1		0.028	0.031
	yes	0.52	0.29–0.93		0.017
Digestive[1]					
	no	1		0.060	0.016
	yes	2.09	0.97–4.51		0.033
Reproductive[2]					
	no	1		< 0.001	0.047
	yes	0.22	0.11–0.44		0.011
Herd AMY[3]		1.03		0.002	

Abbreviations: OR = Estimated Odds Ratio, CI = 95% Confidence Interval, Est(p) = Estimated probability of the outcome.
Herd was included as a random effect (intercept, *P* = 0.014).
[1] All gastrointestinal diseases and clinical ketosis.
[2] Treatments for all fertility disorders and metritis.
[3] Annual mean milk yield per cow in the herd. The EST(logit(p)) was −0.030, corresponding to an 1.03 decrease in odds for unassisted death for every 100 kg increase in the yield. SE(logit(p)) was 0.010.

the cow confirming the need for antibiotics. After this, the veterinarian could leave medicines for the farmer to continue the treatment. It is mandatory to record all treatments and medicines used at an individual animal level, and the recordings are collected into the national database.

An injury, disease or cluster of diseases can be an immediate or underlying cause of death, a "starter" for a chain that leads to death. Sometimes, a disease can be associated with death without being causal (McConnel et al., 2010; McConnel and Garry, 2017; Hagner et al., 2023). The underlying causes (or diagnoses) that lead to death have been shown to vary during different stages of lactation and with parity (Hagner et al., 2023). Additionally, Wäsle et al. (2017) and Hagner et al. (2024) reported that nearly half of the cows that died on farm had necropsy findings indicative of multiple concurrent diseases. For example, in the studies of Hagner et al. (2023 and 2024), 34% of the autopsied cows had active inflammatory udder lesions and mastitis was considered as the final underlying diagnosis of death in 27% of the cases, but it was the only diagnosis in just 13% of the cases. In 61% of the mastitis cases, it interacted with other simultaneous diseases, most commonly with arthritis. In our study, we did not have access to necropsy findings. Therefore, we only described farmer-reported reasons for death and culling, to support the reasoning and discussion of our modelling results, together with previously published literature.

The reasons for death and slaughter are multiple (Fetrow et al., 2006) and a farmer typically selects the one that is the most recent or the most relevant. Often only one reason gets recorded to a database, which can lead to under- or overreporting of some reasons. In general, cow-side diagnoses agree poorly with autopsy findings, but farmeŕs observations of mastitis, calving disorders, locomotion diseases and accidents have been shown to moderately agree with necropsy findings (McConnel et al., 2009; Thomsen et al., 2012; Hagner et al., 2023). Even though the agreement with autopsy result is only poor to moderate, the farmeŕs reasoning is very important, especially in cases of euthanasia. For example, a cow with mastitis can be euthanised mainly because of poor feet, and only the farmer knows what the primary reason for his decision is. However, the decision–making is very farm-specific, and it should further be studied with a larger number of farmers, as it seems that the proportion of euthanised cows of overall mortality has increased, at least in Finland (Sarjokari et al., unpublished data).

Smaller proportion of the DIED cows had been treated by a veterinarian, compared to other cows in our study. This result seems logical, as sometimes the only visible sign for a cow is her sudden death, leaving no time for veterinary treatments. In early lactation, cowś immunity is compromised (Shahid et al., 2015), and therefore, diseases may be more severe or complicated with several symptoms, leading to a high mortality risk (Thomsen et al., 2007) and to increased odds of euthanasia (Thomsen and Sørensen, 2009).

The large differences between herds in the risk for on-farm death between treated and non-treated cows, and the low number of cases in some of the categories need to be kept in mind when interpreting the results from modelling the associations between VETs and on-farm death. In most herds, the difference in the risks for on-farm death was close to zero, but in some herds, the explored diseases seemed to be strongly associated with on-farm mortality. These findings highlight the need to explore this kind of data very thoroughly also at herd level, both in benchmarking and problem−solving at herd level and in future studies.

Overall, in our study, VETs for calving difficulty and digestive tract diseases were associated with higher odds of DIED, and VET for digestive tract diseases also with higher odds of being EUT compared to cows without the VET. They were also among the most frequent farmer-reported causes of death. These results were in line with earlier studies (Bicalho et al., 2007; Shahid et al., 2015; Rilanto et al., 2020). Also, Hagner et al. (2023) who autopsied

Table 6
Results from modelling the associations between veterinary treatments and the outcome of the cow euthanised on-farm (n = 416). The comparison group was the dairy cows that were alive in herd at the end of the study period (n = 7 726).

Variable		OR	CI	*P*	Est(p)
Breed					
	Ayrshire	1		0.078	0.062
	Holstein	1.22	0.98–1.53		0.075
Parity					
	1 st	1		< 0.001	0.039
	2 nd	1.55	1.15–2.10		0.059
	3 +	3.83	2.93–5.01		0.135
Calving season					
	Sep - Dec	1		0.008	0.056
	Jan - April	1.29	0.99–1.67		0.071
	May - Aug	1.48	1.16–1.90		0.081
Milk fever					
	no	1		< 0.001	0.045
	yes	2.49	1.62–3.82		0.104
Mastitis					
	no	1		0.009	0.085
	yes	0.62	0.43–0.89		0.055
Digestive[1]					
	no	1		0.001	0.043
	yes	2.65	1.62–4.34		0.107
Claw and leg[2]					
	no	1		0.007	0.051
	yes	1.87	1.18–2.94		0.091
Reproductive[3]					
	no	1		< 0.001	0.116
	yes	0.32	0.22–0.46		0.040

Abbreviations: OR = Estimated Odds Ratio, CI = 95% Confidence Interval, Est(p) = Estimated probability of the outcome.
Herd was included as a random effect (intercept, $P < 0.001$).
[1] All gastrointestinal diseases and clinical ketosis.
[2] Claw and leg diseases and trauma.
[3] Treatments for all fertility disorders and metritis.

Table 7
The direction of the associations between veterinary treatments and the outcome of a dairy cow: died unassisted or euthanised on-farm. The results are based on two different models, presented earlier in this paper in Tables 5 and 6.

VET for	DIED	EUT
Calving difficulty	+	ns
Milk fever	ns	+
Mastitis	–	–
Digestive[1]	+	+
Claw and leg[2]	ns	+
Reproductive[3]	–	–
Other[4]	ns	ns

Abbreviations: VET = veterinary treatment, DIED = died unassisted, EUT = euthanised, ns = non-significant in the model.
[1] All gastrointestinal diseases and clinical ketosis.
[2] Claw and leg diseases and trauma.
[3] Treatments for all fertility disorders and metritis.
[4] All other treatments and diagnosis codes not mentioned before.

319 dairy cows that had died or were euthanised on farm reported that calving-associated or digestive disorders comprised 12 and 15% of the underlying diagnosis of death, respectively. The most common necropsy findings in the digestive tract in these cows were rumenitis, abomasal ulcers or displaced abomasum.

Overall, in the current study, VETs for milk fever or claw and leg were associated with higher odds of euthanasia, compared to cows without a VET recorded for such a disorder. In Finland, the claws of almost all cows are trimmed by professional claw trimmers, and veterinarians only treat some of the most severely lame cows, which explains the low treatment incidence. Previous studies have reported that milk fever and lameness markedly increase culling risk in early lactation (Rajala-Schultz and Gröhn, 1999; Rilanto et al., 2020). Locomotion disorders are common findings in cows that died on farm (Thomsen et al., 2012; Hagner et al., 2023). Also, those are frequently observed in cows sent to livestock markets and abattoirs in Canada (Stojkov et al., 2020a and 2020b) and prior to transport to slaughter in Denmark (Dahl-Pedersen et al., 2018).

In contrast to some earlier studies (Reimus et al., 2018), in our study population, VET for mastitis decreased the odds of being DIED or EUT, compared to cows not having the VET. When looking at the herd-specific risk differences for death or euthanasia between treated and non-treated cows, we noticed that in about one-third of the farms, it was below zero, and in about one-third above zero. When a veterinarian treats a cow with mastitis, the prognosis is expected to be relatively favourable, whereas a cow with severe mastitis and poor prognosis may be euthanised, without treatment. This may partially explain our finding. In a necropsy-based study in Finland, mastitis was the most common underlying diagnosis of on-farm deaths, being involved in 27% of the cases, and in some of those, the farmer had not reported signs of mastitis prior to coẃs death or euthanasia (Hagner et al., 2023 and 2024). According to previous studies, the parity and lactation stage of the cow, severity of symptoms and mastitis pathogen involved (Gröhn et al., 1998; Pinedo et al., 2010; Cha et al., 2013; Thomsen, 2023; Thomsen and Houe, 2023), as well as the farmeŕs attitudes towards mastitis treatments and culling (Nyman et al., 2007; Jansen et al., 2009; Haine et al., 2017) determine the out-

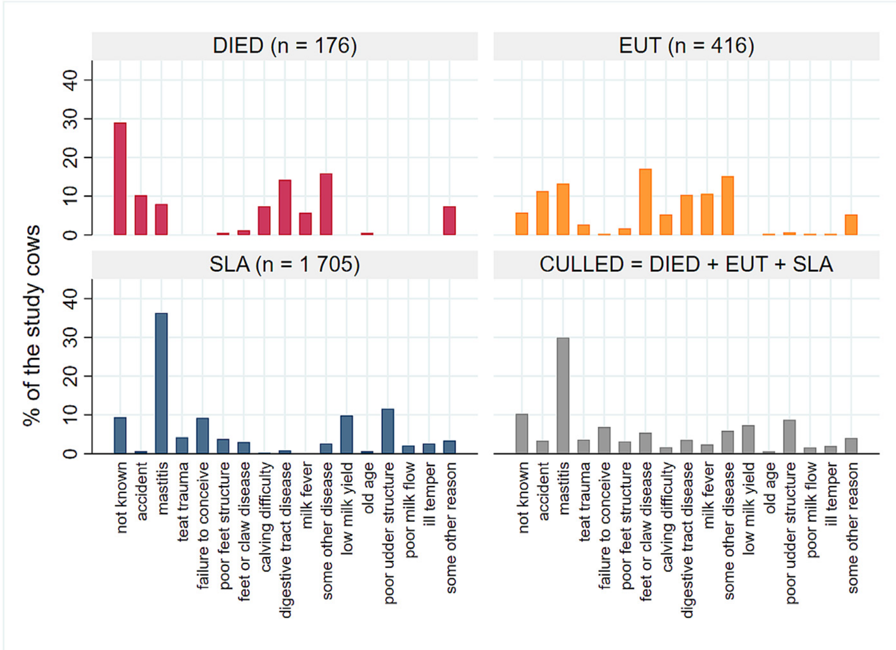

Fig. 6. Farmer-reported reasons for death and culling of dairy cows, stratified by way of exiting the herd: died unassisted (DIED) or euthanised (EUT) on farm, or sent to slaughter (SLA).

come of a cow with mastitis. We observed that a VET for reproductive diseases was associated with lower odds of being a DIED or EUT cow, which may indicate a farmeŕs wish to keep a relatively healthy cow in a herd (Rajala-Schultz and Gröhn, 1999). In our study, the group of reproduction disorders included many different diagnoses, including treatments for infertility and for infectious diseases, therefore, detailed conclusions cannot be made.

Differences between Ayrshire and Holstein cows

Nearly all our study herds (95%) had both AY and HOL cows. In herds with two breeds with slightly different needs, feeding and facilities like stall adjustments are seldom optimal for both breeds, potentially with effects on survival and way of exiting the herd. Also, if a farmer aims for a more uniform herd or herd with one breed only, that influences his / her decision–making. Even though the overall survival for AY and HOL cows was similar in our study population, HOL cows died on farm with higher odds than AY cows. Lower survival rates for HOL cows compared to other breeds or cross-bred animals have also been observed by earlier studies (Heins et al., 2006; Maia et al., 2014; Shahid et al., 2015). Moreover, in our study, AY cows had died on farm or been slaughtered at slightly older age than HOL cows, but we did not observe a clear difference between the peak times in lactation of exiting herd. However, there are competing risks between on-farm deaths and slaughter (Maia et al., 2014). A cow that a farmer would have sent to slaughter, might die on-farm before the planned culling, and that the earlier event determines the outcome of the cow. Breed differences in survival and the predisposing factors for on-farm deaths could be interesting subject to study in more detail in future.

In our study, problems with calving were a more frequent farmer-reported reason for death or culling for 1st parity AY than HOL cows. This is in contrast with Heins et al. (2006) who reported more dystocia among Holsteins, especially in their first calving, compared to crossbred animals. Our findings might partly be explained by the trend that many Finnish farmers with multiple breeds in their herds aim for a Holstein herd and therefore breed AY cows with beef semen. In Finland, bull calves are raised for meat, and cows with low genetic value are often inseminated with beef semen. Cross-bred calves are bigger than purebred, and big calves have been reported to increase the risk for dystocia and on-farm mortality (Shahid et al., 2015; Bicalho et al., 2007).This reasoning is supported by Alvåsen et al (2014), who also reported higher odds of mortality in herds with multiple breeds. In our study, a VET for feet and claw problems was associated with higher odds for euthanasia, but with large between-herd variations. This finding is in line with an earlier Finnish study (Sarjokari et al., 2013) that reported a range of 2–62% herd–level lameness prevalences and higher odds for lameness among HOL compared to AY cows. Also, feet and claw problems were a more frequently reported reason for euthanasia for 1st parity HOL than AY cows.

Died, euthanised, slaughtered or alive – does it matter?

We observed differences in the cow characteristics and farmer-reported reasons for death and culling among cows that exited herds by different ways. Moreover, the veterinary treatment history of the cows that died unassisted on farm differed from that of the euthanised cows and varied between individual herds. In practical herd, health management in the field, cowś breed, parity, stage of lactation and entire disease and treatment history of cases of on-farm deaths should be analysed, together with in-depth evaluation of the herdś production environment and farm routines in preventive measures and record keeping. In research, data on treatment history and reasons for culling have been dominated by slaughtered cows and DIED and EUT cows have often been treated as one group. However, considering the results of the current and of previous studies, these groups appear to differ in the predisposing factors and reasons for death (Compton et al., 2017; Thomsen and Houe, 2018; Hagner et al., 2023). Therefore, we agree with Compton et al. (2017) and Thomsen and Houe (2018) suggesting that in attempts to find ways to decrease the mortality of dairy cows, various groups of cows should be explored separately. Also, herd-specific analyses should be utilised in future studies.

We observed that first–parity Holstein cows had significantly higher odds of dying on-farm, compared to first–parity Ayrshire cows. Cow health, welfare, milk yield and length of her productive life, as well as the number of replacement heifers raised all play a role in the herd́s lifetime productivity, as recently reviewed by De Vries and Marcondes (2020). Lifetime milk yield of cows is also associated with greenhouse gas emissions produced (Grandl et al., 2019; De Vries and Marcondes, 2020). Grandl et al (2019) underlined that greenhouse gas emissions per kg of energy–corrected milk produced are especially high for cows that exit the herd during the first lactation. Also, these cows have not yet repaid their rearing costs. Therefore, further studies should aim at gaining more knowledge on how to minimise the number of cows exiting the herd during their first lactation.

Economically and ethically sustainably produced milk for human consumption is the most important goal for dairy industry. In the dairy industry with constantly fluctuating world market prices and changing demands for responsibility, milk producers continuously seek ways to stay profitable, and this has led to intensification of production through increasing herd sizes, preference for Holstein cows and higher milk yields (ICAR, 2023). Mortality of dairy cows, and the proportion of mortality out of total culling, has increased during the last decades (Compton et al., 2017) and the increase seems to be associated with both the cow characteristics and genetics, along with the structural changes in the dairy industry. Thomsen et al. (2006), Alvåsen et al. (2012 and 2014), and Reimus et al. (2018) all observed that the risk of mortality increased with increasing herd size: they studied mortality of cows included in the national Danish, Swedish, and Estonian cattle databases in herds with at least 10, 20 or 40 cows, depending on the study. In the Danish study, the odds for mortality increased by 1.05 for every 50-cow increase in the herd size (Thomsen et al., 2006). In the Swedish studies, the mortality events per 100 cows and hazard of mortality increased with every change from a smaller to larger herd size category of 20–49, 50–99, 100–199 and 200+ (Alvåsen et al., 2012) and higher mortality of both primiparous and multiparous cows in larger herds was observed (Alvåsen et al., 2014). In the Estonian study, the hazard of mortality slightly increased for both primiparous and multiparous cows with every 20-cow increase in the herd size (Reimus et al., 2018). The results of previous research forecast that if we do not actively seek ways to reduce on-farm mortality, the increasing trend might continue.

Information gained from the analyses of disease treatment records and reasons for death and culling can be valuable in enhancing cow welfare, productive lifespan and production efficiency in dairy farms. When possible, those data should be accompanied with pathology diagnosis, especially in situations with increased mortality. To achieve more comprehensive and accurate data at farm and at national level, autopsy findings and reasons for death and culling should be recorded in more detail in Dairy Herd Improvement or other herd health databases.

Representativeness of the study population

The data used in this study were collected as a part of a larger research project conducted in the early 2010 's (Sarjokari et al., 2018). The enrolled study herds were considerably larger than typical Finnish dairy herds at the time, but they were chosen then because they were believed to represent future Finnish farms. Since then, herd sizes have continued to grow, and automatic milking systems have become more common, and the study herds represent the current Finnish dairy farm sizes and milking systems well. In 2011, the 76 herds in our study represented 23% of Finnish herds of similar size and housing system (n = 324). They had comparable production levels (9 173 vs 9 055 kg average annual milk yield) and same age (4.6 years) of cows at exiting the herd, as other herds of that size. Even though the data originate from 2011, the recording system and the codes for cows exiting the herd, farmer-reported reasons of mortality and culling, or VET diagnoses have not changed after the data were collected. Moreover, the proportions of the main VET diagnoses have remained consistent in Finland from 2011 to 2020 (unpublished data, and dairy cattle health reports presented by Faba Coop, the latest six reports can be found at https://faba.fi/fi/karjan-hyvinvointi/terveys/terveys-tarkkailu accessed 27.10.2024).

Limitations of this study

Unfortunately, we did not have veterinary identification data available and therefore, were not able to account for the heterogeneity arising from different veterinarians in our modelling. However, we grouped VETs into simple entities, with the aim of minimising misclassification and reducing variability in diagnoses of individual diseases. Data from animal health registers can be affected by data entry errors, missing data and completeness by which data are recorded into the databases (Espetvedt et al., 2012; Wolff et al., 2012; Rintakoski, 2014). These aspects may have impacted our data, but an inspection of the data was performed to find any illogical and/or obvious data entry errors and herds with low recording activity were excluded.

The number of observations for DIED and EUT cows was small, limiting the power of the regression models. Also, following only one lactation might have led to underestimation of the role of some diseases in earlier lactations for multiparous cows. Including the whole productive life and disease history of the cows in the analysis would give more information on the effects of different combinations of diseases. Therefore, in the future, this subject should be studied with a larger set of data with herd–specific analyses and broader set of variables (e.g. including dry period length, calving interval, age at first calving), and with in-depth semi-qualitative studies. Ideally, a study with a large number of cows and multiple lactations, very precise treatment data, farmer interviews for each of the cases, and thorough postmortem examinations could be carried out.

Conclusions

We observed differences in the cow characteristics and farmer-reported reasons for death and culling among cows that died unassisted, were euthanised, slaughtered, or stayed alive in a herd. Holstein cows died on farm more often compared to Ayrshire cows. The veterinary treatment history of the cows that died unassisted on farm was slightly different from that of the euthanised cows, and herd-specific differences in the risks for on-farm deaths for treated and non-treated cows were observed. Overall, calving difficulty and digestive tract diseases increased the odds of dying unassisted, and milk fever, digestive tract and claw and leg diseases the odds of being euthanised. More research is needed to better understand mortality and to manage dairy herds optimally. We suggest including the way cows exit the herd in future research, into routine statistics monitored within the dairy industry, and more detailed herd–specific analyses into advisory tools for benchmarking and problem–solving in individual dairy herds.

Supplementary material

Supplementary Material for this article (https://doi.org/10.1016/j.animal.2025.101497) can be found at the foot of the online page, in the Appendix section.

Ethics approval

This paper is based on analysing routinely collected Dairy Herd Improvement data. No new ethical approval was required.

Data and model availability statement

None of the data were deposited in an official repository. Data can be obtained by contacting the corresponding author.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Declaration of interest

None.

Acknowledgements

We warmly thank all the dairy farmers participating in this study and making their herds data available.

Financial support statement

This study was funded by the Ministry of Agriculture and Forestry in Finland and Valio Ltd, under the project "Grouping strategies in Large dairy farms" (2454/312/2009). Walter Ehrström's foundation, and The Finnish Veterinary foundation funded writing this article.

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