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A decision support system based on disease scoring enables dairy farmers to proactively improve herd health

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Abstract: Decision support systems (DSSs) enable dairy farmers to make informed and timely decisions on herd health management. However, the lack of a disease scoring system by category and severity limits the application of this approach. In this study, we developed an innovative approach to dairy herd health management by establishing a novel scoring system for dairy herd health management aimed at providing a more nuanced understanding of disease impact. For this purpose, we retrieved 5-year data from 2 558 disease diary records of 798 primiparous and multiparous cows housed on a Czech farm and classified 125 production diseases into six categories, namely lameness, mastitis, postpartum diseases, digestive system, reproductive diseases and other diseases. Based on this metric, we developed a data-driven DSS for farm management. Using this DSS, we identified markers of disease categories for efficient veterinary monitoring on dairy farms. This DSS highlighted a decreasing trend of average monthly disease scores, yet the prevalence of postpartum and other diseases increased during the same period, due to changes in reproduction management within the herd. These findings underscore the need for data-driven targeted interventions for promoting the herd health. Therefore, our scoring model not only provides a comprehensive framework for dairy herd health monitoring and improvement but also advances dairy farming by providing a decision support system easily applicable to dairy farms based on available data recorded in disease diaries.

Keywords: dairy cows; descriptive analysis; disease scoring system; farm management; production disease

Dairy herd health management (Bowen 2016; Damiaans et al. 2020) is crucial for effective farm management (Ferchiou et al. 2021) within the precision farming approach (Loucka et al. 2023).

To this end, new approaches have recently been developed towards sustainable dairy farming (Ufitikirezi et al. 2024) based on data-driven decision making by applying artificial intelligence (AI), data analysis, and big data analysis (Cabrera 2021). Case in point, machine learning can predict health trends at dairy herd and individual cow levels (Parker Gaddis et al. 2016), for example according to monitoring of eating and rumination time (Codl et al. 2023).

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Improving the herd health management using the general resilience of dairy cows (Kasna et al. 2022) requires the more closely monitoring of production diseases (Islam et al. 2020). Production diseases, such as mastitis, lameness, reproductive disorders and vulval discharge, decrease milk production, having a major economic impact on a dairy farm (Kossaibati and Esslemont 1997; Kasna et al. 2023). Previous studies have shown both the combined, long-term effects of these diseases (Carvalho et al. 2019) and the economic impact of individual diseases, including lameness (Robcis et al. 2023) and postpartum diseases on the herd size (Dubuc and Denis-Robichaud 2017). Research efforts have also been made to classify production diseases into 5 categories and to assess their effects on production and reproduction (Masia et al. 2022).

In dairy farming, several studies have developed scoring systems, such as the KalfOK system, to evaluate the quality of young cattle in dairy herds using 12 key indicators (Santman-Berends et al. 2018) towards improving animal health and welfare on farms. Some authors (Moller et al. 2023) calculated the agreement between 2 scoring systems for calves, namely a Visual Analog Scale (VAS) and the Wisconsin Calf Health Scoring Chart (WCHSC). Other authors scored the herd health using qualitative research based on questionnaires examining the risks of intramammary infections and subclinical mastitis in areas with herds of different sizes and characteristics (Savignano et al. 2008). Overall dairy herd health was also directly compared between dairy farms using scoring systems in Serbia (Stankovic et al. 2014) and France (Coignard et al. 2013), but not in the Czech Republic.

Decision support systems (DSSs) have been developed for controlling individual diseases, including the bovine pestivirus syndrome (Bennett 1992) and mastitis (Allore et al. 1995). DSSs enable farmers to design a targeted control strategy by providing them with reference values for comparison. Another DSS for tracking the dairy herd health at dairy cow or herd levels known as Dairy Brain (Ferris et al. 2020) uses near-real-time data streams to generate decision support information for farm management. DSS monitoring of dairy herd health improves the cow and herd health, decreasing the number of cows for transport Cockram (2021). However, the lack of a disease scoring system by category and severity limits the application of this approach. Moreover, such research has never been conducted on Czech farms, promoting DSS-based monitoring of production diseases in this context.

Considering the above, this study aims to improve the herd health by developing a DSS based on a new dairy disease scoring system for proactive farm management. We developed this new scoring system for the data analysis of dairy herd health by retrieving available data from dairy disease records, a common standard on Czech farms. This scoring model-based DSS is a novel method for data-driven decision making in dairy farm management.

MATERIAL AND METHODS

In this study, we extracted data on a herd of 798 primiparous and multiparous cows recorded for 5 years, from March 2018 to April 2022, in the disease diary using the middleware application "Portal farmáře". The disease data included cow identification, date of disease diagnosis, and the type of disease, totalling 125 disease types. These data were initially classified into 5 disease groups, namely reproductive diseases, digestive tract, lameness, mastitis, and postpartum diseases, as outlined in Table 1. Figure 1 shows a flowchart of the digitalisation and data processing procedure from the dairy disease records to the final scoring results. Our scoring model may be used to compare the dairy herd health between various farms, thereby identifying differences and the farms with the healthiest herds whose procedures should be adopted by farms with less healthy dairy herds. Another potential application of our scoring model is the development of a common metric per cow as a comparable parameter among several farms towards establishing shared animal health criteria.

Data preprocessing

All data were prepared data for developing the scoring model in this study. The disease records were converted from PDF files into an Excel spreadsheet. Then, all duplicities were removed during the data filtering step (Lee et al. 2020). As a result, 125 diseases were identified in a total of 2 558 disease records and classified into 6 categories, the five categories described above and a category entitled "other diseases".

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Table 1. Basic statistics for the ovarian response, and the number of recovered embryos per cow per flushing

Disease	Disease category	Disease severity
Abscess in the subcutaneous tissue	other diseases	1
Acidosis (metabolic acidosis) – rumen content	other diseases	1
Acyclicity	reproduction diseases	2
Acarosis – infestation by arthropods (parasitic conditions, mainly affecting the skin)	other diseases	1
Acute ruminal acidosis (lactic acidosis)	digestive system	3
Acute catarrhal mastitis	mastitis	3
Arthritis – joint inflammation	lameness	3
Arthrosis	lameness	1
Aseptic inflammation of the flexor tendon sheath (*Tendovaginitis flexorum digitalis nonpurulenta*)	lameness	1
Atypical puerperal paresis	postpartum diseases	2.5
Bronchopneumonia – lung inflammation	other diseases	2
Cystitis – bladder inflammation	other diseases	1.5
Cysts – ovarian cyst syndrome	reproduction diseases	2
Digital dermatitis (DD)	lameness	2
Digital dermatitis M-1 stage – initial DD (M1)	lameness	2
Digital dermatitis M-2 stage – typical DD (M2)	lameness	2
Dislocation of the spleen	postpartum diseases	3
E3 – purulent endometritis	reproduction diseases	2
E4 – pyometra	reproduction diseases	2
Endometritis (after the 20th day postpartum)	reproduction diseases	2
Subcutaneous hematoma	other diseases	1.5
Haemorrhagic enteritis (diarrhoea with blood)	digestive system	3
Haemorrhagic mastitis	mastitis	3
Purulent hollow organ wall (bovine contagious abortion) (wall ulcer)	lameness	2
Purulent joint inflammation of the claw	lameness	3
Fever/elevated temperature	other diseases	2
Low-grade fever/temperature increase up to 1 °C	other diseases	1
Moderate fever/temperature increase up to 2 °C	other diseases	1
Very high fever/temperature increase over 3 °C	other diseases	1
High fever/temperature increase up to 3 °C	other diseases	1
Foot ulcer – Rusterholz ulcer (RV)	lameness	2
Foot ulcer – atypical localization	lameness	2
Chronic and latent ruminal acidosis (SARA) – with increased DM	other diseases	2
Chronic catarrhal mastitis	mastitis	2
Indigestion/reduced ruminal activity in cattle	digestive system	1.5
Intertrigo (inguinal dermatitis)	other diseases	1
Other calving disorders	postpartum diseases	2
Other disorders in energy metabolism, carbohydrate, and fat metabolism	other diseases	1
Catarrhal enteritis (diarrhoea)	digestive system	2.5
Ketosis – clinical primary	postpartum diseases	2
Ketosis – clinical primary – severe	postpartum diseases	2
Ketosis – clinical primary – mild	postpartum diseases	2
Ketosis – clinical primary – moderate	postpartum diseases	2
Ketosis – subclinical primary	postpartum diseases	2

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Table 1 to be continued

Disease	Disease category	Disease severity
Ketosis – subclinical primary – moderate	postpartum diseases	2
Contractures of flexor tendon sheaths (overstraining)	lameness	1.5
Blood in milk – haemolactia	mastitis	1
Limping	lameness	2
Mild mastitis – acute	mastitis	1
Clinical mastitis	mastitis	2
Mastitis without microbiological findings	mastitis	1
Mastitis with isolated G+ golden Staphylococcus	mastitis	3
Metritis + putrid discharge	mastitis	1.5
Metritis + purulent discharge	mastitis	1.5
Metritis = postpartum uterine inflammation	postpartum diseases	2
Mild lameness = grade 1	lameness	1
Mild ruminal stasis	digestive system	1
Dead foetus – internal	postpartum diseases	3
Necrobacillosis of interdigital space (N)	lameness	2.5
Necrosis of claw tip (NS)	lameness	2.5
Oral cavity diseases	other diseases	1.5
Joint diseases	lameness	1.5
Musculoskeletal disorders (except hooves), lameness	lameness	1.5
Muscle diseases	lameness	1.5
Tendon diseases	lameness	1.5
Oedema – udder oedema around calving	postpartum diseases	1
Papillomatosis	other diseases	1
Parasitic diseases	other diseases	1.5
Sole ulcer (PV)	lameness	2
Periarthritis – inflammation around the joint	lameness	1.5
Peritarsitis – inflammation around the hock	lameness	1.5
Bruising/contusion – contusion	other diseases	2
Polyarthritis – joint inflammation	other diseases	2.5
Uterine injury during calving	postpartum diseases	2.5
Vaginal injury during calving	postpartum diseases	1.5
Vulvar injury during calving	postpartum diseases	1.5
Calving disorders	postpartum diseases	1.5
Vascular disorders	other diseases	1.5
Spontaneous dislocation of the spleen	postpartum diseases	3
Prolonged uterine involution	reproduction diseases	1.5
Decrease in productive performance	other diseases	1
Rumen tympany (acute)	digestive system	3
Diarrhoea	digestive system	2
Pyelonephritis – kidney pelvis inflammation	other diseases	3
Recurring chronic tympany	digestive system	2.5
Secondary ketosis – moderate	postpartum diseases	2
Moderate (catarrhal) mastitis – acute	mastitis	3
Moderate lameness = grade 2	lameness	2.5
Severe (catarrhal) mastitis – acute	mastitis	3

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Table 1 to be continued

Disease	Disease category	Disease severity
Severe mastitis (parenchymatous)	mastitis	3
Severe lameness = grade 3	lameness	2.5
White line disease (T)	lameness	1
Rumen tympany (= bloating)	digestive system	2
Typical puerperal paresis (stages 1 and 2)	postpartum diseases	2
Recumbency – puerperal paresis	postpartum diseases	2
Recumbency postpartum – other than paresis	postpartum diseases	2
Recumbency due to musculoskeletal disease	lameness	3
Claw ulcer (V)	lameness	2
Claw tip ulcer (VS)	lameness	2.5
Claw tip ulcer/necrosis (VS/NS)	lameness	2.5
Uterine prolapse	postpartum diseases	2.5
Markedly reduced ruminal activity	other diseases	1.5
Uterine retention	postpartum diseases	2
Intestinal inflammation – enteritis (diarrhoea)	digestive system	2
Cessation of ruminal activity	digestive system	1
Mammary gland quarter/body injuries	other diseases	2
Skin, subcutaneous, and fur injuries	other diseases	1.5
Pelvic injuries	other diseases	2.5
Musculoskeletal injuries	lameness	2
Teat injuries	other diseases	2
Udder injuries	other diseases	2

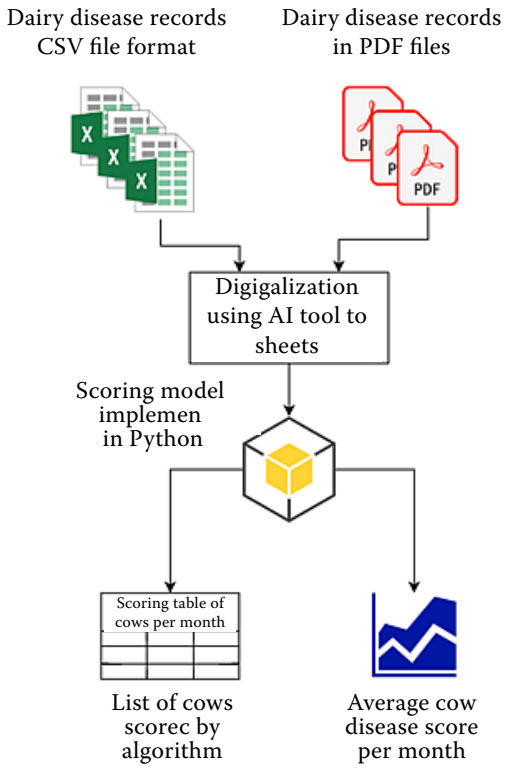

Figure 1. Flowchart of the digitalisation process of dairy disease records

Data categorization and disease scoring

Our novel scoring system of dairy herd health was created as shown in Figure 2. In the first step, all diseases were listed. In the second step, the diseases were scored with a severity number expressing how serious the disease is for the life cycle of a dairy cow.

All diseases were assessed and scored by a veterinarian. Once scored, the diseases were then classified into 6 disease categories (Table 2), according to Shabalina et al. (2020).

Expression of mathematical scoring model

The scoring expression has the following data structure:

- Cow identification.
- Date of disease occurrence.
- Disease name.
- Disease category.
- Disease severity score.

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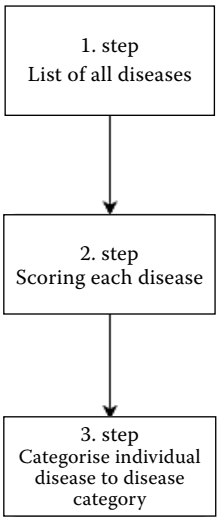

Figure 2. Stages of the overall scoring system of dairy diseases

Mathematical formula of scoring system

- Set of diseases D: This is the set of all possible disease names.
- Cow set C: This set represents all cows in the herd.
- Disease severity score $S(D)$: this score is assessed as described in Table 3.
- Sum scores of diseases of cow count per day:

$$S_l = \sum_{k=1}^{C}\sum_{j=1}^{M}\sum_{i=1}^{D} S\left(D_i\right)_{j,k} \quad (1)$$

where:
$S\left(D_i\right)_{j,k}$ – occurrence of disease i with score $S(D_i)$ and of cow k from all cows C on day j from all days in month M.

- Average score per cow k in month:

$$O_l = \frac{S_l}{C} \quad (2)$$

where:
O_l – the sum score in month l.

- Sum of scores per cow k in month l: $S_{l,k}$.

The formula for calculating the trend of diseases

$$SSR = \sum_{i=1}^{m}(O_l - (\beta_0 + \beta_1.l))^2 \quad (3)$$

Table 2. Disease categories and descriptions

Disease category	Group description
Lameness (Sahar et al. 2022)	diseases related to the cow's locomotor apparatus
Mastitis (De Vliegher et al. 2012)	various difficulties associated with mastitis
Postpartum diseases (Dubuc et al. 2011)	diseases occurring after calf birth
Digestive system (Hall and Mertens 2017)	diseases related to the digestive tract
Reproductive diseases (Gilbert 2016)	conditions affecting the reproductive system, including fertility problems and complications during pregnancy
Other diseases	other disease types occurring during the lifetime of a cow

where:
$l \in (1, m)$;
m – the last month;
O_l – the observed average score per cow in month l;
l – the month index or time variable;
β_0 and β_1 – the coefficients determined using the least squares method;

$$T = \beta_0 \text{ and } \beta_1.\ l$$

where:
T – the calculated trend of several months;
$\beta_1 > 0$ – suggest an increasing trend of average scores over the months;
$\beta_1 < 0$ – suggests a decreasing trend;
$\beta_1 \approx 0$ – indicates a stable trend, with no significant increase or decrease over time.

Table 3. Disease score expressing the levels of disease severity

Disease severity score	Group description
1	mild disease
1.5	mild-to-moderate disease
2	moderate disease
2.5	moderate-to-severe disease
3	severe disease (high risk of culling)

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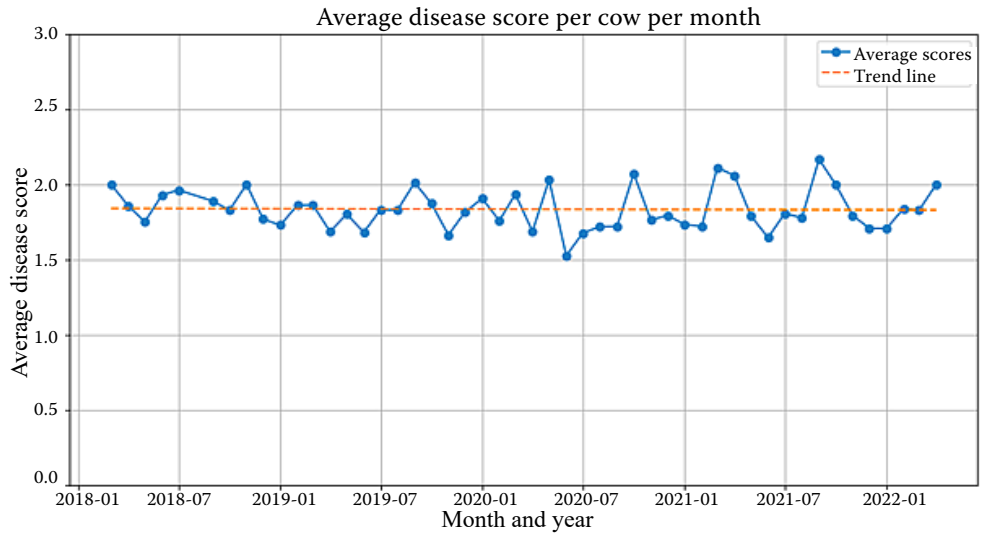

Figure 3. Average disease score per month

RESULTS

The time series of average disease scores per cow per month is shown in Figure 3.

The average disease scores per cow ranged from 1.2 to 2.4. The trend line was calculated by linear regression. The monthly trend of average disease scores per cow in a dairy herd decreased for more than 5 years. Based on this information, farmers can improve their herd health from a long-term perspective. The average disease score was 1.83, with a minimum of 1.53 and maximum of 2.17. The equation of the linear trend line is also included in the legend:

$$T = 1.84 - 6.5.\ 10^{-6}x \quad (4)$$

Resultant $P = 0.89$ expressed that no significant trend was detected.

Table 4. Trends of disease categories

Disease category	Disease category severity	Trend line equation	Slope *P*-value	Trend detection
Digestive system	moderate	$y = -0.006\ 73x + 1.00$	0.680 587	no significant trend
	severe	$y = 0.000\ 61x + 0.84$	0.972 524	no significant trend
Lameness	mild	$y = 0.004\ 54x + 1.16$	0.786 799	no significant trend
	moderate	$y = -0.081\ 84x + 8.83$	0.314 342	no significant trend
	severe	$y = -0.001\ 22x + 0.52$	0.942 695	no significant trend
Mastitis	mild	$y = 0.067\ 76x + 9.15$	0.438 122	significant decreasing trend
	moderate	$y = -0.285\ 31x + 11.38$	0.000 152	significant increasing trend
	severe	$y = 0.393\ 67x + 11.37$	0.003 932	no significant trend
Other diseases	mild	$y = 0.026\ 79x + 5.12$	0.634 769	no significant trend
	moderate	$y = 0.038\ 11x + 0.70$	0.053 738	no significant trend
	severe	$y = 0.000\ 61x + 0.17$	0.934 569	no significant trend
Postpartum diseases	mild	$y = 0.005\ 10x + 0.48$	0.672 440	no significant trend
	moderate	$y = 0.015\ 92x + 3.50$	0.704 176	no significant trend
	severe	$y = 0.034\ 29x + 1.50$	0.210 044	no significant trend
Reproduction diseases	mild	$y = -0.000\ 77x + 0.05$	0.727 673	no significant trend
	moderate	$y = -0.172\ 24x + 10.95$	0.028 302	significant decreasing trend

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Evaluation of total disease scores in the dairy cow population

Disease severity was classified using score intervals outlined in the following charts and tables. The DSS system was defined based on three disease severity levels: "Mild", "Moderate", and "Severe". The "Mild" category included scores from 1 to 1.5, indicating the lowest severity. Scores between 2 and 2.5 were classified as "Moderate" disease severity. Lastly, disease severity scores equal to 3 were categorised as "Severe", representing the highest severity level.

This scoring system aims to provide a more nuanced understanding of disease impact.

Table 4 presents the results of trends by production disease category. The DSS provides mastitis control, primarily at the moderate level. However, other diseases showed an overall increase in prevalence across all severity levels. Postpartum diseases showed increased rates, indicating the need for targeted interventions. In contrast, DSS highlighted a decrease in reproductive diseases, particularly at the moderate level. These findings underscore the need for tailored DSS strategies aimed at addressing specific health concerns and the complexity of dairy cow management in promoting the overall herd health.

Figure 4 shows a decreasing trend of moderate diseases of the digestive system, albeit with a slight

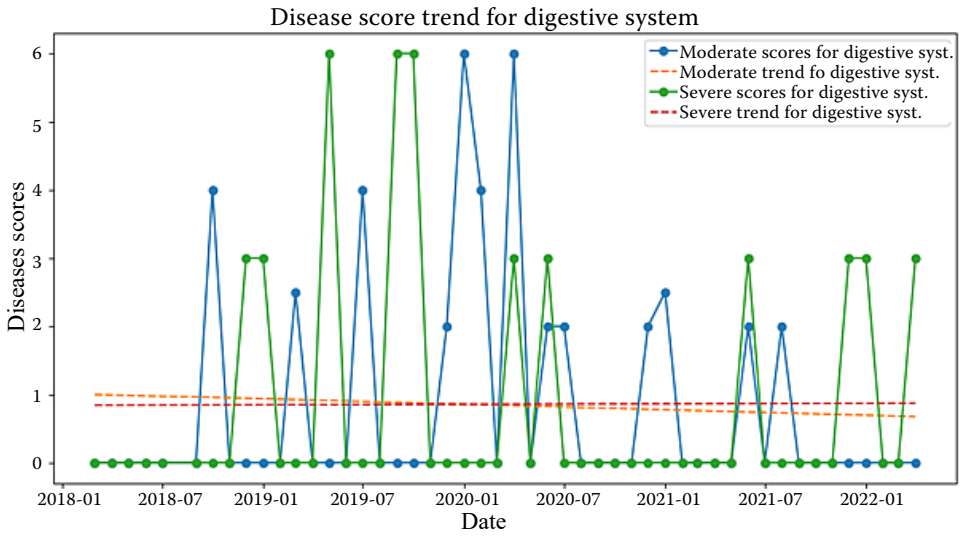

Figure 4. Sum of scores for digestive system

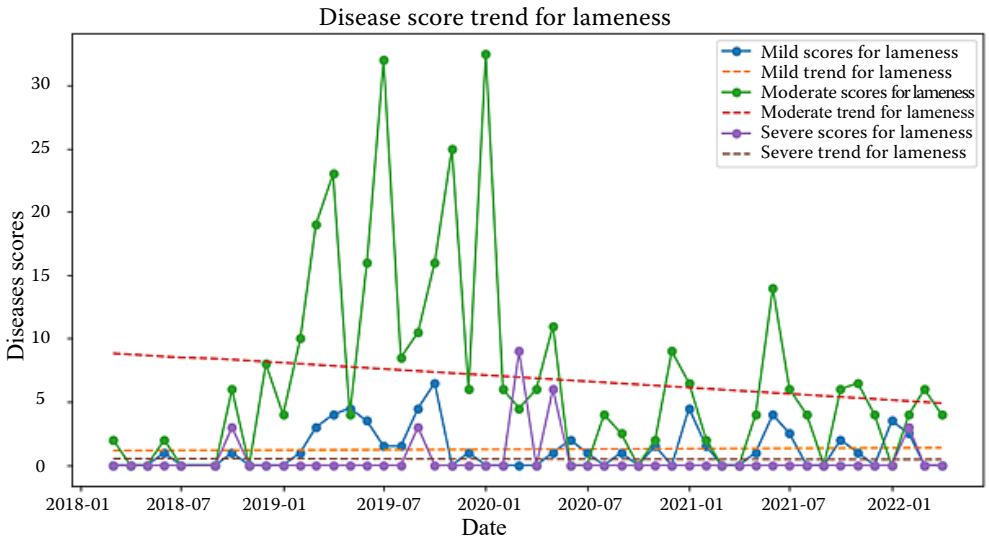

Figure 5. Sum of scores and trends for lameness

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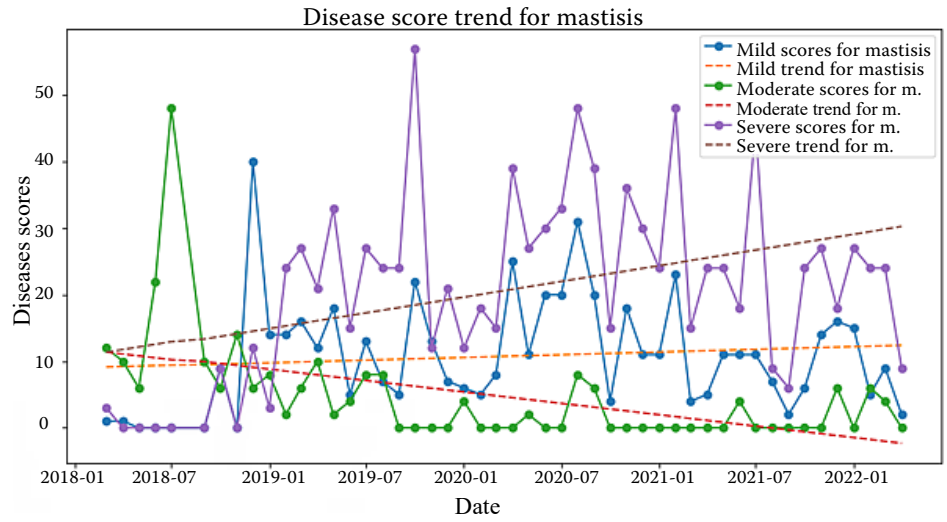

Figure 6. Sum of scores for mastitis disease category

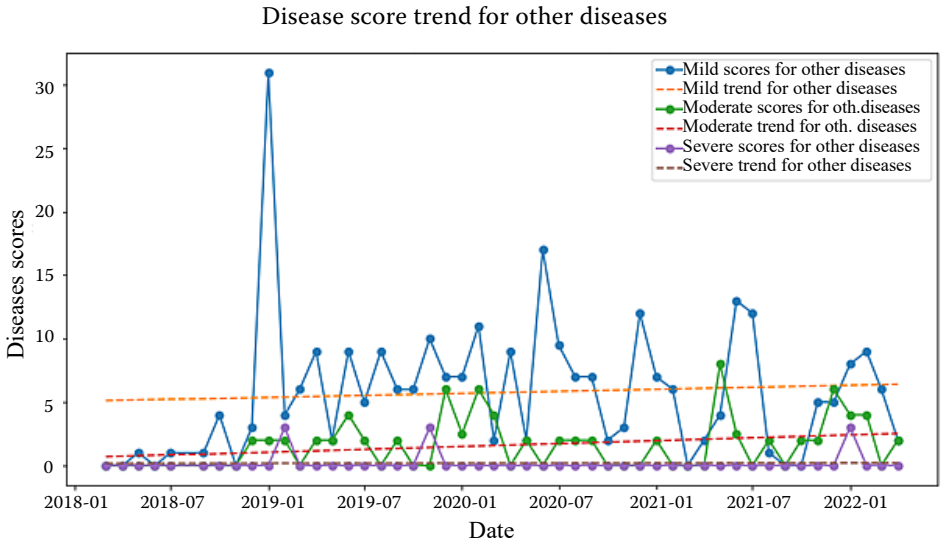

Figure 7. Sum of scores for "Other diseases" category

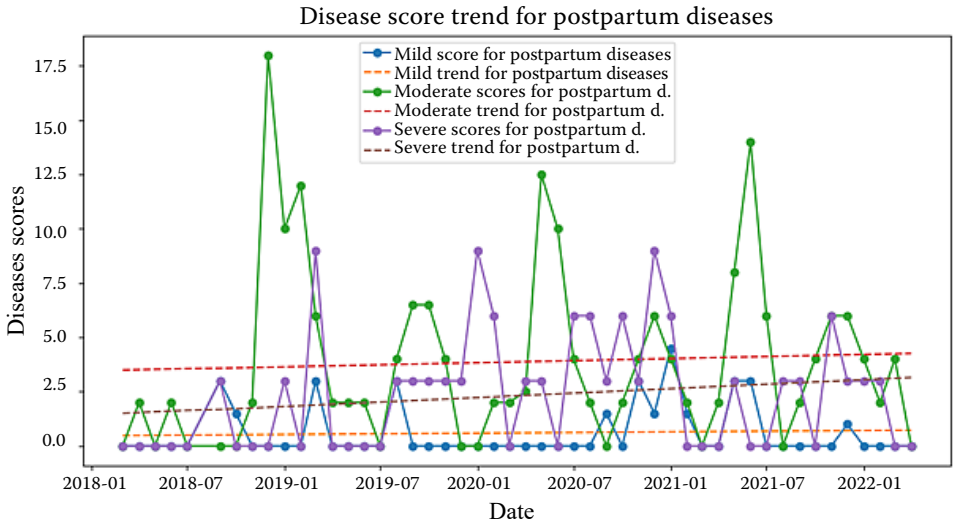

Figure 8. Sum of scores for postpartum disease category

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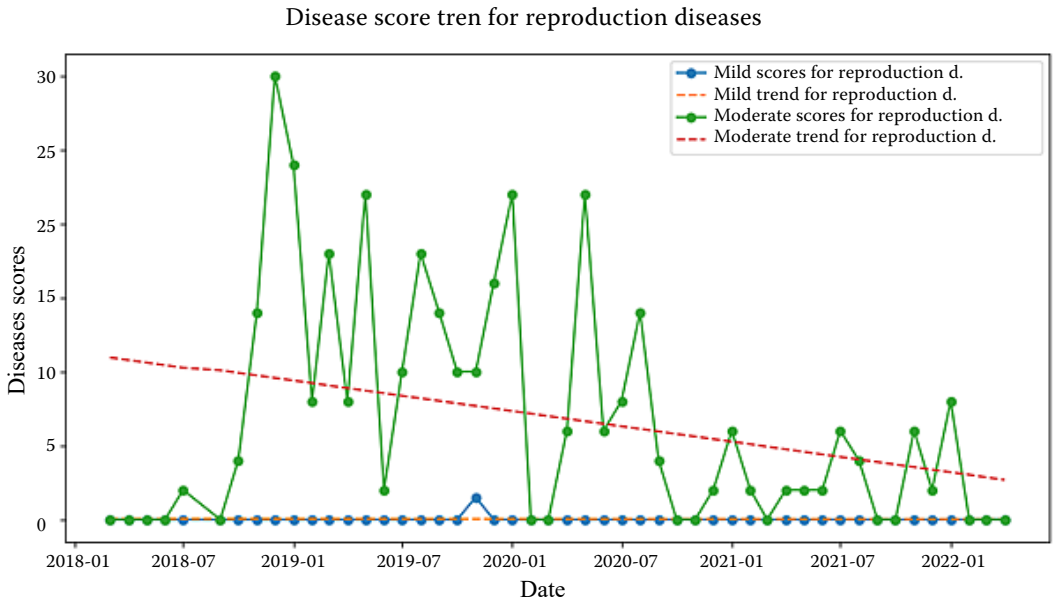

Figure 9. Sum of scores for reproductive disease category

increase in severe diseases of this category. These results demonstrate that our DSS enables farmers to identify differences in disease severity within the same category.

Figure 5 shows a marked decrease in moderate lameness diseases, which account for most diseases in this category. Notwithstanding this prevailing decrease, the remaining severe and mild lameness diseases increased slightly over time. These findings support our assertion above that a scoring model-based DSS enables farmers to differentiate diseases by severity in the same category, regardless of the category.

Figure 6 shows that severe mastitis displayed an increasing trend. Conversely, moderate mastitis significantly decreased over time, whereas mild disease scores showed a nearly linear trend.

In the category of "Other diseases", the score trends shown in Figure 7 slightly increased over time across all disease severities. However, mild diseases had higher scores than moderate diseases in nearly all months of the studied period. Furthermore, severe diseases almost invariably scored 0, except for two months.

The scores of postpartum diseases slightly increased over time, regardless of the disease severity. Nevertheless, the most significant increase was observed in the scores of severe postpartum diseases (purple), as shown in Figure 8.

The category of reproductive diseases showed decreasing trends for all disease severities in Figure 9.

DISCUSSION

Using this scoring model-based DSS, dairy farmers can set al.rt levels for specific trends on a single farm or a set of farms according to a common metric of the dairy herd health. These alert thresholds can be defined by farm management (McBride and Johnson 2006) based on critical states previously identified by farm and by disease category.

Our analysis revealed an average overall disease score of 4.27, indicating the average level of disease burden in this dairy cow population. The 95% confidence interval of the average scores ranged from 0 to 12.39, suggesting a considerable spread in disease severity among the cows. These findings indicate a varied health status within the population and highlight the need for a differentiated approach to health management and disease treatment. A different outcome in reproductive diseases is the result of a change in the approach, and this new method of monitoring through a metric approach allows for tracking changes in disease incidence over time.

The novel overall scoring model proposed in this study can be used by dairy farmers, dairy farm consultants and veterinary staff (Armengol et al. 2022) to monitor the dairy herd health status. The other scoring systems also have cumulative scoring units. In addition, the disease severity score can be modified to meet veterinary needs. The scoring system designed in this study also defined an overall score.

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The practical results of scoring metrics are useful for decision-making of dairy farmers according to herd health trends (Cabrera 2021) and for diagnosing and improving the dairy herd health by decreasing disease trends (Enevoldsen et al. 1995). Decreasing disease trends increases animal health and welfare and decreases the number of cows selected for culling and requiring transport to a slaughterhouse (Cockram 2021), therefore it brings a positive impact on the herd-level economics. This proactive monitoring approach helps to increase milk yields by improving the cow health (De Vliegher et al. 2012), and prevents global warming by a decreased use of antibiotics (Park 2022) and/or by achieving the more effective application of timed artificial insemination protocols (Boudaoud 2023).

Figures 4–9 show trends by disease category. These results can be used for decision-making based on herd health trends broken down into different classes of diseases.

These trends are starting points for projections about dairy herds in longer time periods and may be used as metrics for decision-making about the current status of dairy herd health in combination with farm alerts (Eckelkamp and Bewley 2020). Such alerts enable farmers to quickly apply practical prevention measures for decreasing disease scores in specific categories. This framework provides a DSS for dairy farm management to evaluate the effectiveness of veterinary treatments of production diseases.

CONCLUSION

Our novel overall scoring framework for DSS enables dairy farmers to proactively improve the herd health. Such a data-driven DSS can be applied to a wide research area as a universal comparison methodology for dairy farm herd health management by monitoring the dairy herd health status using severity disease metrics over long periods. Therefore, these findings overcome limitations associated with the lack of digitalisation of disease data and electronic records with insufficient metadata on disease severity. The significance of the observed results and relationships is based on the generally accepted assumption of correlations between milk yield, reproduction, and the health of dairy cows, as confirmed by numerous studies, such as Vacek et al. (2007). This fact is practically utilised in the management and breeding of Holstein cattle through the use of selection indices (Pribyl et al. 2004).

Conflict of interest

The authors declare no conflict of interest.

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