


# Economic costs of veterinary drug and antibiotic use in large Hungarian dairy cattle herds

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## RESEARCH ARTICLE



### ABSTRACT

Veterinary medicine costs are a major component to the economic losses caused by diseases in dairy cattle herds. This study aimed to quantify veterinary drug costs with a particular emphasis on antibiotics, in relation to key production parameters on eight large Hungarian dairy farms (average: 864 cows per herd) from 2017 to 2019. Veterinary drug costs were analysed by product group and indication, with antibiotic costs further categorised by substance class and indication. The average annual cost of veterinary drugs was €75.4 per cow and 0.80 € cents\*L<sup>-1</sup> milk. Antibiotics accounted for the largest share (39.7%) of total drug costs. Main indications were udder diseases (29.6%), reproductive disorders (26.5%), lameness (11.8%), digestive (11.5%) and respiratory diseases (10.0%). The average annual cost of antibiotics was €29.9 per cow and 0.32 € cents\*L<sup>-1</sup> milk. On average, 51.8% of antibiotic costs were treating mastitis, 27.8% for lameness, 12.1% for respiratory and digestive diseases and 8.3% for reproductive failures. Most antibiotic costs were for cephalosporins (63.2%), fluoroquinolones (11.1%) and antibiotic combinations (9.5%) (e.g., amoxicillin and clavulanic acid), followed by tetracyclines, macrolides and penicillins. The majority of veterinary drug costs in the surveyed Hungarian dairy herds were attributable to antibiotics, followed by hormones and vaccines.

### KEYWORDS

dairy cattle, veterinary drug costs, antimicrobials, antibiotics, indication of antibiotics, classification of antibiotics

## INTRODUCTION

The primary objective of a dairy cattle farm is to increase profit, which can be achieved by reducing costs, improving productivity, or increasing product quality. Production indicators and costs in the sector are strongly influenced by the genetic capacity of the herd, modern and continuously evolving husbandry technologies and the health status of individual animals. The latter is therefore essential to assess, and, if necessary, be improved (Ózsvári et al., 2016; Varga and Ózsvári, 2004). Veterinary drug use, particularly antibiotics, plays a significant role in managing the health status of dairy cattle and maintaining farm profitability (Roskam et al., 2023). However, the widespread and sometimes inappropriate use of antibiotics in livestock farming is a growing concern due to its link to antimicrobial resistance (AMR), which has serious implications for both animal and human health (Pires et al., 2024; Sharma et al., 2018). This makes it essential for dairy farms to monitor and optimise drug use practices, ensuring both economic efficiency and compliance with public health standards (Acosta et al., 2025; Trinchera et al., 2025).

In the dairy sector, one of the most significant herd health problems causing financial losses is mastitis, with an estimated annual cost of £300 million in the UK (Hillerton and

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Berry, 2005). Van Soest et al. (2016) examined the preventive and treatment costs of mastitis in Dutch dairy herds and reported substantial between-farm variation, suggesting that the effectiveness of drug use could be improved. To achieve this, reliable information on the treatment costs of mastitis is required to adequately assess the effectiveness and profitability of udder health programs at the cow, herd and sector levels. Mastitis is primarily treated with antibiotics, thus linking it to food safety concerns (Heikkilä et al., 2012). Moreover, reducing the overuse of antibiotics for treating mastitis and other diseases is critical for controlling costs and minimising the risk of AMR, which is an increasingly significant issue for dairy farms worldwide (Muloi et al., 2025).

The expansion of intensive dairy farms has led to a higher incidence of respiratory diseases with significant economic consequences (Esslemont et al., 1999). Calf diarrhoea accounts for a considerable share of production losses in the United States (Sawant et al., 2005). Furthermore, Bellows et al. reported that reproductive failures (e.g., retained placenta, endometritis) result in losses of \$473–484 million per year to producers, which is approximately six times higher than the losses caused by respiratory diseases (Bellows et al., 2002). Hormones can be used to treat reproductive failures, but establishing appropriate general conditions (housing, feeding, animal health) is a prerequisite for improving reproductive performance at the herd level (Gundling et al., 2012).

Economic losses caused by diseases vary across countries and regions, but the underlying economic principles remain consistent (Halasa et al., 2007). For example, Rasmussen et al. (2024) estimate global annual losses due to dairy cattle diseases at around \$65 billion, primarily driven by mastitis, lameness, ketosis and related reproductive disorders. It is important to quantify them through herd-specific analyses, as one of the direct contributors to economic damage is the cost of medicines required to treat animals. Surveys of drug use can therefore support improved herd management (Halasa et al., 2007). Antibiotic use in livestock farming has come under increasing scrutiny, particularly within the European Union, where strict regulations govern its use to mitigate the risk of AMR. The European Medicines Agency (EMA) has emphasised the importance of prudent and rational antibiotic use in food-producing animals to safeguard both animal and public health (Marco-Fuertes et al., 2022; EMA, 2023). This context is crucial for understanding antibiotic costs and usage patterns in dairy farms, particularly for treating prevalent diseases such as mastitis, reproductive failures and foot diseases. Effective antibiotic stewardship requires continuous monitoring of drug use and the adoption of alternative herd management strategies focused on disease prevention and overall herd health (Ruegg, 2022).

Understanding the economic impact of veterinary drug costs is crucial for dairy farmers, as it directly affects profitability and reflects the overall health and productivity of the herd. By providing detailed insights into the distribution of veterinary drug costs and antibiotic use, our study aims to equip farmers and stakeholders with the knowledge needed to make informed decisions, optimise herd management practices and ultimately improve the sustainability of the

dairy sector. A thorough understanding of veterinary drug costs is also essential for promoting the responsible and prudent use of antibiotics.

The objectives of our study are (1) to calculate the cost of veterinary medicinal products including antibiotics, per cow and per litre of milk based on the total drug costs in eight large-scale Holstein-Friesian dairy farms in Hungary and (2) to determine the distribution of veterinary drug costs and antibiotics by product group and indication.

## MATERIALS AND METHODS

### Study design and data collection

A structured questionnaire was developed to collect information about veterinary drug use and costs, including antibiotics, on large-scale dairy farms. The questionnaire was designed in collaboration with veterinary practitioners ( $n = 3$ ) and researchers ( $n = 3$ ) to ensure relevance and comprehensiveness. A pilot version of the questionnaire was tested with three veterinary farm practitioners and revised accordingly to improve clarity and applicability. Revisions were made based on the feedback received prior to distributing the survey to participants.

The commercial Holstein-Friesian farm inclusion criteria for the study were the following: 1) dairy cattle farms with a minimum of 300 Holstein-Friesian cows; 2) continuous participation in performance testing including milk recording, 3) use of computerised on-farm records including detailed records of veterinary treatments, drug use and their costs and 4) willingness to provide information and data to authors. Farms that did not meet these criteria, or those with incomplete or inconsistent veterinary records, were excluded from the study.

This study applied a mixed-method design, integrating both quantitative and qualitative data collection and analysis. It consisted of structured, parameter-based questions requiring respondents to provide numeric or factual data rather than selecting from predefined options. The first part gathered general information on farm characteristics, including herd size (average and milking cows), number and type of barns, housing technology (e.g. freestall or deep bedding), milking system (type, brand, capacity) and disease management practices (e.g. separation of sick cows, disease-free status). The second section focused on technological and production parameters, such as annual milk production and marketed milk volumes, milk yield per lactation and per year, milk fat and protein content, average somatic cell count (SCC), length of lactation and calving intervals and annual culling rates. The third part of the questionnaire addressed data related to veterinary drug costs: information was collected on the types and amounts of veterinary medicinal products used, unit prices and their use by product group and indication (e.g. udder diseases, lameness, respiratory diseases). This structure enabled the collection of consistent and comparable data across farms and provided the basis for the subsequent cost analysis per cow and per litre of milk.

A total of eight Hungarian dairy farms participated in the survey, which was conducted between February and September 2020 through structured personal interviews based on the questionnaire. Prior to the start of the survey, all veterinarians provided written consent to participate in the research. Participation was voluntary and respondents remained anonymous. The obtained data were processed using Microsoft Excel™ 2016 (Microsoft Corporation, Redmond, WA, USA) software.

### Data analysis

After data collection, the purchased veterinary drugs for each farm were grouped by product group and indication. Using the quantity purchased and unit price data for each drug by year and herd, we calculated the total expenditure for each type of drug and then aggregated the results to obtain the total drug cost for all surveyed farms. Taking into account the total number of cows and the total milk produced, the annual cost of veterinary medicines per cow and per litre of milk was calculated for each group, allowing comparisons across the three-year period. Cost data were initially recorded in Hungarian Forints (HUF) and then converted into Euros (EUR) based on the average annual exchange rates of the National Bank of Hungary: 309.21 HUF = 1 EUR in 2017, 318.87 HUF = 1 EUR in 2018 and 325.35 HUF = 1 EUR in 2019, with a three-year average of 317.81 HUF = 1 EUR.

Veterinary drugs were categorised into six product groups based on pharmacotherapeutic application: 1) antibiotics; 2) hormones; 3) vaccines; 4) surgical and medical preparations; 5) vitamins; and 6) antiparasitics. The surgical and medical preparations group included the anti-inflammatories, analgesics, diagnostic materials and all the other surgical and medical preparations that could not be classified in other groups. Minerals, trace elements and amino-acid supplements were included in vitamins group.

Veterinary drugs were also classified based on their indication (the specific disease or condition they were used to treat: 1) udder diseases (e.g., clinical mastitis); 2) reproductive failures (e.g., retained placenta and endometritis); 3) lameness; 4) digestive diseases (e.g., calf diarrhoea); 5) respiratory diseases (e.g., calf pneumonia); 6) metabolic diseases (e.g., ketosis); and 7) other surgical and medical preparations. The last indication group encompassed materials and treatments not easily classified in other categories, including diagnostic tools and other miscellaneous medical preparations.

Furthermore, the cost of antibiotic use was analysed in greater detail. Antibiotics were divided into four groups according to their indications: antibiotics used for the treatment of udder diseases, lameness, respiratory and digestive diseases, and reproductive failures. Antibiotic costs were calculated per cow and per litre of milk. Antibiotic expenditures were also classified by active substance, both within each indication and in aggregate. Combination antibiotics were further subdivided into five groups based on their active substances.

## RESULTS

### Farm characteristics

The main production data of the farms for 2017–2019 are shown in Table 1. The total number of cows across all farms was 6,777 in 2017, 6,940, in 2018 and 7,025 in 2019 ( $n = 20,742$ ), with an average herd size of  $864 \pm 403$  cows ( $n = 8$ ; min 451, max 1,973). All farm used freestall housing technology. Diseased cows (e.g., those with clinical mastitis) were kept in separate barns on 62.5% of the surveyed farms. The milking systems used included DeLaval (50.0%), Fullwood (25.0%), and Alfa Laval and SAC (12.5% each). All herds were free of tuberculosis, brucellosis and bovine leukosis and 37.5% of the herds were also free of infectious

Table 1. Yearly production data of the surveyed dairy farms (2017–2019)

Indexes	2017	2018	2019
Average number of cows	847 ± 363; min. 451; max. 1,561	868 ± 402; min. 466; max. 1,701	878 ± 490; min. 469; max. 1,973
Annual milk production (kg/farm)	7,849,821 ± 4,230,942; min. 3,877,017; max. 16,803,790	8,193,442 ± 4,794,469; min. 4,334,174; max. 18,871,945	8,523,768 ± 5,465,600; min. 4,374,294; max. 21,020,980
Marketed/produced milk (%)	97.5; min. 92.8; max. 100.0	97.8; min. 96.3; max. 100.0	98.1; min. 96.9; max. 100.0
Average milk yield per lactation (kg)	10,299 ± 1,572; min. 8,755; max. 12,505	10,383 ± 1,519; min. 8,934; max. 12,505	10,547 ± 1,298; min. 9,200; max. 12,505
Average milk yield per year (kg)	9,589 ± 1,145; min. 8,294; max. 10,900	9,858 ± 812; min. 8,980; max. 10,900	9,580 ± 974; min. 8,302; max. 10,900
Average milk fat (%)	3.78 ± 0.19; min. 3.60; max. 4.10	3.77 ± 0.16; min. 3.60; max. 4.10	3.75 ± 0.24; min. 3.50; max. 4.20
Average milk protein (%)	3.34 ± 0.11; min. 3.23; max. 3.50	3.37 ± 0.13; min. 3.23; max. 3.60	3.32 ± 0.10; min. 3.20; max. 3.50
Average SCC	417,286 ± 129,719; min. 300,000; max. 630,000	364,000 ± 77,609; min. 300,000; max. 523,000	382,875 ± 117,412; min. 280,000; max. 636,000
Average length of lactation (days)	400 ± 57; min. 278; max. 454	390 ± 50; min. 278; max. 434	375 ± 38; min. 278; max. 415
Average length of calving interval (days)	400 ± 64; min. 320; max. 475	406 ± 61; min. 320; max. 496	398 ± 59; min. 320; max. 494
Number of culled cows per year	272 ± 150; min. 107; max. 552	272 ± 132; min. 149; max. 508	299 ± 179; min. 160; max. 664

bovine rhinotracheitis (IBR) and bovine viral diarrhoea (BVD). Additionally, 12.5% of the farms were free from paratuberculosis, salmonellosis and cryptosporidiosis.

### Distribution of drug costs by product group

The distribution of yearly drug costs by product group between 2017 and 2019 is shown in Table 2. Antibiotics accounted for a significant portion of the costs over three years, but they showed the largest year-to-year decrease. The use of surgical and medical preparations also declined, although to a lesser extent. In contrast, the use of vitamins and antiparasitics steadily increased during the study period.

The average annual drug costs in dairy herds showed a slight decrease when expressed both per cow and per litre of

milk. The cost per cow was €77.3 in 2017, slightly decreased to €76.0 in 2018, and dropped further to €73.0 in 2019. This resulted in a three-year average of €75.4 per cow. A similar trend was observed in the antimicrobial costs per litre of milk, which amounted to 0.83 € cents in 2017, 0.80 € cents in 2018 and 0.75 € cents in 2019. The overall average across the three years was 0.80 € cents per litre.

The average yearly drug costs per cow and per litre of milk by product group are shown in Fig. 1. Averaged over the three-year period, antibiotics accounted for 39.7% of the total cost of medicines. Hormones also represented a considerable share of costs (21.9%), followed by vaccines (15.8%) and surgical and medical preparations (11.9%). Vitamins accounted for 5.8% and antiparasitics for 4.9% of the total veterinary drug costs.

Table 2. Distribution of drug costs by product group in 2017–2019 (EUR, %)

Product group	2017 (n = 6,777)		2018 (n = 6,940)		2019 (n = 7,025)	
	EUR	%	EUR	%	EUR	%
Antibiotics	221,408.2	42.3	215,622.1	40.9	183,762.5	35.9
Hormones	121,937.3	23.3	123,534.2	23.4	96,136.0	18.8
Vaccines	74,953.2	14.3	72,915.5	13.8	99,801.0	19.5
Surgical and medical preparations	70,225.0	13.4	60,525.3	11.5	56,150.5	11.0
Vitamins	26,078.5	5.0	27,545.9	5.2	37,537.9	7.3
Antiparasitics	9,434.7	1.8	27,321.9	5.2	39,166.4	7.6
<b>Total</b>	<b>524,036.9</b>	<b>100.0</b>	<b>527,465.0</b>	<b>100.0</b>	<b>512,554.2</b>	<b>100.0</b>

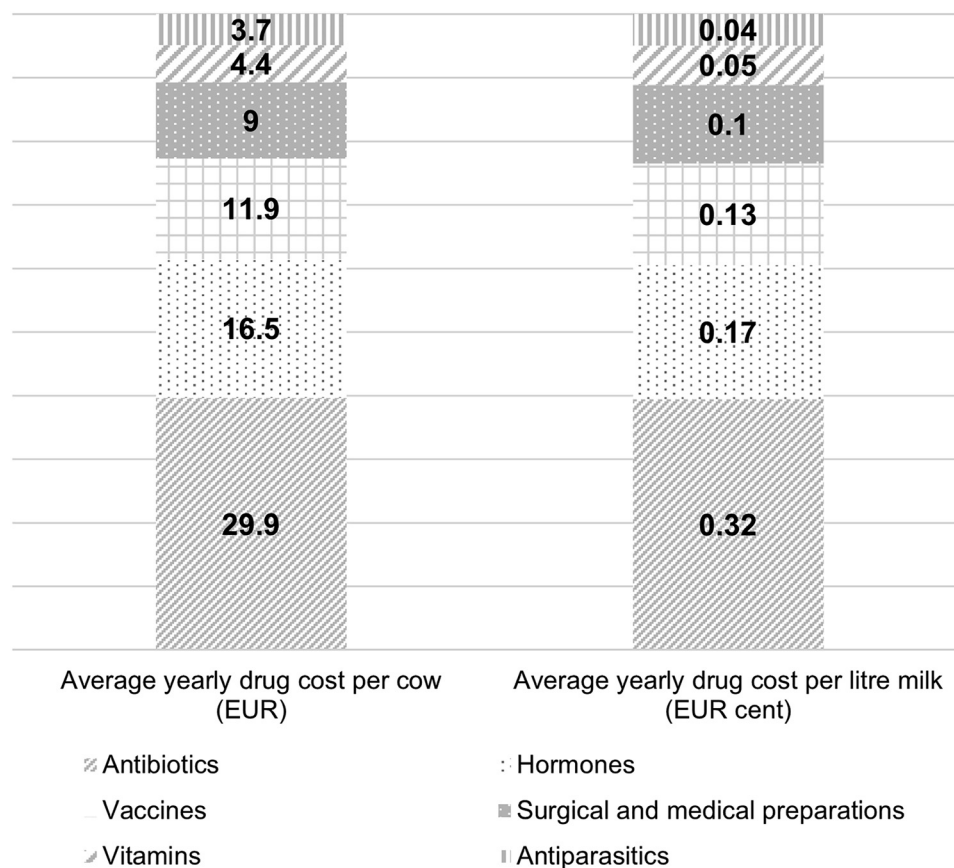


Fig. 1. Distribution of average yearly drug costs per cow and per litre of milk by product group in 2017–2019 (% , n = 20,742)

### Distribution of drug costs by indication

The distribution of drug costs by indication between 2017 and 2019 is shown in Table 3. The largest amount was spent on veterinary medicinal products used for the treatment of mastitis; their share stagnated over the three years examined. The share of drug costs for digestive diseases and antiparasitics increased the most. The share of drug costs intended for the treatment of reproductive failures decreased year by year. The share of veterinary medicinal products used for lameness, respiratory diseases and metabolic diseases varied yearly, at the same time, that of other surgical and medical preparations stagnated in the examined period.

The average yearly drug cost per cow and per litre of milk by indication is shown in Fig. 2. The share of total drug cost for the treatment of udder diseases was the largest (29.6%). Drugs used to treat reproductive disorders ranked second (26.5%). Treatments for lameness (11.8%) and digestive diseases (11.5%) followed in third and fourth place, respectively. Medications for respiratory diseases made up 10.0% of the total. Antiparasitic products contributed 4.9%, while drugs addressing metabolic problems accounted for 4.6%. Products intended for other surgical or general medical interventions represented only a minor share of the costs (1.1%).

Table 3. Distribution of drug costs by indication in 2017–2019 (EUR, %)

Indication	2017 (n = 6,777)		2018 (n = 6,940)		2019 (n = 7,025)	
	EUR	%	EUR	%	EUR	%
Udder diseases	159,418.0	30.4	146,299.9	27.7	157,977.4	30.8
Reproductive failures	150,284.6	28.7	142,829.5	27.1	120,750.0	23.6
Lameness	64,919.8	12.4	77,848.2	14.8	42,562.4	8.3
Digestive diseases	54,666.9	10.4	58,542.3	11.1	66,015.2	12.9
Respiratory diseases	51,520.3	9.8	48,023.1	9.1	57,281.2	11.2
Antiparasitics	9,434.7	1.8	27,321.9	5.2	39,166.4	7.6
Metabolic diseases	28,741.1	5.5	21,545.5	4.1	21,733.8	4.2
Other surgical and medical preparations	5,051.6	1.0	5,054.7	1.0	7,067.7	1.4
<b>Total</b>	<b>524,036.9</b>	<b>100.0</b>	<b>527,465.0</b>	<b>100.0</b>	<b>512,554.2</b>	<b>100.0</b>

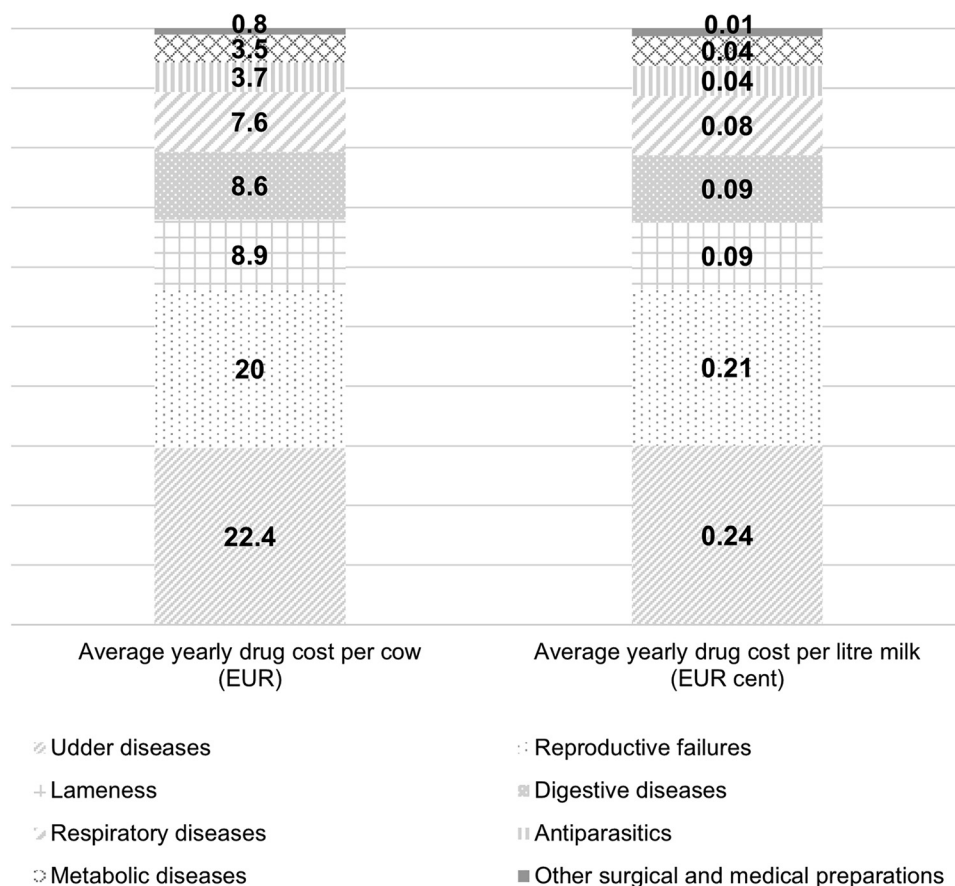


Fig. 2. Distribution of average yearly drug costs per cow and per litre of milk by indication in 2017–2019 (%), n = 20,742)

### Distribution of antibiotic costs by indication

The distribution of antibiotic costs by indication in the surveyed dairy farms between 2017 and 2019 is shown in Table 4. The largest share of antibiotics was used to treat udder diseases, although this proportion varied from year to year. In contrast, the share of antibiotics used for the treatment of reproductive failures showed a continuous decline over the three years.

We also examined the distribution of the average annual antibiotic cost per cow and per litre of milk (Fig. 3). More than half of the average annual antibiotic cost was attributable to udder diseases and almost 30% to foot diseases. Antibiotics used for the treatment of respiratory and digestive diseases and reproductive failures together accounted for about one-fifth of the total antibiotic cost.

### Antibiotic costs by class of active substance

The distribution of average annual antibiotic costs per cow and per litre of milk by active substance classification is shown in Table 5. Based on the three-year average, the highest expenditure was associated with cephalosporins (63.2%), including ceftiofur, cefquinome, cefapirin and cefoperazone. Fluoroquinolones (primarily enrofloxacin and marbofloxacin) and various antibiotic combinations (mainly penicillin-aminoglycoside combinations and amoxicillin-clavulanic acid) ranked second and third, each accounting for nearly 10% of total antibiotic costs. Tetracyclines (mainly oxytetracycline and chlortetracycline), macrolides (mainly tilmicosin and tulathromycin) and penicillins (mainly amoxicillin-cloxacillin) each represented a similar proportion of overall antibiotic costs. Phenicol (primarily florfenicol), lincosamides (mainly lincomycin), potentiated sulfonamides and polypeptide antibiotics were grouped under the "Others" category. Additionally, aminoglycosides and pleuromutilins were used only in minimal quantities within this group.

The annual antibiotic cost per cow showed a steady decline over the three-year period. In 2017, the average cost was the highest, reaching 32.7 €/cow/year. This slightly decreased in 2018 to 31.1 €/cow/year, followed by a more pronounced reduction in 2019, when the cost dropped to 26.2 €/cow/year. The overall three-year average was 29.9 € per cow per year. When considering antibiotic cost per litre of milk produced, a similar pattern can be observed. In 2017, the cost was 0.35 € cents per litre of milk, which decreased to 0.33 € cents\*L<sup>-1</sup> in 2018, and further declined to 0.27 €

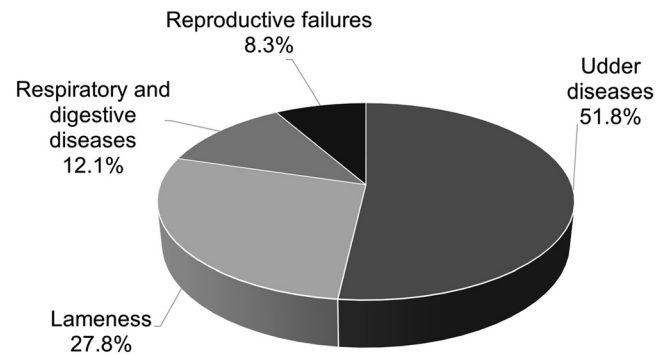


Fig. 3. Distribution of average yearly antibiotic costs by indication in 2017-2019 (%),  $n = 20,742$

Table 5. Distribution of antibiotic costs by active substance classification in 2017-2019 (EUR, %)

Antimicrobial drug classification	Costs (EUR)	Share within indication (%)
Cephalosporins	401,321.7	63.2
Fluoroquinolones	70,345.3	11.1
Combinations*	60,760.8	9.6
Tetracyclines	27,181.7	4.3
Macrolides	26,177.8	4.1
Penicillins	23,280.8	3.7
Others**	25,953.7	4.1
<b>Total</b>	<b>635,021.8</b>	<b>100.0</b>

\*Combinations: 1. Penicillin-aminoglycoside combinations (e.g., benzylpenicillin-procaine, dihydrostreptomycin, neomycin).

2. Amoxicillin-clavulanic acid. 3. Lincosamide-aminoglycoside combinations (lincomycin, neomycin, spectinomycin).

4. Penicillin-polypeptide antibiotic combinations (amoxicillin, ampicillin, colistin). 5. Combination of other antibiotics (e.g., bacitracin, chlortetracycline, oxytetracycline).

\*\*Others: lincosamides, phenicols, sulfonamides, polypeptides, aminoglycosides, pleuromutilins.

cents\*L<sup>-1</sup> in 2019. The average across all three years amounted to 0.32 € cents\*L<sup>-1</sup> milk per year.

Antibiotic costs by disease category were also analysed by active substance classification. Among the cephalosporins, the highest costs were associated with cefquinome, cefoperazone, and cefapirin, with the smallest share attributed to cefalexin for udder disease treatment (Fig. 4). Cephalosporins accounted for the highest share of total antibiotic cost. In addition to cephalosporins, antibiotic combinations (mainly penicillin-aminoglycoside combinations) and

Table 4. Distribution of antibiotic costs by indication in 2017-2019 (EUR, %)

Indication	2017 ( $n = 6,777$ )		2018 ( $n = 6,940$ )		2019 ( $n = 7,025$ )	
	EUR	%	EUR	%	EUR	%
Udder diseases	115,282.1	52.1	96,979.3	45.0	109,444.6	59.6
Lameness	60,879.5	27.5	71,835.5	33.3	39,874.0	21.7
Respiratory and digestive diseases	25,512.3	11.5	28,398.0	13.2	21,024.9	11.4
Reproductive failures	19,734.4	8.9	18,409.4	8.5	13,419.0	7.3
<b>Total</b>	<b>221,408.2</b>	<b>100.0</b>	<b>215,622.1</b>	<b>100.0</b>	<b>183,762.5</b>	<b>100.0</b>

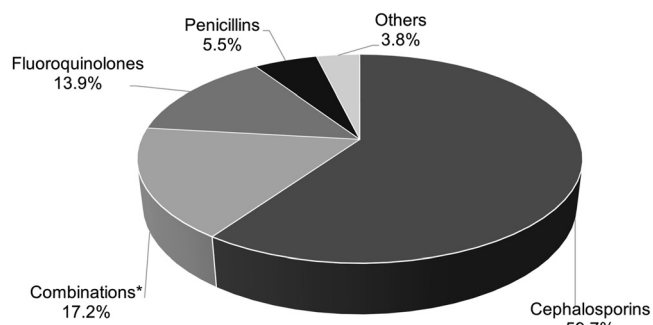


Fig. 4. Distribution of costs of antibiotics used to treat udder diseases by active substance classification in 2017–2019 (%;  $n = 20,742$ )

\*Combinations: 1. Penicillin-aminoglycoside combinations (e.g., benzylpenicillin-procaine, dihydrostreptomycin, neomycin). 2. Amoxicillin-clavulanic acid. 3. Lincosamide-aminoglycoside combinations (lincomycin, neomycin, spectinomycin). 4. Penicillin-polypeptide antibiotic combinations (amoxicillin, ampicillin, colistin). 5. Combination of other antibiotics (e.g., bacitracin, chlortetracycline, oxytetracycline)

fluoroquinolones (mainly marbofloxacin and enrofloxacin) also represented substantial shares. Penicillins ranked fourth, with amoxicillin and cloxacillin being the most commonly purchased. In the “Others” category, antibiotics containing sulfadiazine-trimethoprim and oxytetracycline each accounted for more than 1% of costs, whereas all other antibiotics together represented less than 1% (e.g., lincosamide-aminoglycoside combinations, lincomycin, spiramycin).

Cephalosporins (particularly cefapirin), tetracyclines and penicillins were used to treat reproductive failures, accounting for 69.2, 28.9 and 1.8% of costs for this indication, respectively. Two antibiotic classes were purchased to treat lameness: cephalosporins (95.4%) and tetracyclines (4.6%). Among the cephalosporins, ceftiofur and cequinome together represented 95.2% of the indication-specific costs. Oxytetracycline and chlortetracycline were also procured but in much smaller quantities.

In contrast to the other indication groups, fluoroquinolones (mainly enrofloxacin) and macrolides (mainly tilmicosin and tulathromycin) were the most frequently purchased antibiotics for the treatment of respiratory and digestive diseases, rather than cephalosporins (Fig. 5). Among phenicols, florfenicol accounted for 12.0% of costs for these indications. Lincomycin (lincosamides) and amoxicillin (penicillins) also represented notable shares, while tildipirosin and colistin each accounted for approximately 5% of costs. The “Others” category represented 11.8% of the total cost for this indication group, with penicillin-, polypeptide-, lincosamide- and aminoglycoside-containing combinations each accounting for more than 1%. Fluoroquinolones (difloxain and marbofloxacin) contributed similarly, while the share of amoxicillin-clavulanic acid remained below 1%. Tiamulin and doxycycline were purchased in the smallest amounts.

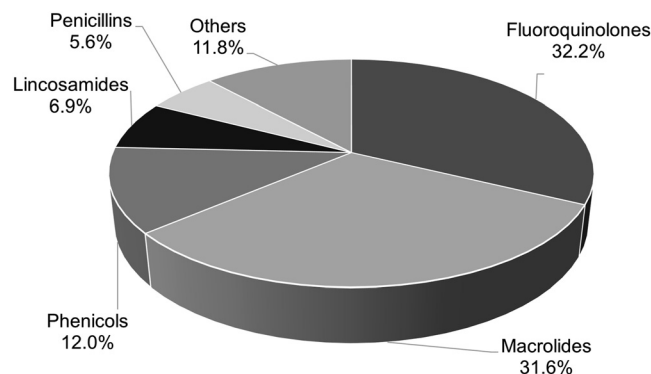


Fig. 5. Distribution of costs of antibiotics used to treat respiratory and digestive diseases by active substance classification in 2017–2019 (%;  $n = 20,742$ )

## DISCUSSION

### Veterinary drug costs by product group

The distribution and dynamics of veterinary drug costs provide insight into treatment strategies, disease prevention practices and economic priorities in dairy production (Steenefeld et al., 2024). This pattern has also been explored in previous Hungarian studies (Ózsvári et al., 2003a; Varga and Ózsvári, 2004), which examined veterinary drug expenditures across different farms and time periods. While the three-year average distribution of costs by product group and indication cannot be fully compared due to differences in economic circumstances across years, trends in veterinary drug use can still be evaluated. In our study, antibiotics accounted for the largest share of drug costs by product group (39.7%). Their share showed the largest reduction over time, consistent with the results of Ózsvári et al. 2003a, whereas Varga and Ózsvári (2004) reported an increase in usage rate. The year-on-year decrease in antibiotic cost ratio in our study may be related to the increased use of vaccines and vitamins, which play an important role in disease prevention (McAllister et al., 2024).

A notable amount (21.8%) was spent on hormones, although their share decreased significantly during the study period. Hormonal preparations are commonly used on dairy farms to treat acyclicity, silent heat and endometritis (Changtes et al., 2024). When combined with other hormones, these treatments are generally more effective compared to using gonadotrophin-releasing hormone (GnRH) or human chorionic gonadotrophin (hCG) alone (Gundling et al., 2012), which may lead to overall cost savings.

Vaccines, the third most costly category (15.8%), showed an upward trend, in line with the findings of Varga and Ózsvári (2004). Most vaccines were used to prevent respiratory and digestive diseases. The increased use of vaccines may be linked to the higher incidence of these diseases and the limited effectiveness or narrow protection of some vaccines against gastrointestinal pathogens, necessitating more frequent vaccination (Vlasova and Saif, 2021).

Surgical and medical preparations ranked fourth. Their share decreased in parallel with antibiotic costs, particularly in the treatment of lameness and reproductive failures. Anti-inflammatory and analgesic drugs were frequently used together with antibiotics to reduce pain and inflammation in foot diseases, using ketoprofen in lameness treatment (Wilson et al., 2025). However, further optimization of lameness treatment, by increasing the use of non-antibiotic therapeutic options, would support compliance with the EU's strict regulations on antibiotic use in livestock (Nunan, 2022; Rigueira and Perecmanis, 2024). The European Union has implemented measures to reduce antibiotic use in agriculture, aiming to minimise misuse and overuse and thereby slow the development of antimicrobial resistance (AMR) (Ghimpețeanu et al., 2022). Farm management practices strongly influence the incidence and treatment of foot diseases and reproductive disorders: improved housing, better hygiene and optimised nutrition can reduce lameness incidence and thus the need for antibiotics (Pluym et al., 2017). In line with EU regulations, a proactive approach to herd health management could reduce antibiotic use, particularly for foot diseases and reproductive disorders (Garvey, 2022), improve animal welfare and contribute to the wider goal of reducing AMR on dairy farms.

Vitamins, used primarily for preventing and treating metabolic diseases, showed increased costs over the years. This trend indicates a growing awareness of metabolic problems, often linked to feeding errors and inversely correlates with declining antibiotic use, supporting the importance of prevention (Ózsvári et al., 2003a). The increasing use of vitamins was consistent with findings reported by Ózsvári et al. (2016). Because gastrointestinal nematodes can reduce milk production and cause other economic losses, effective parasite control is essential (Ali et al., 2018).

Comparing costs per cow and per litre of milk with other studies is challenging due to differences in data collection and time periods (Kuipers et al., 2016). Nevertheless, cost shares and trends can be compared. In our study, the average annual drug cost per cow was €75.4. Ózsvári et al. 2003a and Szerémi (2007) reported lower costs (€41.8–70.6), while other studies found higher values (€79.1–95.3) in Hungary (Ózsvári et al., 2016; Varga and Ózsvári, 2004). Drug cost per litre of milk showed a slight continuous decrease, while average yearly milk production per cow increased on the surveyed farms. In Szerémi's survey (2007), drug cost per litre remained unchanged, whereas Varga and Ózsvári (2004) reported an increase in both cost per litre and cost per cow. In our study, the average annual drug cost per litre of milk was €0.80, while other Hungarian studies reported higher costs (€0.85–1.47) (Ózsvári et al., 2016; Szerémi, 2007; Varga and Ózsvári, 2004).

### Veterinary drug costs by indication

Our results show that the largest share of drug costs was associated with udder diseases (29.6%), and this proportion remained stable, similar to the findings of Ózsvári et al.

(2016) and Szerémi (2007). Udder infusions were the primary treatment, with parenteral preparations used less frequently. The reduction in infusion use significantly contributed to the declining cost share of mastitis treatment. The drug cost per cow for udder diseases was €22.9 in our study. Halasa et al. (2007) reported similar values (€22 per cow per year) and slightly higher costs (€28–31 per cow per year) for mastitis treatment, while Ózsvári et al. (2003b) reported only €4.2 in 2003.

The second largest share of drug costs was for reproductive failures (26.5%), with a year-on-year decrease. Improved reproductive performance may be due to a reduction in twin calvings, which lowers the incidence of retained placenta and shortens the calving interval (Fodor et al., 2019). A decline in endometritis cases may also have contributed, as this condition adversely affects conception rates (Kern et al., 2018). In our study, the annual drug cost per cow for reproductive failures was €20.0, lower than the earlier results reported by Bellows et al. (2002) (€26.5–53.2 per cow per year).

Drug costs for treating lameness ranked third (11.8%). Their share within total drug costs slightly increased over the study period. This trend may reflect genetic selection prioritising milk yield over longevity traits, including foot conformation (Ózsvári, 2017). More frequent preventive hoof care can reduce lameness incidence and associated costs (Ózsvári et al., 2007). In our study, the annual drug cost per cow for lameness was €8.9, significantly higher than reported in previous Hungarian studies (Ózsvári et al., 2007; Ózsvári, 2017).

Drug costs for digestive diseases increased during the study period, possibly due to vaccine efficacy issues and high-grain feeding (Plaizier et al., 2018). Similarly, drug costs for respiratory diseases showed a slight increase, likely linked to a higher incidence of bovine respiratory disease complex (BRDC), which causes severe symptoms in calves (Ózsvári et al., 2012). In our study, the average annual drug cost per cow for respiratory diseases was €7.6. Ózsvári et al. (2012) estimated the total loss per cow from BRDC to be €19, of which drug costs accounted for 8.4% (€1.6), a much lower cost, even considering that the estimate was made over 10 years ago.

Metabolic disorders significantly affect lactation performance, fertility and longevity. Most occur around calving and are associated with the transition from the dry period to lactation (Kang et al., 2025; Magro et al., 2024). In the EU, there is a growing demand for animal nutrition products that can replace antibiotics. Probiotics were used by 69.6% of the surveyed farms to reduce stress, optimise rumen fermentation and complement medical treatments (Várhidi et al., 2022). The amount spent on treating metabolic diseases decreased during the study period, likely due to improved feed quality. Nonetheless, metabolic disorders remain a significant risk as genetic selection continues to emphasise milk production (Pacheco et al., 2025). The stable share of costs for other surgical and medical preparations likely reflects the unchanged use of veterinary surgical products.

### Antibiotic costs by indication

In our survey on the distribution of antibiotic costs by indication, the largest share was associated with the treatment of udder diseases (51.8%), similar to Szerémi's findings (2007) (54%), but lower than the results reported in other Hungarian and Dutch studies (68–70%) (Ózsvári et al., 2003a, 2016; Kuipers et al., 2016). Based on these findings, it can be concluded that antibiotic use on dairy farms is primarily linked to udder health management. Kuipers et al. (2016) found that the share of veterinary preparations used for udder diseases decreased significantly on Dutch dairy farms, which contrasts with our study, where the share of these products increased the most. The second most significant group was antibiotics used to treat lameness (27.8%), a higher proportion than reported in several Hungarian studies (Ózsvári et al., 2003a, 2016; Szerémi, 2007). Antibiotic costs related to respiratory and digestive diseases ranked third (12.1%) and were likewise higher than in the same studies. In contrast, antibiotics used for reproductive failures accounted for only 8.3% of total antibiotic costs, a smaller share than previously observed (Ózsvári et al., 2003a, 2016; Szerémi, 2007).

The ranking of antibiotic costs by indication broadly reflects the prevalence of different diseases in dairy herds. For example, mastitis was the most common disease on dairy farms in Austria and Argentina, followed by lameness, reproductive disorders and respiratory diseases (Obritzhauser et al., 2016; González Pereyra, 2015). After mastitis, lameness is one of the most costly diseases and has a major impact on farm profitability (Ibishi et al., 2022). In our study, lameness was frequently treated with antibiotics, particularly cephalosporins and penicillins, despite the availability of alternative strategies such as non-antibiotic anti-inflammatory drugs. This highlights the role of precision livestock farming and evidence-based protocols in promoting targeted medication use through improved diagnostics and digital health monitoring (Neculai-Valeanu et al., 2024), as the overuse of antibiotics for conditions like lameness may not always be justified and can contribute to antimicrobial resistance. In the current global context, where AMR poses a growing threat, studies such as this help inform better antibiotic use practices in dairy farming and support the global effort to combat AMR.

In this study, the decrease in antibiotic cost per cow was driven by reduced use of antibiotics for treating foot diseases and reproductive disorders. In other surveys, the downward trend in antibiotic use was primarily attributed to reduced use for mastitis treatment (Kuipers et al., 2016; Ózsvári et al., 2016). In our study, the average antibiotic cost per cow was €29.9, higher than the values reported in several other Hungarian studies (€19.6–23.5) (Szerémi, 2007; Ózsvári et al., 2003a, 2016), with the exception of one estimate (€42.8) (Varga and Ózsvári, 2004). In the Netherlands, Kuipers et al. (2016) calculated an average annual antibiotic cost of €70–84 per cow between 2005 and 2012, which was higher than our estimate; however, their calculations also included veterinary fees for farm visits. The antibiotic cost

per litre of milk decreased over the surveyed years, averaging €0.32 per litre, similar to other Hungarian studies (€0.34–0.35 per litre) (Ózsvári et al., 2016; Szerémi, 2007).

### Antibiotic costs by active substance classification

Regarding the distribution of antibiotic costs by active substance classification, cephalosporins accounted for the largest share (63.2%), followed by fluoroquinolones and antibiotic combinations, each contributing around 10%. The high share of these three groups is due to their use in treating udder diseases, particularly via udder infusions. In previous Hungarian studies, Szerémi (2007) also found high shares for combined preparations and cephalosporins, while Ózsvári et al. (2016) reported a high rate of fluoroquinolones, findings consistent with our study. Tetracyclines (mainly oxytetracycline and chlortetracycline), macrolides (mainly tilmicosin and tulathromycin) and penicillins (mainly amoxicillin–cloxacillin) each accounted for nearly 4% of the total cost. The use of phenicols, lincosamides, and potentiated sulfonamides was minimal. A review found that penicillins (ampicillin), cephalosporins (ceftiofur), tetracyclines and potentiated sulfonamides were the most frequently used antibiotics in herds in low- and middle-income countries (Cuong et al., 2018). On English dairy farms, beta-lactam antibiotics, aminoglycosides (including combinations), tetracyclines, and macrolides were predominantly used (Hyde et al., 2017). Penicillins (53.3%) and potentiated sulfonamides (49.8%) were the most commonly used antibiotics in Danish and Swiss cattle farms, with tetracyclines and macrolides also having relatively large shares in both countries in terms of milligrams per kg biomass (mg/BM) between 2007 and 2013. Most tetracyclines were used as uterine tablets, indicating a high incidence of reproductive disorders on the studied farms (Carmo et al., 2017).

Our survey found that cephalosporins, combined antibiotics, fluoroquinolones and penicillins were primarily used for the treatment of udder diseases, consistent with previous Hungarian studies (Ózsvári et al., 2016; Szerémi, 2007). Several international studies also cite these as the most common antibiotic groups for mastitis treatment and during the dry-cow period, as reflected in our survey: cefapirin, penicillin combinations and penicillins (Cuong et al., 2018; Saini et al., 2012; Grave et al., 1999; De Campos et al., 2021), cefquinome and cefoperazone (Firth et al., 2017); amoxicillin-clavulanic acid and fluoroquinolones (Kuipers et al., 2016). The large share of cephalosporins and combined antibiotics is due to the frequent use of udder infusions in mastitis treatment and during the dry-cow period (Li et al., 2024; Miller et al., 2025). In the latter case, antibiotics containing multiple active substances are more effective; some preparations even contain prednisolone, which improves udder condition. The route of administration also affects usage: because fluoroquinolones are mainly administered by injection, their share is large (Ózsvári et al., 2016).

According to our analysis, cephalosporins (mainly ceftiofur) and tetracyclines (mainly oxytetracycline) were used

to treat lameness, similar to previous results (Ózsvári et al., 2016; Szerémi, 2007). Ceftiofur and oxytetracycline were also used in large quantities in Wisconsin dairy herds (Pol and Ruegg, 2007). Cephalosporins are administered by injection for systemic treatment and their high use suggests a stronger emphasis on foot health in the herds we examined. Tetracyclines are used in local therapy, usually as sprays or aerosols and as injections in calves (Ózsvári et al., 2016). Their advantage is that they have no withdrawal period.

Fluoroquinolones, macrolides, phenicols, lincosamides and penicillins are commonly used to treat respiratory diseases in Hungary (Ózsvári et al., 2016), with macrolides (>90%) being the most frequently used antibiotic group for treating BRDC (Ózsvári and Búza, 2015). Amoxicillin among penicillins and enrofloxacin and marbofloxacin among fluoroquinolones proved to be the most effective (Ózsvári et al., 2016). In Argentina, González-Pereyra et al. (2015) also found tilmicosin to be one of the most commonly used antibiotics for respiratory diseases, consistent with our findings. In the United States, ampicillin, ceftiofur, florfenicol and spectinomycin were used in the highest quantities for treating respiratory diseases (Sawant et al., 2005). International studies confirm that macrolides (tildipirosin, tulathromycin, gamithromycin), fluoroquinolones and third-generation cephalosporins (ceftiofur) are effective against *Pasteurella* spp. that cause BRDC; the latter is effective against almost all BRDC-causing bacteria, although it was not used in the herds we surveyed. The macrolides listed above are also effective against *Mannheimia haemolytica* and penicillins and enrofloxacin are effective against *Pasteurella* spp. and *Haemophilus somnus* (Kurcubic et al., 2014; Nautrup et al., 2013; Stanton et al., 2010; Torres et al., 2013). Fluoroquinolones and penicillins were frequently used in our study to treat digestive diseases, similar to Eibl et al. (2021), who found that fluoroquinolones, sulfonamides and penicillins were mainly used to treat these conditions. According to that study, the frequent use of fluoroquinolones is due to concern about septicaemia in cases of neonatal calf diarrhoea. In a previous Hungarian survey, different antibiotic combinations and aminoglycosides were also frequently used to treat enteritis in calves (Szerémi, 2007). In our study, the share of these antibiotic preparations was small, suggesting that the disease was relatively infrequent during the years examined.

We also found that cephalosporins, tetracyclines and penicillins were used to treat reproductive failures, similar to previous Hungarian studies, where cephalosporins were used in late puerperium and at the end of the puerperal period as uterine infusions, while tetracyclines and penicillins were used immediately after calving in early puerperium as uterine tablets (Ózsvári et al., 2016; Szerémi, 2007). Cefapirin and oxytetracycline were primarily used to treat endometritis and cows with postpartum uterine diseases were treated with oxytetracycline (Kern et al., 2018). These three active substances also had the highest shares in our study.

Our results show that the majority of antibiotic costs during the study period were attributable to the treatment of

mastitis, reproductive disorders and foot diseases. These findings underscore the need for greater adherence to EU regulations that promote the prudent use of antibiotics (Schmerold et al., 2023). Implementing preventive herd health management strategies, such as vaccination, improved nutrition and biosecurity, can significantly reduce the need for therapeutic antibiotic interventions (EFSA and ECDC, 2023). By optimising these practices, farms can reduce their reliance on critical antibiotics such as cephalosporins and fluoroquinolones, which are crucial in human medicine. The EU's One Health approach advocates reducing antibiotic use not only to enhance farm profitability but also to protect public health. Encouraging the integration of these practices could therefore contribute to a sustained reduction in antibiotic use across Hungarian dairy farms (WHO, 2023).

## Limitations

This study uses pre-COVID data (2017–2019); while it may not capture subsequent changes in regulation, market conditions, or disease pressure, it provides a solid baseline for trend analyses and post-COVID comparisons. Although the dataset covers more than 20,000 cows, it comes from only eight large commercial farms, so farm-level practices may bias estimates and limit generalisability to all Hungarian dairy operations. Moreover, cost estimates reflect contemporaneous prices and HUF-EUR exchange rates; later price inflation, supply-chain shifts, and product availability could alter absolute veterinary drug costs. Future research including more farms and more recent (post-COVID) years would improve national representativeness and provide valuable insights into how antibiotic-use patterns have evolved.

## CONCLUSIONS

This study quantifies veterinary drug and antibiotic costs in Hungarian dairy herds and identifies drivers of high use. Most expenditures were for antibiotics, followed by hormones and vaccines. The main cost-driving health problems were udder diseases, reproductive failures, lameness and respiratory and digestive diseases, consistent with previous Hungarian and international studies. Among antibiotics, cephalosporins (primarily ceftiofur, cefquinome, cefapirin, cefoperazone) and fluoroquinolones (enrofloxacin, marbofloxacin) accounted for the highest costs. Because these classes are critical in human medicine, coordinated, ongoing antimicrobial stewardship is essential.

Hungary is among countries with high antibiotic use in dairy farming. Reductions would require sustained veterinary oversight and a proactive, prevention-focused herd-health strategy, regular veterinary consultations, farmer training in best practices, strengthened biosecurity and standardized protocols, along with appropriate antimicrobial alternatives. Such measures can lower disease incidence and, consequently, reliance on antibiotics in large Hungarian dairy herds.

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*Author contributions:* LÓ: conceptualization, methodology, validation, investigation, resources, writing - original draft preparation, writing - review and editing, supervision, project administration, funding acquisition. AD: conceptualization, validation, investigation, writing - review and editing. MM: conceptualisation, methodology, validation, formal analysis, data curation, writing - original draft preparation, writing - review and editing, visualization. All authors have read and agreed to the published version of the manuscript.

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