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# Associations between animal health indicators, antimicrobial use, and antimicrobial resistance on Swiss dairy farms

**Inaugural-Dissertation**

zur Erlangung des Doktortitels der
Vetsuisse-Fakultät, Universität Bern

vorgelegt von

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Tierarzt
von Erlenbach im Simmental, Bern

**2025**

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UNIVERSITY OF BERN

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Vetsuisse Faculty University of Bern 2025

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## Associations between animal health indicators, antimicrobial use, and antimicrobial resistance on Swiss dairy farms

Farm animal health and welfare have been ongoing concerns for farmers, consumers, and society for a long time. Antimicrobial resistance (AMR) and its relationship with antimicrobial use (AMU) have been identified as global public health challenges. A set of established health and welfare indicators (HWI) for dairy cows and the increasing availability of detailed farm-level AMU data enabled us to carry out this study with the objectives to (i) investigate the relationship between HWI and farm-level AMU, (ii) capture the current situation of AMR in dairy cows and calves on the study farms, and (iii) identify associations between AMR presence, AMU, and management practices in Swiss dairy farms. HWI were assessed on all study farms and current farm AMU was quantified using antimicrobial prescription data. Associations between lower AMU and good health and welfare were found for overall farm health and welfare and for several individual HWI. Pooled fecal samples were used to assess the presence of AMR in the study farms. No significant associations were observed between AMU and the presence of AMR. The results of this study may help to understand how AMU is related to HWI in dairy cows and support monitoring and benchmarking efforts to reduce AMU while maintaining high levels of cow health and welfare. Further research on a larger scale is needed to obtain more generalizable results and to further investigate the complex and multifactorial relationship between AMU and AMR.

**Keywords**
Dairy cows, Antimicrobial use, Antimicrobial resistance, Animal health, Animal welfare

University of Bern | University of Zurich vetsuisse-faculty

Bern, 10.10.2025

Place, date

Signature, Gertraud Schüpbach

Bern, 10.10.2025

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**Zusammenfassung/Abstract in Deutsch**

Vetsuisse-Fakultät Universität Bern 2025

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**Zusammenhang zwischen Tiergesundheitsindikatoren, Antibiotikaverbrauch und Antibiotikaresistenzen bei Schweizer Milchviehbetrieben**

Die Gesundheit von Nutztieren ist jeher ein wichtiges Anliegen von Landwirtschaft, Konsumierenden und unserer Gesellschaft. Antibiotikaresistenzen (AR) und deren Zusammenhang mit dem Antibiotikaverbrauch (ABV) wurden als globale Herausforderungen für die öffentliche Gesundheit identifiziert. Etablierte Tiergesundheitsindikatoren (TGI) für Milchkühe und die zunehmende Verfügbarkeit von ABV-Daten ermöglichten die Durchführung dieser Studie mit den Zielen: (i) Zusammenhänge zwischen TGI und ABV zu untersuchen, (ii) die AR-Lage der Studienbetriebe zu erfassen und (iii) Zusammenhänge zwischen AR, ABV und Managementfaktoren zu identifizieren. Auf allen Studienbetrieben wurden die TGI erhoben und der aktuelle ABV wurde anhand von Antibiotika-Verschreibungsdaten quantifiziert. Zusammenhänge zwischen tiefem ABV und guter Tiergesundheit wurden für die Gesamtbeurteilung der Betriebe sowie für einzelne TGI gefunden. Sammelkotproben wurden entnommen, um die AR-Lage der Betriebe zu beurteilen. Es wurden keine signifikanten Zusammenhänge zwischen ABV und dem Auftreten von AR beobachtet. Die Ergebnisse dieser Studie können: (i) dazu beitragen, den Zusammenhang zwischen ABV und TGI bei Milchkühen zu verstehen und (ii) Monitoring und Benchmarking zur Reduktion des ABV bei gleichbleibendem Tiergesundheitsniveau unterstützen. Grössere Studien sind nötig, um besser generalisierbare Resultate zu erhalten und um komplexe und multifaktorielle Zusammenhänge zwischen ABV und AR weiter zu untersuchen.

**Keywords**
Milchkühe, Antibiotikaverbrauch, Antibiotikaresistenzen, Tiergesundheit, Tierwohl

Bern, 10.10.2025

Ort, Datum

Unterschrift, Gertraud Schüpbach

Bern, 10.10.2025

Ort, Datum

Unterschrift, Beat Thomann

# Publikationsmanuskript:

Nachfolgend das Publikationsmanuskript:
Adrian Minnig, Véronique Bernier Gosselin, Silja Griss, Gertraud Schüpbach-Regula, Mireille Meylan, Guy-Alain Schnidrig, Beat Thomann,
Associations between animal health indicators, antimicrobial use, and antimicrobial resistance on Swiss dairy farms,
Preventive Veterinary Medicine,
Volume 245,
2025,
106688,
ISSN 0167-5877,
https://doi.org/10.1016/j.prevetmed.2025.106688.

Preventive Veterinary Medicine 245 (2025) 106688

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

# Associations between animal health indicators, antimicrobial use, and antimicrobial resistance on Swiss dairy farms

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ARTICLE INFO

*Keywords:*
Dairy cows
Cattle
Animal health
Animal welfare
Switzerland
Management practices

ABSTRACT

Farm animal health and welfare have been ongoing concerns for farmers, consumers, and society for a long time. Antimicrobial resistance (AMR) and its relationship with antimicrobial use (AMU) have been identified as global public health challenges. A set of established health and welfare indicators (HWI) for dairy cows and the increasing availability of detailed farm-level AMU data enabled us to carry out this study with the objectives to (i) investigate the relationship between HWI and farm-level AMU, (ii) capture the current situation of AMR in dairy cows and calves on the study farms, and (iii) identify associations between AMR presence, AMU, and management practices in Swiss dairy farms. High AMU farms ($n = 22$) and low AMU farms ($n = 28$) were recruited based on prescription records in the national AMU database. Current farm AMU was assessed quantitatively using an animal treatment index (ATI) based on antimicrobial prescription data. A combination of animal-based and data-based health indicators were assessed on all study farms and used to form a total health and welfare score (HWS). Associations between lower ATI and good health and welfare were found for the total HWS (estimate: −0.144, $p = 0.03$) and the partial score for HWI related to health (-0.111, $p = 0.01$). Several individual HWI (e.g. productive lifespan of cows, participation in animal welfare programs) were found to be significantly associated with either AMU group (high vs. low), ATI, or both. Pooled fecal samples were used to assess the presence of AMR in the study farms. Commensal *Escherichia coli* isolates from calves and cows were most commonly resistant to tetracyclines (36 % and 3 %, respectively), followed by penicillins (34 % and 1 %) and sulfonamides (32 % and 1 %). No significant associations were observed between AMU and the presence of AMR (overall and for specific antimicrobial classes) on the study farms. Several management practices reported by farm managers during interviews (e.g. feeding of waste milk with antimicrobial residues to calves) were significantly associated with AMU group and ATI, but none were associated with the presence of AMR. The results of this study may help to understand how AMU is related to HWI in dairy cows and support monitoring and benchmarking efforts to reduce AMU while maintaining high levels of cow health and welfare. Further research on a larger scale is needed to obtain more generalizable results and to further investigate the complex and multifactorial relationship between AMU and AMR.

## 1. Introduction

Health and welfare of farm animals have been ongoing concerns for farmers, consumers, and society at large for a long time. Especially in recent years, public awareness of farm animal welfare standards and sustainable livestock production has increased in the European Union and in Switzerland (EFSA, 2015; Richter et al., 2025). Despite the agricultural sectors' significant contribution to global greenhouse gas emissions (FAO, 2021), many consumers prioritize high welfare standards above environmentally friendly production (Ammann et al., 2024). Because there is no clear and broadly accepted legal definition of animal welfare (Linstädt et al., 2024), it is hard to quantify this concept in its full complexity. However, welfare of animals, including their health, can be assessed using different indicators (Fraser, 1995). Such

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https://doi.org/10.1016/j.prevetmed.2025.106688
Received 27 June 2025; Received in revised form 7 September 2025; Accepted 8 September 2025
Available online 9 September 2025

health and welfare indicators (HWI) in dairy cows can be animal-, resource- or management-based indicators assessed on-farm, or they can be data-based indicators calculated using routinely collected data. For Swiss dairy herds, Lutz et al. (2022) demonstrated that data-based HWI alone cannot fully reflect the welfare status of herds but can give insights into certain welfare aspects and complement indicators assessed on-farm.

Antimicrobial use (AMU) in livestock and the development of antimicrobial resistance (AMR) in bacteria in animals, humans and in the environment are major public health issues. High AMU and improper use of antimicrobials can contribute to the development and the spread of AMR (Caneschi et al., 2023; Loo et al., 2019). The burden of AMR threatens both animal and human health and welfare (Naghavi et al., 2024; Prestinaci et al., 2015), and is one of the most pressing health threats of the 21st century (The Lancet, 2024). It is therefore crucial to have adequate surveillance systems to monitor AMU and the emergence and spread of AMR. In Switzerland, a national antimicrobial reporting system ("Informationssystem Antibiotika in der Veterinärmedizin", IS ABV) was launched in 2019 (FSVO, 2020; Schnidrig et al., 2024). Since the introduction of IS ABV, all antimicrobial prescriptions must be recorded electronically, and veterinarians in Switzerland are required to transmit these records to a centralized database.

The availability of detailed prescription data can assist in identifying potential drivers of AMU and support guided interventions to reduce AMU (Köchle et al., 2024). It is important to note that a reduction in AMU should never be at the expense of a reduction in animal and human health and welfare standards. While the total amount of antimicrobials (kg of active substance) used in different Swiss livestock species has decreased or been stabilized in recent years, an increase in the amount of antimicrobials used and in the number of treatments per 1000 animals has been observed in dairy cows in all years since prescription data have been recorded (FSVO, 2024). Because of diverse housing and management conditions, a wide range of factors can affect the choice of antimicrobial substances, their dosages, and application routes in dairy farms. Farm characteristics, such as herd size (Köchle et al., 2024; Lardé et al., 2021), and management practices, including biosecurity, can affect farm-level AMU (Holstege et al., 2018; Uyama et al., 2022).

The relationship of dairy cow health and welfare with AMU remains largely unclear. For dairy cows in Switzerland, detailed data are available on animal movements, breeding, milk production, and slaughter. Given the availability of HWI evaluated for Swiss dairy farms and of detailed, reliable data on farm-level AMU, investigating associations between HWI and AMU could provide valuable insights into their relationship and help to better understand reasons for AMR emergence. The association of certain management practices with AMU in Swiss tie stalls has been investigated by Köchle et al. (2024), but there is a lack of knowledge on how these practices are associated with AMU and AMR on Swiss dairy farms independently of housing type.

The present study has therefore the objectives of assessing health and welfare in cows on Swiss dairy farms using established HWI, and to investigate their relationship to farm-level AMU. A further objective is to capture the current situation of AMR in dairy cows and calves on the study farms and to identify associations between presence of AMR, AMU, and management practices.

## 2. Material and methods

### 2.1. Study population

In this cross-sectional observational study, 50 dairy farms were recruited from farms registered in the IS ABV database. This sample size was calculated using the online application EpiTools (Sergeant, 2018) with an assumed prevalence of risk factors for high AMU of 30 % and an odds ratio of 5 (95 % confidence, 80 % power). Farm eligibility criteria were a yearly average herd size of at least 20 cows, regular delivery of commercial milk, and, preferably, membership in a breeding association. In total, 10'978 farms in Switzerland met these requirements. For this selection pool of farms, the Federal Food Safety and Veterinary Office (FSVO) provided anonymized and aggregated IS ABV prescription data from the year 2021. This was the latest complete annual AMU data available at the time of farm recruitment. Within IS ABV, antimicrobial prescriptions for livestock are entered as either treatment prescriptions (for single animals or a group of animals) or as antibiotics dispensed on stock (DoS). The latter represents a prescription category in which veterinarians in Switzerland can, under certain conditions, dispense antibiotics to farmers, who then apply the medications themselves (Schnidrig et al., 2024). Unlike treatment prescriptions, DoS prescriptions can only be entered at the species level (e.g. "cattle"), meaning that they cannot be attributed to dairy cows or other production types specifically. To reduce uncertainty in total dairy cow AMU possibly introduced by non-dairy cow specific DoS prescriptions, the 10 % of farms with the highest proportion of DoS prescriptions [total kg of active substance] out of all prescriptions [total kg of active substance] were excluded. Antimicrobial treatment prescriptions for dairy cows (parenteral, intramammary, and intrauterine application) were then used to calculate the farm specific animal treatment index (ATI, Equation 1). DoS prescriptions were not included in ATI calculations because information on the target production type, the number of animals treated, and the dosage are not available for this prescription type. Farms were ranked according to their ATI for dairy cows (in the year 2021) and categorized as high AMU (1000 farms with the highest ATI) and low AMU (2000 farms with the lowest ATI) farms. The category of low AMU farms consisted of 1000 farms with the lowest ATI, which was still larger than zero, and 1000 zero AMU farms (ATI of zero and zero DoS prescriptions), randomly selected out of all 1813 zero AMU farms within the farm selection pool.

Equation 1: Calculation of animal treatment index (ATI) to quantify AMU for dairy cows at farm level using antimicrobial treatment prescriptions.

$$ATI = \Sigma \frac{no.\, of animals treated \times no.\, of\, active\, substances \times no\, of\, treatment\, days}{no.\, of animals\, in\, herd\, or\, in\, group} \quad (1)$$

Because the farm addresses and AMU data were confidential, it was not possible for the research team to contact the farmers directly. Therefore, the FSVO contacted a total of 2948 farmers (n = 1952 low AMU and n = 996 high AMU farms) once by email in December 2022, and provided them with basic information about the study. Farmers willing to participate provided their contact information using the online survey tool "LimeSurvey" (Limesurvey GmbH, 2023). In total, 23 high AMU farm managers and 78 low AMU farm managers responded to this call (n = 101 responses in total, response rate of 3.4 %). Because one high AMU farm manager decided not to participate in this study after receiving further information, only 22 high AMU farms were recruited. Based on the total target number of 50 farms, the 28 low AMU farms were selected to match the geographical distribution of the high AMU farms as closely as possible. Owners of these 50 farms (n = 22 high AMU and 28 low AMU farms) were contacted by phone to give further information on the study and to arrange on-farm visits for data collection.

### 2.2. Health and welfare indicator set

In the frame of the "Smart Animal Health" research project, health and welfare assessment in different Swiss livestock species and possible health and welfare benchmarking methods for farms were described (Lutz et al., 2022; Thomann et al., 2023). A HWI-set combining on-farm indicators originating from the WelfareQuality® project of the European Union (de Graaf et al., 2017; Knierim and Winckler, 2009; WelfareQuality®, 2016) and data-based indicators from routinely collected data in Switzerland was developed within the Smart Animal Health project. For some on-farm indicators, the methods detailed in the

WelfareQuality® assessment protocol for dairy cows were slightly modified to adapt them to the conditions of dairy farming in Switzerland. In this country-specific approach, indicators were divided into the four categories of (1) health; (2) husbandry and nutrition; (3) appropriate behaviour; and (4) freedom from pain, suffering, harm and anxiety as outlined in the Swiss Animal Welfare Act (Federal Assembly of the Swiss Confederation, 2005). The final indicator set used for this study, consisting of 13 on-farm indicators and 12 data-based indicators, is shown in Table 1.

### 2.3. Farm visits and data collection

#### 2.3.1. Assessment training and tools used

All study farms were visited by one of two veterinarians employed at the *anonymized* Institute, University of *anonymized*. To standardize on-farm indicator scoring, training sessions in person and online were performed by both assessors. Inter-observer agreement was tested for multiple HWI using reference images available from an online animal health and welfare assessment training tool (BOKU, 2025). The resulting weighted kappa values indicated moderate to strong agreement (McHugh, 2012) between the two assessors. One mock farm visit was conducted prior to the actual data collection period to further improve agreement. A digital assessment tool based on a LimeSurvey questionnaire (Limesurvey GmbH, 2023) was created and used by both assessors. This tool contained reference images from the WelfareQuality® project as a guidance for scoring on-farm indicators and was implemented into the App "Offline Surveys" (Offline Surveys App, 2022) to enable offline use.

#### 2.3.2. Farm visits and data acquisition

The 50 study farms were visited by assessor 1 (first author, n = 39 farm visits) or assessor 2 (third author, n = 11 farm visits) between February and September 2023. Visits were carried out between morning milking and evening milking, and took between 1.5 and 3 h of time depending on farm size and local infrastructure. All on-farm indicators were assessed on lactating dairy cows, dry cows housed together with the dairy cows, and close-up pregnant heifers housed together with the dairy cows. On farms with ≤ 30 dairy cows present during a visit, all dairy cows were scored, while on larger farms (> 30 dairy cows present) on-farm indicators were assessed for a random sample of 30 dairy cows representative of the whole herd (systematic sampling of every $x^{th}$ cow, with x corresponding to the total number of animals divided by 30). Detailed assessment methods for specific indicators can be found in Supplementary Table 1.

After all indicators were assessed, a questionnaire on management practices potentially associated with AMU was filled out with the farm manager. The questionnaire was divided into the sections general information about the farm, information on all livestock present, health management practices, management of calves, internal and external biosecurity, and AMU.

A combination of public data (content and access regulated under public law) and private data (owned by farmers and/or private organizations such as breeding associations) was used to calculate data-based indicators. All data necessary for indicator calculations were recorded between January 1st 2020 and December 31st 2023. Animal movement data, records of births and deaths of all cattle, and official milk testing data were provided by the FSVO. Breeding associations provided data on milk yield, fat yield, protein yield, and individual animal somatic cell counts (SCC). Because four farm managers were not members of a breeding association, no data to calculate the indicators "Proportion of cows with SCC > 150'000 cells/ml", "Proportion of cows with fat to protein ratio > 1.5", and "Proportion of cows with fat to protein ratio < 1" were available. These four farms were still included in the study because they were categorized as high AMU farms and no equivalent replacement farms were available.

#### 2.3.3. Health and welfare indicator scoring

Health and welfare were quantified at the level of individual indicator scores, partial scores (pHWS, i.e. scores per category according to the four categories described above (i.e. health, husbandry and nutrition, appropriate behaviour, and freedom from pain, suffering, harm and anxiety), and a total health and welfare score (HWS). Indicator-specific threshold values were used to build these scores. Threshold values consist of a "target value" and an "alarm value" as they are used in health and welfare self-assessment in Germany (KTBL, 2020). For each indicator, a farm could score one, two, or three points depending on their result in relation to the indicator-specific threshold values. The resulting pHWS represent the summary score over all indicators in each category, in proportion to the maximum score reached, considering that even for the worst possible score, a minimum of 1 point per indicator is attributed (Equation 2). The same principle applies for HWS which represents the total score over all indicators from the four categories. The concept of target and alarm value scoring is illustrated in Fig. 1. The target value does not necessarily represent an optimal state, but reflects the fact that results better than the target value (target zone) suggest the absence of problems in animal health and welfare for this indicator. Indicator results worse than the alarm value (alarm zone) signal health and welfare issues and a need for action regarding the specific indicator. Results between target and alarm values (early warning zone) mean that the respective HWI-aspects should be monitored closely. Detailed methodology on HWI selection (based on multicollinearity analysis, on-farm feasibility and expert feedback) and the setting of target and alarm values (expert elicitation using a modified Delphi method (Stebler et al., 2015)) was part of a related project and will be published in separate publications.

Equation 2: Calculation of partial- and total health and welfare score, (p)HWS. The minimum achievable score (all indicator results worse than alarm value) corresponds to the number of indicators used for calculation multiplied by 1 point. The maximum achievable score (all indicator results better than target value) corresponds to the number of indicators used for calculation multiplied by 3 points.

$$(p)HWS[\%] = \frac{(\Sigma\ all\ single\ indicator\ scores) - minimum\ achievable\ score}{maximum\ achievable\ score - minimum\ achievable\ score} \times 100 \quad (2)$$

#### 2.3.4. AMU data

The antimicrobial prescription data of all study farms were provided by the FSVO with written informed consent from farm managers and their respective farm veterinarians. Data included cattle treatment prescriptions and DoS prescriptions administered and recorded by the farm veterinarian during the time period of January 1st 2020 until December 31st 2023. The unprocessed prescription data in IS ABV may contain implausible entries due to input errors, inaccuracies or faulty data transmission. Prescriptions containing such anomalies were removed by the FSVO using the methods described by Schnidrig et al. (2024). For the purpose of the present study, AMU was quantified using high and low AMU farms and the Switzerland-specific ATI. This count-based unitless AMU metric indicates the average number of antimicrobial treatment-days per year an animal received (FSVO, 2025). It was calculated across all antimicrobial classes using dairy cow treatment prescriptions (independent of application route) according to Equation 1. A dairy farm ATI value of five for example could be interpreted to mean that each dairy cow on a farm was treated with one antimicrobial agent for five days within a one-year period. ATI values were calculated for the years 2021, 2022, and 2023. For combination antimicrobial formulations, including formulations containing sulfonamides and trimethoprim, respective antimicrobial agents were considered as separate active substances when calculating ATI. Aggregated prescription data provided by the FSVO were used to calculate a simplified ATI (sATI) for each antimicrobial class. In contrast to total ATI, this sATI is

**Table 1**
Health and welfare indicators (HWI) assessed on the 50 study farms in 2023. HWI are divided into the four categories of health (n = 11 HWI), husbandry and nutrition (n = 7 HWI), appropriate behaviour (n = 3 HWI), and freedom from pain, suffering, harm, and anxiety (n = 4 HWI). Unless stated otherwise, data-based indicators were calculated for a time period starting 365 days before the day of the farm visit. More detailed information on indicator assessment and calculations can be found in Supplementary Table 1.

| No. | Category | Health and Welfare Indicator | Indicator type | Definition |
|---|---|---|---|---|
| 1 | Health | Cow mortality rate | Data-based | $\frac{\textit{no. of dairy cow deaths}}{\textit{average yearly dairy cow herd size}} \times 100$ |
| 2 | Health | Peri- and postnatal calf mortality rate of primiparous cows | Data-based | $\frac{\textit{no. of stillbirths and calf deaths within the first 48h post partum of calves born from primiparous dairy cows}}{\textit{total no. of calves born from primiparous dairy cows}} \times 100$ |
| 3 | Health | Peri- and postnatal calf mortality rate of multiparous cows | Data-based | $\frac{\textit{no. of stillbirths and calf deaths within the first 48h post partum of calves born from multiparous dairy cows}}{\textit{total no. of calves born from multiparous dairy cows}} \times 100$ |
| 4 | Health | Culling rate within 150d after calving (involuntary departures) | Data-based | $\frac{\textit{no. of dairy cows which died, were euthanized, or slaughtered within the first 150d post partum}}{\textit{average yearly dairy cow herd size}} \times 100$ |
| 5 | Health | Productive lifespan of culled cows [days] | Data-based | Average productive lifespan (first calving until death) of dairy cows which died, were euthanized or slaughtered [days] |
| 6 | Health | Proportion of cows with calving interval over 430d | Data-based | $\frac{\textit{no. of dairy cows with a calving interval} > 430 \textit{ days}}{\textit{no. of dairy cows with a calculable calving interval}} \times 100$ |
| 7 | Health | Mean bulk tank milk somatic cell count (BTSCC) [cells / ml] | Data-based | Mean bulk tank milk somatic cell count of the last 13 monthly measurements prior to the farm visit (official milk testing) [cells / ml] |
| 8 | Health | Proportion of cows with SCC > 150'000 cells/ml | Data-based | $\frac{\textit{no. of dairy cow individual somatic cell count measurements} > 150'000 \textit{ cells/ml}}{\textit{total no. of dairy cow individual somatic cell count measurements}} \times 100$ |
| 9 | Health | Proportion of cows with fat to protein ratio > 1.5 | Data-based | $\frac{\textit{no. of dairy cows with a fat to protein ratio} > 1.5 \textit{ within 60d post partum}}{\textit{no. of dairy cows with calculable fat to protein ratio within 60d post partum}} \times 100$ |
| 10 | Health | Proportion of cows with fat to protein ratio < 1.0 | Data-based | $\frac{\textit{no. of dairy cows with a fat to protein ratio} < 1.0 \textit{ within 60d post partum}}{\textit{no. of dairy cows with calculable fat to protein ratio within 60d post partum}} \times 100$ |
| 11 | Health | Proportion of cows with signs of lameness | On-farm | $\frac{\textit{no. of dairy cows showing any sign of lameness}}{\textit{no. of dairy cows assessed during farm visit}} \times 100$ |
| 12 | Husbandry and Nutrition | Participation in BTS (animal welfare program for good housing) | Data-based | For dairy cows, the BTS program ("Besonders tierfreundliche Stallhaltungssysteme") provides financial incentives for loose housing systems with a comfortable lying area separated from the feeding area (Federal Assembly of the Swiss Confederation, 2013; Odermatt et al., 2019). |
| 13 | Husbandry and Nutrition | Participation in RAUS (animal welfare program for outdoor access / pasture) | Data-based | For dairy cows, the RAUS program ("Regelmässiger Auslauf im Freien") provides financial incentives for providing cows with regular exercise in an outdoor run in the winter and in a pasture during summer (Federal Assembly of the Swiss Confederation, 2013; Odermatt et al., 2019). |
| 14 | Husbandry and Nutrition | Proportion of too lean cows | On-farm | $\frac{\textit{no. of dairy cows with a body condition score} \leq 2.25}{\textit{no. of dairy cows assessed during farm visit}} \times 100$ |
| 15 | Husbandry and Nutrition | Cleanliness of upper legs and flanks | On-farm | $\frac{\textit{no. of dairy cows with dirty upper hind legs and/or dirty flanks}}{\textit{no. of dairy cows assessed during farm visit}} \times 100$ |
| 16 | Husbandry and Nutrition | Cleanliness of udder and teats [% of herd] | On-farm | $\frac{\textit{no. of dairy cows with dirty udders and/or teats}}{\textit{no. of dairy cows assessed during farm visit}} \times 100$ |
| 17 | Husbandry and Nutrition | Cleanliness of drinkers | On-farm | Inspection of all drinkers available to dairy cows and overall assessment of cleanliness of these drinkers (clean or partially dirty vs. dirty) |
| 18 | Husbandry and Nutrition | Number of cows per drinker | On-farm | $\frac{\textit{no. of dairy cows present during farm visit}}{\textit{no. of functioning drinkers available to dairy cows}} \times 100$ |
| 19 | Appropriate Behaviour | Proportion of cows with avoidance distance > 1 m | On-farm | Proportion of dairy cows showing an avoidance reaction at > 1 m distance when being locked in the feeding rack and approached from the front in a standardized way by the assessor. |
| 20 | Appropriate Behaviour | Displacement rate (agonistic interactions) | On-farm | No. of displacements (one cow displacing another cow) observed during observation of the herd from outside the pen (standardized per hour and 30 cows) |
| 21 | Appropriate Behaviour | Head butt rate (agonistic interactions) | On-farm | No. of head butts (one cow hitting another cow) observed during observation of the herd from outside the pen (standardized per hour and 30 cows) |
| 22 | Freedom from Pain, Suffering, Harm, and Anxiety | Qualitative behaviour assessment (QBA) "calm" [% of herd] | On-farm | QBA considers the expressive quality of how animals behave and interact with each other and the environment i.e. their "body language" (WelfareQuality®, 2016)<br>For the term "calm", the assessor observes the herd from outside the pen and judges the expressive quality of the term from 0 % (entirely absent) to 100 % (dominant across all observed cows) |
| 23 | Freedom from Pain, Suffering, Harm, and Anxiety | Qualitative behaviour assessment (QBA) "playful" [% of herd] | On-farm | For the term "playful", the assessor observes the herd from outside the pen and judges the expressive quality of the term from 0 % (entirely absent) to 100 % (dominant across all observed cows) |
| 24 | Freedom from Pain, Suffering, Harm, and Anxiety | Qualitative behaviour assessment (QBA) "fearful" [% of herd] | On-farm | For the term "fearful", the assessor observes the herd from outside the pen and judges the expressive quality of the term from 0 % (entirely absent) to 100 % (dominant across all observed cows) |
| 25 | Freedom from Pain, Suffering, Harm, and Anxiety | Qualitative behaviour assessment (QBA) "uneasy" [% of herd] | On-farm | For the term "uneasy", the assessor observes the herd from outside the pen and judges the expressive quality of the term from 0 % (entirely absent) to 100 % (dominant across all observed cows) |

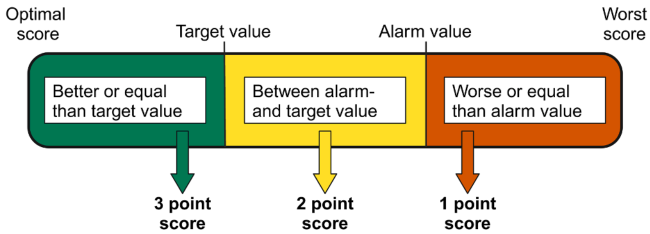


**Fig. 1.** Illustration of the threshold value concept using defined target and alarm values to classify single health and welfare indicator results and attribute a score of 1, 2, or 3 points per indicator.

calculated without the factor of treatment days per antimicrobial class (Equation 3). This factor was not available on the level of specific antimicrobial classes in the AMU data obtained.

Equation 3: Calculation of simplified animal treatment index (sATI) to quantify AMU for dairy cows per antimicrobial class using antimicrobial treatment prescriptions.

$$sATI = \Sigma \frac{no.\ of\ animals\ treated \times no.\ of\ ative\ substances}{no.\ of\ animals\ in\ herd\ or\ in\ group} \quad (3)$$

#### 2.3.5. Fecal sampling and determination of AMR

To assess the current situation of AMR on the study farms, pooled fecal samples were taken on the 50 farms. Three pooled fecal samples from dairy cows (five cows each) and one pooled fecal sample from five pre-weaning calves were taken rectally from randomly chosen (every $x^{th}$) animals. Animals currently under antimicrobial treatment or those with signs of diarrhea were not sampled. Approximately equal amounts of feces from each sampled animal were placed into 50 ml conical centrifuge tubes. This resulted in a total of four pooled samples per farm and 200 samples in total. Samples were kept cool until same-day transport to the veterinary diagnostic laboratory LaboRvet AG. Samples were inoculated on *Enterobacterales*-selective medium (MacConkey Agar No. 3, Thermo Fisher Scientific). One isolate per plate was selected, regrown in pure culture, and species identification was confirmed by MALDI-ToF mass spectrometry. The Broth microdilution method on Sensititre™ EUVSEC3 plates (Thermo Fisher Scientific) was used for antimicrobial susceptibility testing of isolates. Minimal inhibitory concentrations (MIC) of isolates were compared to epidemiological cut-off (ECOFF) values obtained from the MIC distribution website of the European Committee on Antimicrobial Susceptibility Testing (MIC EUCAST, 2025) to classify isolates as susceptible or resistant. Isolates without phenotypically detectable acquired resistance mechanisms (wild type) according to EUCAST guidelines will be referred to as "susceptible" in this article, while non-wild type isolates with these mechanisms will be referred to as "resistant". For azithromycin, the tentative ECOFF value (based on $< 5$ distributions) on the EUCAST MIC distribution website was used because no ECOFF value based on more distributions was available. For sulfamethoxazole, the cut-off value from the manual of reporting antimicrobial resistance data (EFSA et al., 2024) was used because no ECOFF value was available in the EUCAST database. Antimicrobial active substances were categorized into antimicrobial classes throughout this paper. Sulfonamides and trimethoprim were considered as separate antimicrobial classes and the same applied to tetracyclines and tigecyclines. Nalidixic acid and ciprofloxacin were categorized as belonging to the class of quinolones. Quinolones, 3rd and higher generation cephalosporins, macrolides and ketolides, glycopeptides, and polymyxins were defined as "Highest Priority Critically Important Antimicrobials" (HPCIA) according to the classification of the World Health Organization (WHO, 2019). "HPCIA resistant" is defined in this paper as an isolate being resistant to at least one antimicrobial active substance of the classes belonging to the HPCIA. "Multidrug resistance" (MDR) is defined in this paper as an isolate being resistant to at least three different antimicrobial classes. The occurrence of AMR at farm level is defined in this paper as at least one *E. coli* isolate from either of the age groups on a farm being resistant to at least one antimicrobial active substance tested. Farm-level AMR is further differentiated in this paper into AMR against an active substance from any antimicrobial class (AMR combined) and AMR against an active substance belonging to a specific antimicrobial class.

### 2.4. Data preparation and analysis

Data were cleaned, analyzed and visualized using R (R, version 4.3.3, 2023) with RStudio (RStudio, version 2024.09.1, 2024). On-farm HWI were calculated using data assessed during farm visits. Data-based HWI were calculated for a time period starting 365 days before the day of the farm visit. For HWI recorded monthly, such as bulk tank somatic cell count (BTSCC) from official milk testing, the last 13 recorded measurements prior to the farm visit were used for indicator calculations. More detailed information on how each HWI was calculated is available in Supplementary Table 1. In two farms, one data-based HWI could not be calculated. For one farm, no cows had died, were euthanized or slaughtered during the time period used to calculate the indicator "productive lifespan of culled cows". For another farm, no official milk testing results were available to calculate the indicator "BTSCC". For both values, the farmers' estimations recorded in the management practices questionnaire were used to replace these missing values. Productive lifespan of culled cows and BTSCC were standardized with a z-transformation. Missing values due to four farms not being members of a breeding association were imputed using the median values from all study farms.

Logistic regression models were used to investigate the relationship between the outcome variable of AMU group (high and low AMU farms) and independent variables. For the outcome variable of ATI, an ordinary linear regression model did not provide a reasonable model fit when residuals were visually inspected on a quantile-quantile plot and results from the Shapiro-Wilk normality test were considered ($W = 0.85$, $p < 0.001$). Instead, a generalized linear regression model with a gamma distribution and the identity link function was chosen for the outcome variable of ATI. The ATI was transformed by adding a constant value of 1 to each observation to avoid problems related to calculations with values of 0. Distribution fit was assessed visually using multiple goodness of fit plots from the fitdistrplus package (Delignette-Muller and Dutang, 2015) and with a Kolgomorov-Smirnov test ($p = 0.37$), both indicating a good fit of the gamma distribution to the variable ATI. Independent variables tested in the univariable logistic regression models and in the univariable generalized linear regression models were HWS, pHWS, single indicator results, AMR presence in any antimicrobial class, and management practices. Additional univariable logistic regression models were used to find associations between the presence of AMR per antimicrobial class (outcomes) and the respective sATI per antimicrobial class. No over- or underdispersion was detected in any of the binomial models when considering dispersion ratios and estimations of overdispersion parameters calculated using the performance package (Lüdecke et al., 2021). Fig. 2 gives an overview of all relationships investigated and the different levels of analyses.

## 3. Results

### 3.1. Farm characteristics and management practices

The 50 study farms were located in 13 of the 26 Swiss cantons (8 farms in the French-speaking and 42 in the German-speaking part of Switzerland). Dairy cows were housed in tie stalls and free stalls on 9

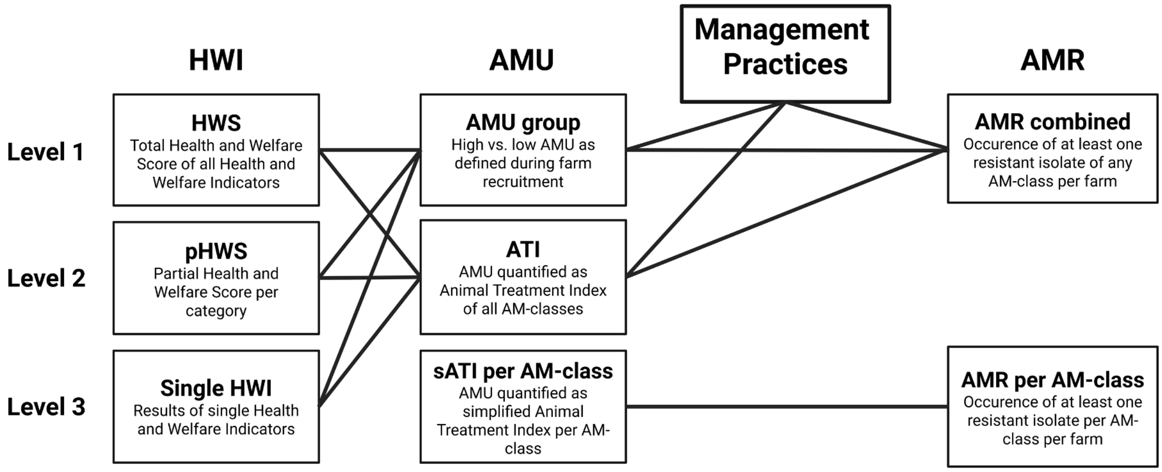


**Fig. 2.** Overview of the three main interest fields of this study, health and welfare indicators (HWI), antimicrobial use (AMU), and antimicrobial resistance (AMR) with their different levels of analyses. Lines connecting the levels represent investigated relationships between HWI and AMU, and AMU, AMR, and management practices. (AM-class, antimicrobial class).

and 41 farms, respectively. The average herd size was 36 (range: 21 – 69) in high AMU farms and 37 (range: 20 – 94) in low AMU farms. Twenty-eight farms kept a single breed of dairy cows and 22 farms had mixed dairy cow herds. The most common breeds were Holstein Friesian, Swiss Fleckvieh, and Brown Swiss kept on 60 %, 44 %, and 22 % of farms, respectively. Conventional farming and integrated production (IP)-Suisse were the most prevalent production types (32 % and 30 %, respectively), followed by farms delivering milk to cheese factories (no feeding of preserved silage, 20 %), organic farms (14 %), and farms with other production labels (4 %). Livestock other than cattle was kept on 72 % of study farms. Poultry (36 %), pigs (26 %), and small ruminants (24 %) were the most common species, and 24 % of farms kept other animals including equids, bees, and New World camelids. Herd average yearly milk yield per cow was 7842 kg (range: 3928–10432 kg). Farm characteristics were similar in both high and low AMU groups. Descriptive results on management practices from the questionnaire are shown in Table 2.

### 3.2. Health and welfare

The average total health and welfare score of all study farms was 67 % (range: 50–84 %). Per category, average partial scores were 66 % (range: 27–91 %) for health, 73 % (range: 50–100 %) for husbandry and nutrition, 80 % (range: 33–100 %) for appropriate behaviour, and 53 % (range: 12–88 %) for freedom from pain, suffering, harm, and anxiety. Results of single health and welfare indicators (HWI) are presented in Table 3. Among all farms, 52 % of HWI lie in the target zone (better than target value), 32 % in the early warning zone (between target and alarm value) and 16 % in the alarm zone (worse than alarm value) (Fig. 3). Indicators with the best results in terms of health and welfare were participation in the animal welfare program RAUS (98 % of farms), cleanliness of drinkers (96 % of results within the target zone) and heat butt rate (84 % of results within the target zone). The highest frequency of results in the alarm zone was found for the HWI cleanliness of udder and teats (40 %), proportion of cows with calving interval over 430 days (34 %), productive lifespan of culled cows, and proportion of uneasy cows in Qualitative Behaviour Assessment (QBA) (both 28 %). The distribution of results from all HWI within the target zone, early warning zone, and alarm zone by AMU group are shown in Fig. 3.

### 3.3. AMU

Farm-level median ATI for all 50 study farms during the years 2021, 2022, and 2023 were 0.55 (interquartile range $Q_1$ – $Q_3$ (IQR): 0.15 – 6.66), 1.68 (IQR: 0.34 – 4.38), and 2.6 (IQR: 1.08 – 5.45) respectively. Because of the method used for farm recruitment, average ATI in high vs. low AMU farms was noticeably different for the year of 2021 (7.44 (range: 5.13 – 11.80) vs. 0.25 (range: 0.00 – 0.96), respectively). This difference in ATI was also observed for the following years, albeit to a lesser extent (2022: 5.42 (range: 1.88 – 16.81) vs. 0.69 (0.00 – 2.35); 2023: 7.00 (range: 1.26 – 20.77) vs. 1.59 (0.00 – 7.58)). Within this three-year period, 13 farms in the low AMU group had at least one year without any antimicrobial treatment prescription (ATI = 0). No farm had an ATI of zero in more than two years, meaning that at least one treatment prescription was recorded on all farms during the three-year period. The most common causes for antimicrobial treatment stated by farmers during qualitative interviews were mastitis treatment and dry-off therapy (74 %), urogenital and fertility disorders (14 %), disorders of the musculoskeletal system (8 %), and others (4 %).

### 3.4. AMR

Out of all 200 commensal *E. coli* isolates from fecal samples collected on study farms, 26 (13 %) were resistant to at least one tested drug. The proportion of isolates resistant to at least one drug was significantly higher in pre-weaning calves (40 %) than in cows (4 %) (logistic regression estimate for cows: $-2.773$, $p < 0.01$). Multidrug resistance and resistance against HPCIA were found in 17 (8.5 %) and six (3 %) isolates, respectively. Descriptive results from AMR testing for both age groups are shown in Table 4. Isolates from calves and cows were most commonly resistant to tetracycline (tetracyclines, 36 % and 3 %), followed by ampicillin (penicillins, 34 % and 1 %) and sulfamethoxazole (sulfonamides, 32 % and 1 %). Results for all 15 tested antimicrobials for both age groups are presented in Fig. 4. At the farm level, at least one resistant isolate was found on 22 farms (44 %). The 17 MDR isolates were found on 15 different farms (nine low AMU farms, six high AMU farms), and the six isolates resistant against HPCIA were found on six different farms (four low AMU farms, two high AMU farms).

**Table 2**
Results from the questionnaire on management practices conducted with farm managers of the 50 study farms in 2023.

| Management Practice | High AMU farms (n = 22) | Low AMU farms (n = 28) | All study farms (N = 50) |
|---|---|---|---|
| Milk pathogen detection before antimicrobial mastitis treatment during lactation [mean][a] | 93 % of cases | 68 % of cases | 79 % of cases |
| Antimicrobial dry-off therapy strategy | | | |
| Blanket dry cow treatment (BDCT) | 4/22 (18 %) | 3/28 (11 %) | 7/50 (14 %) |
| According to SCC[b] and milk pathogen detection results | 6/22 (27 %) | 7/28 (25 %) | 13/50 (26 %) |
| According to SCC only | 12/22 (55 %) | 9/28 (32 %) | 21/50 (42 %) |
| Never | 0/22 (0 %) | 9/28 (32 %) | 9/50 (18 %) |
| Proportion of cows (within-herd) with antimicrobial dry-off therapy [mean] | 50 % of cows | 28 % of cows | 38 % of cows |
| Use of teat sealers at drying-off (non-antimicrobial) | | | |
| Always | 4/22 (18 %) | 6/28 (21 %) | 10/50 (20 %) |
| Partially (based on SCC) | 8/22 (36 %) | 4/28 (14 %) | 12/50 (24 %) |
| Never | 10/22 (45 %) | 18/28 (64 %) | 28/50 (56 %) |
| Feeding of waste milk to calves[c] | | | |
| Yes | 14/22 (64 %) | 11/28 (39 %) | 25/50 (50 %) |
| No | 6/22 (27 %) | 17/28 (61 %) | 25/50 (50 %) |
| Mastitis vaccinations in dairy cows | | | |
| Yes | 1/22 (5 %) | 2/28 (7 %) | 3/50 (6 %) |
| No | 21/22 (95 %) | 26/28 (93 %) | 47/50 (94 %) |
| Presence of a calving box | | | |
| Yes, not used as sick cow box | 9/22 (41 %) | 16/28 (57 %) | 25/50 (50 %) |
| Yes, also used as sick cow box | 6/22 (27 %) | 11/28 (39 %) | 17/50 (34 %) |
| No | 7/22 (32 %) | 1/28 (4 %) | 8/50 (16 %) |
| Presence of a separate sick cow box | | | |
| Yes | 2/22 (9 %) | 7/28 (25 %) | 9 (18 %) |
| No | 20/22 (91 %) | 21/28 (75 %) | 41 (82 %) |
| Housing of newborn calves | | | |
| In individual hutches alone or with conspecific | 19/22 (86 %) | 17/28 (61 %) | 36/50 (72 %) |
| In group housing (> 2 calves) | 3/22 (14 %) | 11/28 (39 %) | 14/50 (28 %) |
| Availability of clean individual hutches for newborn calves | | | |
| Always a cleaned individual hutch available | 10/22 (45 %) | 12/28 (43 %) | 22/50 (44 %) |
| Not always a cleaned individual hutch available | 9/22 (41 %) | 5/28 (18 %) | 14/50 (28 %) |
| No housing of calves in individual hutches | 3/22 (14 %) | 11/28 (39 %) | 14/50 (28 %) |
| Cleaning of individual hutches | | | |
| Only addition of fresh straw bedding | 1/22 (5 %) | 2/28 (7 %) | 3/50 (6 %) |
| Mucking out only | 7/22 (32 %) | 5/28 (18 %) | 12/50 (24 %) |
| Mucking out and cleaning with pressure washer | 11/22 (50 %) | 10/28 (36 %) | 21/50 (42 %) |
| No housing of calves in individual hutches | 3/22 (14 %) | 11/28 (39 %) | 14/50 (28 %) |
| Cleaning of calf group housing | | | |
| Less frequently than monthly | 10/22 (45 %) | 14/28 (50 %) | 24/50 (48 %) |
| Monthly or more frequently | 10/22 (45 %) | 8/28 (29 %) | 18/50 (36 %) |
| No group housing of calves | 2/22 (9 %) | 6/28 (21 %) | 8/50 (16 %) |
| Purchase of cattle | | | |
| Yes | 11/22 (50 %) | 16/28 (57 %) | 27/50 (54 %) |
| No | 11/22 (50 %) | 12/28 (43 %) | 23/50 (46 %) |
| Contact with cattle from other herds | | | |
| Youngstock (calves and / or heifers) of study farms reared externally | 9/22 (41 %) | 14/28 (50 %) | 23/50 (46 %) |
| Seasonal alpine pasture[d] | 13/22 (59 %) | 8/28 (29 %) | 21/50 (42 %) |
| Participation in dairy cow exhibitions | 3/22 (14 %) | 10/28 (36 %) | 13/50 (26 %) |
| None | 4/22 (18 %) | 4/28 (14 %) | 8/50 (16 %) |
| Specific order followed in daily work with cattle[e] | | | |
| Yes | 11/22 (50 %) | 8/28 (29 %) | 19/50 (38 %) |
| No | 11/22 (50 %) | 20/28 (71 %) | 31/50 (62 %) |
| Regular stock management by a veterinarian | | | |
| Yes | 6/22 (27 %) | 6/28 (21 %) | 12/50 (24 %) |
| No | 16/22 (73 %) | 22/28 (79 %) | 38/50 (76 %) |

[a] Intramammary and / or systemic treatment of subclinical mastitis cases
[b] SCC: Individual cow milk somatic cell count
[c] Feeding of milk containing antimicrobial residues within the treatment and / or withdrawal period
[d] Seasonal communal alpine pasturing of dairy cows and / or heifers
[e] Examples for a specific work order are from "clean" to "dirty" work or milking cows with high SCC last

### 3.5. Relationships between HWI and AMU

When investigating the relationship between dairy cow health and welfare and farm-level AMU, we found several significant associations in univariable analyses. Higher total HWS (estimate: −0.144, $p = 0.03$) and a higher pHWS health (-0.111, $p = 0.01$) were associated with lower ATI (ATI of farms in 2023) (Fig. 5). The four single HWI head butt rate (-0.301, $p = 0.004$), proportion of uneasy cows in QBA (0.168, $p = 0.01$), culling rate within 150d after calving (0.185, $p = 0.04$), and productive lifespan of culled cows (1.624, $p < 0.001$) were significantly associated with higher ATI. A trend for lower BTSCC (-0.734, $p = 0.1$) was found to be associated with higher ATI.

Regarding the relationship between HWI and AMU group (high vs. low AMU farms), no significant associations between total HWS or any

**Table 3**
Partial- and total health and welfare scores and single health and welfare indicator results of numeric (n = 22) and categorical (n = 3) indicators assessed on the 50 study farms in 2023. SD, standard deviation; Min, Minimum; Max, Maximum.

| Indicator No. | Total and Partial Scores, and Single HWI indicator results | Mean | SD | Median | Min | Max |
|---|---|---|---|---|---|---|
| | HWS (total score) | 67 | 8.7 | 68 | 50 | 84 |
| | pHWS health | 66 | 14 | 68 | 27 | 91 |
| | pHWS husbandry and nutrition | 73 | 14 | 71 | 50 | 100 |
| | pHWS appropriate behaviour | 80 | 18 | 83 | 33 | 100 |
| | pHWS freedom from pain, suffering, harm and anxiety | 53 | 18 | 50 | 12 | 88 |
| 1 | Cow mortality rate | 2.4 | 4.2 | 0 | 0 | 26 |
| 2 | Peri- and postnatal calf mortality rate of primiparous cows | 7 | 9.9 | 0 | 0 | 43 |
| 3 | Peri- and postnatal calf mortality rate of multiparous cows | 5 | 4.7 | 3.8 | 0 | 19 |
| 4 | Culling rate within 150d after calving (involuntary departures) | 9.3 | 7.7 | 8.2 | 0 | 36 |
| 5 | Productive lifespan of culled cows [mean, in days] | 1555 | 588 | 1498 | 620 | 3025 |
| 6 | Proportion of cows with calving interval over 430d | 19 | 16 | 15 | 0 | 72 |
| 7 | BTSCC [cells / ml] | 132'694 | 52'036 | 127'637 | 63'125 | 323'217 |
| 8 | Proportion of cows with SCC > 150'000 cells/ml[a] | 22 | 12 | 21 | 3.5 | 55 |
| 9 | Proportion of cows with fat to protein ratio > 1.5[a] | 11 | 6.8 | 12 | 0 | 29 |
| 10 | Proportion of cows with fat to protein ratio < 1.0[a] | 12 | 9.5 | 9 | 0 | 40 |
| 11 | Proportion of cows with signs of lameness | 3.7 | 4.1 | 3.5 | 0 | 13 |
| 14 | Proportion of too lean cows | 6 | 5.1 | 5.8 | 0 | 20 |
| 15 | Cleanliness of upper legs and flanks | 16 | 17 | 11 | 0 | 73 |
| 16 | Cleanliness of udder and teats | 16 | 11 | 16 | 0 | 53 |
| 18 | Number of cows per drinker | 11 | 7.1 | 10 | 2 | 35 |
| 19 | Proportion of cows with avoidance distance > 1 m | 4.7 | 11 | 0 | 0 | 67 |
| 20 | Displacement rate (agonistic interactions) | 5.5 | 4.3 | 5.9 | 0 | 18 |
| 21 | Head butt rate (agonistic interactions) | 2.3 | 2.7 | 2 | 0 | 14 |
| 22 | QBA "calm" | 80 | 10 | 83 | 58 | 97 |
| 23 | QBA "playful" | 54 | 20 | 58 | 0 | 97 |
| 24 | QBA "fearful" | 14 | 13 | 12 | 0 | 70 |
| 25 | QBA "uneasy" | 15 | 12 | 12 | 0 | 70 |
| 12 | BTS | | | | | |
| | Yes | 41/50 (82 %) | | | | |
| | No | 9/50 (18 %) | | | | |
| 13 | RAUS | | | | | |
| | Yes | 49/50 (98 %) | | | | |
| | No | 1/50 (2 %) | | | | |
| 17 | Cleanliness of drinkers | | | | | |
| | Clean | 48/50 (96 %) | | | | |
| | Dirty | 2/50 (4 %) | | | | |

[a] Based on 46 farm results only because breeding association data was not available from four farms

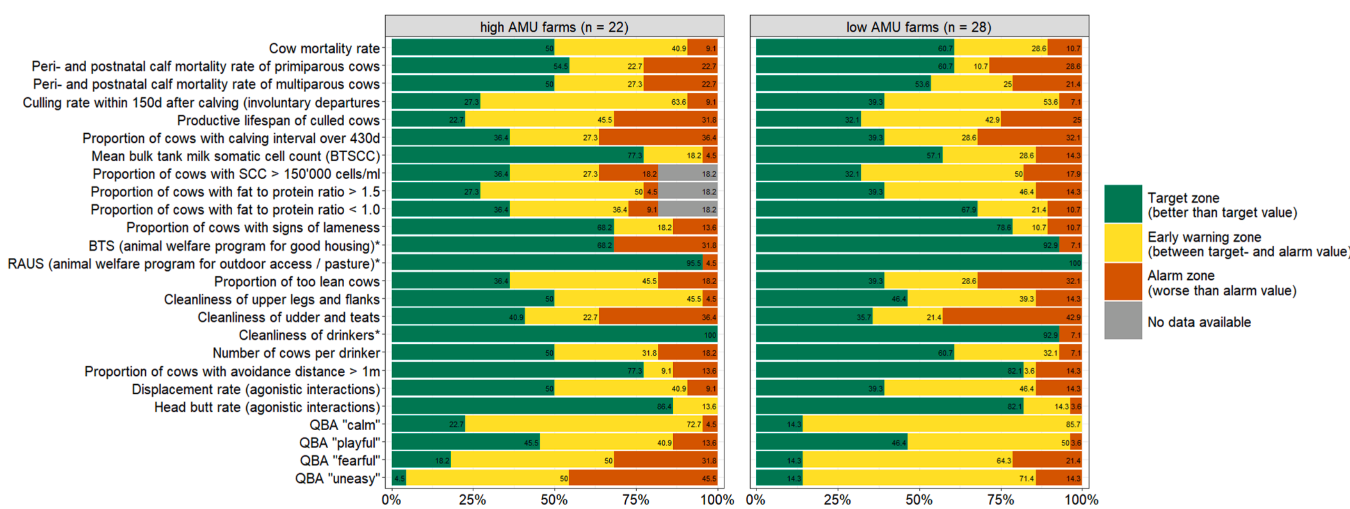


**Fig. 3.** Proportions of health and welfare indicator farm results from high and low antimicrobial use (AMU) study farms assessed in 2023 within the target zone (green, result better than target value), early warning zone (yellow, result between target and alarm value), and alarm zone (orange, result worse than alarm value). Results from the binary indicators BTS, RAUS, and cleanliness of drinkers were classified into either the target- or the alarm zone. Missing values in three indicators are due to no available breeding association data in four farms. QBA: Qualitative Behaviour Assessment.

of the four pHWS were found in the regression models. Two single HWI were found to be significantly associated with AMU group. Farms participating in the animal welfare program BTS were less likely to be in the high AMU group (-1.803, p = 0.04), whereas farms with a higher proportion of uneasy cows were more likely to be in the high AMU group (0.08, p = 0.03). As in the model using ATI as an outcome, a trend was found for farms with a lower BTSCC result to be among the high AMU farms (-0.619, p = 0.07).

**Table 4**
Antimicrobial resistance of commensal *E. coli* isolates overall, against multiple antimicrobial classes (multidrug resistant, MDR), and against highest priority critically important antimicrobials (HPCIA) in dairy cows and calves of the 50 study farms in 2023; Percentages in "MDR" and "HPCIA resistant" represent proportions of all isolates, not of resistant isolates.

| | Overall | Fully susceptible | Resistant | MDR resistant[a] | HPCIA resistant[b] |
|---|---|---|---|---|---|
| Age group | | | | | |
| Calf | 50 | 30 (60 %) | 20 (40 %) | 15 (30 %) | 4 (8.0 %) |
| Cow | 150 | 144 (96 %) | 6 (4.0 %) | 2 (1.3 %) | 2 (1.3 %) |
| Total | 200 | 174 (87 %) | 26 (13 %) | 17 (8.5 %) | 6 (3 %) |

[a] Resistant to at least three different antimicrobial classes
[b] Resistant to Highest Priority Critically Important Antimicrobials (HPCIA) according to the classification of the World Health Organization (WHO, 2019)

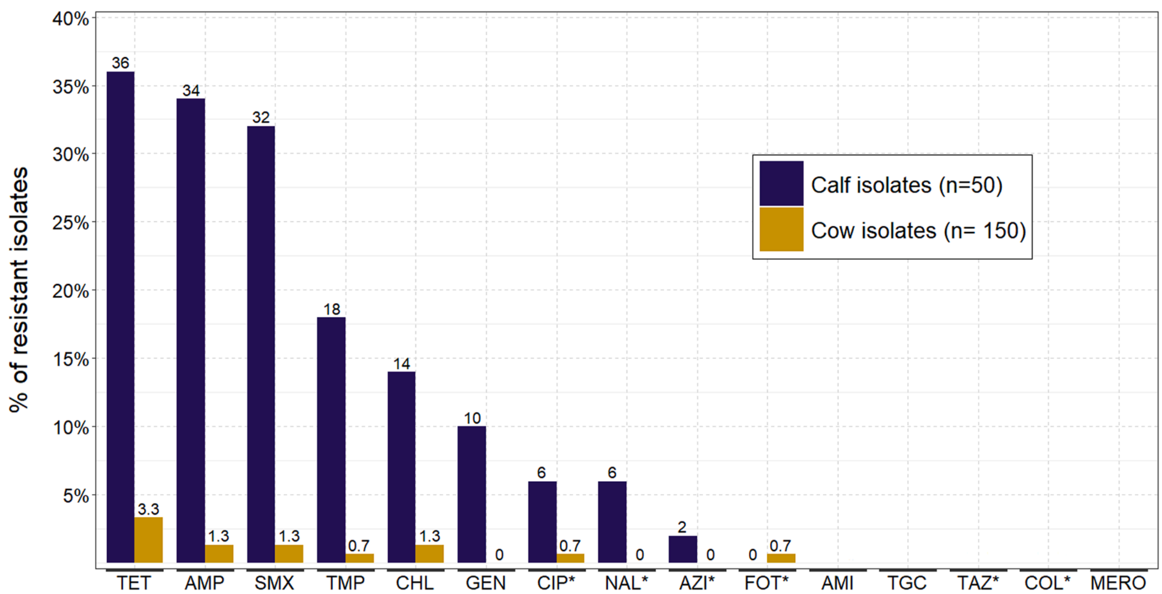


**Fig. 4.** Percentage of resistant isolates of all isolates tested in calves and cows by antimicrobial active substance; Cumulative percentages exceed 100 % because of multidrug resistances of isolates TET - Tetracycline, AMP - Ampicillin, SMX -Sulfamethoxazole, TMP - Trimethoprim, CHL - Chloramphenicol, GEN - Gentamicin, CIP - Ciprofloxacin, NAL - Nalidixic Acid, AZI - Azithromycin, FOT - Cefotaxime, AMI - Amikacin, TGC - Tigecycline, TAZ - Ceftazidime, COL - Colistin, MERO –Meropenem. *Highest Priority Critically Important Antimicrobials.

Other than the indicators listed above, no HWI showed any significant association with AMU group or ATI. Results from univariable regression models for AMU group and ATI and their associations with HWS and pHWS are shown in Table 5, and results for single HWI can be found in Supplementary Table 2.

### 3.6. Relationships between AMU, AMR, and management practices

Neither AMU group nor ATI were significantly associated with AMR combined. At the level of specific antimicrobial classes, no significant associations between sATI per class and AMR per class were found for any antimicrobial class.

The management practices of feeding waste milk containing antimicrobial residues to calves, the proportion of cows dried off with antimicrobials, and milk pathogen detection before antimicrobial treatment of subclinical mastitis during lactation (intramammary and / or systemic) were all associated with high AMU farms and higher ATI. The presence of a calving box used only for calving and a calving box also used as a sick pen, as opposed to having no calving box, were both more common in low AMU farms. Group housing of newborn calves (> 2 calves) was associated with lower ATI. Univariable associations between all management practices and both AMU group and ATI are shown in Table 6.

No significant associations were found between any management practice and AMR combined. All results from the regression models exploring associations between AMR and AMU as well as management practices are available in Supplementary Tables 3 and 4.

## 4. Discussion

### 4.1. Health and welfare

Health and welfare of dairy cows was quantified using a newly developed scoring system based on established HWI. The mean total HWS was 67 % (range: 50–84 %), and across all farms and indicators, only 16 % of the results fell within the alarm zone. These findings were considered indicative of a generally good health and welfare status. However, comparable results are lacking because the assessment on our study farms was the first time this HWI-set was applied in the field. More farm assessments will be needed to put HWI results from this study into context and, if necessary, to adjust the scoring system. Partial HWS showed considerable variations between farms and low category scores could point to areas with room for improvement. However, pHWS results should be interpreted with caution because of the limited number of study farms (n = 50) and because, for the two categories of appropriate behaviour and freedom from pain, suffering, harm, and anxiety, only three and four HWI respectively were used to build these scores. Single HWI will only be discussed in relation to AMU, as elaborating on indicator-specific results and their significance for health and welfare would go beyond the scope of this study.

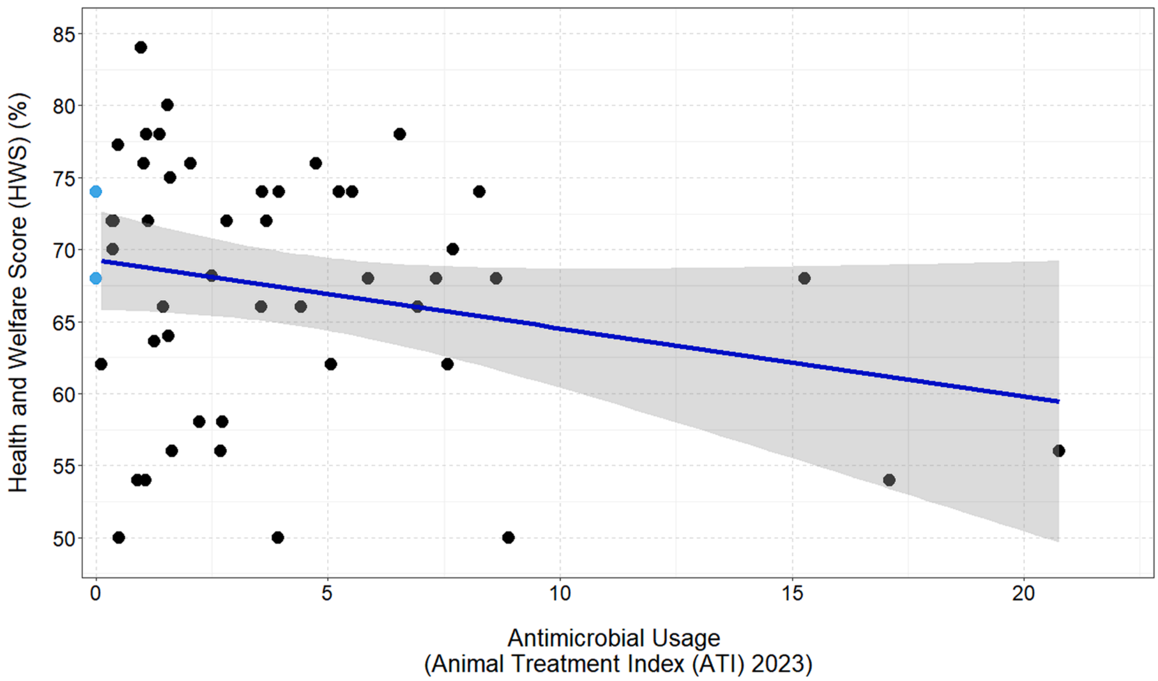


**Fig. 5.** Relationship between antimicrobial use (AMU) quantified using the animal treatment index (ATI) for the year 2023 and the health and welfare score (HWS) of all study farms. Dots represent study farms, blue dots indicate farms without any antimicrobial treatments (ATI = 0). The regression line shows the association between higher HWS and lower AMU with the 95 % confidence interval (grey band).

**Table 5**
Results of the logistic regression models using antimicrobial use group (AMU, high vs. low) and the generalized linear regression models using animal treatment index calculated for dairy cows (ATI, for the year 2023), showing univariable associations between total and partial health and welfare scores (HWS) and AMU based on data collected in 50 dairy cow farms in 2023. (SE, standard error).

| | AMU group | | | | ATI | | | |
|---|---|---|---|---|---|---|---|---|
| | Estimate | SE | z-value | p | Estimate | SE | t-value | p |
| HWS (total score) | −0.025 | 0.034 | −0.759 | 0.448 | −0.144 | 0.066 | −2.186 | 0.029 |
| pHWS health | −0.021 | 0.016 | −1.299 | 0.194 | −0.111 | 0.042 | −2.636 | 0.011 |
| pHWS husbandry and nutrition | 0.011 | 0.016 | 0.643 | 0.520 | −0.033 | 0.034 | −0.988 | 0.328 |
| pHWS appropriate behaviour | −0.010 | 0.020 | −0.507 | 0.612 | −0.034 | 0.041 | −0.836 | 0.407 |
| pHWS freedom from pain, suffering, harm, and anxiety | −0.005 | 0.021 | −0.217 | 0.828 | 0.027 | 0.032 | 0.824 | 0.414 |

### *4.2. AMU*

Antimicrobial use was quantified using dairy cow ATI, which is a count-based AMU metric as opposed to other weight- or dose-based metrics such as defined daily doses (DDD) or defined course doses (DCD) proposed by the European Medicines Agency (EMA, 2015). Although DDD or DCD could be calculated using IS ABV prescription data (Köchle et al., 2024), we chose to use the ATI as this metric will be used in national benchmarking systems. Comparison of ATI values calculated for the study farms with other AMU data in dairy cows is difficult for multiple reasons. Firstly, study farms were sampled from farms with extremely low or high AMU, which are not representative of the average dairy farm. The ATI of all farms within our sampling pool (n = 10’978 farms) in the year 2021 averaged 2.33 compared to values of 7.44 and 0.25 for high and low AMU study farms in the same year. Secondly, comparisons between ATI and DDD or DCD are most likely not very meaningful because of inherent differences when calculating these metrics. Thirdly, even comparisons between different AMU estimations all using DDD or DCD are hard to make because of different data collection methodologies, different standard weights and definitions of metrics used (Köchle et al., 2024).

### *4.3. Relationship between HWI and AMU*

The present study demonstrated a significant association of higher total HWS with lower ATI (-0.144, p = 0.03). This association was, however, not substantiated between total HWS and AMU group (-0.025, p = 0.4). Similarly, higher pHWS health was associated with lower ATI (-0.111, p = 0.01), but no significant association with AMU group was found (-0.021, p = 0.2). Although the groups of high and low AMU farms, defined based on their 2021 AMU data, could still be clearly differentiated based on their AMU in the following two years, within group variations of farms’ ATI over time still occurred. Assuming that HWI remained relatively stable over time, these variations in ATI may be the reason why the associations found between total HWS and ATI could not be substantiated for the outcome variable of AMU group. In their systematic review on the link between animal welfare and AMU in captive animals, Rodrigues da Costa and Diana (2022) found only five empirical studies in dairy cattle and concluded that there was scarce evidence for this link across all captive animal species. Literature investigating the association between a set of HWI or combined scores and dairy farms’ AMU is even more limited. Mazza et al. (2021) assessed animal welfare on 79 Italian dairy farms and investigated its relationship to AMU measured in a modified DDD unit. The welfare score used by the

**Table 6**
Results of the logistic regression models using antimicrobial use group (AMU, high vs. low) and the generalized linear regression models using animal treatment index calculated for dairy cows (ATI, for the year 2023), showing univariable associations between management practices and AMU based on data collected in 50 dairy cow farms in 2023. (SE, standard error).

| Management practice | AMU group | | | | ATI | | | |
|---|---|---|---|---|---|---|---|---|
| | Estimate | SE | z-value | p | Estimate | SE | t-value | p |
| Milk pathogen detection before antimicrobial mastitis treatment during lactation[a] | 0.033 | 0.015 | 2.262 | 0.024 | 0.044 | 0.009 | 4.785 | < 0.001 |
| Antimicrobial dry-off therapy strategy | | | | | | | | |
| Blanket dry cow treatment (BDCT) | 0.000 | 0.882 | 0.000 | 1.000 | 1.248 | 2.213 | 0.564 | 0.576 |
| According to SCC[b] and milk pathogen detection results | −0.442 | 0.710 | −0.622 | 0.534 | 0.750 | 1.648 | 0.455 | 0.652 |
| According to SCC only | Referent | | | | Referent | | | |
| Within-herd proportion of antimicrobial dry-off therapy | 0.020 | 0.009 | 2.215 | 0.027 | 0.072 | 0.019 | 3.890 | < 0.001 |
| Use of teat sealers at drying-off (non-antimicrobial) | | | | | | | | |
| Always | 0.182 | 0.756 | 0.241 | 0.810 | 0.918 | 1.512 | 0.607 | 0.547 |
| Partially (based on SCC) | 1.281 | 0.728 | 1.759 | 0.079 | 2.725 | 1.810 | 1.505 | 0.139 |
| Never | Referent | | | | Referent | | | |
| Feeding of waste milk to calves[c] | | | | | | | | |
| Yes | 1.350 | 0.604 | 2.234 | 0.025 | 3.450 | 1.122 | 3.074 | 0.003 |
| No | Referent | | | | Referent | | | |
| Mastitis vaccinations in dairy cows | | | | | | | | |
| Yes | −0.480 | 1.259 | −0.381 | 0.703 | 0.623 | 2.943 | 0.212 | 0.833 |
| No | Referent | | | | Referent | | | |
| Presence of a calving box | | | | | | | | |
| Yes, not used as sick cow box | −2.552 | 1.183 | −2.157 | 0.031 | −5.025 | 2.551 | −1.970 | 0.055 |
| Yes, also used as sick cow box | −2.521 | 1.147 | −2.197 | 0.028 | −4.746 | 2.527 | −1.878 | 0.067 |
| No | Referent | | | | Referent | | | |
| Presence of a separate sick cow box | | | | | | | | |
| Yes | −1.204 | 0.861 | −1.399 | 0.162 | −1.759 | 1.246 | −1.412 | 0.165 |
| No | Referent | | | | Referent | | | |
| Housing of newborn calves | | | | | | | | |
| In group housing (> 2 calves) | −1.411 | 0.732 | −1.927 | 0.054 | −2.522 | 1.029 | −2.452 | 0.018 |
| In individual hutches alone or with conspecific | Referent | | | | Referent | | | |
| Availability of clean individual hutches for newborn calves | | | | | | | | |
| Always a cleaned individual hutch available | −0.770 | 0.703 | −1.095 | 0.273 | −0.985 | 1.734 | −0.568 | 0.574 |
| Not always a cleaned individual hutch available | Referent | | | | Referent | | | |
| Cleaning of individual hutches | | | | | | | | |
| Mucking out only | 1.030 | 1.358 | 0.758 | 0.448 | 3.091 | 2.305 | 1.341 | 0.189 |
| Mucking out and cleaning with pressure washer | 0.788 | 1.300 | 0.606 | 0.544 | 1.827 | 1.942 | 0.941 | 0.354 |
| Only addition of fresh straw bedding | Referent | | | | Referent | | | |
| Cleaning of calf group housing | | | | | | | | |
| Less frequently than monthly | −0.560 | 0.630 | −0.889 | 0.374 | −2.010 | 1.511 | −1.330 | 0.191 |
| Monthly or more frequently | Referent | | | | Referent | | | |
| Purchase of cattle | | | | | | | | |
| Yes | −0.288 | 0.572 | −0.503 | 0.615 | −0.394 | 1.265 | −0.311 | 0.757 |
| No | Referent | | | | Referent | | | |
| Contact with cattle from other herds | | | | | | | | |
| Youngstock (calves and / or heifers) of study farms reared externally | −0.442 | 0.826 | −0.535 | 0.593 | −1.557 | 1.800 | −0.865 | 0.392 |
| Seasonal alpine pasture[d] | 0.693 | 0.935 | 0.741 | 0.459 | 1.556 | 2.396 | 0.650 | 0.519 |
| Participation in dairy cow exhibitions | −1.792 | 1.291 | −1.388 | 0.165 | −1.812 | 2.042 | −0.887 | 0.380 |
| None | Referent | | | | Referent | | | |
| Specific order followed in daily work with cattle[e] | | | | | | | | |
| Yes | 0.916 | 0.597 | 1.534 | 0.125 | 1.464 | 1.340 | 1.093 | 0.280 |
| No | Referent | | | | Referent | | | |
| Regular stock management by a veterinarian | | | | | | | | |
| Yes | 0.318 | 0.664 | 0.479 | 0.632 | 1.029 | 1.599 | 0.644 | 0.523 |
| No | Referent | | | | Referent | | | |

[a] Intramammary and / or systemic treatment of subclinical mastitis cases
[b] SCC: Individual cow milk somatic cell count
[c] Feeding of milk containing antimicrobial residues within the treatment and / or withdrawal period
[d] Seasonal communal alpine pasturing of dairy cows and / or heifers
[e] Examples for a specific work order are from “clean” to “dirty” work or milking cows with high SCC last

authors consisted of indicators covering farm management and staff training, housing systems, and animal-based measures. In contrast to our results using ATI, no significant relationship between the animal welfare score and AMU or between the category score of animal-based welfare measurements and AMU was found by Mazza et al. (2021). The authors stated limited farm sample size as a possible reason for their findings, and hypothesized that less welfare conscious farmers may not pay as much attention to animals and their diseases and thus administer fewer antimicrobial treatments. This was also underlined by another finding of the same authors, as two farms with zero AMU scored among the lowest in their animal welfare ranking. This is opposed to our findings, where the three farms with zero AMU (ATI = 0) in the year 2023 all had HWS equal to or above the median score of all study farms. Participation in the present study was voluntary, and the response rate was low. Thus, farms neglecting treatment despite poor health status would likely not have participated in this study.

Several single HWI results were found to be significantly associated with AMU group or ATI. The proportion of uneasy cows in QBA was positively associated with ATI, and the rate of head butts (agonistic interaction) between cows was negatively associated with ATI. These findings should be interpreted with caution because there is conflicting evidence on the correlation of QBA with animal health in livestock species (Phythian et al., 2016; Rutherford et al., 2012) and because agonistic interactions in dairy cows are influenced by a variety of factors (Krahn et al., 2024), which we did not control for. Participation in the Swiss animal welfare program BTS was less common in the group of high AMU farms, but no significant association with ATI was found. Participation in BTS has been previously associated with beneficial effects on dairy cow health (Regula et al., 2004)), with incidence of veterinary treatments (Odermatt et al., 2019), and with reduced AMU (Spycher et al., 2002; van Aken et al., 2022). High culling rates within 150d after calving were associated with high ATI, and productive lifespan of cows was shorter in farms with high ATI. The former association aligns with findings that culling rates are maintained when no more HPCIA are used and overall AMU is reduced in dairy farms (Turner et al., 2018).

No significant associations with AMU were found for any of the other HWI in this study. While some indicators may simply not be associated with AMU or we were not able to detect such associations in our study, there is evidence of a relationship for selected indicators in other studies. Literature in dairy calves shows that a reduction in AMU does not affect mortality rates (Gomez et al., 2021). The same has been demonstrated for veal calves (Bokma et al., 2020). Moreover, improving welfare on veal calf farms can lead to lower mortality rates and reduced AMU (Moser et al., 2020). In another study, udder health was improved over time by implementing an animal health and welfare planning strategy with the goal of reducing drug use (not exclusively antimicrobials) on organic dairy farms (Ivemeyer et al., 2012). The same authors also found that the incidence of abnormal milk fat to protein ratios indicative of ruminal acidosis or imbalanced energy supply remained stable and that lameness treatments slightly increased while drug use was reduced. The authors attributed the latter finding to increased awareness of farmers due to the implemented strategy leading to earlier and more frequent treatments for lame cows.

### *4.4. Current situation of AMR on the study farms*

The proportion of *E. coli* isolates resistant to any of the tested antimicrobial classes was 40 % in pre-weaning calves and 4 % in dairy cows. Pre-weaning calves having the highest prevalence of AMR when compared to other cattle age groups has often been reported in the literature (Massé et al., 2021; Springer et al., 2019; Werner et al., 2023). A suspected reason for this is that the gut of calves at this age is highly susceptible to colonization with resistant bacteria (Gonggrijp et al., 2023). A complete susceptibility of 60 % of all calf isolates found in the study farms is in line with the prevalence of 66.3 % fully susceptible *E. coli* isolates reported in the Swiss Antibiotic Resistance Report of 2024 (, 2024). Other authors have found full susceptibility prevalences of 38–49 % among pre-weaning calf isolates (Werner et al., 2023; Massé et al., 2021) These two authors also reported susceptibility prevalences between 80 % and 86 % among dairy cow isolates, which is lower than the 96 % found in the present study.

Commensal *E. coli* isolates from calves and cows were most commonly resistant to tetracyclines (36 % and 3 %, respectively), followed by penicillins (34 % and 1 %) and sulfonamides (32 % and 1 %). These antimicrobial classes are commonly used to treat bacterial diseases in calves in Switzerland and in many European countries (Pipoz and Meylan, 2016; SARR, 2024). The prevalence of AMR to different antimicrobial classes in calves was slightly above that reported for randomly sampled slaughter calves in Switzerland in 2023 (SARR, 2024). In the SARR, the prevalence of AMR among commensal *E. coli* from calves was 26.8 % for tetracyclines, 26.3 % for sulfonamides, and 23.7 % for penicillins. We found that 30 % of calf isolates and 1.3 % of cow isolates were multidrug resistant. A higher prevalence of MDR of 40.4–51 % (pre-weaning calves) and 5.9–8 % (cows) was found in Austria and Canada, respectively (Werner et al., 2023; Massé et al., 2021). In contrast, a lower prevalence of MDR (21.6 %) was reported for slaughter calves in the SARR. Because slaughter calves are usually older than the pre-weaning calves sampled in the present study, differences in AMR are likely attributable to decreasing rates of AMR with increasing calf age (Becker et al., 2022b; Gay et al., 2019; Schönecker et al., 2019).

### *4.5. Relationships between AMU, AMR, and management practices*

We did not find any significant association between AMU (either at the group level or quantitatively as ATI) and AMR combined of commensal *E. coli* in the present study. Evidence of relationships between overall AMU and AMR in dairy farm settings is relatively scarce. A trend for farm overall AMU to be associated with the presence of MDR in commensal *E. coli* was demonstrated in Austrian and Canadian dairy herds (Uyama et al., 2024; Werner et al., 2023). Mixed German dairy and beef herds with regular AMU were shown to have a higher prevalence of extended-spectrum β-lactamase (ESBL)-producing *E. coli* than a control group of farms not having used any antimicrobials in the past half year or longer (Schmid et al., 2013). Finding such relationships at farm or herd level is difficult (Werner et al., 2023), but clear evidence relating AMU to AMR is available when looking at the bigger picture on a national or international level. From 2018 – 2021, total national AMU of at least 26 European countries was negatively associated to complete susceptibility in *E. coli* isolates from slaughtered food-producing animals (JIACRA, 2024).

In contrast to our results, associations between high AMU per antimicrobial class and the presence of AMR to the respective class were demonstrated by other authors. Such associations in *E. coli* isolates were found for tetracyclines, penicillins, sulfonamides, and quinolones (Werner et al., 2023), and for cephalosporins (Gonggrijp et al., 2016; Tragesser et al., 2006) in dairy farms, and for tetracyclines and penicillins in veal calves before slaughter (Becker et al., 2022a).

In the present study, the feeding of waste milk containing antimicrobial residues to calves (during treatment, withdrawal period, or both) was significantly associated with higher AMU at the group and ATI level. This practice was carried out in 50 % of study farms, which aligns with earlier findings in Switzerland of 47 % (Bernier Gosselin et al., 2022). The observed association might be explained by waste milk being more likely to be fed to calves in high AMU farms as a way to dispose of large quantities of milk from treated cows, in order to avoid total loss of this milk. Feeding waste milk to calves changes their fecal microbiota (Penati et al., 2021) and selects for antimicrobial resistant bacteria (Firth et al., 2021; Foutz et al., 2018; Maynou et al., 2017; Springer et al., 2019). Although waste milk feeding was not associated with AMR in the present study, its positive association with AMU should raise concerns about this practice. Both the herd proportion of cows dried-off with antimicrobials and the proportion of mastitis cases with pathogen detection in milk before antimicrobial treatment were associated with high AMU at the group and ATI level. These two variables were assessed in the frame of the management practices questionnaire and are therefore based on farmers' estimations, not on AMU prescription or laboratory data. It is not surprising to find a link between more cows dried-off using antimicrobials and overall AMU of farms, especially given that dry-off prescriptions made up > 25 % of all antimicrobial treatments on the study farms in 2023. The average proportion of cows dried-off using antimicrobials was 50 % in the group of high AMU farms and 28 % in low AMU farms. While blanket dry cow treatment (BDCT), versus selective dry cow treatment (SDCT) according to SCC alone, was not associated with AMU in the present study, lower overall AMU when applying SDCT has been reported (Firth et al., 2019). Among all study farms, farmers estimated to have pathogen detection in milk samples done in 79 % of subclinical mastitis cases on average. Five farmers (all in the group of low AMU) indicated to never have milk samples tested before treating subclinical mastitis cases, which is similar to results from two questionnaires in Switzerland, where between 5.2 – 15 % of farmers reported to not test milk samples before treatment (Köchle et al., 2024; Schwendner et al., 2020). The fact that milk samples were tested more frequently on farms with higher AMU in the present study could indicate higher awareness of farmers regularly treating mastitis cases with antimicrobials. This finding should not be interpreted as evidence that pathogen detection in milk leads to higher AMU. Selective treatment of clinical mastitis cases has been associated with a reduction in AMU (de Jong et al., 2023), and pathogen detection in milk samples before treatment is an important measure in prudent use of antimicrobials (Schwendner et al., 2020; Teale and Moulin, 2012).

A calving box was present in 84 % of the study farms, with this space being used only for cows around calving in 50 % of the farms, and the calving box also being used for sick cows in 34 % of the farms. This is similar to findings from the Netherlands and Canada, where 85 % and 88 % of farms respectively had calving boxes, and 29 % (of those having calving boxes) and 53 % (of all farms), respectively, also used these boxes to keep sick cows (Holstege et al., 2018; Uyama et al., 2022). While these authors did not find a significant relationship of use of the calving box with AMU, both availability of a calving box only for its intended purpose and also housing sick cows in calving boxes were more common in low AMU farms in the present study, although this was not associated with ATI. Moving cows to a clean calving box with appropriate space allowance and bedding is important for good calving management and the health of both cows and calves (Mee, 2004), therefore possibly contributing to low AMU. Newborn calves were most commonly kept in individual hutches (72 % of study farms), either alone or in pairs. The Swiss Animal Welfare Law requires calves between two weeks and four months of age to be kept in groups, except for calves housed in individual hutches with permanent access to an outside pen (Federal Assembly of the Swiss Confederation, 2008). Large variations in whether calves are housed individually, in pairs or in larger groups exist in the literature (Hayer et al., 2021; Pipoz and Meylan, 2016; Uyama et al., 2022) and the results largely depend on how housing conditions were defined by the authors. We did not expect group housing of calves (> 2 calves) to be associated with lower ATI because it is often recommended to keep newborn calves individually in clean spaces to minimize the risk of neonatal disease. However, this finding should be interpreted with caution because the calculated ATI used was not related to pre-weaning calves and because others have not found any association between group housing and AMU specific to calves younger than 60 days (Uyama et al., 2022).

### 4.6. Study limitations and strengths

Voluntary participation of farmers may have introduced a selection bias, as farms with lower health and welfare status of their animals may not have responded to the study call. In addition, because of our study design, the low response rate, and the relatively small numbers of 22 high AMU farms and 28 low AMU farms, the participating farms are not representative for Swiss dairy farms in general. Furthermore, outlier results for HWI and farm AMU can have a considerable effect on regression analysis outcomes in small sample sizes as in our study. The imputation of missing values as applied in this study can negatively affect data quality. However, the impact of imputing missing values on our data was minor because only 1.1 % of values from all study farms across all HWI had to be imputed. We investigated the relationships between HWI, AMU, AMR, and management practices using univariable regression analyses only. This approach provides a broad insight into associations, but the results should be interpreted with caution as they are not adjusted for possible confounders or correlations between predictor variables. Consequently, this approach did not allow us to detect complex interactions among multiple predictor variables potentially influencing the outcome. Additionally, we did not test for possible associations between HWI and management practices, as it was not the focus of this study. Similarly, there may be associations between variables of interest that we were not able to detect because of the limited sample size of study farms. The cross-sectional observational design of this study allows for statements on associations between (i) HWI and AMU and (ii) between AMR, AMU, and management practices but not for causal inference for these relationships. To the best of our knowledge, the study conducted by Mazza et al. (2021) and the present study represent the first attempts to link an animal welfare score comprised of multiple HWI to AMU on dairy farms. Additionally, including multiple HWI that measure aspects of positive animal welfare (PAW, e.g. avoidance distance, QBA) is a unique feature of this study and sets it apart from other research covering mostly traditional health (e.g. lameness, BCS) or production parameters. Including indicators of PAW is becoming more relevant as definitions of animal welfare are changing and the absence of disease or negative states alone is no longer sufficient to ensure high welfare standards (Mattiello et al., 2024; Rault et al., 2025). On-farm HWI and management practices were recorded during a single visit per farm and therefore only represent the current state at the time of the visit. Multiple visits per farm would have allowed us to better estimate these parameters over time, but were not feasible due to limited time and resources. Quantification of AMU using the ATI slightly underestimates AMU on Swiss farms because DoS prescriptions cannot be attributed to a specific age group and are therefore omitted when calculating farms' ATI. However, excluding farms with a high proportion of DoS prescriptions during recruitment in the present study ensured that the AMU of farms was mostly comprised of regular treatment prescriptions, reducing uncertainty in our AMU estimates. Prescription patterns with a high proportion of DoS prescriptions could indicate less prudent use of antimicrobials. Thus, the a priori exclusion of these farms may have led to a bias during farm recruitment. The outcome variable AMU group (high vs. low) does account for DoS prescriptions and complements the ATI to give a more complete estimation of total farm AMU. Although these two groups of farms were defined during recruitment for the year 2021, they could still be clearly differentiated in the years 2022 and 2023. Still, results from analyses using AMU group should be interpreted with caution because the grouping is based on data recorded two years before HWI and management practices were assessed. The farm-level ATI we calculated comprised all applied antimicrobial treatments and we did not investigate what influence the application route might have on the relationships among AMU, HWI, AMR, and management practices. While the present study focuses on farms' overall AMU, possible effects of different application routes (e.g. systemic vs. intramammary) on the development of AMR for example (Fonseca et al., 2023; Nobrega et al., 2018) should be kept in mind when interpreting the results presented here. In general, prescription data from the IS ABV provide precise AMU data, limit bias from other recording alternatives (e.g. omissions in paper treatment journals), and can be used to compare AMU among farms (Köchle et al., 2024). Pooling of fecal samples to determine the presence of AMR in four isolates per farm does not allow us to draw conclusions for all pre-weaning calves and lactating dairy cows present on farm during sampling. However, the methodology of pooling feces from five animals applied here can be used to capture AMR populations at farm level (Massé et al., 2021; Uyama et al., 2024). While most resistant isolates were found in pre-weaning calves, the ATI used to relate AMU to AMR was based on prescriptions in dairy cows alone. The reason for this was that available AMU data did not allow us to calculate an ATI specific to pre-weaning calves because this age category is grouped together with fattening calves, weaned rearing calves, and heifers. Another reason why estimating youngstock AMU is difficult is that rearing calves and heifers from 23 out of 50 study farms were reared externally on different farms. In a study on the association between AMU and AMR, the authors stated that AMU in calves alone was unlikely to be the reason for high AMR prevalence in calves of their study farms because calf treatments only accounted for < 5 % of reported AMU (Werner et al., 2023).

## 5. Conclusions

The first aim of this study was to investigate the relationship between HWI and farm-level AMU in dairy cows. Associations between better scores and lower AMU were found for the total HWS, the pHWS health, and for several single HWI. These findings could be of interest when designing future health and welfare monitoring and antimicrobial stewardship programs, but further research on a larger scale is required to obtain more generalizable results. A second objective was to determine the current situation of AMR in the study farms and to investigate the relationships between AMU, the presence of AMR, and management practices. Several management practices, including the feeding of waste milk to calves were associated with higher AMU. The AMR outcomes could not be linked to either AMU or management practices on the study farms. This highlights the complexity behind the development of antimicrobial resistance at farm level and the need to better understand the underlying mechanisms to design efficient prevention strategies.

## CRediT authorship contribution statement

**Mireille Meylan:** Writing – review & editing, Validation, Methodology, Funding acquisition. **Gertraud Schüpbach-Regula:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Silja Griss:** Writing – review & editing, Investigation. **Véronique Bernier Gosselin:** Writing – review & editing, Validation, Resources, Methodology, Funding acquisition. **Adrian Minnig:** Writing – original draft, Visualization, Investigation, Formal analysis, Data curation. **Beat Thomann:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Guy-Alain Schnidrig:** Writing – review & editing, Validation, Data curation.

## Ethics approval

This animal study was approved and authorized by the FSVO and all Cantonal Veterinary Offices concerned, authorization number: ZH207/2022. Written informed consent for the participation of all animals involved in this study was obtained from their respective owners.

## Funding

This project was funded by the Federal Food Safety and Veterinary Office, FSVO; Project number 1.22.02. The Swiss Army Veterinary Service supported this work through a paid externship for the main author but had no involvement in the conduct of research or the preparation of the article.

## Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Adrian Minnig reports financial support was provided by Federal Food Safety and Veterinary Office. Guy-Alain Schnidrig reports a relationship with Federal Food Safety and Veterinary Office that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

We would like to thank all participating farmers and veterinarians for enabling us to collect data. Also, we are thankful to Holstein Switzerland, Braunvieh Switzerland, and Swissherdbook for their assistance with data acquisition.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2025.106688.

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# Anhänge:

Nachfolgend die Anhänge zum Publikationsmanuskript, auch verfügbar online unter:
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# Supplementary Material

Supplementary Table 1: Definition of health and welfare indicators assessed during farm visits on the 50 study farms in 2023. Definitions of all indicators, assessment methods for on-farm indicators and details on indicator calculations for data-based indicators. Unless otherwise stated, data-based indicators were calculated for a time period starting 365 days before the day of the farm visit.

| No. | Health and Welfare Indicator | Indicator Type | Calculation of data-based indicators, assessment methods for on-farm indicators |
|---|---|---|---|
| 1 | Cow mortality rate | Data-based | $\frac{no.\,of\ dairy\ cow\ deaths}{average\ yearly\ dairy\ cow\ herd\ size} \times 100$ |
| 2 | Peri- and postnatal calf mortality rate of primiparous cows | Data-based | $\frac{no.\,of\ stillbirths\ and\ calf\ deaths\ within\ the\ first\ 48h\ post\ partum\ of\ calves\ born\ from\ primiparous\ dairy\ cows}{total\ no.\,of\ calves\ born\ from\ primiparous\ dairy\ cows} \times 100$<br>Postnatal calf mortality was defined until 48h post partum to avoid underestimation of mortality rates due to false reports from farmers. Because of financial incentives for reporting the birth of a live calf (instead of a stillbirth) to the animal movement data system, it is assumed that a proportion of stillbirths are falsely reported as live calves being born and dying on the second day post partum. |
| 3 | Peri- and postnatal calf mortality rate of multiparous cows | Data-based | $\frac{no.\,of\ stillbirths\ and\ calf\ deaths\ within\ the\ first\ 48h\ post\ partum\ of\ calves\ born\ from\ multiparous\ dairy\ cows}{total\ no.\,of\ calves\ born\ from\ multiparous\ dairy\ cows} \times 100$<br>Postnatal calf mortality was defined until 48h post partum to avoid underestimation of mortality rates due to false reports from farmers. Because of financial incentives for reporting the birth of a live calf (instead of a stillbirth) to the animal movement data system, it is assumed that a proportion of stillbirths are falsely reported as live calves being born and dying on the second day post partum. |
| 4 | Culling rate within 150d after calving (involuntary departures) | Data-based | $\frac{no.\,of\ dairy\ cow\ which\ died, were\ euthanized, or\ slaughtered\ within\ the\ first\ 150d\ post\ partum}{average\ yearly\ dairy\ cow\ herd\ size} \times 100$ |
| 5 | Productive lifespan of culled cows [days] | Data-based | Average productive lifespan (first calving until death) of dairy cows which died, were euthanized, or slaughtered [days]<br>Cows slaughtered were only included in calculations if the slaughter took place within one day after the cow had left its origin farm. This was done to exclude departures of dairy cows which were later used as suckler cows for example. |

| | | | |
|---|---|---|---|
| 6 | Proportion of cows with calving interval over 430d | Data-based | $\frac{no.\,of\ dairy\ cows\ with\ a\ calving\ interval > 430\ days}{no.\,of\ dairy\ cows\ with\ a\ calculable\ calving\ interval} \times 100$<br>Cows were only taken into account if they became pregnant on the target farm. For this purpose, it was checked whether the respective cow was continuously on the target farm between the previous calving and a theoretical (calculated) first day of pregnancy |
| 7 | Mean bulk tank milk somatic cell count (BTSCC) [cells / ml] | Data-based | Mean bulk tank milk somatic cell counts of the last 13 monthly measurements prior to the farm visit (official milk testing) [cells / ml] |
| 8 | Proportion of cows with SCC > 150'000 cells/ml | Data-based | $\frac{no.\,of\ dairy\ cow\ individual\ somatic\ cell\ count\ measurements > 150'000\ cells\ /\ ml}{total\ no.\,of\ dairy\ cow\ individual\ somatic\ cell\ count\ measurements} \times 100$ |
| 9 | Proportion of cows with fat to protein ratio > 1.5 | Data-based | $\frac{no.\,of\ dairy\ cows\ with\ a\ fat\ to\ protein\ ratio > 1.5\ within\ 60d\ post\ partum}{no.\,of\ dairy\ cows\ with\ calculable\ fat\ to\ protein\ ratio\ within\ 60d\ post\ partum} \times 100$<br>Unrealistic measurements of milk fat (< 1.5% and > 9% (< 2% and > 12% for Jersey cows)) and milk protein (< 1% and > 7%) contents were removed before calculating the indicator. |
| 10 | Proportion of cows with fat to protein ratio < 1.0 | Data-based | $\frac{no.\,of\ dairy\ cows\ with\ a\ fat\ to\ protein\ ratio < 1.0\ within\ 60d\ post\ partum}{no.\,of\ dairy\ cows\ with\ calculable\ fat\ to\ protein\ ratio\ within\ 60d\ post\ partum} \times 100$<br>Unrealistic measurements of milk fat (< 1.5% and > 9% (< 2% and > 12% for Jersey cows)) and milk protein (< 1% and > 7%) contents were removed before calculating the indicator. |
| 11 | Proportion of cows with signs of lameness | On-farm | $\frac{no.\,of\ dairy\ cows\ showing\ any\ sign\ of\ lameness}{no.\,of\ dairy\ cows\ assessed\ during\ farm\ visit} \times 100$<br>Farm visits were timed so that the last herd hoof trimming was at least one week before the visit to collect data for the present study. Different assessment criteria were used depending on the housing system:<br>Assessment in tie stalls: Cows tied in the stall were observed from behind. A cow was considered lame if one of the following criteria was observed: (i) clearly not putting full weight on one leg; (ii) repeated shifting of weight from one leg to the other; (iii) predominantly standing on the edge of the lying area; (iv) only very reluctantly putting weight on one leg when being made to shift weight from one leg to the other |

| | | | |
|---|---|---|---|
| | | | Assessment in free stalls: Cows are locked in the feeding rack and their gait is observed for at least eight steps on a level, smooth and sure-footed surface after being released individually from the feeding rack. Indicators of lameness are: (i) irregular foot fall; (ii) uneven temporal rhythm between hoof beats; (iii) weight not borne for equal time on each of the four feet |
| 12 | Participation in BTS (animal welfare program for good housing) | Data-based | For dairy cows, the BTS program ("Besonders tierfreundliche Stallhaltungssysteme") provides financial incentives for loose housing systems with a comfortable lying area separated from the feeding area(Federal Assembly of the Swiss Confederation, 2013; Odermatt et al., 2019). |
| 13 | Participation in RAUS (animal welfare program for outdoor access / pasture) | Data-based | For dairy cows, the RAUS program ("Regelmässiger Auslauf im Freien") provides financial incentives for providing cows with regular exercise in an outdoor run in the winter and in a pasture during summer(Federal Assembly of the Swiss Confederation, 2013; Odermatt et al., 2019). |
| 14 | Proportion of too lean cows | On-farm | $\frac{no.\,of\ dairy\ cows\ with\ a\ body\ condition\ score\ \leq\ 2.25}{no.\,of\ dairy\ cows\ assessed\ during\ farm\ visit} \times 100$<br>Cows are locked in the feeding rack and their body condition score (BCS) is assessment from behind. Cows with a BCS ≤ 2.25 are considered as "too lean". |
| 15 | Cleanliness of upper legs and flanks | On-farm | $\frac{no.\,of\ dairy\ cows\ with\ dirty\ upper\ hind\ legs\ and\ /\ or\ dirty\ flanks}{no.\,of\ dairy\ cows\ assessed\ during\ farm\ visit} \times 100$<br>Assessment according to the WelfareQuality® assessment protocol for dairy cows (WelfareQuality®, 2016) |
| 16 | Cleanliness of udder and teats [% of herd] | On-farm | $\frac{no.\,of\ dairy\ cows\ with\ dirty\ udders\ and\ /\ or\ teats}{no.\,of\ dairy\ cows\ assessed\ during\ farm\ visit} \times 100$<br>Assessment according to the WelfareQuality® assessment protocol for dairy cows (WelfareQuality®, 2016) |
| 17 | Cleanliness of drinkers | On-farm | Inspection of all drinkers available to dairy cows and overall assessment of cleanliness of these drinkers (clean or partially dirty vs. dirty)<br>Assessment according to the WelfareQuality® assessment protocol for dairy cows (WelfareQuality®, 2016) |
| 18 | Number of cows per drinker | On-farm | $\frac{no.\,of\ dairy\ cows\ present\ during\ farm\ visit}{no.\ of\ functioning\ drinkers\ available\ to\ dairy\ cows} \times 100$ |
| 19 | Proportion of cows with avoidance distance > 1m | On-farm | Proportion of dairy cows showing an avoidance reaction at > 1m distance when being locked in the feeding rack and approached from the front in a standardized way by the assessor. |

| | | | |
|---|---|---|---|
| | | | Assessment according to the WelfareQuality® assessment protocol for dairy cows (WelfareQuality®, 2016) |
| 20 | Displacement rate (agonistic interactions) | On-farm | No. of displacements (one cow displacing another cow) observed during observation of the herd from outside the pen (standardized per hour and 30 cows)<br>Assessment according to the WelfareQuality® assessment protocol for dairy cows (WelfareQuality®, 2016) |
| 21 | Head butt rate (agonistic interactions) | On-farm | No. of head butts (one cow hitting another cow) observed during observation of the herd from outside the pen (standardized per hour and 30 cows)<br>Assessment according to the WelfareQuality® assessment protocol for dairy cows (WelfareQuality®, 2016) |
| 22 | Qualitative behaviour assessment (QBA) "calm" [% of herd] | On-farm | Assessment modified after the WelfareQuality® assessment protocol for dairy cows (WelfareQuality®, 2016)<br>Observation of cows was performed according to the WelfareQuality® assessment protocol, but only for the four terms “calm”, “playful”, “fearful”, and “uneasy”. A visual analogue scale was used for scoring and results were later transformed onto a 0 – 100% scale to represent the proportion of the herd represented by the respective term. |
| 23 | Qualitative behaviour assessment (QBA) "playful" [% of herd] | On-farm | |
| 24 | Qualitative behaviour assessment (QBA) "fearful" [% of herd] | On-farm | |
| 25 | Qualitative behaviour assessment (QBA) "uneasy" [% of herd] | On-farm | |

Supplementary Table 2: Results of both the logistic regression models using antimicrobial use group (AMU, high vs. low) and the generalized linear regression models using animal treatment index calculated for dairy cows (ATI, for the year 2023), showing univariable associations between health and welfare indicators and AMU based on data collected in 50 dairy cow farms in 2023 (std. error, standard error).

| **Relationship between HWI and AMU group (high vs. low AMU farms)** | | | | | | |
|---|---|---|---|---|---|---|
| **model** | **indicator** | **estimate** | **std. error** | **z-value** | **p.value** | **p_value_star** |
| 23 | QBA_uneasy | 0.080 | 0.036 | 2.225 | 0.026 | * |
| 17 | BTS_yes | -1.803 | 0.865 | -2.085 | 0.037 | * |
| 5 | MeanSCC | -0.619 | 0.346 | -1.787 | 0.074 | . |
| 7 | Productive_lifespan | -0.511 | 0.317 | -1.611 | 0.107 | |
| 12 | Cleanliness_upper_leg | -0.028 | 0.020 | -1.359 | 0.174 | |
| 22 | QBA_calm | 0.037 | 0.029 | 1.252 | 0.211 | |
| 10 | Lameness | 0.077 | 0.071 | 1.095 | 0.274 | |
| 1 | Mortality_rate | 0.088 | 0.084 | 1.052 | 0.293 | |
| 25 | QBA_fearful | 0.024 | 0.023 | 1.051 | 0.293 | |
| 2 | Culling_rate | 0.040 | 0.039 | 1.029 | 0.304 | |
| 6 | SCC_over_150000 | -0.021 | 0.027 | -0.806 | 0.420 | |
| 11 | Lean_cows | -0.046 | 0.058 | -0.790 | 0.429 | |
| 24 | QBA_playful | -0.009 | 0.014 | -0.636 | 0.525 | |
| 9 | Fat_protein_ratio_high | -0.026 | 0.044 | -0.585 | 0.558 | |
| 13 | Cleanliness_udder | -0.015 | 0.026 | -0.575 | 0.566 | |
| 3 | Stillbirths_primiparous | -0.016 | 0.030 | -0.547 | 0.585 | |
| 21 | Displacement_rate | -0.035 | 0.068 | -0.520 | 0.603 | |
| 19 | Avoidance_distance | 0.011 | 0.026 | 0.433 | 0.665 | |
| 14 | Calving_interval_long | 0.006 | 0.018 | 0.350 | 0.726 | |
| 8 | Fat_protein_ratio_low | 0.011 | 0.031 | 0.344 | 0.731 | |
| 16 | Cows_per_drinker | -0.009 | 0.041 | -0.229 | 0.819 | |
| 20 | Headbutt_rate | -0.025 | 0.108 | -0.227 | 0.820 | |
| 4 | Stillbirths_multiparous | -0.005 | 0.061 | -0.085 | 0.933 | |
| 18 | RAUS_yes | -15.854 | 1,455.398 | -0.011 | 0.991 | |
| 15 | Clean_drinkers_yes | -16.399 | 1,696.734 | -0.010 | 0.992 | |
| | | | | | | |
| **Relationship between HWI and ATI (ATI 2023)** | | | | | | |
| 7 | Productive_lifespan | -1.624 | 0.309 | -5.257 | 0.000 | *** |

| | | | | | | |
|---|---|---|---|---|---|---|
| 20 | Headbutt_rate | -0.301 | 0.099 | -3.030 | 0.004 | ** |
| 23 | QBA_uneasy | 0.168 | 0.064 | 2.631 | 0.011 | * |
| 2 | Culling_rate | 0.185 | 0.089 | 2.086 | 0.042 | * |
| 5 | MeanSCC | -0.734 | 0.433 | -1.694 | 0.097 | . |
| 15 | Clean_drinkers_yes | -2.554 | 1.679 | -1.521 | 0.135 | |
| 10 | Lameness | 0.270 | 0.179 | 1.509 | 0.138 | |
| 21 | Displacement_rate | -0.169 | 0.124 | -1.355 | 0.182 | |
| 24 | QBA_playful | -0.040 | 0.029 | -1.353 | 0.182 | |
| 6 | SCC_over_150000 | -0.058 | 0.045 | -1.304 | 0.199 | |
| 1 | Mortality_rate | 0.283 | 0.224 | 1.262 | 0.213 | |
| 17 | BTS_yes | -2.513 | 2.090 | -1.202 | 0.235 | |
| 12 | Cleanliness_upper_leg | -0.032 | 0.030 | -1.078 | 0.286 | |
| 8 | Fat_protein_ratio_low | -0.059 | 0.058 | -1.017 | 0.314 | |
| 3 | Stillbirths_primiparous | 0.064 | 0.072 | 0.887 | 0.380 | |
| 16 | Cows_per_drinker | -0.064 | 0.077 | -0.830 | 0.411 | |
| 18 | RAUS_yes | -11.528 | 14.142 | -0.815 | 0.419 | |
| 9 | Fat_protein_ratio_high | -0.067 | 0.094 | -0.717 | 0.477 | |
| 22 | QBA_calm | -0.033 | 0.060 | -0.551 | 0.585 | |
| 25 | QBA_fearful | -0.019 | 0.042 | -0.461 | 0.647 | |
| 14 | Calving_interval_long | 0.018 | 0.041 | 0.448 | 0.656 | |
| 4 | Stillbirths_multiparous | 0.051 | 0.140 | 0.364 | 0.717 | |
| 11 | Lean_cows | 0.038 | 0.125 | 0.303 | 0.763 | |
| 13 | Cleanliness_udder | 0.017 | 0.057 | 0.301 | 0.765 | |
| 19 | Avoidance_distance | -0.008 | 0.053 | -0.157 | 0.876 | |

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Supplementary Table 3: Results of the logistic regression models showing univariable associations between animal treatment index calculated for dairy cows (ATI, for the year 2023) and AMR combined (occurrence of at least one resistant isolate for any antimicrobial class per farm) and between simplified animal treatment index calculated for dairy cows (sATI, for the year 2023) and AMR per class (occurrence of at least one resistant isolate in a specific antimicrobial class per farm) based on data collected in 50 dairy cow farms in 2023 (std. error, standard error; CI, confidence interval).

| **predictor variable** | **outcome variable** | **estimate** | **std. error** | **CI** | **p.value** |
|---|---|---|---|---|---|
| AMU group (high) | AMR combined | -0.905 | 0.594 | -0.237 – 2.113 | 0.128 |
| ATI | AMR combined | -0.105 | 0.080 | -0.287 – 0.036 | 0.191 |
| sATI penicillins | AMR per class penicillins | -0.302 | 0.418 | -1.187 – 0.486 | 0.470 |
| sATI aminoglycosides | AMR per class aminoglycosides | -6.376 | 4.043 | -17.316 – -0.802 | 0.115 |
| sATI sulfonamides | AMR per class sulfonamides | -15.107 | 7.749 | -34.253 – -3.679 | 0.051 |
| sATI tetracyclines | AMR per class tetracyclines | -1.505 | 1.549 | -5.003 – 1.280 | 0.331 |
| sATI diaminopyrimidines | AMR per class diaminopyrimidines | -9.263 | 8.111 | -31.202 – 3.164 | 0.253 |
| sATI quinolones | AMR per class quinolones | -5.158 | 13.580 | -49.552 – 12.930 | 0.704 |
| sATI cephalosporins | AMR per class cephalosporins | -618.154 | 197198.135 | NA – 41052.717 | 0.997 |
| sATI macrolides | AMR per class macrolides | -477.075 | 175562.392 | NA – 36777.697 | 0.998 |

Supplementary Table 4: Results of the logistic regression models showing univariable associations between management practices and AMR combined (occurrence of at least one resistant isolate in any antimicrobial class per farm) based on data collected in 50 dairy cow farms in 2023 (std. error, standard error).

| model | management practice | estimate | std. error | z-value | p.value | p_value_star |
|---|---|---|---|---|---|---|
| 1 | mastitis_vaccination_yes | -0.480 | 1.259 | -0.381 | 0.703 | |
| 2 | teat_seal_always | 0.000 | 0.737 | 0.000 | 1.000 | |
| 2 | teat_seal_for_certain_cows | -1.099 | 0.766 | -1.434 | 0.152 | |
| 3 | dry_off_usage_always | 0.383 | 0.880 | 0.435 | 0.663 | |
| 3 | dry_off_usage_SCC_bact | -1.109 | 0.790 | -1.403 | 0.161 | |
| 4 | antimicrobial_dry_off | -0.001 | 0.008 | -0.168 | 0.867 | |
| 5 | calving_box_yes | 1.216 | 0.950 | 1.280 | 0.200 | |
| 5 | calving_box_yes_also_sickbox | 0.857 | 0.910 | 0.942 | 0.346 | |
| 6 | sickbox_yes | 0.022 | 0.741 | 0.030 | 0.976 | |
| 7 | waste_milk_yes | -0.325 | 0.572 | -0.569 | 0.569 | |
| 8 | waste_milk_only_fattening | -0.480 | 0.744 | -0.645 | 0.519 | |
| 8 | waste_milk_all | -0.208 | 0.672 | -0.309 | 0.757 | |
| 9 | stock_management_yes | -0.125 | 0.670 | -0.187 | 0.852 | |
| 10 | purchase_animals_yes | 0.039 | 0.572 | 0.069 | 0.945 | |
| 11 | contact_alpine_pasture | -1.099 | 1.065 | -1.032 | 0.302 | |
| 11 | contact_exhibitions | 2.303 | 1.304 | 1.766 | 0.077 | |
| 11 | contact_rearing_external | 0.424 | 0.841 | 0.504 | 0.614 | |
| 12 | work_order_yes | -0.838 | 0.611 | -1.372 | 0.170 | |
| 13 | bacteriology_mastitis | -0.006 | 0.009 | -0.690 | 0.490 | |
| 14 | housing_calves_groups | -0.065 | 0.636 | -0.102 | 0.919 | |
| 15 | calf_hutches_always | 0.588 | 0.702 | 0.837 | 0.402 | |
| 16 | cleaning_hutches_cleaning | 0.788 | 1.300 | 0.606 | 0.544 | |
| 16 | cleaning_hutches_only_mucking | 0.000 | 1.369 | 0.000 | 1.000 | |
| 17 | cleaning_groupbox_less_frequently | 0.116 | 0.637 | 0.181 | 0.856 | |

# Danksagung

Ich möchte mich herzlich bei Prof. Dr. Gertraud Schüpbach und Dr. Beat Thomann für ihre stets hilfreiche und kompetente Betreuung während dieser Dissertation bedanken. Ich habe die Zusammenarbeit mit meinen Betreuungspersonen sehr geschätzt und bin dankbar für die Unterstützung und die vielen spannenden Diskussionen.

Ein grosses Dankeschön möchte ich auch allen anderen Mitarbeitern des Veterinary Public Health Instituts (VPHI) aussprechen. Ich konnte stets auf fachliche Unterstützung und gute Kollegialität im Team zählen und habe auch ausserhalb meines Dissertationsgebietes vieles mitgenommen für meine Zukunft.

An dieser Stelle möchte ich ausserdem allen weiteren Personen danken, mit denen ich im Verlauf dieser Dissertation zusammenarbeiten durfte. Namentlich gilt mein Dank dem Team der Wiederkäuerklinik Bern, Rindergesundheit Schweiz (RGS), der Arbeitsgemeinschaft Schweizerischer Rinderzüchter (ASR), dem Veterinärdienst der Armee, dem Bundesamt für Lebensmittelsicherheit und Veterinärwesen (BLV), welches dieses Projekt finanzierte und allen teilnehmenden Landwirten und Privattierärzten, welche dieses Projekt dank ihrer Bereitschaft und Offenheit erst ermöglichten.

Ein letztes grosses Dankeschön gilt meiner Familie und meinen Freunden, auf deren Hilfe, Verständnis und Unterstützung ich stets zählen kann.

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