Risk factors for antimicrobial use in pig farms: a cross-sectional study in the Netherlands

Panagiotis Mallioris (✉ p.mallioris@uu.nl)
Utrecht University

Roosmarijn E.C. Luiken
Utrecht University

Tijs Tobias
Utrecht University

John Vonk
De Varkenspraktijk Obrechtstraat 2, 5344 AT, Oss

Jaap A. Wagenaar
Utrecht University

Arjan Stegeman
Utrecht University

Lapo Mughini-Gras
Utrecht University

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Abstract

Background

Antimicrobial use (AMU) has decreased by 63% in Dutch pig farms since 2009. However, this decrease has stagnated in recent years. The problem mainly pertains to weaners, which have a six-fold higher AMU compared to sows/suckling piglets and fatteners. The aim of this study was to identify farm-level characteristics associated with i) total AMU among weaners, sows/sucklings and fatteners and ii) use of specific antimicrobial classes in the former two age groups.

Methods

In 2020, data from 154 Dutch pig farms were collected and analyzed in a cross-sectional study. These data included information on AMU and farm characteristics, focusing on weaners. A mixed-effects conditional Random Forest analysis was applied to select the subset of farm characteristics that was best associated with AMU.

Results

Overall, the main risk factors for total AMU in weaners were vaccination for PRRS vaccination in sucklings, being a conventional (vs organic or “The Better Life label”) farm, high within-farm pig density and early weaning. The largest protective effects for total AMU for sows/sucklings were *E. coli* vaccination of sows and having a search boar from own production. Regarding the other outcomes of those two age groups several risk factors overlapped such as farmer’s non-tertiary education, not having free-sow systems during lactation and conventional farming while another risk factor of interest for weaners were having fully slatted floors. In fatteners, the highest risk for their AMU was PRRS vaccination of sucklings.

Conclusions

Several on-farm characteristics associated with AMU in Dutch pig farms were identified. Some have been found elsewhere too, but others were novel, such as farmer’s education, lower pig aggression and free-sow systems, which were associated with decreased AMU. Certain farm practices can reduce structurally the need for AMU, as their effect is mediated through improvement of environmental conditions, biosecurity and animal welfare mitigating as such the risks of disease and stress in animals.

1. Background

Antimicrobial resistance (AMR) has been listed by the World Health Organization (WHO) as one of the top ten global threats to human health [1] with one of the main reservoirs being the livestock sector [2]. In the
Netherlands since 2009, significant actions have been undertaken which lowered AMU by 70.8% in livestock and by 63% in pigs based on farm level prescription data measured by the Netherlands’ Veterinary Medicines Institute (SDa). However, the reduction rate has stagnated and currently 21% of pig farms are above that SDa defined action threshold [3] (that is yearly updated and interventions on farms are introduced to reach it). Based on these national AMU data, it is clear that weaners were the highest consumers of antimicrobials in 2021 [3] and similar is the case for other EU countries [4]. Specifically, the mean consumption of antimicrobials in weaners was 20.5 DDDA$_F$ (Defined Daily Dosage for Animals per livestock Farm) while AMU in sows and suckling piglets was 3.2 DDDA$_F$ and in fatteners 2.8 DDDA$_F$. DDDA$_F$ equals to the total number of treated kg of animals at a particular farm for a specific year based on antimicrobials supplied and standardised treatment dosages divided by the average number of kg of animals present [3]. As routine usage (metaphylaxis and prophylaxis) is prohibited by law since 2011 [5] in the Netherlands (in the European Union (EU) as a whole, such regulation took force in 2022 [6]), the actual herd health status is the main driver of AMU (i.e. only therapeutic application). As a result, the conditions and practices at the farm level (including farmer’s background) that provide the ground for infectious disease outbreaks to emerge (either by easing transmission and/or by enhancing clinical manifestation) are expected to have informative prediction power over AMU.

Indeed, in livestock farming, AMU is known to be influenced by various groups of management factors [7], while it is not uncommon for antimicrobials to be used as “remedies” for improper biosecurity [8]. Two literature reviews on risk assessment studies for AMU in pig production systems have indicated various important aspects of both internal and external biosecurity [9][10]. For example, concerning internal biosecurity, lower within-farm stocking densities, vaccination, all-in and all-out systems (AIAO) at all stages and older weaning age (among others) have been associated with lower AMU, whereas shorter farrowing rhythms and poor air quality with higher AMU. Regarding external biosecurity, mixing of animals from different farms is a known risk factor, whereas proper quarantine of incoming animals, being organic/extensive farm and low chance of other pig herds presence within 500 m have shown to have protective effects. Apart from biosecurity other factors are at play too, such as nutrition, micro-climate conditions, environmental richness and behavioural factors such as farmers’ knowledge and awareness on AMU and AMR [11] but also farmers’ perceived motivations and barriers [12].

In this study, we assessed all main technical characteristics of pig production that could influence AMU in total and per class to support further decrement. The main objective was to determine the impact of different farm characteristics on AMU in Dutch pig farms. Apart from the opportunity of using a detailed survey here of added value are also the epidemiological models developed as they can provide results both at the population and individual level due to their non-parametric nature. Specifically, we aimed to answer the question of which (modifiable) farm characteristics and management-related factors are associated with: 1) total AMU in sows and suckling piglets, weaners, and fatteners, and 2) with use of specific antimicrobial classes in sows/sucklings and weaners?

2. Results
The average AMU per farm was 14.4 DDDA/Y of the farms in the study population (median was 9.8 DDDA/Y; for the whole 2019 census SDa data these numbers were 16.8 and 8.1 DDDA respectively [13]). In weaners specifically the mean AMU was 11.01 DDDA/Y, while in sows/sucklings and fatteners it was 2.5 and 2.1 DDDA/Y, respectively. Overall, tetracyclines, penicillins, trimethoprim-sulphonamides and macrolides-lincosamides were the most used antimicrobial classes. Figure 1 summarizes all AMU results per antibiotic class and age group.

The associations between farm characteristics and the different AMU outcomes are shown in Figs. 2, 3 and 4. Hereafter, when a result is expressed in DDDA/Y, it refers to the expected change in AMU in total or of a specific antimicrobial class, and when it is expressed in percentage, it refers to the change in the relative probability of using a specific class.

Overall, in weaners, the largest risk effects were found for application of PRRS vaccination in sucklings, being a conventional farm and having higher densities than the production scheme of the farm allows (2.8, 2.4 and 2.2 higher DDDA/Y, respectively). Then, inspection of clinically diseased animals at least twice a day with immediate isolation and presence of fully slatted floors in weaners' buildings followed (1.5 and 1.1 DDDA/Y, respectively). The last three variables (in terms of effect size towards total AMU for weaners) were lower post weaning aggressive behavior (a score for overall aggressive behavior of weaners on a Likert scale was given by the veterinarian), longer lactation and open sow periods (period from weaning to next insemination) (-0.4, -0.3, -0.1 DDDA/Y respectively). For AMU in sows/sucklings, the largest effects were observed for *E. coli* vaccination of sows, having a boar for estrus detection from own production, presence of a loading bay and having a hygiene lock per stall (vs having one for whole farm mainly) (-0.5, -0.4, 0.4 and 0.3 DDDA/Y, respectively). Applying *Mycoplasma* vaccination followed as a risk along with having foot baths and cleaning and disinfecting equipment that has been used on other farms (0.22, 0.20, 0.12 DDDA/Y respectively). For fatteners, PRRS vaccination in sucklings, having a hygiene lock per stall and following a farrowing cycle of one, two or three (vs four, five) had the three largest effect sizes (0.76, 0.75 and -0.43 DDDA/Y, respectively). Figure 4 contains all results for these three outcomes.

Regarding the class specific outcomes, only the top two largest effects from each category are mentioned here but Figs. 2 and 3 summarize all results. In weaners, more tetracycline use (which had the highest DDDA/Y values) was associated with being a conventional farm (vs not; i.e. organic but also “Better Life label 1” or “Beter Leven 1” in Dutch [14]) and with inspections for clinically diseased animals taking place twice a day with immediate isolation (14.5% and 6.3%, respectively). For tetracycline use in sows and sucklings farmer’s tertiary education was the most protective factor and being a conventional farm was the largest risk (-10.9% and 8.0% respectively). For penicillin use in weaners, having clear separation of clean and dirty zones in the indoor area of the farm and having a search boar from own production were the risk factors with the largest effect (5.2% and 5.0%, respectively). In sows/sucklings, penicillin use was associated with being a conventional farm as risk factor and changing the needle when vaccinating sows per pen (vs not; i.e. every few pens or until the needle breaks) as protective (9.6% and -6.2% respectively). Use of trimethoprim-sulphonamides in weaners was positively associated with starting the farm round
with visiting the diseased animals first (7.2%) and negatively associated with having a free sow system during lactation (-6.9%). For the same class in sows/sucklings, contact of companion animals with production animals and not having a specific order when visiting the sick animals had the largest effects (-10.6% and 2.7%, respectively). Lastly, for macrolides-lincosamides, their probability of being used in sows/sucklings was associated with having a loading bay and storing the equipment individually per stable (-7.6% and 5.9%, respectively). For their amount to be used in weaners, farmer's tertiary education and mixing of slow growers had the top two effect sizes (-0.30 and 0.26 DDDA/Y, respectively). For their probability of being used in weaners, farmer's tertiary education and housing weaners in the same building with sows or gilts were most protective (-5.8% and −4.3%, respectively).

Given the relatively large number of outcomes and predictors in this study, the epidemiological importance of a variable was not necessarily based on its effect size alone, but also on whether it appeared as significant both for total AMU and the probability of using an antimicrobial class in a specific age group. Factors consistently associated with at least two AMU outcomes (i.e. total AMU and a specific class) were the following. Longer average lactation length was correlated with decreased probability of using trimethoprim-sulphonamides, tetracyclines and penicillins (-0.1%, -0.4% and −0.05%, respectively) and total AMU in weaners (-0.074 DDDA/Y). Having a boar for estrus detection from own production was associated with less total AMU in sows/sucklings (-0.4 DDDA/Y) and lower relative probability of using macrolides/lincosamides in the same age group (-3.6%). Being a conventional farm was associated with increased total AMU in weaners (2.4 DDDA/Y) and use of tetracyclines in them (14.5%). Inspecting clinically affected animals at least twice a day with immediate isolation showed a positive association with total AMU in weaners (1.5 and 0.25 DDDA/Y, respectively) and increased the probability of using tetracyclines there (6.3%). Lastly, lower post-weaning aggression was associated negatively with total AMU in weaners (-0.41 DDDA/Y) and the probability of using macrolides/lincosamides in them (-1.6%), while presence of a fully slatted floor in the same age group appeared as risk for both total AMU and probability of using penicillins (1.07 DDDA/Y and 4.9% respectively).

### 3. Discussion

In this study, potential associations between farm characteristics and AMU were assessed using cross-sectional data from 154 pig farms in the Netherlands in 2019. The extra class specific AMU outcomes studied here were found previously to be driven by at least one distinctive disease aetiology for group treatments [15], which indicates that there is merit in looking at their associated risk factors. The focus of this study was on weaners, as they appear to be the animal category for which antimicrobials are mostly prescribed and used in Dutch pig sector [3].

The main protective factors for AMU in sows and suckling piglets, were *E. coli* vaccination in sows, having an self-reared boar for estrus detection, farmer's tertiary education and not being a conventional farm (either organic or “Beter leven 1”). *E. coli* vaccination in sows is known to protect for neonatal diarrhoea [16]. Another issue related to vaccination is needle management. Here, changing the needle
every few pens (vs not, which included mostly farmers that changed the needle when it was not functional anymore) was protective against penicillin use. Repeated use of needles is of concern for pathogen transmission and inflicting larger punctures [17]. For further reduction of stress and higher pig welfare, needle-free vaccines can be considered [18][19] but here such correlation was not found. Having a closed herd is among the best farm practices in terms of external biosecurity [20][21]. Also farmer’s education is a key (indirect) determinant of prudent AMU, as it promotes suitable on-farm practices and AMR awareness [11]. Interestingly, in developing countries, farmer’s education tends to be low whereas in developed ones misconceptions (e.g. about AMR increasing by extensive AMU) are often present [11]. The higher AMU risk in conventional vs organic farms may derive either from higher animal densities [22] that act as stressor and favour pathogen transmission, but also from the policy of organic production that requires the farm to be extremely prudent with AMU in general (Regulation (EU) 2018/848 [23]).

Given that organic farms indeed are quite different in terms of practices compared to the conventional ones, stratified analysis was also performed. The results were similar and thus it was chosen to include organic and conventional farms in one analysis. Previous studies have shown that organic farms have also lower resistance levels in their *E. coli* isolates compared to conventional ones [24][25]. Additionally, frequent checks of drinking water and obtaining water from a public supplier (instead of a private water well or similar) were protective factors. Biosecure drinking water management is vital for pig health as it can be a common transmission pathway of pig pathogens and resistance [26].

In weaners, several factors associated with the AMU outcomes were shared with the other age groups, such as being a conventional farm, having a self-reared boar for oestrus detection and farmer’s education. Among the main factors associated with total AMU in weaners, we found PRRS vaccination in sucklings as risk and having a free-sow system during lactation along with lower post-weaning aggression as protective. Although the finding for PRRS vaccination could be a result of reverse causality (as farms experiencing recurrent outbreaks tend to use them more), there are vaccine related drawbacks too, including failure to prevent infection/transmission as well as modified-live PRRS vaccines that can revert to virulence [27][28][29]. Furthermore, free-sow systems seem to be an alternative option to the farrowing crates, allowing sows and piglets to display natural behaviours [30]. Although, there is the risk of more crushed piglets however, it seems that overall survival between those two types is comparable [31]. Also here, higher aggression in weaners was associated with more AMU while it appears to be involved in various health issues [32]. Interestingly, better animal welfare due to less stress has been linked to reduced AMU [33] and overall here we found comparable evidence. Higher within-farm densities than the adopted production scheme requires was the third largest risk for total AMU in weaners and was followed by inspecting clinically diseased animals frequently, but this is a finding most likely related to reverse causality and it mirrors the importance of regular checks and immediate isolation of animals that need additional care. The presence of fully slatted floors for weaners appeared to pose a significantly increased risk too, with unsuitable flooring causing wounds and limiting normal behaviour in pigs being a well-known risk factor [34]. Longer lactation lengths (mainly the contrast between early and late weaning; i.e. 23–28 vs 40–50) showed a protective effect and it is known to provide more immunocompetent piglets which show better performance and viability later on [35][36]. Interestingly, AMU in weaners was
higher for farms that bought suckling piglets of 9kg (thus, lactation did not took place there) even from farms that applied short lactation periods of 23 to 28 d. Mixing of slow growers (i.e. ‘leftover pigs’) after delivery of normal pigs was also identified as a risk factor for total use of macrolide-lincosamides. In general, this type of risk can occur not only on the last production stage but throughout the whole production flow even at farms with All-In/All-Out (AIAO) and it is associated with impaired health and growth performance [37]. Lastly, visiting diseased animals at the beginning of the farm-round was also an important risk for use of trimethoprim-sulphonamides while it is known to be a practice of low internal biosecurity standards [38].

For fatteners, having a hygiene lock per building and PRRS vaccination in sucklings appeared as risks for their total AMU and having a farrowing system of one, two or three weeks (vs four or five) as protective. The latter appeared as protective for macrolides-lincosamides in sows/sucklings too but was in contrast with the finding of one and two weeks being a risk for use of tetracyclines in the same age group and previous research [39]. This inconsistency most likely is it due to residual confounding or sampling bias while literature suggests that four to five weeks farrowing rhythm might be preferable because shorter cycles favour within-farm transmission [40], though this practice is closely related to the length of lactation period.

The main limitations of the current study are to be found in its cross-sectional design that is prone to reverse causality, as well as residual confounding and selection bias, considering that this is an observational study. Moreover, the crude effect of the risk factors could be quantified here and could not be discriminated into indirect or direct (i.e. the causal pathway contains or not the disease presence as mediator, respectively) but the use of Random Forest allow also for quantification not only of population-level effects but of individual too. Lastly, the focus here was on practices that are correlated with AMU and thus are related to spread of bacterial pathogens but many pig conditions are also due to viral infections and some are polymicrobial in their nature. However, important farm-level transmission routes of both viral, bacterial and parasitic pathogens overlap creating common intervention targets. Combining these results with a risk assessment towards specific diseases (the ones found to drive our AMU outcomes used here) can provide quantified evidence for tailor made farm-level interventions as it provides also the mediator but without underestimating the limitations of observational studies in detecting causal effects.

4. Conclusions

In this study on 154 Dutch pig farms, several associations between total and class-level antimicrobial usage and on-farm technical characteristics were identified, providing a comprehensive overview of factors driving AMU and therefore provide potential targets for farm-level interventions to control diseases and thereby reduce AMU. While the factors identified here were mainly confirmatory in nature (as they have been described before), there were some exceptions such as weaner’s aggression, free-sow systems during lactation, and farmer’s tertiary education, which were associated with decreased AMU.
5. Materials and methods

5.1. Study design and data collection

In 2020, data on 154 multiplier pig farms in the Netherlands were collected using a cross-sectional study design. Information on AMU overall and per antimicrobial classes along with a wide range of farm's structure and management characteristics was gathered with a digital questionnaire. The data collection period lasted 12 months and the data reflected the farms’ situation during the whole year of 2019. The AMU data were already recorded by the farm quality assurance systems in a harmonized way for statutory reporting to the SDa. In total, 34 different veterinarians from the major five veterinary practices specialized in porcine medicine across the Netherlands completed the surveys. Farms were selected randomly from veterinarian's customer farms that had at least weaners. Weaners were our main interest since in the Netherlands, it is the group with the highest AMU [3]. As the prior suckling period is closely related to the weaning phase, sows and suckling piglets were studied too, while fatteners were included only at the total AMU level and not per antimicrobial class. The internal participation rate per practice is unknown to us. The questionnaires were filled out by the veterinarians themselves in cooperation with the farmers where needed. Both veterinarians and farmers were informed about the study aim and gave consent for analysis of anonymised data for research purposes. Financial compensation for the labour time spent in filling out the questionnaires was provided to the veterinarians according to their standard hourly rates.

The questionnaires collected AMU data for 11 antimicrobial classes: aminoglycosides, amphenicols, combinations, macrolides-lincosamides, other (here only spectinomycine was reported), penicillins, pleuromutilins, polymyxins, quinolones, tetracyclines and trimethoprim-sulphonamides. These classes were defined according to SDa classification [3] and guidelines published by the Dutch Royal Society for Veterinary Medicine (KNMvD) regarding AMU in pigs [41]. Total AMU and AMU per antimicrobial class were expressed as Defined Daily Dosage per Animal per Year (DDDA/Y). For DDDA/Y, AMU is equal to the amount of active substances divided by the total weight of the number of animals (standardized weights are used for each age category [42]) in the farm and mean authorized dosage [43] showing the average number of authorized dosages the average animal is exposed to and can be interpreted also as the average number of days an animal is treated (with standardized daily dosages) in the farm within a year [44]. The AMU outcomes of interest were: total AMU in sows/sucklings, weaners, and fatteners; use or not of macrolides-lincosamides, penicillins, tetracyclines and trimethoprim-sulphonamides in sows/sucklings and weaners (separately); and total use of macrolides-lincosamides in weaners. These additional class specific AMU outcomes were included as they were linked to at least one disease aetiology for applying a group treatment in the respective age group from previous risk analysis of the same dataset [15].

As discussed above previous research has shown that non-medical risk factors occur within several aspects of farming and can play a significant role in a farm's total AMU [7][9][10]. Here, with the collected data about farm characteristics, it was possible to include an extensive list of factors providing an overview of the main technical aspects of pig production, as well as the possible pathogen transmission
pathways, internal and external biosecurity standards, housing conditions, vaccination schemes, feed and water quality, husbandry practices, structural features (e.g. number of workers, production type among others) and a few characteristics of the farmer such as educational background. The survey was constructed based on the input from Dutch pig veterinarians, scientific literature and other similar surveys (e.g. Biocheck UGent [45]) while the focus was on the weaning phase given the high AMU there. **Table S1** in supplementary material contains the descriptive statistics of all the variables present in different models (see Additional file 1). Also, in the supplementary material the full survey can be found (see Additional file 2).

### 5.2. Statistical analysis

A variable selection procedure was applied to identify risk factors at the farm level for AMU. We used a mixed-effects conditional Random Forest analysis with “MixRF” [46] and “party” R packages [47]. Two nested random intercepts for each veterinarian within each veterinary practice was applied to correct for potential clustering given the study design. A Random Forest model was preferred to address the various interaction effects [48] that are expected among the risk factors given the complexity of a livestock farm. Variable selection was applied manually using the steps from the “binomialRF” R package [49][50] but by using a conditional Random Forest with mixed-effects (hereinafter referred to as CmRF model). This novel algorithm has greatly reduced computational time as it uses significantly less models and iterations to conclude compare to others [49]. The steps of the selection algorithm were as follows:

1. Run a CmRF model with all $X_j$ variables from initial set.
2. Tabulate the frequency counts of root node splitting variables.
3. Calculate the probability of randomly selecting $X_j$ using Eq. 2.

$$p_{root} = \frac{1}{m} \left[ 1 - \prod_{g=1}^{m} \frac{P-g}{P-(g-1)} \right]$$

With $P$ being the total number of $X_j$ and $m$ being the number of subsampled variables for each tree (i.e. $P/3$).

4. Conduct a binomial exact test for significance of a variable $X_j$ with Eq. 3.

$$P \left( X_j = F_j | V \right) = \binom{V}{F_j} p_{root}^{F_j} \left( 1 - p_{root} \right)^{V-F_j}$$

With $F_j$ the frequency counts of $X_j$ and $V$ the total number of trees.
After correcting for the family wise error, we selected $X_j$ variables with Bonferroni adjusted p-value < 0.05

The above was iterated 10 times using the “binomialRF Model Averaging” method [49][50] where in each run an additional 10% of total features randomly without replacement were added. Variables present in less than half of the iterations were considered noisy and thus not selected. A specific optimal subset for each AMU outcome was defined with the above steps. Furthermore, in all final selected models, the effect size for each variable was estimated using the method of partial dependence as performed in the “rfUtilities” R package [51][52]. The steps of this algorithm included the following:

i. Run a CmRF model with all variables $X_j$ selected for a specific AMU outcome from the above algorithm.

ii. Estimate partial dependence (for a single variable of interest $X_E$), i.e.:

a. Create D datasets ($d = 1, ..., D$; where D is the number of unique values of $X_E$). For all observations in the $d^{th}$ dataset, only let them take one value for the variable $X_E$ while keeping values of all other variables unchanged.

b. Pass the $d^{th}$ dataset through the CmRF model and average its prediction for all observations (if the outcome is binary average the probability of having 1).

c. Repeat Part b for each of the D datasets.

iii. Construct a point estimate of the proposed effect size by fitting a weighted least square model with the response being the sample averaged CmRF predictions obtained in step ii and the explanatory variable being the corresponding value $X_E$ used to generate each prediction and a weight based on the frequency of each value the explanatory variable takes on in the original data.

Due to randomness intrinsic to the random forest algorithm, the results varied slightly across runs; thus, the two-step selection algorithm was applied iteratively twenty times and variables appearing in all iterations were kept. Subsequently normal and Sidak adjusted bootstrapped confidence intervals were calculated with 200 iterations. As conditional Random Forest [47] handle missingness using surrogate splits [53] the level of 60% in the predictors was allowed. However, due to missingness, it was not possible to calculate conditional importance of the predictors in each model and because unconditional importance gives biased results when correlated variables are present [54][55], this measure was avoided. Variables with low variation (< 10%) were excluded too. The open-source environment R version 4.0.3 [56] was used for all analyses.

Declarations

Ethics approval and consent to participate

This study was based on de-identified farm registry data. No sampling of animals or human subjects was performed, so no ethical approval was required.
Consent for publication

Not applicable.

Availability of data and materials

Anonymized data related to the current study are available from authors at reasonable request and R code for the models and graphs developed here is available at https://github.com/forestiy/CIAOCIAO_pigs.

Competing interests

All authors confirm that there are no potential conflicts of interest.

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Authors’ contributions


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References


46. Jiebiao Wang, Chen LS. MixRF: A Random-Forest-Based Approach for Imputing Clustered Incomplete Data [Internet]. 2016. Available from: https://cran.r-project.org/package=MixRF


Figure 1
Total antimicrobial use of all 154 farms per class and age category; the three categories appear in the same order as in the legend.

Figure 2

Farm characteristics associated with the use of specific antimicrobial classes in weaners. Colours represent the classes, the size of the symbols represent the number of outcomes this characteristic was associated with (including also the rest AMU outcomes), and the shape shows whether in any of these cases (affecting more than two outcomes) the association was of the same direction. Effect sizes are shown in decreasing order for each AMU outcome. Each point shows the expected change (%) in the relative probability of using an AB class, if it is positive it is a risk and if it is negative it is protective; the four outcomes appear in the same order as in the legend.
Figure 3

Farm characteristics associated with the use of specific antimicrobial classes in sows/sucklings. Colours represent the classes, the size of the symbols represent the number of outcomes this characteristic was associated with (including also the rest AMU outcomes), and the shape shows whether in any of these cases (affecting more than two outcomes) the association was of the same direction. Effect sizes are shown in decreasing order for each AMU outcome. Each point shows the expected change (%) in the relative probability of using an AB class, if it is positive it is a risk and if it is negative it is protective; the four outcomes appear in the same order as in the legend.
Figure 4

Farm characteristics associated with the total AMU in weaners, sows/sucklings and fatteners. Colours represent the outcomes, the size of the symbols represent the number of outcomes this characteristic was associated with (including also the rest AMU outcomes), and the shape shows whether in any of these cases (affecting more than two outcomes) the association was of the same direction. Effect sizes are shown in decreasing order for each AMU outcome. The effect size shows the expected change in DDDA/Y; if it is positive it is a risk and if it is negative it is protective; the four outcomes appear in the same order as in the legend.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfile1.docx
- Additionalfile2.pdf