Antimicrobial use in food-producing animals: a Rapid Evidence Assessment of stakeholder practices and beliefs

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Abstract

Food-producing animals throughout the world are likely to be exposed to antimicrobial (AM) treatment. The crossover in AM use between human and veterinary medicine raises concerns that antimicrobial resistance (AMR) may spread from food-producing animals to humans, driving the need for further understanding of how AMs are used in livestock practice as well as stakeholder beliefs relating to their use. A Rapid Evidence Assessment (REA) was used to collate research on AM use published in peer-reviewed journals between 2000 and 2016. Forty-eight papers were identified and reviewed. The summary of findings highlights a number of issues regarding current knowledge of the use of AMs in food-producing animals and explores the attitudes of interested parties

regarding the reduction of AM use in livestock. Variation between and within countries, production types and individual farms demonstrates the complexity of the challenge involved in monitoring and regulating AM use in animal agriculture. Many factors that could influence the prevalence of AMR in livestock are of concern across all sections of the livestock industry. This REA highlights the potential role not only of farmers and veterinarians but also of other advisors, public pressure and legislation to influence change in the use of AMs in livestock.

Introduction

Food-producing animals throughout the world are likely to be exposed to antimicrobial (AM) treatment. Whilst AM use may vary widely between and within countries, species, production systems and individual farms (Sawant and others 2005), over the last 50 years AMs have formed a key part of animal agriculture, especially in the developed world (Busani and others 2004). Yet debate is growing over the implications for human health of using AMs in food-producing animals. The crossover in AM use between human and veterinary medicine has also given rise to concerns that resistance to AMs may be spread from food-producing animals to human beings.

As a response to these concerns, national and international bodies including the World Health Organisation, the World Organisation for Animal Health (OIE) and the Food and Agriculture Organisation of the United Nations have called for AMs to be used responsibly and appropriately by all those who administer them. On a national level, guidance and legislation surrounding AM use in food-producing animals varies considerably (Scott and others 2015).

In order to better understand the role that AMs currently play in human and veterinary medicine, recent calls have highlighted the need for improved monitoring of AM use, particularly in food-producing animals (Gonzalez and others 2010). Monitoring usage alone, however, reveals little about what is driving AM use in practice, such as the beliefs, motivations and activities of stakeholders involved at ground level, particularly farmers and their veterinarians. Such understanding is vital if a true assessment is to be made as to whether AMs are being used as advised (i.e. responsibly and appropriately), as well as to identify potential motivators and barriers to change in practices that may be necessary to meet these requirements.

As part of a larger project, a Rapid Evidence Assessment (REA) was conducted to investigate what is currently known about the use of AMs in food-producing animals, encompassing their use at farm level, the practices and perceptions of the stakeholders involved in their administration, and the availability and validity of data on their use in practice. REAs are increasingly promoted as a valid alternative to systematic reviews of the research literature when time constraints do not allow a full systematic review to be undertaken, and are completed in full acknowledgement of the trade-off between a review being exhaustive and it being feasible to complete within a limited period of time (Ganam 2010; Thomas and others 2013). REAs allow for the comprehensive and descriptive assessment of a defined body of literature and, as Varker and others (2015) point out: ‘rigorous methods for locating, appraising and synthesizing evidence from previous studies can be upheld and results can be produced in a fraction of the time required for a full systematic review’. Moreover, REAs also ‘serve as an informative brief that prepares stakeholders for discussion on a policy issue (Varker and others 2015).

While the application of the REA methodology to more qualitative and social material is generally less common than its use in quantitative and technological review (Thomas and others 2013), the increasingly acknowledged explanatory power of qualitative evidence, and its particular relevance here in the case of the ongoing debate over AMR, make a strong case for such evidence- where robustly and convincingly generated- to be appropriately and collectively reviewed.

Materials and methods

The validity of the REA method is in large part dependent upon the transparency of the process employed to identify and select papers for consideration. Consequently, a comprehensive description of the overall REA methodology adopted here, time span and search strategies are reported in Figure 1 and in the Supplementary Material. Although the methodology adopted and the restricted number of scientific publications did not allow for an exhaustive appraisal of the study design and validity of every study included, this was not the purpose of the REA.

Results

In total, 48 peer-reviewed papers fell within the remit of addressing current practice and attitudes towards AM use in food-producing animals. Highlights of the papers identified and general overviews are presented, by species, in the text. For a comprehensive summary of the papers identified by the REA, please see Supplementary Material.

Comparison of findings by production system

Pigs

In some countries, the largest proportion of single-species AMs sold for food-producing animals are intended for pigs (VMD, 2014). This may result from the fact that pigs are commonly treated as a group rather than as individuals (Merle and others 2012; Sjolund and others 2015; Sjolund and others 2016; Timmerman and others 2006), although individual treatments were most common in Sweden (Sjolund and others 2016). Furthermore, it has been suggested that a shift over the last decade from in-feed to in-water group treatments has led to an increase in antimicrobial use on pig farms (Fertner and others 2016). Across Belgium, France, Germany and Sweden, weaned pigs tended to have more treatments than suckling or finishing pigs (Sjolund and others 2016).

AM use by class

Chauvin and others (2002) noted that French pig veterinarians prescribed numerous AMs to pigs, often prescribing many for similar purposes. Overall, tetracyclines were identified as being prescribed frequently (typically for respiratory conditions), as were peptides (colistin), macrolides (both predominantly for enteric conditions), benzylpenicillins, beta-lactams, doxycycline and amoxicillin (Bashahun and Odoch 2015; Chauvin and others 2002; Moreno 2012; Sjolund and others 2016; Timmerman and others 2006; van Rennings and others 2015). Fluoroquinolones and cephalosporins were either not used at all or used in low levels (Chauvin and others 2002; Sjolund and others 2015; Sjolund and others 2016; Timmerman and others 2006), and were often used as injectables administered to individual animals.

AM dosing

Considerable variation in AM use was identified, with treatment durations ranging from 1-21 days. The number of daily dosages (NDD) per average pig year ranged from 0-400, indicating that while some farms managed to rear pigs without the use of AMs, others exceeded the defined (registered) animal daily dose for one year (Van der Fels-Klerx HJ 2011). Inappropriate dosing was identified as being a common factor, with reports of 50-75% of oral AM formulations underdosed, and 41->90% of parenteral formulations overdosed (Chauvin and others 2002; Trauffler and others 2014). Vaccination is often touted as an alternative to AM use in production animals, and one paper reported vaccination rates ranging from 11-87% (Stevens, 2007). Group prophylactic or metaphylactic treatments were also common (Timmerman and others 2006). Using AMs prophylactically was considered both justifiable and prudent by both veterinarians and farmers (Coyne and others 2014; Stevens 2007), although many farmers felt that the amount of AMs used for this purpose could be reduced (Stevens 2007).

Cattle

Within the dairy sector, treatments for mastitis along with dry cow therapy administered at the end of lactation made up a large proportion of the AMs administered (Brunton and others 2012; Gonzalez Pereyra and others 2015; Higgins and others 2012; Stevens and others 2016; Swinkels and others 2015). In some countries, routine preventive use of AMs in all cows is forbidden, so AM dry cow therapy can only be used in cows with pre-existing intramammary infections (Swinkels and others 2015). One study comparing organic and conventional systems found the types of antibiotic tubes and injectables used were very similar, although while 85% of conventional farmers used dry cow tubes on all cows at drying off, only 18% of organic farmers did the same (Brunton and others 2012).

AM use by class

Critically important AMs such as 3^{rd} and 4^{th} generation cephalosporins were used for mastitis extensively in the UK, Belgium and the US (Brunton and others 2012; Stevens and others 2016; Zwald and others 2004), but less so in Italy and Switzerland (Busani and others 2004; Gonzalez and others 2010; Green and others 2010). The use of beta-lactams including penicillins, aminoglycosides, tetracyclines, aminocyclitols, lincomycin and trimethoprim/sulphonamide groups was reported in Argentinian, German, Swiss and American studies (Gonzalez Pereyra and others 2015; Green and others 2010; Merle and others 2012).

A small number of dairy herds in two US studies reported using AM products that are either explicitly prohibited for use in dairy cattle (Zwald and others 2004) or not recommended in food-producing animals (Cattaneo and others 2009); this practice was also reported in Nigeria (Ojo and others 2016).

Calf treatment

Calves appear to receive more AM treatments than older animals in dairy production in Sweden and Germany (Merle and others 2012; Ortman and Svensson 2004), although lower use was reported in calves than dairy cows in Argentina (Gonzalez Pereyra and others 2015). Fluoroquinolones were extensively used to treat enteritis in Argentina and Italy (Busani and others 2004; Gonzalez Pereyra and others 2015). A Swedish study (Ortman and Svensson 2004) found that 61% of farmers administered AM treatment without prior consultation with a veterinarian, although veterinarians became increasingly involved in treatment as the animals got older.

AM dosing

Treatment durations were reported to be longer for injectable preparations than for oral preparations (Ortman and Svensson 2004). Inappropriate dosing was reported, with overdosing compromising the stated withdrawal period and underdosing possibly acting as a risk factor for the development and spread of antimicrobial resistance (AMR) (Gonzalez and others 2010). Duration of mastitis treatment was occasionally or frequently extended beyond the duration initially specified (Swinkels and others 2015), and low numbers of farmers said they always completed a course of AMs presented for a given condition (Sawant and others 2005).

One of the risk factors for the spread of AMR is the exposure of calves to AMs through the provision of antibiotic waste milk. Although this practice is commonplace (Brunton and others 2012; Zwald and others 2004), waste milk is not the only means by which calves may be exposed to AMs. Commercial milk substitute containing prescription antibiotics was often reported (Brunton and others 2012; Zwald and others 2004).

Italian veterinarians reported often or sometimes administering AMs before the onset of clinical signs of diarrhoea (20%) and respiratory disease (28%), while 62% prescribed

AMs prophylactically against mastitis at drying off, and often reported failure of AM treatment (Busani and others 2004).

Other species

A study into the use of antibiotics in intensive poultry farms in Uganda found that the majority (96.7%) of study participants frequently used antibiotics in their animals and that 33.3% (n=10) used antibiotics for growth promotion, furthermore it was reported that 'most' of the participants admitted to selling their products within the meat withdrawal times (Bashahun and Odoch 2015). Another study assessing the usage and practices of antimicrobial use in production animals in Nigeria surveyed producers farming chicken, turkey, guinea fowl, geese, duck, horse, cattle sheep, goat, dog, rabbit and quail. This study found that AMs were widely used in all production animals, and frequently used for prophylaxis, including the use of critically important AMs for this purpose. The use of antimicrobials banned for use in humans and animals was also reported (Ojo and others 2016).

Attitudes, beliefs and external influences on AM use

Factors influencing farmers' use of AMs

Type of production system, high production costs and an inability to reinvest in infrastructure were identified as factors that UK veterinarians and pig farmers felt influenced their AM usage, with the implication that AMs were being relied upon in the short term (Coyne and others 2014; Stevens 2007). Farmers who reported that their farm environment could be improved were significantly more likely to use in-feed AMs for their growers and finishers than those who did not (Stevens 2007). In the UK, farm type was found to influence in-feed AM use, and in Austrian pig herds, farm type was found to impact average AM consumption (Stevens 2007; Trauffler and others 2014). In Austria, farm size had no significant impact on AM consumption, although there was an effect of the individual veterinarian on the therapy indication and active substance chosen (Trauffler and others 2014). In Belgian pig herds, a negative association was identified between biosecurity score and treatment incidence (based on used daily dose); fewer prophylactic AM group treatments were given in herds with higher biosecurity (Laanen and others 2013). Farmers in Nigeria also acknowledged that readily available AMs may encourage non-adherence to hygienic principles and management (Ojo and others 2016).

In beef cattle, herd size and farm type (cow-calf only or multiple operation type) had an influence on AM use (Green and others 2010).

A survey of dairy farmers in England and Wales found that only 17% of farmers would ask for veterinary advice before administering antibiotics to their animals (Jones and others 2015). In Ohio, over three-quarters (77%) of dairy veterinarians surveyed believed their clients followed protocols for AM use, while only 23% stated that they supplied protocols for AM use every time they prescribed them (Cattaneo and others 2009). Veterinarians in an Ohio-based survey also believed that their clients frequently used AMs without veterinary consultation (Cattaneo and others 2009). Similar findings were reported for Pennsylvania dairy farmers (Sawant and others 2005) as well as Nigerian farmers (Ojo and others 2016). Farmer AM treatment threshold was, however found to have no correlation with the use of protocols or frequency of veterinary visits in US farmers from Michigan and Ohio (Habing and others 2016).

Owners and managers of US feedlots perceived the expectations of many other members of the feedlot network (packers, retailers, consumers) to be important considerations in their own decision-making regarding AM use and also reported having a moral obligation to the cattle to treat with AMs, but degree of this perceived obligation varied by circumstance (McIntosh and Dean 2015). Concern for the public health impact due to AM use in livestock seemed to affect AM use of farmers from Ohio and Michigan, US, as those with more concern about this had a significantly higher treatment threshold in their animals (Habing and others 2016).

Extending treatment duration for clinical mastitis was found to be a social norm among farmers in the Netherlands and Germany (Swinkels and others 2015). In addition, some farmers reported extending treatment because it made them feel like ‘good farmers’ (Swinkels and others 2015). Danish organic dairy farmers also tended to perceive AMs as the treatment method with the best prognosis as well as the most responsible method to aid animal welfare and end animal suffering (Vaarst and others 2003).

Farmers’ knowledge of correct AM use

Just over half (53%) of 71 English and Welsh dairy farmers responding to a survey, reported knowledge of the Responsible Use of Medicines in Agriculture Alliance’s (RUMA) guidelines for use of AMs in cattle production in the UK, and 30% were not aware of concerns over the use of 3^{rd} and 4^{th} generation cephalosporins (Jones and others 2015). Furthermore, 20% of these farmers admitted that they do not always complete a full course of AMs as prescribed (Jones and others 2015). Spanish farmers are also “not very knowledgeable” about the proper use of AMs, and some may not be clear about the differences between curative and preventive uses (Moreno 2014). Approximately half (14/30) of Ugandan farmers were not aware of withdrawal periods for antibiotics (Bashahun and Odoch 2015). Farmers from various European countries tended to think they used AMs more judiciously and less frequently than their peers (Coyne and others 2014; Visschers and others 2015).

One study identified ‘learning processes’ that farmers used to implement new health practices, along with the role of the veterinarian and other technical advisors who facilitated farmers to implement change by aiding these learning processes (Fortane and others 2015).

Farmers’ motivation for AM use and reduction

Just over 70% of surveyed dairy farmers from England and Wales agreed that reducing AM use in their herd over the next year would be a good thing, with 59% stating that they had the skills and knowledge to do so (Jones and others 2015). Restricting AM use was also considered important by 87% of Dutch dairy farmers (Scherpenzeel and others 2016) . Both the UK and Dutch farmers as well as farmers from Belgium, France, Germany, Sweden and Switzerland cited a reduced cost of production as the primary reason driving them to reduce AM use (Brunton and others 2012; Jones and others 2015; Scherpenzeel and others 2016; Visschers and others 2015). Dutch farmers also cited ‘improving public health’ as one of the most positive outcomes of restricting AM use (Scherpenzeel and others 2016). French pig farmers cited various reasons for choosing to reduce AM use, including health events, new economic and health strategies and ethical considerations (Fortane and others 2015).

Farmer concerns regarding AM reduction

Over half (53%) of British pig farmers believed that AM use resulted in the production of increased amounts and cheaper food, and 21% indicated the use of AMs for growth promotion was justified (Stevens 2007). A minority (18%) of English and Welsh dairy farmers, however, thought that milk production would decline if they reduced AM use in their herds (Jones and others 2015). Spanish farmers also agreed that AMs play a role in enhancing performance parameters (Moreno 2014). Dutch dairy farmers cited uncertainty over recovery of sick cows and the number of sick cows as concerns regarding reduced AM use as well as additional labour requirements and feeling that they were being pushed to follow rules they do not agree with (Scherpenzeel and others 2016). In this same study, Dutch farmers implementing selective dry cow therapy considered ‘financial consequences’ a negative impact of reduced AM use less often than those using blanket dry cow therapy (Scherpenzeel and others 2016).

Farmer attitudes towards AMR

The threat of AMR was typically underplayed by food-producing animal stakeholders (Moreno 2014), with it being felt that there was insufficient evidence to decisively prove the link between using AMs in food-producing animals and the development of AMR in pathogens infecting humans (Coyne and others 2014). Most farmers from South Carolina that participated in one study seemed unconcerned that AM use in animals could lead to resistance among farm workers (Friedman and others 2007), while 58% of conventional farmers from Ohio and Michigan, US, disagreed that antibiotic use in agriculture led to resistant bacterial infections in people. In the UK, 7% of organic farmers felt similarly (Habing and others 2016). UK farmers were uncertain as to whether reduced AM use on their farms would affect animal health and welfare or whether such a decrease would reduce AMR (Jones and others 2015).

Veterinarian attitudes towards AMR

In the UK, veterinarians were cited as farmers' most trusted information source (Jones and others 2015). The majority of Dutch and Flemish veterinarians responding to a survey reported to have become more aware of the need to restrict the use of AMs and were aiming to reduce AM use in their practice as far as possible (Postma and others 2016). In the US, however, a negative correlation between the number of years a US veterinarian had been in practice and their knowledge of AMR was identified (Cattaneo and others 2009). Furthermore, years qualified was associated with veterinarians being less concerned about AMR (Speksnijder and others 2015a) and more confident in their independent prescribing practice (Dean 2011). Ohio dairy veterinarians were more likely to agree that AMR will negatively affect animal health (86%) than human health (63%; Cattaneo and others 2009). Key information sources for prescribing AMs were reported by veterinarians to be other veterinarians, their own personal experience, the label or leaflet accompanying the product, training or literature with which they were familiar, previous experience or the results of culture and sensitivity testing (De Briyne and others 2013; Dean 2011; Gibbons and others 2013; Postma and others 2016).

Veterinarian motivation for prescribing

Veterinarians in the UK, Ireland, the Netherlands and Belgium reported that demands from farmers, advisors or other veterinarians did influence their prescribing; they also felt under more pressure from legislation and public perception than farmers reported (Coyne and others 2014; Gibbons and others 2013; Postma and others 2016; Speksnijder and others 2015b). Dutch and Flemish veterinarians reported to have little concern over the farmers' preference for AM product when prescribing (Postma and others 2016). Social pressure from other feedlot veterinarians and nutritionists, however, was found to have more of an influence on beef feedlot cattle veterinarian attitudes towards AMs; these veterinarians cited their highest perceived expectation for AM prescription was from pharmaceutical companies (Jan 2010). Their levels of trust in other relevant actors (government agencies, other veterinarians, etc.) also influenced their decision making (Dean 2011). A sense of moral obligation to the public was found to be associated with a negative attitude to prescribing AMs (McIntosh and others 2009). The influence of these factors varied in different clinical situations, and social pressure (particularly that of colleagues and co-workers compared to, for example, nutritionists or clients) had more of an influence (Jan 2010). No evidence was found that veterinarians prescribing habits were driven by revenue or profit margin (De Briyne and others 2013; Gibbons and others 2013; Postma and others 2016), and preserving the veterinary pharmacy for future years was found to be a strong motivator for Dutch and Flemish veterinarians to reduce AM use (Postma and others 2016).

In the Netherlands, benchmarking that made the prescription patterns of veterinarians transparent was introduced in the hope of shifting social norms and encouraging veterinarians to self-regulate AM use (Bos and others 2015).

Sensitivity testing

The use of sensitivity testing varied widely between the European countries surveyed, with veterinarians reporting their decision whether to test depended on the animal's response to initial therapy as well as the veterinarian's knowledge of that animal or farm (De Briyne and others 2013). More rapid results and cheaper sensitivity testing were described to be key factors that would encourage veterinarians to make more use of sensitivity testing (De Briyne and others 2013).

Quality of data on AM use

It is challenging to measure on-farm AM usage due to the difficulty in obtaining an accurate account of the dosage and duration of treatment, with farmers often relying on their memory alone for recalling past treatments (Zwald and others 2004) and often under-reporting medicine use (Redding and others 2014). Veterinary records have been found to be more accurate than those of farmers, although both were reported to be incomplete or implausible (Gonzalez and others 2010; Merle and others 2012; Trauffler and others 2014). Data from the VETSTAT system in Denmark indicated that most of the entries from pharmacies were correct, while there were a high percent of errors in data originating from veterinarians and feed mills (Stege and others 2003).

Discussion

The 48 papers identified by the REA and summarised above highlight a number of issues regarding current drivers for the future use of AMs in food-producing animals. Table 1 summarises the key drivers of current antimicrobial use and the identified barriers for change, as taken from the REA. In terms of barriers to change, these summary findings reveal what can be interpreted as a sense of inflexibility particularly in the organisation of production systems and, as a consequence, in the potential 'spaces' for change, but also, though arguably to a lesser extent, in producer sensibilities around the nature of good husbandry. There is also, however, a clear indication that amongst respondents to the various surveys reviewed, there is both an awareness of the issue and a willingness to explore the potentials for change in antimicrobial use.

The huge variation between and within countries, production types and individual farms demonstrates the complexity of the challenge involved in monitoring and regulating AM use in animal agriculture.

Table 1. Identified key drivers and barriers to change of antimicrobial use in food-producing animals

Identified drivers in reducing antimicrobial use
Higher levels of on-farm biosecurity lead to lower prophylactic use
New methods of knowledge exchange and learning improve farmer awareness of and response to more sensible antimicrobial use
Reducing costs of production would encourage reduced antimicrobial use
Farmers recognise and acknowledge the need to reduce antimicrobials
Veterinarians in general support antimicrobial use reduction
No evidence exists that medicine sales by veterinarians are a factor driving overuse of antimicrobials
Better diagnostics or wider use of diagnostics would improve the ability to use medicines more effectively
Wider use of vaccines to prevent disease would reduce antimicrobial use

Identified barriers to more sustainable use
Production system inflexibility hinders reduction in antimicrobial use
High production costs reduce capacity for antimicrobial use reduction
Low capacity for reinvestment in farm buildings reduces capacity for reduction in antimicrobial use
Farmer concern over being a 'good' farmer hinders reduces antimicrobial use
Farmer concern for welfare and health of animals leads to a reluctance to reduce antimicrobial use
Farmer failure to follow treatment guidelines leads to over- or under-dosing of antimicrobials
Farmer belief that antimicrobial use will improve profitability hinders reduction in antimicrobial use
Veterinarians are under pressure from farmers, feed suppliers and others to use antimicrobials
Changes in antimicrobial use in feed regimes (e.g. from feed to water) represents potential for increased antimicrobial use
Farmers initiating treatment without seeking veterinary advice leads to inappropriate use of antimicrobials
Some farmers and veterinarians believe that antimicrobial prophylaxis is justifiable and prudent

The sample sizes and associated response rates in these studies illustrates the difficulties in recruiting participants for AM research, and should be taken into account when interpreting results. Other challenges include concerns about the ease of comparing the findings of studies across methodologies, countries and production systems. While some papers report AM product names, others use classes or active substances to categorise AMs. Complexity increases when the amount of AMs used is considered. A document published by the European Medicines Agency in 2015 set out principles for the calculation of defined daily dose for animals (DDDvet) and defined course dose for animals (DCDvet) as a veterinary equivalent to the defined daily dose developed for human medicine, taking medicine potency into account (EMA 2015). These methods are not globally recognised, however, and there remains a variety of different usage measures or dosage calculations included in the literature (Gonzalez and others 2010; Moreno 2012; Taverne 2015; Timmerman and others 2006).

Over half of the papers included in this REA reported research conducted within the EU. This may reflect the greater regulation of AM use in this region compared to other parts of the world (Scott and others 2015). The research question addressed by this REA focused particularly on pigs, poultry and cattle, yet only two papers on AM use in poultry could be identified for inclusion, suggesting a deficit of published peer-reviewed research in the poultry sector. The majority of papers identified in this REA instead covered AM use in pigs and cattle. Only one study performed within the EU made reference to AM use by a food-producing animal other than pigs and cattle, highlighting the impact of a few prescriptions for quinolones used in aquaculture on kilograms of AMs distributed per month by Danish pharmacies, due to the quantities prescribed (Stege and others 2003). Given the expanding global aquaculture industry, research into current AM use and beliefs in this sector should also be a priority.

There are a number of limitations of conducting an REA rather than an exhaustive systematic review, including biases relating to publication, language and accessibility, although these are not unique to REAs (Thomas and others 2013). Nonetheless, this work demonstrates the valuable contribution of the REA methodology to research when rapid insight into the current status of research in a given area is needed.

Conclusions

Multiple factors which could influence the prevalence of AMR in livestock species - including the improper use of AMs in both the pig and cattle sectors, across all global regions - remain a concern. Prophylactic and metaphylactic use of AMs appears to be common practice across all sectors for which relevant literature was found, largely pig and cattle production within EU countries, but also other sectors worldwide. Literature regarding the use of AMs in poultry production in the EU in particular was lacking from the searches. It is likely that data regarding AM consumption in poultry production are collected by poultry producers in some countries but these data are not available in the published literature. Work should therefore be done to amalgamate and publish any existing data or investigate this area of AM use further. Levels of farmer knowledge with regard to proper and prudent use of AMs varies between groups, although veterinary input regarding the treatment of animals was, on the whole, low across all geographical locations.

Economic concerns and restraints relating to farm infrastructure or production type may limit farmers' ability or motivation to alter AM use in their animals. Veterinary advice, public pressures, input from other advisors and moral obligation influence farmers' attitudes to AM use. Similarly, veterinary prescribing habits have been shown to be influenced by similar factors to differing degrees, and veterinarians' confidence in their own knowledge of the AMs they are prescribing also influence prescribing behaviour. It would stand to reason, therefore, that increasing knowledge of the proper use of AMs as well as awareness of AMR and encouraging a reduction in AM use in all of these sectors is necessary, and this could have synergistic effects when compared to strategies targeting only one group of actors.

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Figure 1. PRIMSA flow diagram illustrating the selection process for the final 48 articles (Moher and others 2009)