ABSTRACT

To tackle antimicrobial resistance, it is vital that farmers’ and veterinarians’ antimicrobial use behaviors and attitudes toward resistance are understood so that we can identify how beliefs and motives influence practices. Current literature details qualitative and quantitative research that explores the knowledge, attitudes and perceptions of dairy farmers and veterinarians with respect to antimicrobial resistance and antimicrobial practices, and the reported findings are varied and conflicting. Our objective was to conduct a systematic review to assess the evidence and knowledge gaps in the published literature. We identified articles via database searches of Embase, Medline, PubMed, Scopus, and Web of Science; we limited findings to published articles available in English with no publication year restrictions. Article screening was conducted at 3 levels: title, abstract, and full text. Of the 349 articles identified, 35 were retained for systematic review. Transparency of reporting was assessed for each study using the Consolidated Criteria for Reporting Qualitative Research (COREQ) framework. Quality was assessed using the Critical Appraisal Skills Programme qualitative checklist. Findings relating to dairy farmers’ and veterinarians’ knowledge, attitudes, and perceptions on antimicrobial resistance and practices were thematically analyzed. The comprehensiveness of reporting was variable: studies reported 5 to 26 of the 32 COREQ checklist items. Five key themes emerged from the data: knowledge and awareness of antimicrobial resistance; factors influencing farmer and veterinarian decision-making; perceived barriers and facilitators to reduced antimicrobial use; perceived responsibility for antimicrobial resistance; and the role of the farmer and veterinarian relationship in reducing antimicrobial use. Awareness of prudent antimicrobial use was not uniform between studies. Many factors influence farmers’ and veterinarians’ decisions to use antimicrobials, including animal welfare and available resources. The farmer–veterinarian relationship is a potential barrier or facilitator of reduced antimicrobial use, depending on the perceived relationship dynamic. Encouraging collaboration between farmers and veterinarians could lead to shared responsibility for reducing antimicrobial use. This review provided a coherent picture of what is currently known and identified gaps in the current knowledge to inform future behavioral intervention research. Increased knowledge, skill development, resources, engagement, and further research to address the gaps we identified are the main recommendations to effectively overcome barriers, elicit appropriate behavior change, and achieve reduced antimicrobial use in dairy cattle.

Key words: antimicrobial resistance, antimicrobial use, dairy farmers, veterinary medicine, systematic review

INTRODUCTION

Antimicrobial resistance (AMR) occurs naturally when microorganisms are exposed to antimicrobial drugs. Under selective pressure, susceptible bacteria are killed or inhibited, and bacteria that are naturally resistant or have acquired AMR have a greater chance of survival and risk of disease spread (Prestinaci, Pezzotti and Pantosti, 2015). Antimicrobial resistance is a major global health challenge (WHO, 2014): many lifesaving interventions such as chemotherapy and organ transplant rely on effective antimicrobials (Teillant et al., 2015), so AMR places humans and animals at substantial increased risk of prolonged illness or death from infection (Lambert et al., 2011). Experts have warned that if AMR continues to rise, so too will the associated social and economic costs (O’Neill, 2014).
Limiting antimicrobial use (AMU) is a vital step in limiting the development of AMR (WHO, 2017). Inappropriate AMU includes over- or underprescribing, inappropriate dosing, incorrect treatment duration or drug choice, and unnecessary use of expensive drugs when established, cheaper, and clinically adequate drugs are available (WHO, 2000). “Prudent use” of antimicrobials involves avoiding inappropriate AMU to preserve antimicrobial efficacy for as long as possible (Centers for Disease Control and Prevention, 2007). Antibiotic use in agriculture can lead to resistance in the environment and implications for public health (Manyi-Loh et al., 2018). It is widely acknowledged that research and policy efforts are needed to reduce agricultural AMU (FAO, 2016). A recent systematic review concluded that interventions that aim to restrict AMU in livestock are associated with reduced AMR in such animals (Tang et al., 2017).

Understanding stakeholder attitudes, decision-making, and the translation of behavioral intentions into sustained behavior change is an increasingly important discipline for policy design (Jones et al., 2015). Studies that explore the reasons for current AMU in agriculture are needed to design effective interventions to promote prudent agricultural AMU (Fischer et al., 2019). Monitoring of AMU in livestock alone reveals little about what drives AMU, so it is important to assess the behaviors of key stakeholders responsible for antimicrobial prescription and administration (Friedman et al., 2007).

It is important to understand the AMU behaviors of dairy farmers and veterinarians and their attitudes toward AMR to identify how their beliefs and motives influence their AMU (Busani et al., 2004). It has been reported that understanding farmers’ motivations to implement recommended practices is necessary for reducing AMU (Poizat et al., 2017) and for measuring knowledge and behaviors that protect both animals and humans from AMR and disease transfer (Friedman et al., 2007). In addition, on-farm AMU needs to be characterized and the key drivers of responsible AMU identified; such findings may be able to inform interventions to reduce AMU on dairy farms (Higham et al., 2018).

Both qualitative and quantitative research methods have been used to explore topics such as the knowledge, attitudes, and perceptions of dairy farmers and veterinarians with respect to AMR and their individual AMU practices. Such research methodologies focus on 1 or 2 of these areas and have presented a range of findings; research exploring all of the above factors is scarce. Previous studies have not followed a common methodology, and the aims of such papers have been broad-ranging. To obtain a more in-depth knowledge of what is currently known, this review aimed to collate and synthesize all available published data relating to the knowledge, attitudes, and perceptions of dairy farmers and veterinarians with respect to AMR and their individual AMU practices. This will provide a coherent picture of what is currently known, identifying commonalities and contradictions in findings between studies and identifying gaps in the current knowledge to inform future behavioral analysis research and AMU intervention design.

**MATERIALS AND METHODS**

**Review Approach**

This review was reported in accordance with the Enhancing Transparency in Reporting the Synthesis of Qualitative Research (ENTREQ) framework, a reporting guideline for the synthesis of qualitative research (Tong et al., 2012). A copy of the framework is available as supplemental information (https://doi.org/10.6084/m9.figshare.13721083). To address the research question, articles of interest were those that explored the knowledge, awareness, attitudes, and perceptions of dairy farmers and dairy veterinarians with respect to AMU and AMR.

**Search Strategy**

In November and December 2019, we undertook a preplanned, comprehensive, systematic search of electronic databases to seek all available studies related to the research question. To obtain relevant articles, we conducted literature searches in Embase, Medline, PubMed, Scopus, and Web of Science. Articles included in the review were obtained predominantly via databases and, where applicable, additional articles were retrieved from the reference lists of published articles. The search terms used in the databases included “dairy farmer,” “dairy veterinarian,” “antimicrobial use,” “antibiotic use,” and “antimicrobial resistance.” We searched each database multiple times using combinations of the previously mentioned terms to yield as many relevant articles as possible. Full details of the search terms used, and results yielded from each database search is available as supplemental information (https://doi.org/10.6084/m9.figshare.13721083). We limited the search criteria for this review to published peer-reviewed articles available in English and placed no publication date limits on the database searches. We included only peer-reviewed journal articles aiming to explore the knowledge, awareness, attitudes, or perceptions of...
dairy farmers or veterinarians in the review. Studies that used surveys, questionnaires, interviews, and focus groups were included.

**Screening and Data Extraction**

Articles were retained for review if the study population consisted of or included dairy farmers and dairy veterinarians. Articles were excluded if the research was focused on the quantity of AMU on farms, did not focus on dairy farmers’ or veterinarians’ perspective with respect to AMU or AMR, or if no independent research method was outlined. Following the removal of duplicates, we screened articles obtained from all sources for eligibility based on title and abstract (n = 211). Articles were deemed eligible if they met the outlined inclusion criteria. Following a full-text review of the remaining articles (n = 76), those deemed eligible (n = 35) were retained for the systematic review. Articles were included only if the data-collection methods were adequately outlined (i.e., if they gave details of the study population, sampling method, and data analysis). Figure 1 illustrates the process of searching, screening, and identifying studies for inclusion in this systematic synthesis.

For each of the articles identified as eligible for this review, all text under the headings “Results” were extracted from the articles and exported into qualitative data analysis software NVivo 12 (QSR International Pty Ltd., Doncaster, Victoria, Australia) for data synthesis.

Transparency of reporting was assessed for each study using the Consolidated Criteria for Reporting Qualitative Research (COREQ) framework (Tong et al., 2007). The quality of the included studies was assessed using the Critical Appraisal Skills Programme Qualitative Research Checklist (Critical Appraisal Skills Programme, 2017). Appraisal was conducted by the first author (SF), and then discussed and agreed upon with the other authors. No study with data relevant to the aim of the review was excluded from the synthesis.

**Data Analysis**

Extracted findings were thematically analyzed inductively, in line with the Braun and Clarke (2006) protocol, allowing for themes to be constructed from the data. Extracted findings from each article were coded line by line to search for information of interest to the research question. All data relating to farmers’ and veterinarians’ knowledge, awareness, attitudes, and perceptions with respect to AMR and reduced AMU were coded. Codes were then grouped along with their related data into potential themes, identifying overlap and commonalities, and themes were refined where necessary (i.e., collapsed or divided). At this stage, extracted findings were re-read to ensure that no data had been missed in earlier coding stages. Coding was performed by 1 author (SF) and reviewed and approved by 2 additional authors (MD and TB).

**RESULTS AND DISCUSSION**

Thirty-five studies, which collected data from 5,537 participants, were deemed relevant for this review. An overview of the study characteristics is presented in Figure 2. The study population was exclusively farmers in 20 articles (only dairy farmers in 17 articles), exclusively veterinarians in 8 articles (only dairy veterinarians in 3 articles), and a multi-stakeholder study population that included dairy farmers and dairy veterinarians in 7 articles. Just over half of the studies used surveys as the data-collection method (54.3%); interviews (25.7%), mixed methods (14.3%), and focus groups (5.7%) were also used. Studies were conducted in mainland Europe (14), the United States (8), the United Kingdom (5), Asia (3), South America (2), North America (1), Oceania (1), and Africa (1). All included studies were published between 2002 and 2019. Thematic analysis identified 5 key themes in the data; themes and sub-themes are presented in Figure 3. Table 1 summarizes the key findings and recommendations based on the systematic review.

Comprehensiveness of reporting varied. Studies reported between 5 and 26 of the 32 COREQ checklist items; findings are summarized in Table 2 (full COREQ assessment of each study is available as supplemental information, https://doi.org/10.6084/m9.figshare.13721083).

**Theme 1: Farmers’ and Veterinarians’ Knowledge and Awareness of AMR**

Previous reports have suggested that a significant proportion of the farming community lacks knowledge of AMR and prudent AMU (WHO, 2015). In the present review, about a quarter of studies explored farmers’ knowledge and awareness of antimicrobials and AMR, and the reported findings varied considerably. Studies of UK and Washington dairy farmers reported high levels of awareness (Raymond et al., 2006; Higham et al., 2018), but studies of South Carolina, Malaysian, Indian, and Peruvian dairy farmers reported lower levels of knowledge and awareness (Friedman et al., 2007; Redding et al., 2014; Chauhan et al., 2018; Sadiq et al., 2018).
Knowledge and awareness of AMR were higher in higher-income countries; knowledge and awareness campaigns aiming to address AMR in dairy cattle should be disseminated globally and be consistent, so that all farmers have access to this information.

Recent reports highlight the need to provide livestock farmers with training in the appropriate use of antimicrobials in animals to tackle AMR (Ozturk et al., 2019). Five studies in this review explored farmer awareness of appropriate AMU, and reported findings varied. Tennessee dairy farmers generally perceived their AMU to be prudent (Ekakoro et al., 2018), but farmers in the United Kingdom, India, and France admitted to lacking knowledge and information about prudent AMU (Jones et al., 2015; Poizat et al., 2017; Kumar and Gupta, 2018). In India, farmers with larger dairy farms were more aware of the importance of animal husbandry practices for improving AMU than those with small farms (Kumar and Gupta, 2018). Many Peruvian and Kenyan farmers lacked an understanding of antimicrobial withdrawal times (Redding et al., 2014; Higham et al., 2016). These findings suggest that prudent AMU guidance should be disseminated globally to enable farmers to engage in practices that reduce the need for
antimicrobials. Because farm sizes vary globally, the ability to reach farmers may differ, and it is important to ensure that farmers receive practical guidance relevant to the scale of their operations.

Previous literature has shown that some livestock farmers do not have sufficient awareness of the severity of the problems that result from AMR (Moreno, 2014; Landfried et al., 2018). We found 10 studies that explored this problem, and farmers’ and veterinarians’ awareness about the risks associated with AMR varied. Many South Carolina, Washington, and UK dairy farmers were aware that increased AMU contributed to the development of AMR (Raymond et al., 2006; Friedman et al., 2007; Jones et al., 2015; Golding et al., 2019). Many Malaysian, Kenyan, and Peruvian dairy farmers were aware that resistant bacteria could be difficult to treat and posed a threat to their animals (Redding et al., 2014; Higham et al., 2016; Sadiq et al., 2018). In India, farmers with large dairy farms were more aware that the overuse of antibiotics increases the reservoir of AMR in the food chain than those with small farms (Kumar and Gupta, 2018). Most veterinarians understood the risks posed by AMU and agreed that it is important that AMU in livestock be restricted. Veterinarians in the United Kingdom demonstrated good awareness and understanding of the risks posed...
Table 1. Main review findings and recommendations made in relation to achieving reduced antimicrobial use on dairy farms based on systematic review

<table>
<thead>
<tr>
<th>Recommendations made based on systematic review</th>
<th>Relevant stakeholder(s)</th>
<th>Findings to support recommendation</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased knowledge</td>
<td>Dairy farmers</td>
<td>Variations in knowledge and awareness of AMR in dairy cattle</td>
<td>Raymond et al., 2006; Friedman et al., 2007; Cattaneo et al., 2009; Redding et al., 2014; Jones et al., 2015; Léger et al., 2015; Speksnijder et al., 2015, 2016; Magalhães Sant’Ana et al., 2017; McDougall et al., 2017; Poizat et al., 2017; Chauhan et al., 2018; Ekakoro et al., 2018; Higham et al., 2018; Kumar and Gupta 2018; Sadiq et al., 2018; Golding et al., 2019</td>
</tr>
<tr>
<td>Minimizing economic risks while reducing on-farm AMU2</td>
<td>Dairy farmers</td>
<td>Concerns about economic risks associated with reducing AMU on farm, such as animal mortality and farm productivity</td>
<td>Raymond et al., 2006; Friedman et al., 2007; Speksnijder et al., 2015, 2016; Magalhães Sant’Ana et al., 2017; Fischer et al., 2019; Golding et al., 2019</td>
</tr>
<tr>
<td>Skill development</td>
<td>Dairy farmer</td>
<td>Variations in awareness of prudent practices</td>
<td>Redding et al., 2014; Jones et al., 2015; Speksnijder et al., 2015, 2016; Scherpenzeel et al., 2016; Orpin, 2017; Poizat et al., 2017; Ekakoro et al., 2018; Higham et al., 2018; Kumar and Gupta 2018; Scherpenzeel et al., 2018; Fischer et al., 2019; Golding et al., 2019; Vasquez et al., 2019</td>
</tr>
<tr>
<td>Improved ability to prevent and manage mastitis and other diseases while reducing AMU via improved biosecurity and herd-management measures</td>
<td>Dairy farmer</td>
<td>Mastitis the most commonly reported reason for AMU in dairy cattle</td>
<td>Vaan et al., 2003; Raymond et al., 2006; Cattaneo et al., 2009; Jones et al., 2015; Speksnijder et al., 2015, 2016; Kayitsinga et al., 2017; Carmo et al., 2018; Ekakoro et al., 2018; Higam et al., 2018; Holstege et al., 2018; Kumar and Gupta, 2018; Fischer et al., 2019</td>
</tr>
<tr>
<td>Increased resources</td>
<td>Dairy farmer</td>
<td>Time constraints and labor burden reported as barriers to achieving reduced AMU</td>
<td>Friedman et al., 2007; Speksnijder et al., 2015, 2016; Poizat et al., 2017; Golding et al., 2019</td>
</tr>
<tr>
<td>Encouraging veterinarians to take on a proactive role in promoting alternatives to antimicrobials</td>
<td>Dairy veterinarian</td>
<td>Varieties seen by many farmers as having the ability to facilitate reduced AMU</td>
<td>Scherpenzeel et al., 2016; Golding et al., 2019</td>
</tr>
<tr>
<td>Encouraging farmers to use veterinary services and advice to reduce AMU</td>
<td>Dairy farmer</td>
<td>Farmers do not always seek veterinary advice because of the fees associated with their services</td>
<td>Friedman et al., 2007</td>
</tr>
<tr>
<td>Further research</td>
<td>Dairy farmer</td>
<td>Limited published data on prophylactic AMU on dairy farms</td>
<td>Busani et al., 2004; Redding et al., 2014; Speksnijder et al., 2015</td>
</tr>
<tr>
<td>Exploring how the opinions of others may influence farmer and veterinarian decision-making about AMU</td>
<td>Dairy farmer</td>
<td>Many farmers and veterinarians motivated by social norms in the industry</td>
<td>Jones et al., 2015; Scherpenzeel et al., 2016; Scherpenzeel et al., 2018</td>
</tr>
<tr>
<td>Determining the influence farmers have on veterinarians’ decisions to prescribe antimicrobials and how this can be minimized</td>
<td>Dairy veterinarian</td>
<td>Some veterinarians perceive pressure from farmers to prescribe antimicrobials, and the perceived skills and knowledge of farmers can influence prescribing decisions</td>
<td>Redding et al., 2013; Speksnijder et al., 2015; Higgins et al., 2017; Golding et al., 2019</td>
</tr>
<tr>
<td>Enabling farmers and veterinarians to work together confidently and effectively to reduce AMU</td>
<td>Dairy farmer</td>
<td>Many farmers and veterinarians open to a more collaborative working relationship to achieve reduced AMU</td>
<td>Magalhães Sant’Ana et al., 2017; Golding et al., 2019</td>
</tr>
</tbody>
</table>

Continued
in terms of animal-welfare threats, farm income, and productivity (Golding et al., 2019). Meanwhile, most Canadian veterinarians agreed that AMU in the dairy industry contributed to decreased antimicrobial efficacy in dairy cattle (Léger et al., 2015). In the Netherlands, almost all veterinarians (92%) agreed or partly agreed that veterinary AMU should be restricted to reduce AMR (Scherpenzeel et al., 2018). These findings suggest that the awareness of the risks associated with AMR is relatively high and widespread. Continuous information transfer of the risks associated with animal health because of AMU and AMR is important to ensure that all stakeholders are aware of the consequences of antimicrobial misuse.

Skepticism in the livestock sector about the contribution of agriculture to AMR has been previously identified, especially in terms of the potential links between agricultural AMU and human health risks (Morris et al., 2016; Etienne et al., 2017). In line with previous findings, we found that awareness of the link between AMR in agriculture and humans was low (20% of studies explored this topic). Although many South Carolina and Washington dairy farmers agreed that AMR could occur in both humans and animals, they showed a lack of concern that the overuse of antimicrobials or AMR in animals could threaten farm workers (Raymond et al., 2006; Friedman et al., 2007). Very few UK, India, or Tennessee dairy farmers perceived the threat of AMR in humans as a result of AMU or AMR in animals (Jones et al., 2015; Ekakoro et al., 2018; Kumar and Gupta, 2018). Only 2 studies explored veterinarians’ awareness of the link between AMR in humans and animals. Some Dutch veterinarians were motivated to reduce their AMU for public health reasons, but others doubted a significant contribution from veterinary AMU to AMR in humans (Speksnijder et al., 2015). Most Canadian dairy veterinarians disagreed on some level that AMU in dairy cattle contributed to resistance in human medicine (Léger et al., 2015). These findings

Table 2. Overview of comprehensiveness of reporting for review studies based on Consolidated Criteria for Reporting Qualitative Research (COREQ) framework

<table>
<thead>
<tr>
<th>COREQ Item</th>
<th>No. of studies (total = 35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain 1: Research team and reflexivity</td>
<td></td>
</tr>
<tr>
<td>Personal characteristics</td>
<td></td>
</tr>
<tr>
<td>1. Interviewer/facilitator</td>
<td>18</td>
</tr>
<tr>
<td>2. Credentials</td>
<td>2</td>
</tr>
<tr>
<td>3. Occupation</td>
<td>9</td>
</tr>
<tr>
<td>4. Gender</td>
<td>5</td>
</tr>
<tr>
<td>5. Experience and training</td>
<td>3</td>
</tr>
<tr>
<td>Relationship with participants</td>
<td></td>
</tr>
<tr>
<td>6. Relationship established</td>
<td>1</td>
</tr>
<tr>
<td>7. Participant knowledge of the interviewer</td>
<td>3</td>
</tr>
<tr>
<td>8. Interviewer characteristics</td>
<td>2</td>
</tr>
<tr>
<td>Domain 2: Study design</td>
<td></td>
</tr>
<tr>
<td>Theoretical framework</td>
<td>10</td>
</tr>
<tr>
<td>9. Methodological orientation and theory</td>
<td></td>
</tr>
<tr>
<td>Participant selection</td>
<td></td>
</tr>
<tr>
<td>10. Sampling</td>
<td>35</td>
</tr>
<tr>
<td>11. Method of approach</td>
<td>22</td>
</tr>
<tr>
<td>12. Sample size</td>
<td>34</td>
</tr>
<tr>
<td>13. Non-participation</td>
<td>4</td>
</tr>
<tr>
<td>Setting</td>
<td></td>
</tr>
<tr>
<td>14. Setting of data collection</td>
<td>30</td>
</tr>
<tr>
<td>15. Presence of non-participants</td>
<td>1</td>
</tr>
<tr>
<td>16. Description of sample</td>
<td>35</td>
</tr>
<tr>
<td>Data collection</td>
<td></td>
</tr>
<tr>
<td>17. Interview guide</td>
<td>33</td>
</tr>
<tr>
<td>18. Repeat interviews</td>
<td>1</td>
</tr>
<tr>
<td>19. Audio/visual recording</td>
<td>12</td>
</tr>
<tr>
<td>20. Field notes</td>
<td>4</td>
</tr>
<tr>
<td>21. Duration</td>
<td>16</td>
</tr>
<tr>
<td>22. Data saturation</td>
<td>5</td>
</tr>
<tr>
<td>23. Transcripts returned</td>
<td>0</td>
</tr>
<tr>
<td>Domain 3: Analysis and findings</td>
<td></td>
</tr>
<tr>
<td>Data analysis</td>
<td></td>
</tr>
<tr>
<td>24. Number of data coders</td>
<td>8</td>
</tr>
<tr>
<td>25. Description of the coding tree</td>
<td>9</td>
</tr>
<tr>
<td>26. Derivation of themes</td>
<td>16</td>
</tr>
<tr>
<td>27. Software</td>
<td>19</td>
</tr>
<tr>
<td>28. Participant checking</td>
<td>0</td>
</tr>
<tr>
<td>Reporting</td>
<td></td>
</tr>
<tr>
<td>29. Quotations presented</td>
<td>11</td>
</tr>
<tr>
<td>30. Data and findings consistent</td>
<td>33</td>
</tr>
<tr>
<td>31. Clarity of major themes</td>
<td>13</td>
</tr>
<tr>
<td>32. Clarity of minor themes</td>
<td>8</td>
</tr>
<tr>
<td>COREQ items per study, average (minimum-maximum)</td>
<td>11 (5–26)</td>
</tr>
</tbody>
</table>
suggest that although farmers and veterinarians have an awareness of some of the potential risks associated with AMR, many believe that the overuse of antimicrobials in agriculture does not affect the development of AMR in humans. To overcome this misconception, improve understanding, and encourage more prudent AMU, evidence-based information about the links between AMU and AMR in livestock and AMR in humans should be promoted to both farmers and veterinarians.

These findings show that although some farmers and veterinarians know that AMR can occur in humans and animals, many do not perceive a risk to human health as a result of agricultural AMU. The gap between knowledge and behavior suggests that farmers and veterinarians hold competing beliefs about what constitutes appropriate use; this can be considered a form of cognitive dissonance (Festinger, 1957) and highlights the need for increased education of farmers and veterinarians about the need for prudent AMU. Awareness campaigns should be targeted at dairy farmers and veterinarians globally to improve understanding of AMR and promote consistent, prudent AMU. Academic research should be translated to farmers and veterinarians in a relatable manner, and continuous transfer of information about AMR risk relating to livestock is needed, with an emphasis on its links to human medicine.

**Theme 2: Determinants of Farmers’ and Veterinarians’ AMU Practices**

**Reasons for AMU in the Dairy Sector.** Previous literature has shown that mastitis is the most frequently occurring disease in dairy cows (Ruegg, 2017) and the most prevalent reason for prescribing antimicrobials in dairy cattle (De Briyne, 2014). We confirmed these findings in the present review: in the 8 studies exploring reasons for AMU, the majority of dairy farmers and veterinarians indicated that their most common reason for AMU was mastitis. The majority of veterinarians studied in Denmark, Portugal, and Sweden, and dairy farmers studied in the United Kingdom, United States, Denmark, and Sweden agreed that mastitis was the most common reason for AMU on dairy farms (Vaarst et al., 2003; Raymond et al., 2006; Jones et al., 2015; Kayitsinga et al., 2017; Carmo et al., 2018; Ekakoro et al., 2018; Higham et al., 2018; Fischer et al., 2019). Respiratory infections such as pneumonia (Jones et al., 2015; Ekakoro et al., 2018; Fischer et al., 2019), lameness, and hoof problems were also noted as common reasons for dairy farm AMU (Raymond et al., 2006; Ekakoro et al., 2018; Fischer et al., 2019). Although antimicrobials are used to treat several conditions in dairy cattle, AMU is linked more significantly to mastitis. Education of farmers and veterinarians about the prevention and management of mastitis with no or minimal AMU is necessary, including strategies such as selective dry-cow therapy, whereby cows with a low probability of an intramammary infection do not receive antibiotics (Kabera et al., 2020).

The use of antimicrobials for disease prevention has been argued in other veterinary contexts (Coyne et al., 2016), and 3 studies in the present review explored prophylactic AMU. Many Italian veterinarians stated that they administered antimicrobials before the onset of mastitis (62%) more often than before the onset of respiratory diseases (28%; Busani et al., 2004). Peruvian dairy farmers and Dutch veterinarians also reported some prophylactic AMU, although they noted that their AMU was primarily therapeutic (Redding et al., 2014; Speksnijder et al., 2015). These findings suggest that prophylactic AMU is uncommon in dairy farming; however, very few studies in this review reported on such use, so findings may not be applicable to the wider dairy sector. Farmers may be apprehensive to fully disclose the degree to which they use antimicrobials for prophylactic reasons as a result of bias. Future research should explore prophylactic use further to obtain a clearer idea of the level at which such AMU occurs in dairy cattle.

**Determinants of Farmer Treatment Choice.** In veterinary medicine, antimicrobials play a crucial role in maintaining animal health and welfare (FAO, 2016; Hudson et al., 2017), so it is not surprising that animal welfare has been highlighted as a driver of AMU in other agricultural sectors (Lhermie et al., 2019). The importance of animal welfare in choosing AMU was confirmed in this review by 3 studies of dairy farmers from the United Kingdom, United States, and Denmark (Vaarst et al., 2003; Jones et al., 2015; Ekakoro et al., 2018; Golding et al., 2019). Farmers in other livestock sectors have reported that they have adequate knowledge of their animals’ behavior and can identify abnormalities that indicate the presence of disease (Landfried et al., 2018). In 4 studies in this review, farmers from Germany, the Netherlands, New Zealand, and the United States reported that experience and the ability to accurately judge their animals’ health influenced AMU decision-making when deciding on treatment options (Raymond et al., 2006; Swinkels et al., 2015; McDougall et al., 2017; Ekakoro et al., 2018). Previous literature has stated that farmers rely strongly on their veterinarian for advice (Lathers, 2001), and some have recommended that farmers rely on knowledgeable veterinarians to make accurate treatment decisions based on credible examinations of their animals (Ruegg, 2006). The effect of veterinary advice on farmer decision-making varied between the 6 stud-
ies we found that explored the topic. Farmers in the Netherlands, New Zealand, Peru, and the United States (Michigan, Minnesota, New York, and Wisconsin) reported that veterinary recommendations were the most important factor in their decision-making (Zwald et al., 2004; Redding et al., 2014; Swinkels et al., 2015; McDougall et al., 2017), but less than half of the dairy farmers studied in Malaysia and Pennsylvania routinely sought veterinary advice or prescriptions before administering antimicrobials (Sawant et al., 2005; Sadiq et al., 2018).

Other factors that influenced farmer AMU decision-making in this review included drug attributes such as perceived efficacy of medicines, withdrawal times, and cost (Redding et al., 2014; Ekakoro et al., 2018); ensuring profitability and financial safeguarding (Jones et al., 2015; Golding et al., 2019); specific cow characteristics (Vaarst et al., 2002; Vaarst et al., 2003); culture and sensitivity testing (Ekakoro et al., 2018); and recommendations of other farmers (Swinkels et al., 2015).

The variety of reported influences on farmer behavior in this review suggests that farmer decision-making is not always straightforward and depends on individual situations as well as on their working relationship with their veterinarian. However, in this review, not all studies explored the reasoning behind farmers’ AMU in the same way; future research should consider investigating such factors further.

**Determinants of Veterinarians’ Prescribing Practices.** Clinical factors such as disease signs, antimicrobial susceptibility, and predicted treatment outcomes motivate antimicrobial prescribing decisions in human medicine (Coenen et al., 2002; Teixeira Rodrigues et al., 2013). In the present review (5 studies), many veterinarians confirmed that these factors play an integral role in antimicrobial prescribing in livestock; many base their treatment decisions on the specific clinical situation. Many veterinarians said it was vital to perform a physical examination of the animal before prescribing (Redding et al., 2013; Chauhan et al., 2018; Golding et al., 2019). Many also considered farm disease history and treatment response (Cattaneo et al., 2009; Redding et al., 2013; McDougall et al., 2017; Golding et al., 2019).

Antimicrobial characteristics motivate antimicrobial prescribing decisions in human medicine (Coenen et al., 2002; Teixeira Rodrigues et al., 2013). Three studies in the present review reported that drug attributes influenced veterinarian decision-making. Drug efficacy, withdrawal time, and ease of administration were considered by some Canadian, Dutch, and UK veterinarians when prescribing antimicrobials (Léger et al., 2015; Speksnijder et al., 2015; McDougall et al., 2017). Perceptions of farmers’ knowledge and abilities were considered by UK and Peruvian veterinarians (Redding et al., 2013; Golding et al., 2019). Profit was not commonly considered when deciding on treatment options; some Canadian and Dutch veterinarians felt that veterinarian profit was no longer a driver for antimicrobial prescribing in the dairy sector (Léger et al., 2015; Speksnijder et al., 2015).

Veterinarians’ perceptions of their clients’ willingness or ability to pay for treatment and likelihood of being adherent in administering the treatments have influenced veterinary prescribing outside of the dairy sector (Mateus et al., 2014). In the present review, veterinarians in 3 studies reported that farmers often influenced their decision-making. Some veterinarians in the United Kingdom and Kenya admitted that they sometimes fulfilled treatment requests to avoid upsetting the farmers (Higham et al., 2016; Higgins et al., 2017), and some Canadian veterinarians dispensed antimicrobials over the counter to regular clients more often (Léger et al., 2015).

In this review, studies exploring veterinarians’ decision-making with respect to prescribing antimicrobials in the dairy sector were scarce. The most common influencer we found of veterinarians’ decision-making was the individual clinical situation and the perceptions of the farmer. Future research should explore how veterinarians can build better relationships with their clients so that they can focus on individual clinical situations rather than on concerns about upsetting farmers.

**Theme 3: Barriers and Facilitators to Reduced AMU in the Dairy Sector**

**Barriers to Reduced AMU.** Deciding whether to continue or withdraw antimicrobial treatment was problematic for many farmers and veterinarians in this review, because of the unpredictable nature of disease and the potential cost of the disease returning when antimicrobials are discontinued. Such concerns are also common in pig production (Sheehan, 2013). Economic constraints such as the cost of disease and changes in farm structures to achieve reduced AMU were limitations reported in Dutch, Swedish, Irish, UK, and US studies (Raymond et al., 2006; Friedman et al., 2007; Speksnijder et al., 2015; Magalhães Sant’Ana et al., 2017; Fischer et al., 2019; Golding et al., 2019). Some farmers in the United States suggested that they did not always consult veterinarians for AMU advice because of their fees (Friedman et al., 2007), but others reported concerns that milk production would decrease if antibiotics were not used for dry-cow treatment (Raymond et al., 2006). Prophylactic AMU was considered necessary by some Dutch veterinarians, who argued that if certain infections were not prevented, they could result
in increased mortality and financial loss (Speksnijder et al., 2015). These findings suggest that many farmers and veterinarians are concerned about the economic risks of reduced AMU. Further research should focus on minimizing the economic risks of reduced AMU.

Previous findings suggest that having a productive farm and taking good care of the animals are important to farmers and central to how they conceptualize a good farmer (Wilkie, 2005; Bock et al., 2007; Ellis, 2014; Shortall et al., 2018). This finding was confirmed by 6 studies in this review: farmers and veterinarians reported that animal welfare was a barrier to reducing AMU. Farmers and veterinarians in the United Kingdom were concerned that reductions could inhibit their ability to treat sick animals and maintain animal welfare (Golding et al., 2019). Farmers in France and the United Kingdom feared that having no antibiotic cover would lead to severe mastitis and death (Orpin, 2017; Poizat et al., 2017). Dutch farmers and veterinarians were unsure whether a cow would recover without antimicrobials (Scherpenzeel et al., 2016; Scherpenzeel et al., 2018), and many Dutch veterinarians reported it was their duty to treat diseased animals for reasons of animal welfare, regardless of the issue of AMR (Speksnijder et al., 2015). Despite these findings, research in the UK dairy sector found that ceasing the use of the highest priority, critically important antimicrobials can occur while maintaining herd health and farm productivity (Turner et al., 2018). These findings highlight farmers’ and veterinarians’ sense of responsibility for animal welfare; they feel that antimicrobials are essential for preserving animal welfare and productivity. Further education about on the efficacy of alternative practices to reduce AMU may build confidence in their ability to maintain animal welfare while reducing AMU.

Time constraints and labor burden were noted as common barriers to reduced AMU in 5 studies (Friedman et al., 2007; Speksnijder et al., 2015; Scherpenzeel et al., 2016; Poizat et al., 2017; Golding et al., 2019). Some South Carolina farmers reported that they did not have time to wait for a veterinarian to make a farm visit; they needed to make quick judgments to avoid infection spread (Friedman et al., 2007). Selective antimicrobial treatments were seen by many Dutch and French farmers as requiring additional work (Scherpenzeel et al., 2016; Poizat et al., 2017), and some Dutch veterinarians agreed that such treatment was generally more labor-intensive than mass medication, and it could be difficult to convince farmers to adopt such practices (Speksnijder et al., 2015). Despite a desire to make greater use of diagnostic testing and an appreciation for its importance to reduce AMU, many veterinarians felt that such testing was often impractical because of delays in obtaining results (DeBriyne et al., 2013; Coyne et al., 2016; Golding et al., 2019) and was used only sometimes by Dutch, Indian, and UK veterinarians when initial treatments were unsuccessful (Speksnijder et al., 2015; McDougall et al., 2017; Chauhan et al., 2018). These findings suggest that when considering interventions and promoting reduced AMU, labor and time requirements should be considered to ensure successful implementation.

Pressure from farmers to prescribe antimicrobials is often highlighted in studies that investigate the prescribing behaviors of veterinarians in a range of veterinary contexts (De Briyne et al., 2013; Gibbons et al., 2013; McIntosh and Dean, 2015; Coyne et al., 2016). We confirmed this finding: in 2 studies, many veterinarians reported that pressure from farmers could limit their efforts to reduce AMU. Some Dutch veterinarians felt pressure to prescribe antimicrobials and sometimes had difficulty persuading farmers to reduce AMU (Speksnijder et al., 2015). Some UK veterinarians reported that it was difficult to prioritize responsible AMU because of conflicts of interest and fear of upsetting farmers (Higgins et al., 2017). Findings in other veterinary contexts have shown that some veterinarians are more influenced by social expectations than by scientific reasoning, acting on client pressure to prescribe even when they felt antimicrobials were unnecessary. This prescribing behavior has also been observed for human antibiotic prescribing practices (Paredes et al., 1996; Tonkin-Crine et al., 2011; Broom et al., 2014; Hockenhull et al., 2017; Smith et al., 2018). Veterinarians have been advised to adopt new communication styles and overcome the assumptions they may have about farmers to ensure engagement with them on disease prevention and antimicrobial stewardship (Jansen et al., 2010). Although many veterinarians highlighted the perceptions of farmers as influencing prescribing their practices and often limiting their efforts to reduce AMU, few explicitly identified this as a barrier to reducing AMU. Although similar findings have been reported in other veterinary contexts (regarding farmer pressure as a barrier to reduced AMU), such literature in the context of dairy farming is limited and may be worth some focus in future research.

Some Dutch veterinarians noted that high on-farm AMU may be the result of insufficient skills in terms of disease detection and recommended practices on the part of farmers (Speksnijder et al., 2015). Irish veterinarians acknowledged that farmers generally had little awareness of the connection between their husbandry practices and AMR in human medicine, suggesting that until this was understood, farmer behavior would not change (Magalhães Sant’Ana et al., 2017). Although this was highlighted as a barrier to reduced AMU in the present review, we cannot assume that it is the
iew of all veterinarians because of the small number of studies exploring veterinarians’ perceptions of farmers’ skills and knowledge as a barrier to reduced AMU. Future research is needed to determine whether this is a common attitude of veterinarians when dealing with dairy farmers.

Other barriers reported included social constraints (Fischer et al., 2019), industry pressure (Golding et al., 2019), low risk perception (Higgins et al., 2017), skepticism about antimicrobial alternatives (Vaarst et al., 2003), and the fact that antimicrobial treatments are effective and convenient (Pozat et al., 2017). These findings were not as commonly reported, but they should still be given consideration in attempts to reduce AMU, and they may deserve attention in future research.

These findings show that farmers and veterinarians consider many factors to be barriers in reducing their AMU in dairy cattle. Economic constraints, animal welfare, structural limitations (time constraints and labor requirements), individual attitudes to AMR, pressure felt by veterinarians from farmers, and veterinarians’ perceptions of farmers were commonly reported barriers to reduced AMU. To overcome the main barriers identified by this review, future research should explore how AMU can be reduced with minimal economic risk, how the efficacy of alternative practices can be promoted while maintaining animal welfare, and how pressure on veterinarians from farmers can be reduced. From these findings, we recommend that interventions aimed at reducing AMU consider labor and time requirements, and that they provide the skills and knowledge necessary to efficiently achieve reductions.

Facilitators of Reduced AMU. Previous research suggests herd management and improved biosecurity as a cost-effective and feasible approach to disease prevention, and an alternative to reliance on routine AMU (Postma et al., 2015; Rojo-Gimeno et al., 2016). Improved biosecurity and management practices have been associated with reduced AMU in pig production (Laanen et al., 2013; Arnold et al., 2016; Postma et al., 2016). On-farm management measures and disease-prevention controls were welcomed by many farmers and veterinarians in this review (8 studies) as facilitators of reduced AMU. Disease prevention with consistent health management practices was considered important by veterinarians in Denmark, Portugal, Switzerland, and the United States (Cattaneo et al., 2009; Speksnijder et al., 2015; Carmo et al., 2018). Similarly, many Indian, Swedish, Dutch, and US dairy farmers agreed that practices such as proper nutrition, housing, breeding, and infection control were important for reducing AMU (Ekakoro et al., 2018; Holstege et al., 2018; Kumar and Gupta, 2018; Fischer et al., 2019). Vaccinations were also seen by some farmers and veterinarians as a means of reducing AMU (Cattaneo et al., 2009, Ekakoro et al., 2018) and as a cost-effective strategy for controlling the spread of AMR by Indian farmers (Kumar and Gupta, 2018). On-farm diagnostic testing was considered a facilitator of reduced AMU by Irish veterinarians (Magalhães Sant’Ana et al., 2017), and some Tennessee dairy farmers reported that such testing has led to a reduction in AMU (Ekakoro et al., 2018). Correct diagnostic processes and early disease detection were considered important by some US dairy farmers and Dutch veterinarians to avoid unnecessary AMU (Speksnijder et al., 2015; Ekakoro et al., 2018). These findings suggest that many farmers and veterinarians in this review (and possibly outside its scope), see improved herd management and biosecurity measures as important steps for reducing AMU while maintaining productivity and animal welfare, and these practices should be promoted to encourage behavior change.

Increasing farmers’ ability to implement alternative practices enhances their efficiency in reducing AMU (Visschers et al., 2016). Programs aimed at increasing awareness of AMU and AMR may contribute to a reduction in agricultural antimicrobial sales (Carmo et al., 2017). Relevant and targeted information is vital when aiming to change behavior, and for the targeted population to pay attention to information, education must be tailored to their needs and knowledge (Kreuter et al., 1999). In this review, farmers and veterinarians considered training and education to be important for facilitating reduced AMU (5 studies). Some UK veterinarians felt that giving farmers the skills to implement selective therapy facilitated reduced AMU (Higgins et al., 2017) and some Tennessee dairy farmers supported the need for additional farmer training on infection prevention and control to reduce AMU (Ekakoro et al., 2018). Many veterinarians supported increased veterinary education about prudent AMU and alternative practices to promote the use of such practices among clients and facilitate reduced AMU (Magalhães Sant’Ana et al., 2017; Poizat et al., 2017; Carmo et al., 2018). These findings suggest that education of farmers and veterinarians is fundamental in the fight against imprudent AMU in dairy cattle. Combined with the desire for increased knowledge relating to AMU and AMR, expressed by farmers, these findings highlight the importance of education and its potential to help facilitate reduced AMU.

The potential economic rewards of profitability and reduced costs were reported as the most important driver of AMU behavior change in pig farming (Visschers et al., 2015). Some Dutch veterinarians were concerned that higher tariffs for their services would
decrease farmers’ motivation to consult them, so they considered low tariffs to be essential for animal health and appropriate AMU (Speksnijder et al., 2015). To reduce farm AMU, it has been suggested that farmers and veterinarians be given incentives to make reduced AMU more salient in their day-to-day operations, perhaps by using financial incentives such as those recently used in the English National Health Service (Islam et al., 2018). Some Indian veterinarians were concerned about the lack of incentive for farmers to withhold antimicrobial treated milk, stating that incentives for withholding would prevent antimicrobial-tainted milk from entering the food chain (Chauhan et al., 2018). In this review, farmers and veterinarians confirmed the importance of such financial facilitators for reduced AMU. In the Netherlands, some noted “financial consequences” as one of the most positive aspects of reducing AMU (Scherpenzeel et al., 2016), and some French veterinarians stated that they highlighted the cost benefit of alternative medicines to farmers to promote reduced AMU (Poizat et al., 2017). These findings suggest that to many farmers and veterinarians, economic rewards for reducing AMU have the potential to facilitate and encourage behavior change. Because economic burden has been highlighted in this review as a barrier to reducing AMU, we need to promote the evidence showing that farms can remain productive and profitable while reducing AMU.

Veterinarians may have the scope to take on a more proactive role in promoting preventative medicine to farmers, as a way of reducing AMU (Higgins et al., 2013). In this review, some farmers highlighted the role their veterinarians could play in reducing AMU. Dutch farmers felt that veterinarians could help facilitate change because they are farmers’ main advisors and supporters of reduced AMU (Scherpenzeel et al., 2016); UK farmers also expressed a desire for guidance from their veterinarians to reduce AMU because of the support and motivation they provide (Golding et al., 2019). These findings were limited in the scope of this review, but coupled with reports from many farmers about the key role of veterinarians in their decision-making, they suggest that veterinarians can play a pivotal role in promoting AMU reduction.

Improved policy and regulation of AMU in livestock was deemed necessary by Irish and Indian veterinarians to reduce AMU (Magalhães Sant’Ana et al., 2017; Chauhan et al., 2018). Some veterinarians from Denmark, Portugal, and Switzerland also advised that mandatory interventions applied by national or international authorities appeared to work best in reducing AMU in the past (Carmo et al., 2018), and many Dutch veterinarians felt that policies to reduce AMU should be equal in all countries to maintain a fair, competitive market and prevent illegal antimicrobial trade (Speksnijder et al., 2015). Farmers in the United Kingdom reported that they saw government and industry bodies as having the resources and expertise to conduct research and produce evidence-based guidelines to facilitate reduced AMU (Golding et al., 2019). These findings suggest that farmers and veterinarians would be accepting of the introduction or revision of evidenced-based policies and regulations to reduce AMU. Many veterinarians and farmers may be open to harmonization of regulations in all countries, but this would need to be a potential focus for future research because of the limited findings in this review.

These findings show that farmers and veterinarians perceive numerous factors as having the potential to facilitate reduced AMU. From these findings, future research recommendations include the promotion of herd health management and biosecurity measures, and the improved education of farmers and veterinarians about alternative practices to increase their confidence in their ability to reduce AMU. Promotion of evidence that farms can remain productive and profitable with reduced AMU is necessary to overcome the uncertainty that exists among some farmers and veterinarians. Veterinarians can play a pivotal role in promoting reduced AMU, and harmonization of regulations and policy regarding AMU should be considered by future research as ways to improve AMU in the dairy industry.

**Theme 4: Farmers’ and Veterinarians’ Responsibility to AMR and Desire to Reduce AMU**

Prudent use of antimicrobials in livestock is the responsibility of veterinarians and farmers, and so both need to be aware of the effect their AMU can have (Reyher et al., 2017). In the present review, 60% of studies reported on farmers’ and veterinarians’ perceived responsibility for AMR. Some UK farmers expressed ownership of their role in improving AMR (Golding et al., 2019) but among Malaysian farmers, those with a larger herd size perceived their role in tackling AMR as more important (Sadiq et al., 2018). Dairy farmers in Germany and the Netherlands felt that meat-producing farmers were responsible for agricultural AMR (Swinkels et al., 2015), and some UK and Malaysian farmers saw veterinarians as responsible for managing the emergence of AMR (McDougall et al., 2017; Sadiq et al., 2018). Research has found that this external attribution of responsibility to others is a major barrier to behavioral change and must be understood, accounted for, and managed in policy development (Rüegg et al., 2017). These findings suggest that not all farmers recognize the role they play in the development and spread of AMR.
Previous literature has advised that enabling behavioral change requires farmers and veterinarians to perceive their own roles and actions as efficacious and important in relation to AMR (Fishbein and Cappella, 2006). In this review, many UK and Irish veterinarians acknowledged their responsibility to prescribe appropriately and had a sense of ownership in promoting reduced AMU (Magalhães Sant’Ana et al., 2017; Goldberg et al., 2019). Some US veterinarians believed that many individuals contributed to AMR, including themselves (Cattaneo et al., 2009). Although many Dutch veterinarians appeared to be motivated to reduce veterinary AMU for public health reasons, others doubted the contribution of veterinary AMU to human health (Speksnijder et al., 2015). These findings suggest that although some veterinarians perceive their role in AMR to important, further education is needed to help them consider their own practices as important for mitigating the spread of AMR.

Many Dutch, UK, and US farmers agreed that it is important to reduce AMU (Jones et al., 2015; Scherpenzeel et al., 2016; Kayitsinga et al., 2017). Some UK farmers felt that people in the industry would respect them for reducing their AMU (Jones et al., 2015), and Dutch farmers felt they could still be a good farmer while using fewer antimicrobials (Scherpenzeel et al., 2016). Some Dutch veterinarians also agreed that it was important to restrict livestock AMU, many trusting that they could be a good veterinarian and farmers could still be good farmers with less AMU (Scherpenzeel et al., 2018). These findings suggest that farmers and veterinarians are motivated by being considered “good” by their peers and industry colleagues and by conforming to the social norms of the industry, which may facilitate reduced AMU. In this review, we found few studies that focused on the opinions of others as a facilitator for reduced AMU; this question may need to be considered by future research.

Previous literature stated that veterinarians and farmers are not always aware of the public health risks associated with extensive agricultural AMU and do not always feel responsible for the problematic outcomes, lowering their motivation to change their behavior (Coyne et al., 2016; Visschers et al., 2016; Ritter et al., 2017). The perceived ability to reduce AMU varied among farmers in this review. Many UK and US farmers felt they had the ability to reduce AMU (Higham et al., 2018; Vasquez et al., 2019), and some Swedish farmers admitted they could make more efforts to reduce AMU (Fischer et al., 2019). Dutch and French farmers felt that reducing their AMU could be difficult, and although many veterinarians felt a responsibility to tackle AMR, some still considered prophylactic AMU necessary to safeguard animal welfare (Speksnijder et al., 2015; Poizat et al., 2017). These findings show that the perceived ability of farmers and veterinarians to reduce AMU is varied, and combined with the concerns and uncertainty associated with reduced AMU, reported in this review, it reinforces the importance of education on alternative practices to enable farmers and veterinarians to confidently reduce their AMU.

Dairy farmers in the United Kingdom and United States reported positive intentions toward prudent AMU (Jones et al., 2015; Vasquez et al., 2019), and farmers and veterinarians in Switzerland supported voluntary programs to reduce AMU (van den Borne et al., 2017). Another study of Dutch veterinarians reported positive attitudes toward policy change to reduce AMU (Scherpenzeel et al., 2018). Shared responsibility between farmers and veterinarians may help behavior change; evidence has shown that farmers’ intentions to change are reinforced by mutual support from their major referents, which include veterinarians and other advisors (Ellis-Iversen et al., 2010). These findings suggest that the intentions of many farmers and veterinarians toward reducing AMU in the dairy sector may be primarily positive and could be beneficial for the introduction of policy and programs designed to reduce AMU. Further research is necessary to reinforce this finding.

Based on these findings, we recommend that the education of farmers and veterinarians be improved so that they recognize the effect their AMU practices can have on AMR in both veterinary and human medicine, and so the responsibility they feel toward the issue is heightened. Research is also needed into how peers and colleagues of farmers and veterinarians in the dairy industry can act as motivators in their desire to reduce AMU.

Theme 5: The Importance of the Farmer–Veterinarian Relationship for Reducing AMU

Just over 50% of the studies in this review reported on the farmer–veterinarian relationship and the role it may play in AMU in the dairy sector.

Communication and Information Transfer Between Farmers and Veterinarians. Several studies reported that veterinarians were farmers’ preferred information source for general farming practices (Garforth et al., 2013) and AMU guidance (Visschers et al., 2015; Visschers et al., 2016). We found that relationships and communication with veterinarians were valued highly by many Dutch, German, UK, and US farmers; veterinarians were often identified as their most credible, reliable, and influential information sources on AMU and AMR (Friedman et al., 2007; Jones et al., 2015; Swinkels et al., 2015; Kramer et al.,
Some Swedish farmers expressed a desire for a trustworthy relationship with their veterinarian, although many reported that they only called on them when they were sure they could not cure the animal themselves (Fischer et al., 2019). Many Peruvian, Dutch, and US farmers did not always seek the advice of their veterinarian before administering antimicrobials (Sawant et al., 2005; Redding et al., 2014; Jones et al., 2015). These findings suggest that although many farmers perceive their veterinarians as credible and important sources of information, they do not always seek their advice; this may be linked to the findings in this review that some farmers feel veterinary fees are too expensive.

Veterinarians’ communication experiences with farmers varied in this review. Many Indian veterinarians reported that by the time a farmer seeks their help they have already tried many unsuccessful treatment strategies (Chauhan et al., 2018). Despite this, many Dutch veterinarians reported that providing advice to farmers was becoming an increasing part of their daily work (Speksnijder et al., 2015). One-on-one meetings between veterinarians and farmers were considered by many US veterinarians to be the most effective way to educate farmers on AMR (Cattaneo et al., 2009). Despite a desire to educate farmers, some Canadian veterinarians were more likely to dispense antimicrobials over the counter to clients they had regular contact with, in contrast to those who they rarely met with (Léger et al., 2015). These findings suggest that many veterinarians have a desire to provide advice and education to farmers, but some acknowledge that they are not always farmers’ first point of contact. Veterinarians have the ability to guide farmers in reducing their AMU, and encouraging farmers to use veterinary services more frequently may help tackle the problem of antimicrobial misuse.

**Farmers’ and Veterinarians’ Perceptions of Each Other.** Previous research has highlighted the need to communicate the importance of restrictive AMU through information channels that farmers perceive to be trustworthy (Ritter et al., 2017). Many Swedish and UK farmers said that they trusted their veterinarians’ AMU information and recommendations (Ekakoro et al., 2018; Fischer et al., 2019; Golding et al., 2019). Some Swedish farmers expressed a desire for a trust-based dialogue with their veterinarian; they wanted their veterinarians to trust in their farming competence and abilities as much as farmers trusted in their medical expertise (Fischer et al., 2019). Veterinarians’ perceptions of their clients’ adherence have been reported previously as a common nonclinical factor that influences antimicrobial prescribing decisions; this influence has also been reported in human medicine (Teixeira Rodrigues et al., 2013; Coyne et al., 2016). Some Peruvian veterinarians admitted that their perception of farmers’ education level and ability to understand drug attributes and pathogens sometimes influenced their prescribing (Redding et al., 2013). Although many UK veterinarians felt that farmers followed their treatment advice, some said that if they were concerned a farmer would not adhere to a treatment plan, they would account for this when prescribing (Golding et al., 2019). Dutch veterinarians reported that because they are only able to make recommendations to prevent disease with no way of enforcing them, they often experienced feelings of frustration with farmers; when a farmer did not follow their advice, they were again confronted with sick animals (Speksnijder et al., 2015). Existing literature advises that generally, veterinarians are perceived as trustworthy referents for farmers, so they can act as a main information source on prudent AMU (Ellis-Iversen et al., 2010; Speksnijder and Wagenaar, 2018). These findings suggest that farmers trust their veterinarians for advice, but some may desire that the trust be reciprocated. This finding highlights the importance of 2-way trust between farmers and veterinarians; future research to increase this trust could improve their relationships and AMU practices.

Some UK veterinarians noted that differences in farmers’ personalities occasionally influenced their prescribing decisions and willingness to raise the topic of antimicrobial stewardship. They sometimes prescribed antimicrobials to prevent awkward situations, noting that it takes time to develop effective relationships with farmers (Higgins et al., 2017; Golding et al., 2019). Dutch and UK veterinarians were sensitive to the financial pressures they believed farmers faced, leaving them limited in their ability to help and hesitant to increase their service tariffs (Speksnijder et al., 2015; Golding et al., 2019). This finding suggests that not all farmers are perceived equally by veterinarians, and that such perceptions depend on the relationships they have with their clients. Farmers’ and veterinarians’ perceptions of each other may contribute to difficulties in reducing AMU; future research should explore this further.

Many Dutch veterinarians perceived that farmers are accustomed to raising their animals with antibiotics (Speksnijder et al., 2015), and client habits were noted by Peruvian veterinarians as a determinant of prescribing (Redding et al., 2013). Some Indian and UK veterinarians considered veterinarians to be their most important information source on mastitis (Swinkels et al., 2015; Kayitsinga et al., 2017), and veterinary recommendations and advice were considered by some Peruvian, Dutch, and UK farmers to be their most important decision-making influences (Redding et al., 2014; Scherpeneel et al., 2016; McDougall et al., 2017). Some Swedish farmers highlighted the importance of a good relationship with their veterinarian, although many reported that they only called on them when they were sure they could not cure the animal themselves (Fischer et al., 2019). Many Peruvian, UK, and US farmers did not always seek the advice of their veterinarian before administering antimicrobials (Sawant et al., 2005; Redding et al., 2014; Jones et al., 2015). These findings suggest that although many farmers perceive their veterinarians as credible and important sources of information, they do not always seek their advice; this may be linked to the findings in this review that some farmers feel veterinary fees are too expensive.
narians perceived that farmers were reluctant to change their behavior and considered it a challenge to change farmers’ AMU (Higgins et al., 2017; Chauhan et al., 2018; Golding et al., 2019). Some Indian veterinarians found that relatively new commercial dairy farmers were more open to modifying practices (Chauhan et al., 2018), and many UK veterinarians believed that a key part of their role was to better educate farmers, and that engaging with a farmer and understanding their needs could affect farmer behavior (Golding et al., 2019). This finding suggests that according to many veterinarians, achieving behavior change among dairy farmers is difficult. Future research should use behavior change theory in an effort to determine evidence-based interventions and strategies that can be aimed at both farmers and veterinarians to achieve reduced AMU.

**Collaboration Between Veterinarians and Farmers.** Research suggests that the reduction of AMU requires participation from all stakeholders responsible for administering antimicrobials, including veterinarians, producers, and animal handlers (Salisbury et al., 2002). Better animal health outcomes may be achieved by collating expert opinions; indeed, the use of multidisciplinary teams in human healthcare has been shown to improve patient outcomes (Mudge et al., 2006; Hickman et al., 2015). Encouraging collaboration between veterinarians and farmers was considered an important strategy for improving antimicrobial stewardship by some UK farmers and veterinarians (Golding et al., 2019). Irish veterinarians believed that collective responsibility among stakeholders had the potential benefit of limiting individual stakeholder ownership of the AMR problem (Magalhães Sant’Ana et al., 2017). Despite a desire to work collectively, some UK farmers and veterinarians demonstrated frustrations toward other stakeholders and colleagues; they felt that their behavior was suboptimal, but others felt that their own antimicrobial stewardship efforts were undermined by other stakeholders and differing practices globally (Golding et al., 2019). This other-blaming (placing the blame for increased AMR and imprudent AMU on other parties) has been observed by stakeholders in both human and veterinary medicine (Labi et al., 2018; Nicholson et al., 2018). It has been suggested that at an individual level, increasing the use of inclusive, One Health stewardship initiatives that target individual knowledge and motivations may overcome other-blaming, because both veterinarians and farmers can feel blamed and stigmatized by others for AMR (Fynbo and Jensen, 2018; Johnson et al., 2018). Although we are aware that tackling AMR is a One Health priority encompassing a multisectoral approach (FAO/OIE/WHO, 2017), only the practices and opinions of dairy farmers and veterinarians were considered in the scope of this review. These findings suggest that farmers and veterinarians may be open to more collaboration. However, the relationship between farmers and veterinarians and its effect on AMU was not a major focus of many of the studies in this review; further research is needed to confirm findings.

Some Danish farmers admitted that although their veterinarians would like closer collaboration, their financial situation would not allow for increased veterinary services (Vaarst et al., 2003), and some Dutch veterinarians acknowledged that low tariffs were needed to encourage farmers to use veterinary services (Speksnijder et al., 2015). Collaboration between farmers and veterinarians can be beneficial in developing antimicrobial stewardship plans on farms (van Dijk et al., 2017), and drawing on a social-identity approach could increase communication and collaboration between groups (Jetten et al., 2017). Promoting the importance of a common fate can strengthen the shared social identity of stakeholders and drive cooperation to achieve shared goals (Gaertner et al., 1993; Turner et al., 1994). In this review, farmers and veterinarians identified each other as influencers on their decision-making and as having the ability to limit and facilitate reduced AMU. Future research should focus on enabling farmers and veterinarians to work together confidently and effectively to achieve their common goal of reduced AMU on dairy farms.

This research has found that communication, individual perceptions, and trust in one another contribute to the working relationships between farmers and veterinarians. Certain aspects of these relationships have been highlighted as having the potential to limit or facilitate reduced AMU. Future research should aim to promote more frequent use of veterinary services by farmers. Attempts to build trust between farmers and veterinarians is recommended to strengthen their relationships and overcome inaccurate perceptions of each other. Habit has been highlighted as a potential reason why farmers do not always consult veterinarians for advice; future research applying behavior change theory to farmer and veterinarian behavior is suggested to help overcome behavioral habits and result in reduced AMU. Overall, future research into the relationship between farmers and veterinarians is necessary to highlight areas that can be targeted to strengthen relationships, promote collaboration, and enable them to work together effectively to reduce AMU.

**Strengths and Limitations**

This research had several strengths and limitations. To the best of our knowledge, this review was the first to systematically combine the existing literature explora-
ing dairy farmers’ and veterinarians’ knowledge and awareness of AMR, as well as their attitudes toward and perceptions of AMU. We have extended previous research findings by summarizing and comparing the literature from a broad range of study designs (interviews, surveys, focus groups), synthesized their primary findings, and reviewed evidence supporting the findings. We have identified potential links between previous study findings, providing scope for further research and potential avenues for promoting reduced AMU in the dairy sector. Although we used a reasonable number of studies in this review (n = 35), almost all were conducted in developed countries, limiting the generalizability of the results on a global scale. The findings of most studies were typically self-reported, so caution should be used with regard to social desirability bias of the findings. We have combined studies carried out over a broad period of time, so data reported by some of the studies may not necessarily reflect current practices, attitudes, knowledge, and perceptions of participants.

**Recommendations for Future Research**

This review identified gaps and scarcities in research investigating the drivers of AMU in dairy cattle. Although we have highlighted many reasons for farmers’ AMU, some factors that were quoted less frequently may provide a deeper insights into the motives behind farmers’ AMU. The effect of herd size on farmers’ perceptions of their AMU practices and its contribution to AMR remains relatively unknown; further research in this area may provide a better indication of how best to promote behavior change with specific farming groups. Further research is needed into the relationship dynamic between farmers and veterinarians and how it can be enhanced to implement reduced AMU on dairy farms. The perceptions farmers and veterinarians have of one another, and the trust they have in each other, remains relatively unexplored and may provide key insights into just how much this relationship may influence on-farm AMU. A deeper understanding of this relationship may help facilitate a collaborative effort between farmers and veterinarians to tackle the global issue of AMR by reducing their use of antimicrobials in dairy cattle.

**CONCLUSIONS**

Farmers’ and veterinarians’ knowledge, awareness, and perceptions of AMU and AMR vary within dairy farming. Increasing awareness of AMR may increase perceived responsibility to tackle AMR. Many factors determine the decision for AMU including animal welfare, time, and labor requirements. Addressing the perceived barriers to reducing AMU may alter decision-making and reduce AMU. The relationship between farmers and veterinarians can be a barrier or facilitator to prudent AMU depending on the perceived relationship dynamic. As a trusted information source for farmers, veterinarians can educate farmers and promote reduced AMU. By altering perceptions of their clients, veterinarians may act as successful antimicrobial stewards, while maintaining a good relationship with farmers. Many farmers and veterinarians are open to collaboration to achieve prudent AMU, which is expected to create a shared responsibility of reducing AMU. Application of behavior change theory is expected to overcome barriers and elicit behavior change to achieve reduced AMU.

**ACKNOWLEDGMENTS**

This study is funded by Department of Agriculture, Environment and Rural Affairs (DAERA; Belfast, UK) NI Postgraduate Studentships as part of a PhD project. The authors have not stated any conflicts of interest.

**REFERENCES**


Orpin, P. 2017. What can we learn from farmers experiences and attitudes to selective dry cow therapy? Cattle Pract. 25:130–139.


ORCIDS
S. Farrell https://orcid.org/0000-0002-3415-8434
C. McKernan https://orcid.org/0000-0002-1985-8328