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Factors influencing dairy cattle farmer use of antimicrobials on farms in New South Wales, Australia

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Antimicrobial use (AMU) in the food chain is a potential driver of antimicrobial resistance. Despite Australia's strong regulation of AMU limited to veterinary prescriptions, a proportion of empirical antimicrobial treatments are administered by dairy farmers to manage common cattle health problems. This cross-sectional survey identified key influences on AMU by dairy cattle farmers within New South Wales, Australia, to detect opportunities for antimicrobial stewardship (AMS) engagement. The study identified existing relationships, resources and attitudes of the dairy farmers that could be optimised for on-farm AMS strategies. Farmers were most highly influenced by veterinary advice and clinical signs of the animal followed by the withholding period and the potential for antimicrobial resistance development. Farmers' high confidence regarding their own knowledge of antimicrobials (>90%), their high regard for veterinary advice (>90%) and high rate of veterinary health care plan use (69%) provides a strong framework to build the profile and practice of AMS on dairy farms. Positive engagement by dairy farmers (survey response of 20%), was achieved by working with the NSW Food Authority. Despite respondents reporting low reliance on formal (government and commercial) organisations for information about AMU, their engagement demonstrates an opportunity for groups with unparalleled access to dairy farmers to drive AMS. An association between frequent use of veterinary advice and respondents keeping ceftiofur on-farm requires further investigation. Quantitative and qualitative analysis of on-farm resources, decision-making, and practices is required to understand how practices relate to veterinary advice and accepted standards of appropriate AMU on dairy farms.

Keywords antimicrobial stewardship; antimicrobial use; Australia; dairy cattle; dairy farmer

Abbreviations AMR, antimicrobial resistance; AMS, antimicrobial stewardship; AMU, antimicrobial use; LLS, NSW Local Land Services; VHCP, Veterinary Health Care Plan; WHO, World Health Organisation; WHP, withholding period

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Antimicrobial use (AMU) and antimicrobial contamination in the environment are recognised drivers of escalating antimicrobial resistance (AMR), posing an increasing threat to health globally.[1, 2] While antimicrobials are an important tool for managing the health and welfare of food-producing animals, addressing unnecessary use has been identified as critical by the World Health Organization (WHO), World Organization for Animal Health (WOAH) and Food and Agriculture Organization of the United Nations (FAO),[1, 3, 4] together known as the Tripartite, as part of the one health measures to combat AMR.

European and North American dairy farmer knowledge, attitudes and practices in AMU have been investigated. Qualitative methodologies (focus groups and surveys) have aimed to understand farmer perspectives on AMU and the barriers and drivers of reducing AMU.[5–7] These demonstrate that farmers have variable perceptions about changing their AMU practices and often downplay the risk of AMR arising from AMU in their own production systems.[8] Veterinarians and other farmers are consistently rated as farmers' preferred sources of AMU information[6, 8, 9] whilst written farm AMU protocols are variable.[8] Barriers to reducing or improving AMU are reported to include lack of time and knowledge[6] and fear of reduced production or increased herd disease.[8] Approval by peers or social networks has been a strong driver of farmers' intention to reduce AMU, whereas the potential for increased farm profitability and public health benefits have been variably perceived.[7, 8]

There is limited published information on this issue in the Australian context. Australia is a conservative regulator of antimicrobials, with registered veterinarians the only legal prescribers of antimicrobials to animals, and registration of antimicrobials for animal use is regulated by the Australian Pesticide and Veterinary Medicines Authority (APVMA). Gentamicin is prohibited and quinolones/fluoroquinolones have never been registered for use in Australian food animals. The APVMA maintains restrictions on the use of third-generation cephalosporins and the livestock industry have voluntarily agreed to only use medically unimportant antimicrobials as growth performance promoters. Australian dairy farmers are required to follow the veterinary prescription in administering antimicrobials to their animals. Dairy companies test milk for compliance with maximum antimicrobial residue limits set by the Australia and New Zealand Food Standards Code and designate commercial penalties should limits be exceeded.[10]

A proportion of empirical antimicrobial treatments are reported to be administered by dairy farmers in managing common cattle health

problems on UK farms.[11, 12] While farmer decision-making and administration of antimicrobials is anecdotally common practice in Australia, the extent of this practice is not formally documented or described. Understanding of the extent and nature of farmer AMU is limited by the absence of detailed public reporting by the veterinary profession, dairy and pharmaceutical industries and regulators. Australian dairy industry bodies actively promote preventative farm management and biosecurity practices. Programs that promote proactive mastitis management, improved transition (from non-lactating to lactating) period management, optimized calf management and cow foot health management indirectly promote reduced AMU by aiming to reduce the burden of disease within herds.[13]

The objectives of this cross-sectional study of NSW dairy (cattle) farmers (herein referred to as farmers) were to characterise on-farm AMU; determine information sources dairy farmers found most useful; identify opportunities for future antimicrobial stewardship (AMS) engagement at the farm level.

Materials and methods

Sample population and sampling strategy

This study was performed using a cross-sectional survey design, implemented by the use of a questionnaire. Dairy farms in NSW producing milk for human consumption are required to be licensed and regularly audited by the NSW Food Authority (NSWFA). All 631 NSW dairy farm licensees at the time of study commencement were defined as the study population. This purposive sampling strategy was chosen to ensure all participants in the sampling frame were known to be practicing dairy farmers and the use of a single state population ensured all participants were governed by the same antimicrobial prescribing regulations. It was calculated that, using a cross-sectional survey, if 90% of the subjects in the population used antimicrobials, with a fixed target population size of 631 and an expected response rate of 20%, the study required 114 respondents to the questionnaire to estimate expected proportions with 5% precision and 95% confidence (epitools.ausvet.com.au/oneproportion).

Recruitment was endorsed by the NSW Chief Veterinary Officer (CVO) and distribution of the questionnaire supported by the NSWFA. Licensees (herein, 'farmers') were invited to participate in the project by letter (all 631) and email where available (216 of 631) sent by NSWFA, using their licensee contact list. Participants could return hard copies in a reply-paid envelope or via an online survey platform (REDCap® Electronic Data Capture tool).[14] Farmers completing the survey were given the opportunity to win one of five $200 vouchers. Information on the study and the weblink were published in two editions of the Dairy NSW monthly e-newsletter. Responses were accepted for a period of 6 weeks. Email reminders were sent at week two and week four of the response period.

Questionnaire design and ethics approval

The questionnaire was developed specifically for this observational cross-sectional survey study and followed a modification of the Tailored Design Method.[14] Experts in AMR and agricultural research fields, dairy farmers and veterinarians were extensively consulted in its development including pretesting the survey with farmers. The term antibiotic was used in the questionnaire as a term familiar to farmers and to focus responses on substances used for treatment of bacterial infection. There were 20 questions in two sections. The first section had four questions about farmer demographics (age, gender, experience and current farming status) and three farm demographics questions (location, herd size, productivity). Three veterinary information questions completed the first section (distance from preferred private veterinary practitioner, recent veterinary use and possession of a veterinary health care plan (VHCP), defined as formal advice from their veterinarian on the use of medications in treating cattle disease commonly seen on their farm). The second section had 10 questions investigating attitudes and activities regarding AMU on their farm, including if they were involved in decision-making about AMU on their farm. Likert scales were used to explore farmer perceptions about the usefulness of AMU information sources; influences on whether and which antimicrobials are used to treat animals on their farm; and confidence about AMU practices on their farm. An open-ended question asked which antibiotic formulations were usually kept on farm. A copy of the survey is available in Appendix S1. Ethics approval was granted by the University of Sydney Human Research Ethics Committee (project number: 2017/642).

Study data management and analysis

Study data were collected and managed using the REDCap Electronic Data Capture tools hosted at the University of Sydney.[15] Online participants entered data directly into the tool and de-identified hard copy surveys were manually entered by the researchers. Data from the open-ended question about antimicrobials kept on hand were manually coded into a Microsoft Excel® spreadsheet before integration with the REDcap output.

Potential for non-response and reporting bias was recognized due to subjects' possible concern about scrutiny of their farming practices or AMU. Conversely, subjects particularly interested in the issue of AMU and AMR in the dairy industry may have been more likely to participate in the survey. To mitigate concern about answering challenging questions during the data collection phase, participants were able to skip questions in the survey. Participant and farm demographic information were collected to evaluate internal and external validity of the study using verified external population and industry data.

Accuracy of data entry was checked by creating numerical and graphical summaries of each variable and investigating outliers. Suspect data entry was cross-checked against hard copies. During analysis, the antimicrobials reported as usually kept on farm were listed by their non-proprietary name and ranked as 'high', 'medium' or 'low' in accordance with the Australian Strategic and Technical Advisory Group (ASTAG) on importance rating for the mitigation of antibacterial resistance.[16] Where necessary, continuous outcome variables were categorized into biologically or conceptually meaningful categories to assist analyses. Where possible, categories were based on known Australian dairy industry averages. Milking herd size (herd size) was classified as small (<250 head), average (250–750 head) or large (>750 head) herds. Daily milk yield per cow (milk yield) was classified as low (<15 L), average (15–20 L) or high (>20 L/day) yield. Farm distance from preferred private veterinary

practitioner (distance from veterinarian) was classified into ≤25 km and >25 km. The number of times respondents had utilised veterinary advice in making animal health decisions in the previous 6 months was classified as frequent (≥6 times) or less frequent (<6 times). Descriptive data analyses were conducted using Microsoft Excel. Only certain analyses of association, determined a priori to be of interest, were performed on this large data set. These included analyses relating to participant demographics, AMU information sources, farms having a formal VHCP and antimicrobials kept on farm. Factors associated with having a VHCP, frequent use of veterinary advice and keeping parenteral antimicrobial formulations on farm were analysed by univariable and multivariable logistic regression models using R Commander® statistical software package.[17] Variables included for analysis were: frequent use of veterinary advice; farm distance from preferred veterinarian; farms keeping ceftiofur on farm; farms with VHCP; milk yield and; herd size. In cases of missing data from discrete items, the respondent was excluded from respective analysis. 'N/A' and 'do not know' responses were excluded from all statistical analyses. Collinearity between pertinent categorical variables was tested using chi-squared analysis prior to conducting multivariable analysis and one of the collinear pairs was excluded from the model. Models were built using a stepwise, forward selection procedure. Variables with a P-value <0.2 after univariable analysis and confounders determined a priori were included in initial multivariable logistic regression models. Interaction terms were tested where relevant. Goodness of fit of multivariable models was assessed using the analysis of variance technique. Variables remained in a model if they significantly improved the fit ($P < 0.05$) or were confounders determined a priori.

Results

Response rate

Of a possible 631 licenced dairy farmers in the target population, 128 responses were received, 126 of which were useable. Hence, a response rate of 20.3% was obtained. Most responses were received by mail (n = 97) with the remaining provided directly into the online survey tool (n = 31).

Respondent and farm demographics

There was a difference of 13 years between the median age of respondents completing the questionnaire online (43 years) and those returning paper-based questionnaires (56 years, $P < 0.01$). Table 1 shows age, gender and work experience of respondents. These were consistent with that reported for Australian farmers in the 2016 Australian census report.[18] Representation of farms by NSW LLS region was consistent with licensee locality data provided by the NSW Food Authority (C. Green, NSWFA, Silverwater, NSW personal communication).

Farms were located up to 100 km from their preferred private veterinarian, with 30% of farms located >25 km away (n = 38). Milking herd size ranged from 40 to 6000 (median 200, mean 335) head of cattle and daily milk yield per cow ranged from 10 to 40 L (median 22 L, mean 22 L), consistent with data reported by Dairy Australia.[19]

Factors influencing AMU and selection by respondents

Nearly all respondents (99%, n = 125) reported they were involved in decision-making about AMU on their farm. More than two-thirds (69%, n = 86) of respondents reported they had a VHCP, defined as formal or informal advice from their veterinarian, which offers guidance on the use of medications in treating the cattle diseases commonly seen on their farm.

Figures 1 and 2 summarise factors influencing AMU and selection by respondents. Veterinary advice and the animal's clinical signs were reported by most respondents as strong or very strong influences on whether an antimicrobial was used (92%, n = 107; 95%, n = 110, respectively) and on which antimicrobial formulation was given to an individual animal (91%, n = 111 and 87%, n = 106).

Withholding period (WHP) was reported by 66% of respondents as having a strong or very strong influence on whether an antimicrobial was used (n = 77) and by 61% of respondents in deciding which antimicrobial formulation to use (n = 74).

Half of the respondents (50%; n = 58) reported that the potential for AMR developing had a strong or very strong influence on whether an antimicrobial was given, and which product was chosen, but conversely, this consideration had no influence on whether an antimicrobial was given or on which antimicrobial was given, for 9% (n = 10) and 16% (n = 16) of respondents, respectively.

Cost of the antimicrobial had the least influence on AMU and selection. Fifty percent (n = 58) of respondents reported antimicrobial cost had slight or no influence on whether antimicrobials were used, and 30% (n = 36) reported antimicrobial cost had no or slight influence on which antimicrobial was given.

Confidence in AMU practices

Figure 3 shows that the majority (90%) of respondents reported they were 'very' or 'moderately' confident that the entire range of antimicrobial practices proposed was done well on their farm.

Table 1. Summary of participant dairy farmer demographics

Gender (n = 125)	Female (30%, n = 38)		Male (70%, n = 87)	
Age and experience	Range	Median	Range	Median
Age (years, n = 125)	25–77	50	28–88	55
Years dairy farming (n = 120)	1–53	25	5–72	37

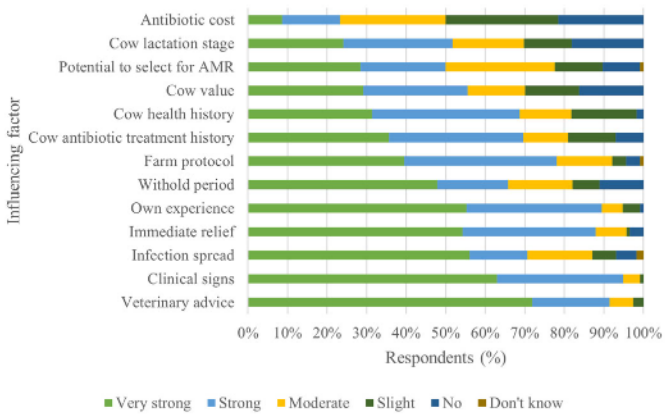

Figure 1. Factors influencing whether an antimicrobial is used to treat an individual animal. Colours indicate the proportion of respondents reporting each factor as very strong, strong, moderate, slight, no or unknown influence.

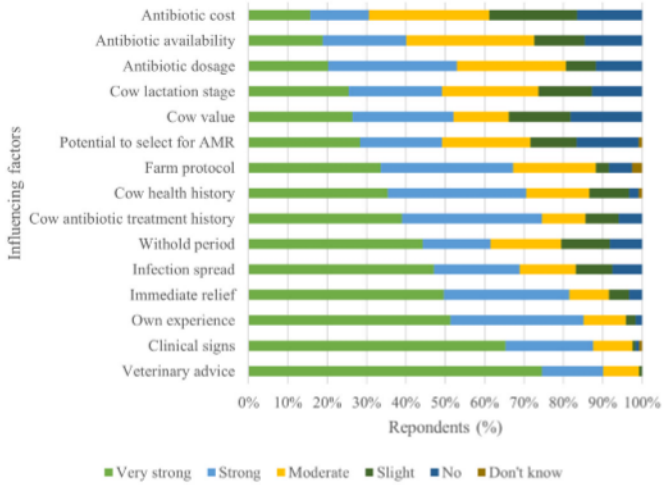

Figure 2. Influences on which antimicrobial is given to an individual animal. Colours indicate the proportion of respondents reporting each factor as very strong, strong, moderate, slight, no or unknown influence.

Antimicrobial products kept on farm

Respondents reported usually keeping 0 to 6 parenteral (median 2) and 0 to 5 intramammary or intrauterine antibiotic formulations (median 1) on their farm (Figures 4 and 5). Parenteral antimicrobials most frequently reported as kept on hand were oxytetracyclines (66%) and narrow spectrum penicillins (62%). Ceftiofur was kept on hand in 24% of farms. Cloxacillin was the most frequently reported intramammary formulation kept on-farm (41.2%). All intramammary formulations reported as kept on hand were low or medium importance according to ASTAG ratings.[16] Of the 102 responses to this open question, 3.9% (n = 4) reported that they did not keep antimicrobials on farm.

Information sources

Most respondents (92%) identified veterinarians as 'always' or 'quite' useful information sources for learning about AMU (n = 113), and their own experience was also ranked very high (84% always or quite useful, n = 106). While all other information sources were reported as less useful than these categories, 34% reported other farmers to be either 'quite' or 'always' useful (n = 40), followed by government resources (27%, n = 33), industry bodies (26%, n = 27) and dairy processing companies (16%, n = 19). Online searches were reported to be at least 'somewhat' useful by 80% of respondents (n = 96). Social media was considered the least useful resource, with 59% (n = 70) of respondents identifying this as 'never' useful (Figure 6).

The number of times respondents had utilised veterinary advice (farm visits, telephone calls, consultant veterinarians or government veterinarians) for making animal health decisions in the preceding 6 months ranged from 0 to 180 (median 17, IQR = 6–20). Over half of respondents (55%) reported frequent use of veterinary advice (≥6 occasions) in the 6 months preceding the survey.

Factors associated with having a VHCP

Traits found to be positively associated at the univariable level with farms having a VHCP were: frequent use of veterinary advice (P < 0.01, OR 3, 95% CI 1.4 to 6.8), farms >25 km from their veterinarian (P = 0.04, OR 2.5, 95% CI 1.1 to 6.2) and farms that kept ceftiofur on farm (P = 0.04, OR 3.4, 95% CI 1.2 to 13). No association was identified between herd size (average herd size P = 0.85; large herd size P = 2.02) or milk yield (average milk yield P = 0.98; high milk yield P = 3.25) and having a VHCP.

Keeping ceftiofur on hand was excluded from the multivariable model due to its association with frequent veterinary use (P = 0.02). The final multivariable model included distance from veterinarian (≤25 km or >25 km), herd size and milk yield. The latter two factors were determined a priori to be rational confounders to having a VHCP, due to the reasonable likelihood of large or high producing herds having more formal management mechanisms in place. Farms located >25 km away from their veterinarian had 3.1 times the odds of having a VHCP than those closer, independent of herd size and milk yield (P = 0.017, 95% CI 1.3 to 8.4).

Factors associated with frequent use of veterinary advice

Farmers who kept ceftiofur on farm (P = 0.02, OR 3.3, 95% CI 1.2 to 9.7), those with a VHCP (P < 0.01, OR 3.0, 95% CI 1.4 to 6.8) and those who reported high milk yield (P < 0.01, OR 30, 95% CI 5.0 to 572) were associated at the univariable level with frequent use of veterinary advice. No association was identified between herd size or farm distance from veterinarian and frequent use of veterinary advice.

Only milk yield remained in the final multivariable model for factors associated with frequent use of veterinary advice. Farmers reporting high milk yield (>20 L/cow/day) had 27 times the odds of frequent use of veterinary advice than those reporting low milk yield (P < 0.001, CI 4.5 to 523).

Factors associated with keeping parenteral antibiotic formulations on farm

Of the 11 parenteral antibiotic formulations reported to be kept on farms, only keeping oxytetracycline and ceftiofur were found to have

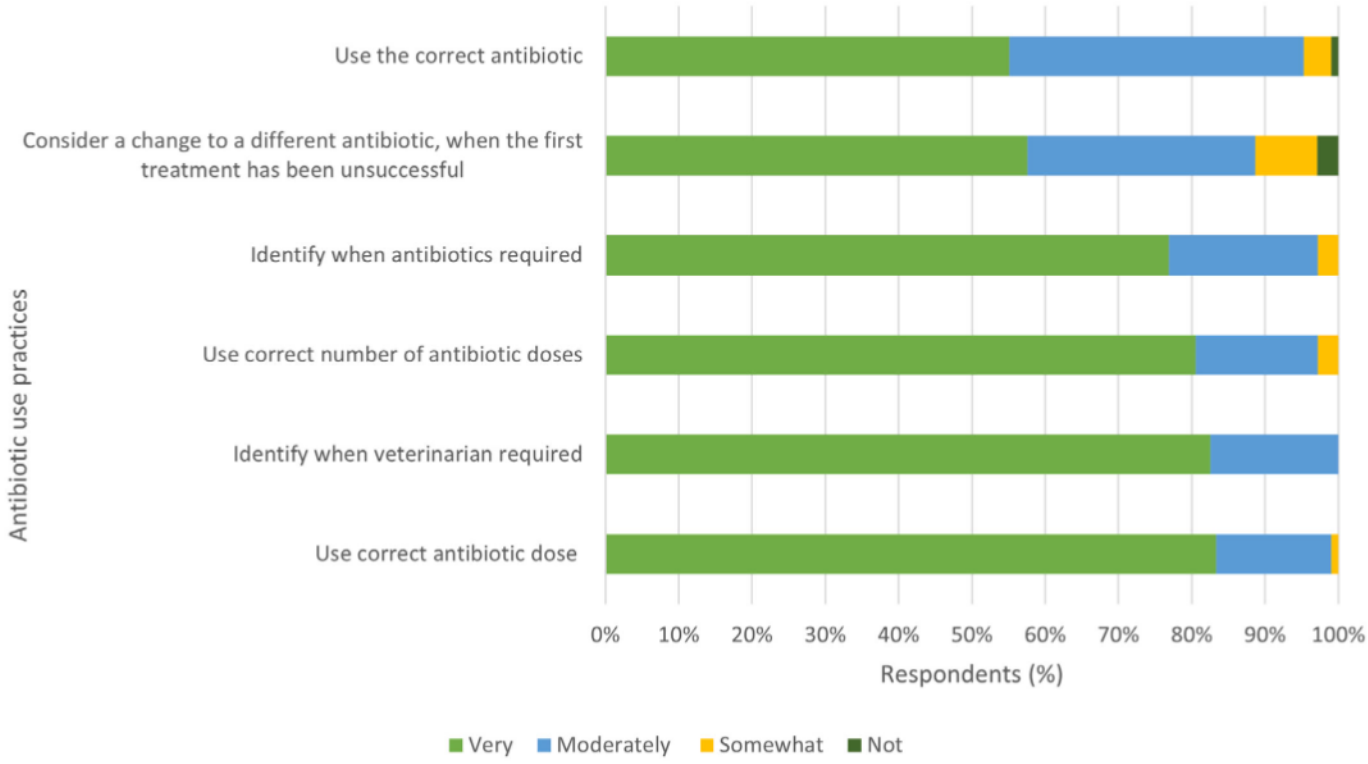

Figure 3. Farmer confidence that antimicrobial use practices are done well on their farm. Colours indicate the proportion of respondents reporting their confidence that each practice is done well on their farm as very confident, moderately confident, somewhat, or not confident.

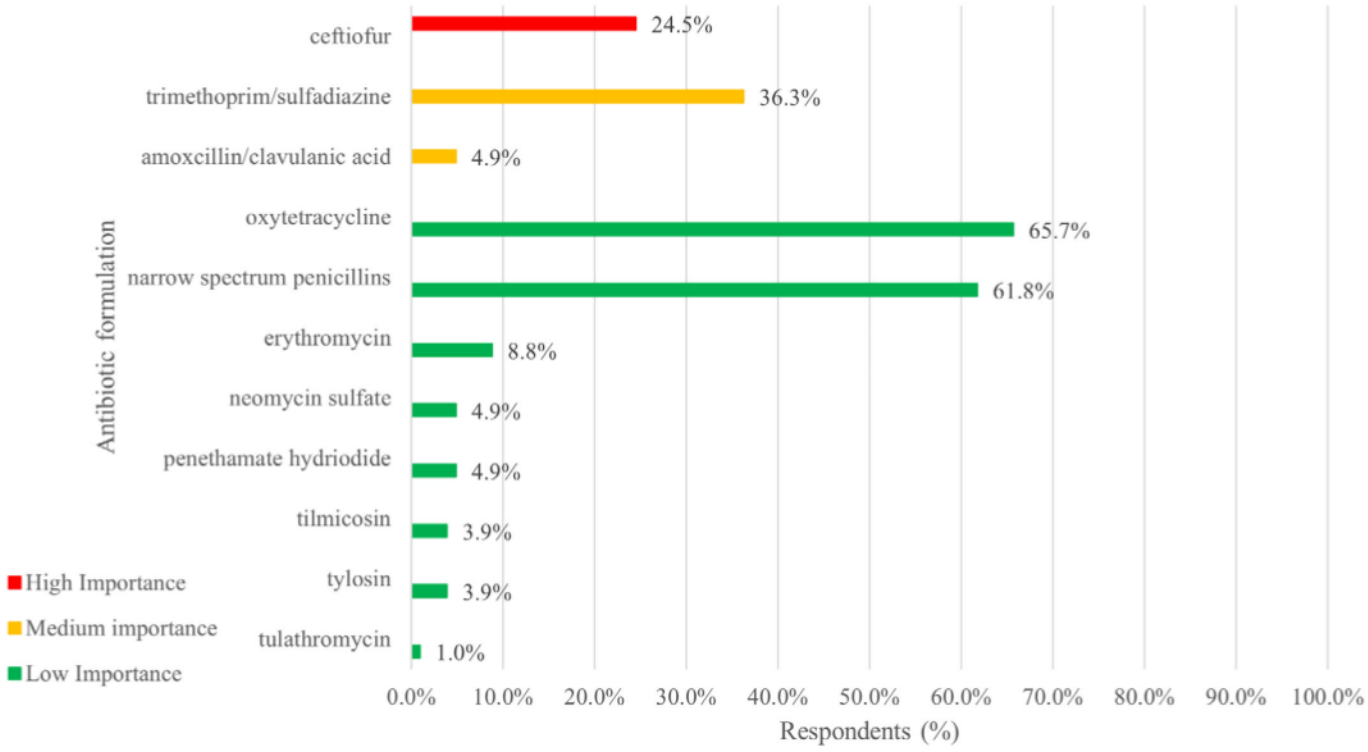

Figure 4. Percentage of respondents keeping different parenteral antimicrobial formulations kept on farm. Colours indicate rank according to the importance ratings and summary of antibacterial uses in human and animal health in Australia.[16]

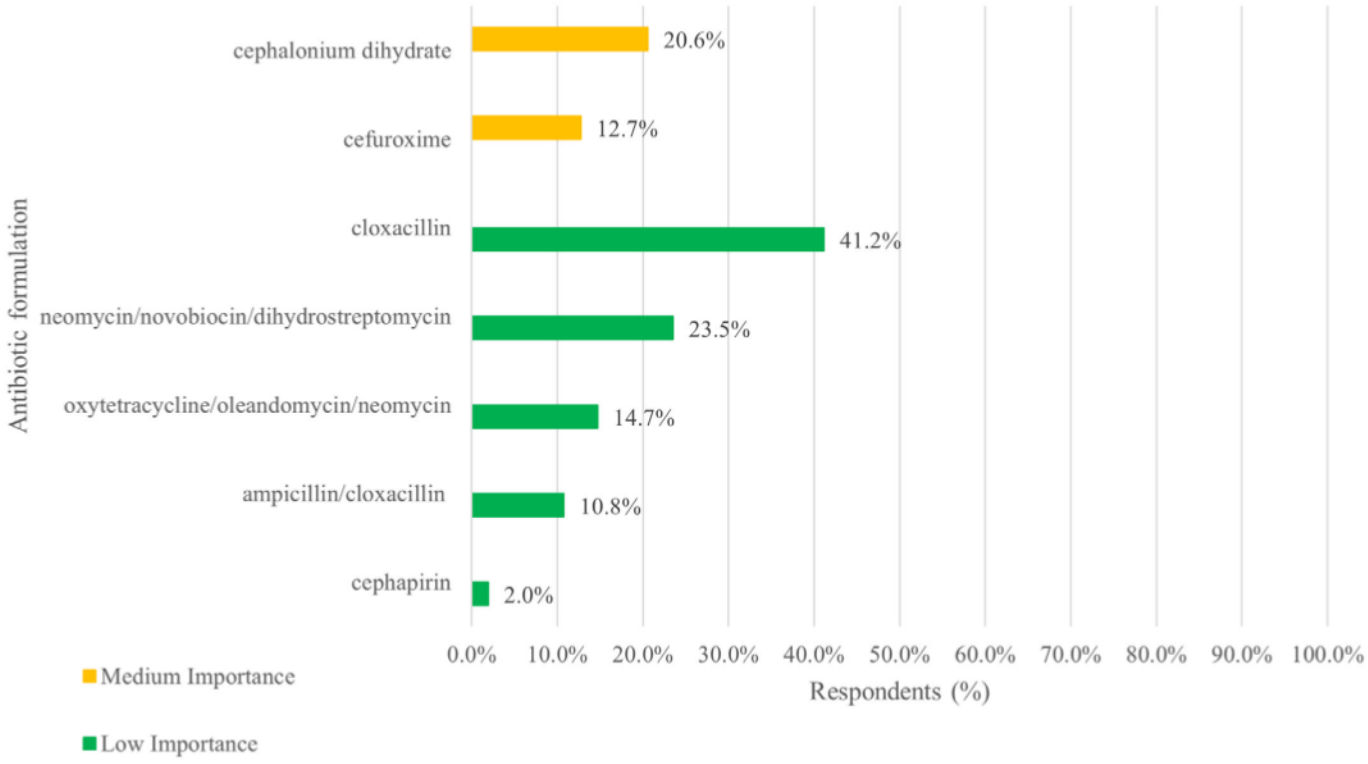

Figure 5. Percentage of respondents keeping different intramammary and intrauterine antimicrobial formulations on farm. Colours indicate rank according to the importance ratings and summary of antibacterial uses in human and animal health in Australia.[16]

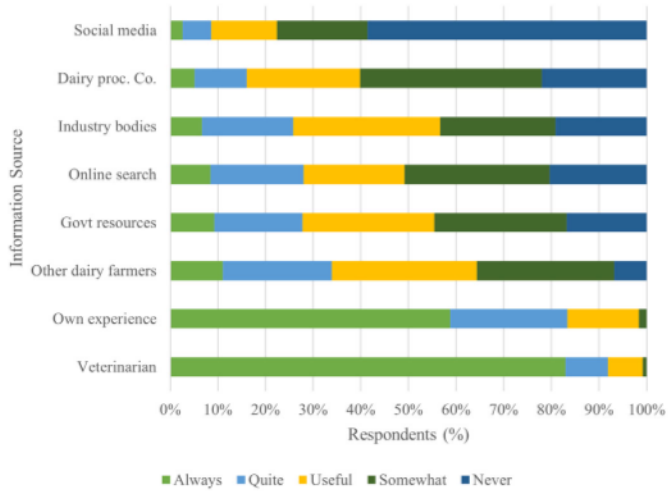

Figure 6. Usefulness of information sources for learning about antimicrobial use. Colours indicate the proportion of respondents reporting each source of information as always useful, quite useful, useful, somewhat useful or never useful.

an association with other factors. Keeping oxytetracycline on farm was associated at the univariable level with frequent use of veterinary advice (P = 0.01, OR 2.8, 95% CI 1.3 to 6.5) and 'average' herd size (P < 0.01, OR 4.5, 95% CI 1.6 to 14.5). No association was identified between keeping oxytetracycline on hand and having a VHCP, farm distance from veterinarian or milk yield.

Respondents reporting keeping ceftiofur on farm were associated at the univariable level with having a VHCP (P = 0.04, OR 3.4, 95% CI 1.2 to 12.6) and frequent use of veterinary advice (P = 0.02, OR 3.3, 95% CI 1.2 to 9.7). No association was identified between keeping ceftiofur on hand and herd size, farm distance from veterinarian or milk yield.

Only frequent use of veterinary advice remained in the final multivariable model for factors associated with keeping ceftiofur on farm. Farmers reporting frequent use of veterinary advice had 3.3 times the likelihood of keeping ceftiofur on farm than those using veterinary advice less frequently (P = 0.02, CI 1.2 to 9.7). No interaction was found between frequent use of veterinary advice and having a VHCP, with respect to keeping ceftiofur on farm (P = 0.14).

Discussion

This study identified existing relationships, resources and attitudes of the dairy farmers that could be optimised for on-farm AMS strategies such as with the NSW Food Authority and veterinarians. Farmers' high confidence regarding their own knowledge of antimicrobials, their high regard for veterinary advice, and high rate of VHCP use (69%) provide a strong framework to further build the profile and practice of AMS on dairy farms. The higher likelihood of keeping ceftiofur on-farm in those farms that report frequent use of veterinary advice requires further investigation to determine the appropriateness of use by the farmer and the governance provided by the prescribing veterinarian.

Veterinarians have a critical role in establishing and monitoring AMS on Australian dairy farms as the strongest influencers and information sources regarding on-farm AMU.[32] Formalised cooperation between veterinarians and the farming sector have been successful in countries such as The Netherlands, where programs overseen by government focus on monitoring antimicrobial usage, setting AMU reduction targets and increased use of preventative management and herd health plans.[20] The nature and impact of veterinary consultation in Australia could be further explored to better understand the veterinarian-farmer relationship with respect to AMU. Studies of veterinarians' actual involvement in their dairy clients' day-to-day AMU have reported low levels of veterinary consultation in practice in the UK.[8] Veterinarians also report numerous barriers to implementing AMS in farm settings, such as pressure to prescribe, lack of client understanding of antimicrobials, client unwillingness to implement management changes and concern about the risk to their own income stream.[8, 20–22] Further investigation into farmer and veterinary attitudes and practices may assist in identifying if these barriers are real or perceived and mechanisms for overcoming them.

Dairy farmers reported being highly confident in the standard of their on-farm AMU practices and considered their own experience the next most useful source of information about AMU after veterinarians. Less than 30% of respondents considered 'formal' information sources such as government and industry bodies to be useful. Notably, despite this low reliance on industry, commercial or government organisations for information about AMU, the participation for this survey was comparable to similar studies[6, 7, 9] and the study itself showed the access and potential future influence of NSWFA in this sector.

No associations were found between farmer confidence and other factors measured in this study. In the absence of information about actual on-farm AMU, no judgement can be made as to whether the high confidence reported is supported by acceptable AMS in practice. Understanding the origins of farmer confidence and intrinsic factors in their AMU, has the potential to reveal highly effective avenues for building awareness of AMR and AMS in the sector.[12]

Virtually all farmers reported they were involved in decision-making on the use of antimicrobials on their farm. VHCPs were widely implemented (69%) and this was associated with being located further from a veterinary service and putatively, with frequent use of veterinary advice. Although the content and value of current VHCPs with respect to AMS are unknown, this level of uptake presents a promising existing conduit for building AMS between veterinarians and farmers. VHCPs demonstrate that veterinarians and farmers share interest in implementing tools to improve management of common health problems on dairy farms in the face of limited access to veterinary advice at the individual case level. Involving farmers in revisions of AMU policy and developing proactive strategies to herd health management reviews has greater potential for meaningful behaviour change beyond simply providing information.[23] Further work is warranted to develop resources to incorporate into VHCPs that support AMS by both farmers and veterinarians and, measure their impact on farm AMU.

Farmers generally kept a limited number of antimicrobial formulations on hand, the majority being antimicrobials of low or medium importance, however, almost one-quarter reported keeping ceftiofur, an antimicrobial of high importance[16] on farm. Despite the global lack of reporting on AMU, these results are consistent with reports from northern hemisphere dairy farms where third and fourth-generation cephalosporins are reported to be used extensively to treat mastitis in the USA, UK and Belgium despite their WHO classification as antimicrobials of high priority critical importance.[8, 24]

Associations identified between frequent use of veterinary advice and respondents keeping ceftiofur on farm may reflect greater access to veterinarians resulting in access to the drug for its appropriate use. The implied routine use (or lack of oversight of use) of ceftiofur as a first-line treatment, by virtue of it being kept on farm, is of concern given its high/critical importance classification in Australia and globally[16, 24] and requires further investigation. The role of veterinarians is critical in farmer training, restricting and governing antimicrobial access and guiding and co-constructing detailed herd health plans to reduce disease and AMU.[23] The Australian Veterinary Association prescribing guidelines for dairy cattle outline the use of third-generation cephalosporins (including ceftiofur) as being important in the treatment of severe and invasive infections when other options are unavailable and wherever possible only after susceptibility testing has been completed.[25] It is unlikely these criteria are consistently met in the on-farm use context.

Most respondents (79%) reported that WHP had at least a moderate influence on which antimicrobial was given. As the only antimicrobial with nil milk WHP available on the Australian market, use of ceftiofur, for this reason, is plausible but was not investigated. Exploring the context and drivers of ceftiofur use and farmer/veterinary perception of the role of ceftiofur in the routine management of disease on Australian dairy farms may identify avenues to reduce or eliminate its use without compromise to animal health or economic outcomes. A balance is needed between the readily and timely access to antimicrobial agents to mitigate disease and improve welfare outcomes for patients and the need for improved veterinary oversight.[26]

Around half of the farmers reported that the potential to select for AMR had a strong or very strong influence on decision-making about AMU. Whether this influence translates to knowledge and practice of appropriate AMU was not assessed. Previous work has identified that even where farmers have awareness of the need for responsible AMU, their understanding of its practical application may be limited.[7] Other influences on farmer use of antimicrobials were broad and altered little between deciding to treat with antimicrobials and subsequent selection of formulation. Major influences, in addition to veterinary advice, were farmer's own experience, clinical signs of the animal, relief of patient suffering and limiting the spread of disease. Similar influences have been reported by veterinarians questioned on their own prescribing behaviours–clinical signs, personal experience and advice from colleagues appear commonly as influences on prescribing, with culture and susceptibility testing results being an influence when possible.[20, 22, 32] Farmer's personal beliefs and experience have been consistently identified as a powerful influencer of animal health decisions.[12, 27, 28] As the ultimate implementers of health interventions for the animals in their care, farmers' influencers need to be understood and utilised to initiate change in AMU practices.[29]

Findings from this study point to three major opportunities for engaging dairy farmers in AMS.

1 Private veterinarians have a significant role to play. VHCPs are currently used or at least, in the possession of, most farmers. There may be the capacity for major stakeholders such as veterinarians, government or industry bodies to optimise these existing references to equip farmers in AMS in a similar way antimicrobial prescribing protocols have been used in human and to some extent, oveterinary medicine.[23, 30–32]
2 Industry and government bodies have an opportunity to provide vital resources in AMS for the dairy industry, given their unparalleled access to farmers and commitment to promoting best practice farming, sustainability of the industry and maintaining Australian dairy's 'clean green' image on the world stage. There are existing farmer capacity-building programs, which utilise veterinarians and could be used as a model for promoting AMS in the broader industry.[33] Importantly, such programs have potential to reach where private veterinary practitioners and VHCPs may not.
3 The strong influence of farmers' own experience and knowledge about AMU, combined with their high levels of confidence cannot be ignored and may be utilised as a driver for change across the industry. Deeper understanding of the origins of farmer confidence around AMU and whether this translates to acceptable use in practice, can inform effective communication on the value of AMS practices to the individual animal, herd, industry and community at large. Generating expectations of suitable AMS in the farming community and driving demand for AMS-conscious prescribing by veterinarians have the potential to drive AMS across the industry.[26]

Strengths and limitations of the study

The recruitment method relied upon participants completing and returning the questionnaire of their own accord. This approach may result in selection bias due to either interest in or antagonism toward the topic and those who hold strong views. The survey included potentially sensitive questions about AMU which may have led to biased reporting due to perceived 'appropriate' responses rather than actual behaviours or opinions. As participants completed the survey independently, reporting bias is also possible due to variable interpretation of the questions. Although extensive preparatory work was undertaken in the questionnaire design phase to limit this bias, participant context and/or differing levels of awareness about the topic may also contribute to reporting bias. Because the survey was conducted anonymously, it is not possible to determine characteristics of non-respondents to the survey, nor seek out further information from specific respondents.

Whilst questionnaires provide a useful means of gathering qualitative information on complex behavioural topics like farm animal health management, the very nature of a questionnaire imposes limitations on the data acquired. Simplification of the topic of AMU on farm, possible variability in interpretation of questions, reporting bias and the inability to further question interesting responses were known trade-offs to the advantages of participant anonymity, practicality and cost efficiency of the survey approach.[14] Regardless, the study has provided valuable first data about AMU by Australian dairy farmers. Follow up with interview-style surveys would be of value as while they examine fewer people, higher quality qualitative data could be gathered.

The sample population from this state-based study equates to 2% of Australia's approximately 5789 registered dairy farms in 2017.[19] Participants' demographic information is representative of the national dairy farmer population when compared to available statistics for farmer age, gender, farm herd size and productivity. However, milk production systems differ due to varying climatic conditions, market requirements and the cost of inputs such as land, feed and water[19, 34] There is more variation in dairy farming systems across Australia compared to within NSW. Year-round and batch production is the most common dairy production system in NSW, where seasonal production is more prominent in Victoria, Tasmania and South Australia.[19] Differences in climate and farming systems may have implications for the types and frequency of disease and its subsequent management and impact on the way in which antimicrobials are used and viewed by farmers operating different systems.

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References

1. WHO. Global action plan on antimicrobial resistance. Available at: http://www.wpro.who.int/entity/drug_resistance/resources/global_action_plan_eng.pdf. 2015. Retrieved 16 June 2018.
2. Manyi-Loh C, Mamphweli S, Meyer E et al. Antibiotic use in agriculture and its consequential resistance in environmental sources: potential public health implications. *Molecules*. 2018;23:795.
3. Cabello FC, Godfrey HP. Even therapeutic antimicrobial use in animal husbandry may generate environmental hazards to human health. *Environ Microbiol* 2016;18:311–313.
4. Munkholm L, Rubin O, Bækkeskov E et al. Attention to the Tripartite's one health measures in national action plans on antimicrobial resistance. *J Public Health Policy* 2021;42:236–248.
5. Saini V, McClure JT, Leger D et al. Antimicrobial use on Canadian dairy farms. *J Dairy Sci* 2012;95:1209–1221.
6. Friedman DB, Kanwat CP, Headrick ML et al. Importance of prudent antibiotic use on dairy farms in South Carolina: A pilot project on farmers' knowledge, attitudes and practices. *Zoonoses Public Health* 2007;54:366–375.
7. Jones PJ, Marier EA, Tranter RB et al. Factors affecting dairy farmers' attitudes towards antimicrobial medicine usage in cattle in England and Wales. *Prev Vet Med* 2015;121:30–40.

8. Hockenhull J, Turner AE, Reyher KK et al. Antimicrobial use in food-producing animals: A rapid evidence assessment of stakeholder practices and beliefs. *Vet Rec* 2017;181. https://doi.org/10.1136/vr.104304
9. McDougall S, Compton C, Botha N. Factors influencing antimicrobial prescribing by veterinarians and usage by dairy farmers in New Zealand. *N Z Vet J* 2017;65:84–92.
10. Dairy Australia. Producing Australian dairy foods. Available at: http://www.nutritionaustralia.org/sites/default/files/Producing%20Australian%20Dairy%20Foods_Printable%20PDF.pdf. 2018. Retrieved 15 September 2018.
11. Marshall BM, Levy SB. Food animals and antimicrobials: impacts on human health. *Clin Microbiol Rev* 2011;24:718–733.
12. Garforth C. Livestock keepers' reasons for doing and not doing things which governments, vets and scientists would like them to do. *Zoonoses Public Health* 2015;62:29–38.
13. Coombe J, Tymms S, Humphris M. Antimicrobial stewardship in the dairy industry: Responding to the threat of antimicrobial resistance. *Aust Vet J* 2019;97:231–232.
14. Dillman DASJCL. *Internet, phone, mail and mixed-mode surveys: the tailored design method*. 4th edition. Hobokan, NJ: Wiley, 2014.
15. Harris PAT R, Thielke R, Payne J et al. Research electronic data capture (REDCap) - a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42:377–381.
16. ASTAG. *Importance ratings and summary of antibacterial uses in human and animal health in Australia*. Commonwealth of Australia, Canberra, Available at: https://www.amr.gov.au/resources/importance-ratings-and-summary-antibacterial-uses-human-and-animal-health-australia. 2018.
17. Fox J, Bouchet-Valat, M. Rcmdr: R Commander. 2018.
18. ABS. Agricultural commodities, Australia 2015–16. Available at: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/7121.02015-16?OpenDocument. 2017. Retrieved 5 September 2018.
19. Dairy Australia. Cows and farms. Available at: https://www.dairyaustralia.com.au/Industry/Farm-facts/Dairy-at-a-glance. 2017. Retrieved 15 September 2018.
20. Postma M, Speksnijder DC, Jaarsma AD et al. Opinions of veterinarians on antimicrobial use in farm animals in Flanders and The Netherlands. *Vet Rec* 2016;179:68.
21. Coyne LA, Latham SM, Dawson S et al. Antimicrobial use practices, attitudes and responsibilities in UK farm animal veterinary surgeons. *Prev Vet Med* 2018;161:115–126.
22. Zhuo A, Labbate M, Norris JM et al. Opportunities and challenges to improving antibiotic prescribing practices through a one health approach: results of a comparative survey of doctors, dentists and veterinarians in Australia. *BMJ Open* 2018;8:e020439.
23. Hyde R, Tisdall D, Gordon P et al. Reducing antimicrobial use on dairy farms using a herd health approach. *In Practice* 2019;41:368–382.
24. WHO. Critically important antimicrobials for human medicine. Available at: https://www.who.int/publications/i/item/9789241515528. 2019. Retrieved 18 September 2019.
25. AVA. Antimicrobial prescribing guidelines for dairy cattle. Available at: https://www.ava.com.au/siteassets/policy-and-advocacy/policies/animal-welfare-principles-and-philosophy/ava-ama-antimicrobial-prescribing-guidelines-for-dairy-cattle-4-01-22-final.pdf. 2022.
26. Atkinson O. Stewardship of veterinary medicines on dairy farms. *Vet Rec* 2019;184:150–152.
27. Hadar L, Fischer I. Giving advice under uncertainty: what you do, what you should do, and what others think you do. *J Econ Psychol* 2008;29:667–683.
28. Kristensen E, Jakobsen EB. Challenging the myth of the irrational dairy farmer; understanding decision-making related to herd health. *N Z Vet J* 2011;59:1–7.
29. Speksnijder DC, Jaarsma DAC, Verheij TJM et al. Attitudes and perceptions of Dutch veterinarians on their role in the reduction of antimicrobial use in farm animals. *Prev Vet Med* 2015;121:365–373.
30. Kaki R, Elligsen M, Walker S et al. Impact of antimicrobial stewardship in critical care: a systematic review. *J Antimicrob Chemother* 2011;66:1223–1230.
31. Chandy SJ, Naik GS, Charles R et al. The impact of policy guidelines on hospital antibiotic use over a decade: a segmented time series analysis. *PLoS One* 2014;9:e92206.
32. Tree M, McDougall S, Beggs DS et al. Antimicrobial use on Australian dairy cattle farms-a survey of veterinarians. *Prev Vet Med* 2022;202:105610.
33. Dairy Australia. Animal management. Available at: https://www.dairyaustralia.com.au/Industry/Farm-facts/Dairy-at-a-glance. 2017. Retrieved 15 September 2018.
34. PWC. The Australian dairy industry: the basics. Available at: https://www.pwc.com.au/industry/agribusiness/assets/australian-dairy-industry-nov11.pdf. PricewaterhouseCoopers. 2011.

Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site: http://onlinelibrary.wiley.com/doi/10.1111/avj.13209/suppinfo.

Appendix S1. Survey: Managing common cattle health problems on Australian dairy farms.

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