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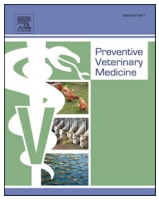

Antibiotic use in the Northern Irish sheep flock: What lessons can be learnt from medicine records and farmer attitudes to improve stewardship of these essential medicines?

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ABSTRACT

Stewardship of antibiotics used in livestock production has come under increasing scrutiny, from both the animal welfare point of view and due to concerns that antibiotic use in livestock may pose a risk to human health through selection pressure to drive development of antibiotic resistant strains of bacteria. Despite this concern, however, antibiotic consumption in the sheep sector is currently poorly described. This study determines the range and quantities of antibiotics used in the Northern Irish (NI) sheep flock as well as exploring drivers for their use. A mixed-methods approach was utilised, with an anonymous online scoping survey, analysis of the medicine records from 52 NI sheep farms and semi-structured interviews undertaken with 27 farmers. Eighteen farmers contributed both records and participated in interviews. Veterinary medicine records were derived from two sources: on-farm medicine books (seven) or veterinary practice sales data (51). As six of these farmers provided information from both sources a total of 52 unique farms participated. Overall, antibiotic use in sheep on the 52 farms sampled was low, with a median value of 11.35 mgPCU^{-1} (mean 13.63 mgPCU^{-1}, sd 10.7; range 0–45.29 mgPCU^{-1}), with all farms below 50 mgkg^{-1}. Critically important antibiotics accounted for 0.21% of all antibiotics purchased. Lameness was the main driver of antibiotic use identified by this study. Others included a range of prophylactic treatments such as oral antibiotics to prevent watery mouth, injectable antibiotics to prevent abortion and following assisted lambing. Farmers acknowledged some of these uses had become habitual over time. The veterinary medicine sales records demonstrated significant sales of antibiotics not authorised for use in sheep, on an ongoing, rather than case-by-case, basis. Farmers were positive about their veterinarian's ability and knowledge to improve flock welfare and productivity, but were unwilling to pay for this advice. However, veterinarians may have facilitated weak medicine stewardship through a failure to adequately challenge farmers seeking antibiotics. Farmers did not maintain accurate or up-to-date on farm medicine or production records in the majority of cases. Despite this lack of on-farm recording, veterinary sales records can be studied in consultation with farmers to provide veterinarians with a farm-specific insight into antibiotic use and related attitudes and behaviours. Farmers and veterinarians can then identify areas and behaviours to target collaboratively, improving antibiotic and wider medicine stewardship, whilst simultaneously improving flock health and productivity.

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1. Introduction

The use of antibiotics in farmed livestock has come under scrutiny because of the increasing development of antimicrobial resistance (AMR) as well as the perceived link between antibiotic use in farmed livestock and the risk of antimicrobial resistance in humans (O'Neill, 2016; WHO, 2021). The potential contribution of sheep to the overall global burden of AMR has been studied less extensively than for other farmed species, particularly cattle and poultry (Dantas Palmeira et al., 2021). There is therefore an ongoing need to conduct research to address this knowledge gap, incorporating social science methodologies to elucidate the opinions and behaviours of key stakeholders involved in antimicrobial prescription and administration in sheep.

In the United Kingdom (UK), all antibacterial medications for use in farm animals fall into the category of POM-V medications and, as such, require prescription by a veterinarian (VMD, 2018). These regulations also obligate farmers to maintain detailed records of all medicine used in their livestock. Together, the legislation and veterinary prescription should provide critical checkpoints on the control of supply of antibiotics into the national flock. Overall, the aim must be careful stewardship, with a reduction in the quantity of antibiotics used, precisely targeting their use through flock health planning and a strong partnership approach between veterinarians and sheep farmers. However, the veterinarian's limited ability to influence sheep farmers' uptake of preventative practices (Kaler and Green, 2013; Bellet, et al., 2015; Nevel, A., 2022) can reduce their role on many farms to predominantly 'fire-brigade' work dealing with emergencies, where antibiotics must be dispensed responsively to restore health and improve animal welfare.

In a review commissioned by the British Government, economist Jim O'Neill (2016) emphasised the need for more surveillance to track antibiotic consumption in both humans and animals. This has led to international targets which have cascaded down to local and sector-specific action. The European Union (EU) laid out aims in 2019 that all antibiotic use within the sheep sector should be recorded, country by country, by 2026, and for all livestock sectors and companion animals, by 2030 (EU, 2019). Antibiotic use is being recorded in approximately 95% of pigs slaughtered in the UK, in the sector's national electronic medicine book (Nevel, M., 2022) and has enabled the UK pig sector to demonstrate a 69% reduction in antibiotic use since 2015 and to commit to further reductions under the Targets Task Force (TTF) initiative by 2024 (Nevel, M., 2022). However, this level of medicine use recording has not been replicated in the ruminant sector (Craig et al., 2020).

Within the EU, data collection on antibiotic use has been led by the European Surveillance of Antimicrobial Consumption Network (ESAC-Net), with a remit to facilitate standardised reporting of antibiotic consumption of veterinary medicines at a national level across the EU Member States (EMA, 2012; EMA, 2015). The metrics they use were derived from those used in the human health sector at a national level, and, as such, are not optimised for farm-level benchmarking (Craig et al., 2020). Human-medicine derived metrics have been redefined to account for the patterns of antibiotic use, and wide range of body masses encountered in veterinary medicine. Metrics currently in use include the milligrams per population corrected unit ($mgPCU^{-1}$) (EMA, 2012), the defined daily dose for animals (DDDvet), and defined course dose for animals (DCDvet) (EMA, 2015). These metrics are discussed in greater detail elsewhere (Davies et al., 2017, Mills, et al., 2018, O'Neill et al., 2020). There remains, however, a lack of universal acceptance for these definitions, and their appropriateness for use in setting benchmarks or thresholds (O'Neil et al., 2020). This has led to numerous other metrics being proposed, and alternative systems of antibiotic use comparison have been developed through national and sector-specific schemes (Craig, et al., 2020). Furthermore, it has been strongly suggested that any metric should emphasise or highlight the use of critically important antibiotics (CIAs) (EMA, 2019; WHO, 2019), as these were identified as a priority area to focus efforts to improve the stewardship of antibiotics (O'Neill, 2016; RUMA, 2017).

Within the UK, the Responsible Use of Medicine in Animals Alliance (RUMA), which was established nearly 20 years before the O'Neill Report (O'Neill, 2016), has developed detailed, sector-specific targets for antibacterial use through their TTF initiative (Glennon, 2016). The TTF also identified a lack of accessible data on medicine use in the sheep sector as a significant barrier to improved stewardship. To facilitate and encourage the recording of medicine use, and antibiotics in particular, the Sheep Antibiotic Guardian Group's core metrics were devised to simplify the benchmarking of antibiotic use on UK sheep farms (RUMA, 2019). To minimise the workload for veterinarians and farmers who wanted to utilise these metrics, a free-to-access online calculator was developed which returned standardised metrics of antibiotic use in sheep based on data entered, such as the number of sheep on the farm and quantity of medicine used (Hyde et al., 2017).

Despite the drive to improve stewardship of antibiotics on sheep farms (Glennon, 2016), and the legal requirement for all farmers to record medicine use (VMD, 2013), there is still a scarcity of published data from the UK sheep flock (Hennessey et al., 2020). There is none pertaining to the national flock in Northern Ireland (NI) or indeed elsewhere on the island of Ireland (Martin, et al., 2020). Davies et al., (2017) collated a convenience sample of anonymised veterinary practice sales records, supplied by eight veterinary practices and representing 207 sheep farms in Great Britain (GB). This dataset indicated a mean antibiotic consumption of 11.4 $mgPCU^{-1}$ (range 0–117 $mgPCU^{-1}$), and the authors confirmed a favourable correlation between $mgPCU^{-1}$ and DCDvet / DDDvet when used to rank flock antibiotic use in the study farms.

All the antibiotics currently authorised for use in sheep in the UK are authorised in at least one other food production species (Anon, 2021). Thus, sales data at the national, wholesaler or veterinary practice level cannot be used to determine the antibiotic use in sheep, nationally or at farm level (Arnold et al., 2021). However, it may be possible, even on mixed species farms, to determine quite accurately the species to which an antibiotic has been given if adequate and accurate farm records exist. The results from individual farms could then be combined centrally to create national estimates for antibiotic use. This is the basis of the Agriculture and Horticulture Development Board's (AHDB) online Medicine Hub system, which was launched in October 2021 for use across the UK to collate farm level medicine use in the beef and sheep sectors at a national level (AHDB, 2021). Specific calls have subsequently been made to engage the sheep sector more fully in its use (Nevel, A., 2022). However, as discussed by Menéndez González et al., (2010), farm level data, even with direct electronic data entry, may contain significant omissions and require time-consuming cleaning prior to uploading for centralised analysis.

Various methods have been explored for the collection and analysis of data concerning farm-level medicine use; these include farm audits combined with a questionnaire (González Pereyra, et al., 2015); veterinary sales data (Davies et al., 2017); antibiotic medicines stored on farm (Rees et al., 2019); and on-farm medicine records combined with analysis of the contents of special waste bins for farmers to store used medicines containers (Doidge, et al., 2021). This work has highlighted challenges in measuring veterinary medicine use, as on-farm records tend to capture only a proportion of the medicine usage (Doidge, et al., 2021). Also, use of veterinary sales data relies on the clear segregation of each item dispensed by species, which is not often undertaken at the point of sale (Arnold et al., 2021). Additionally, data on livestock numbers, age and size would need to be collated in a standardised fashion to permit the most accurate antibiotic use calculations (Menéndez González, et al., 2010).

Given this context, and the need to improve the stewardship of antibiotics by sheep farmers, the study reported here considers the use of antibiotics in a convenience sample of 52 Northern Irish sheep flocks. In addition to determining the quantities and classes of antibiotics used in this sample of sheep, this study sought to identify attitudes and

behaviours of sheep farmers towards, and reasons for, antibiotic use and recording, and areas where veterinarians may engage with their clients collaboratively to achieve better stewardship of antibiotics.

2. Materials and methods

A mixed methods approach was taken, utilising a stand-alone questionnaire, and linked phases comprising veterinary medicine usage and sales records analysis and semi-structured interviews. This programme of work was commenced following ethical approval of the study by the institutional research ethics committee (Approval no. 0010–202101-PGMPHD).

2.1. Questionnaire

The initial scoping study was part of an anonymous online questionnaire, the main focus of which was sheep scab, and which has been reported elsewhere (Crawford, et al., 2022). The questionnaire also included questions addressing the farmer-veterinarian relationship and flock management. Following development, pilot testing was undertaken initially with non-target farmers before launching it online. This questionnaire was made available online between March and June 2021 and promoted widely through social media, printed farming press and radio. The questionnaire was open to all sheep farmers in NI and a partial postcode required to verify location. No incentives were offered for completion of the questionnaire. Results, including free text responses to open questions, were downloaded from the online survey platform (JISC) into spreadsheets (Microsoft® Excel® 2016) for further analysis. Qualitative responses were considered inductively – that is, derived gradually from the data- and organised thematically (Degeling and Rock, 2020).

2.2. Recruitment to medicine record analysis and semi-structured interviews

A range of strategies were used to recruit participants including professional contacts of the first author, industry stakeholder groups, the use of gatekeepers (Hay, 2000) such as lamb buying group co-ordinators and veterinarians, and 'snowball' sampling through other participants (Noy, 2008). No restrictions were applied concerning flock size or other species farmed in addition to sheep. As potential participants came forward, they were offered the opportunity to participate in *either* the medicine usage and sales records analysis phase of the programme *or* the semi-structured interviews *or* both activities (Fig. 1). The first author undertook all recruitment and data collection, including transcription of interviews, and initial analysis of each of the data sets.

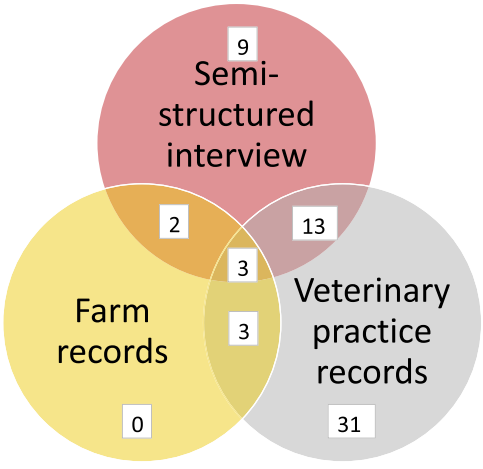

Fig. 1. Number of Northern Irish sheep farmers contributing to each element of the final medicine record analysis and semi-structured interviews.

2.3. Medicine usage and sales records analysis

Quantitative medicine data was obtained by asking farmers to provide consent to either make a copy of their on-farm medicine records and/or to approach their veterinarian(s) to obtain a copy of the record of medicines sold to that farm for a twelve-month period. Recruitment started in June 2021 up until August 2022 and records obtained therefore spanned from June 2020 to August 2022 according to when the farmer enrolled i.e., on the day the farmer enrolled they provided the previous twelve months of medicine records. To be included in the data set for medicine record analysis, each farmer was required to provide (as a minimum) one set of medicine records (on-farm medicine records and/or record of medicines) covering a continuous twelve-month period and participate in a brief discussion about these records. These brief discussions were undertaken in-person, online using video conferencing (Zoom, 2020), or by telephone. This discussion was to identify the classes and numbers of sheep in their flock, and any medicines appearing in the records that were not administered to sheep.

2.4. Where data was incomplete, or information from the discussion clearly contradicted the medicine records, these were excluded from analysis

Where records were supplied from more than one veterinary practice by a farmer, the sales from each practice were combined to determine the farm-level purchase of antibiotic. Where both farm medicine and veterinary sales records were obtained for the same farm, calculations were performed for each and compared. The veterinary sales data was used for subsequent analysis.

To calculate the antibiotic usage on each farm, the antibiotic purchase and livestock data were inputted into the University of Nottingham Sheep Antimicrobial Use Calculator, version 3.5 (SAmUC) (Hyde, et al., 2017). Farm antibiotic use was ranked using each of three antibiotic use metrics - mgPCU^{-1}, DDDvet and DCDvet. Correlation between the ranking outcomes was measured using Spearman rank correlation (Social Science Statistics, 2022).

2.5. Semi-structured interviews

Semi-structured interviews were undertaken with a convenience sample of 27 sheep farmers (mean flock size = 324 ewes). Of these, 18 farmers also participated in sharing their medicine records for analysis (Fig. 1). Interviews took place before (n=15) or after (n=3) medicine record analysis, as circumstances dictated.

The semi-structured interviews focused on medicine use in sheep and its recording, flock management and the relationship with, and role of, their veterinarian in flock management. An interview guide (Appendix A) was developed by the first author and pilot tested with a non-participant farmer, and reviewed prior to each subsequent interview, following the grounded theory approach to qualitative research (Lingard et al., 2008). Interviews were undertaken by the first author between July 2021 and March 2022. Interviews were undertaken face-to-face on farm until Covid-19 restrictions in the autumn and winter of 2021 prevented this. During the period of restrictions, interviews were carried out using online video conferencing (Zoom, 2020) and subsequently both methods were employed based on the interviewee's preference. Interviews commenced with closed questions addressing the farming enterprise's structure, before moving onto open questioning about behaviours and attitudes relating to medicine use and flock health. Where a farmer sharing medicine records had not already completed their brief discussion on the records, and they were available at the time of interview, this aspect was incorporated into the interview. In general, however, the brief discussion was conducted at a separate, later, mutually convenient occasion, following receipt of the medicine records.

The interviews were transcribed and the transcripts were uploaded to NVivo software (QSR International Pty Ltd., 2020) to facilitate thematic coding and analysis (Timonen et al., 2018). Interview recruitment continued until no new significant themes were emerging in the data, i.e., data saturation was achieved (Saunders, et al., 2018). However, theoretical sampling, to gain a better understanding of the emerging themes, was not possible to follow rigorously because of the reluctance of some to participate in semi-structured interviews. This made it difficult to fully address all theoretical sampling targets (Timonen et al., 2018).

Transcripts were coded iteratively, following a modified grounded theory approach involving constant comparison to explore the data and identify new or emerging themes (Lingard, et al., 2008, Timonen, et al., 2018). Where possible, an interview was transcribed prior to further interviews being undertaken, to facilitate reflection on emerging themes and allow the continual evolution of the interview process. This evolution in the interview guide meant that subsequent interviews could be used to seek greater clarity around key behaviours or attitudes that were emerging (Lingard, et al., 2008). At the conclusion of the interview process, all sections for each of the identified themes and behaviours related to antibiotic purchase and use were collated, re-analysed and exemplar quotes identified.

3. Results

3.1. Questionnaire

One hundred and twenty-two valid responses (out of 126 submitted, 97%) were downloaded from the survey platform. Respondent demographics and farm information has previously been reported (Crawford et al., 2022) and is summarised in Table 1. Fourteen farmers (11%) indicated they regularly obtained medicines from more than one veterinary practice and 86 respondents (n=118, 73%) disagreed that farmers should pay their veterinarian for advice.

Responses relating to the relationship between the farmer and their veterinarian are reported in Fig. 2. These questions were optional and individual numbers of responses (n) are shown, for each question and percentages shown are based on these question-specific response rates. Regular, on-farm, advisory visits were only used by five farmers (n=117, 4%). When asked about their relationship with their veterinarian, the majority of respondents felt that they had built a trusting relationship with their veterinarian (n=97, 81%), and that their veterinarian was knowledgeable about both sheep husbandry (n=99, 84%) and sheep disease (n=99, 83%). Respondents also felt that their veterinarian could help them increase production and profit in their flock (n=73, 62%).

3.2. Medicine usage and sales records analysis

3.2.1. Sample size

Recruitment was slow, with a reluctance on the part of farmers to share medicine records, and Covid-19 restrictions limiting face-to-face social interaction with the target population of sheep farmers. Expressions of interest were received from 92 farmers. After this initial engagement, 25 farmers either indicated that they were uncomfortable or unwilling to participate at all (that is share either their farm medicine records or participate in an interview) or failed to supply records they had promised despite follow-up. Three farmers undertook the brief discussion and failed to provide medicine records and a further three farmers were excluded due to extensive contradiction between supplied records and their comments during the brief discussion. This left 61 participants who provided data for analysis; 52 sets of medicine records from one or both sources and 27 semi-structured interviews, with 18 farmers contributing to both (Table 2, Fig. 1). Medicine sales records, included in the final analysis, were received from a total of 24 veterinary practices.

3.2.2. Quantitative medicine data

After the exclusions mentioned above, 50 veterinary medicine sales records and two farm medicine records were used for quantitative analysis. These represented 22 sheep-only and 30 mixed farms, with flock sizes of 30–730 breeding females (mean 276), from across NI (Table 2). The most common additional farming enterprise that the sheep farmers participated in was beef cattle rearing. Segregation of medicine use between the sheep flock and other livestock enterprises was straightforward during discussion with the farmers, who were able to identify the animals and clinical scenarios associated with each purchase. In many cases, certain antibiotics would only be used in cattle and others only in sheep. Recruitment of these 52 farmers took place over 14 months, from June 2021 to August 2022.

Of the six farms included in this analysis that supplied both farm and veterinary records, five of the pairs of records covered the same 12-month period, the sixth pair covered almost consecutive 12-month periods with only a brief overlap. For the five temporally-matched pairs of records, all on-farm records showed lower levels of purchased medicine than were recorded in their veterinary sales records (Fig. 3). On farm records recorded a mean of 44.9% less antibiotic than was recorded in veterinary sales records. The most common reason for farmers opting to share veterinary practice records in preference to their own on-farm records was that they knew these were incomplete. Of farmers suppling medicine records for analysis, six had veterinary sales records originating from more than one practice.

The median annual antibiotic purchased was 11.35 mgPCU^{-1} (mean 13.63 mgPCU^{-1}, range: 0–45.29 mgPCU^{-1}) (Fig. 4). Use of antibiotics classified as CIAs accounted for 0.21% of the total mass of antibiotics used, with these appearing on the sales records of only four (7.5%) farms, served by three veterinary practices. Farmers indicated that these products were predominantly used to treat mastitis. No sales of soluble antibiotic power were identified. Systemic injectable antibiotics accounted for the 89% of all antibiotic purchased (Table 3).

The purchase of products without a UK authorisation for use in sheep was identified in datasets from 71% (37/52) of farms, although all products did have an authorisation for use in another food-producing species. The antibiotic without authorisations were amoxicillin trihydrate / clavulanic acid, cefquinome, lincomycin, marbofloxacin,

Table 1
A summary of the demographic information about the one-hundred and twenty-two Northern Irish sheep farmers who participated in an online survey, and the flock and farm sizes represented in the sample. NVQ – National Vocational Qualification level 2 or 3, HNC – Higher National Certificate, HND – Higher National Diploma.

Gender	Female	Male	Prefer not to say		
	14 (11%)	104 (85%)	4 (3%)		
Age (years)	0–30	30–50	50–65	65+	
	15 (12%)	48 (39%)	41 (31%)	15 (15%)	
Highest agricultural qualification	Nothing formal	NVQ 2 or 3	HNC / HND	Degree or higher	
	53 (44%)	35 (29%)	13 (11%)	20 (17%)	
Flock size (breeding ewes)	1–50	51–100	101–200	Over 201	Store lambs only
	24 (21%)	31 (25%)	31 (25%)	32 (26%)	4 (3%)
Farm size (hectares)	0–9.9	10–19.9	20–29.9	30–49.9	Over 50
	14 (12%)	19 (16%)	42 (35%)	27 (23%)	17 (14%)

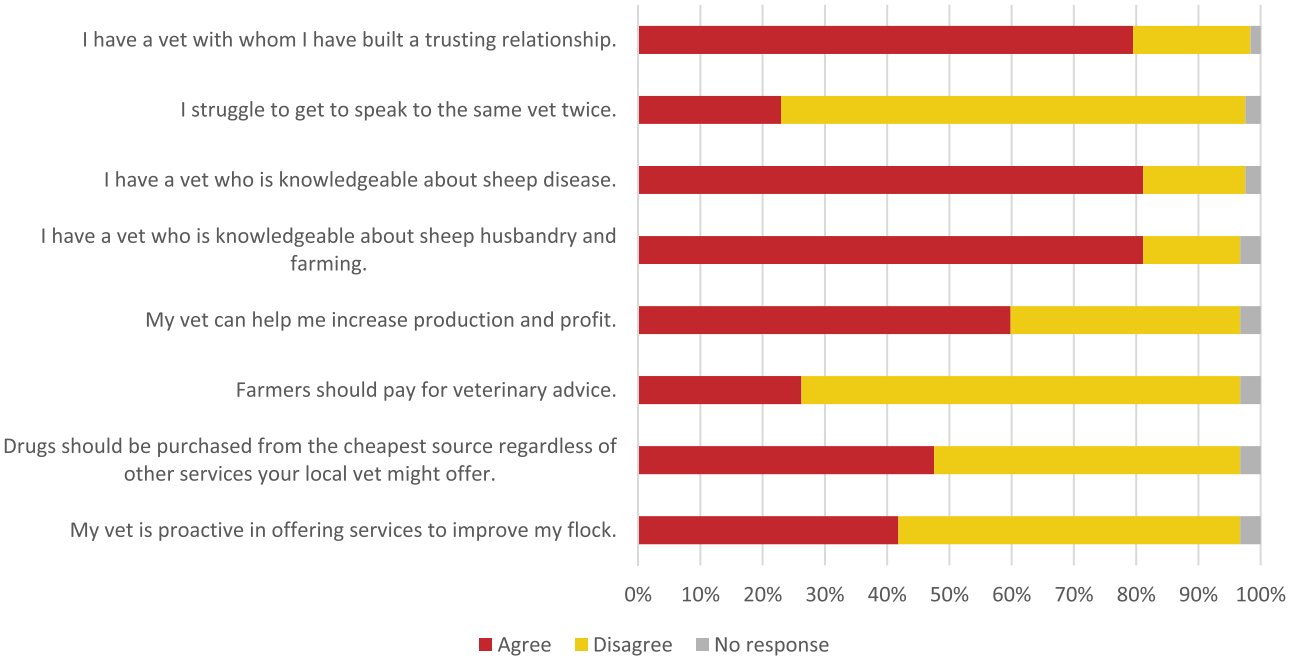

Fig. 2. Percentage of respondents agreeing, disagreeing with, or not responding to statements regarding their relationship with the veterinarian and services obtained from them.

sulfadiazine / trimethoprim, tetracycline HCl, tylosin and tildipirosin. Such antibiotics accounted for over 40% of all injectable antibiotics purchased by the eight largest purchasers of these medicines.

Farms were ranked on their antibiotic usage using the $mgPCU^{-1}$, DDDvet and DCDvet matrices calculated using the SAmUC (Fig. 5). The correlation between each pair of the three metrices was positive and significant ($mgPCU^{-1}$ – DDDvet, $Rs=0.84$, $p<0.01$; $mgPCU^{-1}$ – DCDvet, $Rs=0.90$, $p<0.01$ and DDDvet – DCDvet, $Rs=0.97$, $p<0.01$).

When considering the relative rankings under the three metrices, two outliers are clearly identifiable from the data (Fig. 5). During interview, these farmers stated that they had problems with lameness in sheep. Data from these two farms and two additional farms who also discussed their flock's lameness problem during interview were subject to further analysis (Table 4). This determined the proportion of antibiotic purchased that was used for lameness management, the classes of antibiotics used and how this related to the flock size. Analysis of these farms' records highlighted an ongoing lameness problem, with frequent purchase of antibiotic throughout the year.

Other significant incidental findings from the review of medicine records highlighted misuse of antibiotic on farms through the purchasing of antibiotics by one farmer on behalf of other farmers and inappropriate dosing, such as 10 ml of the combination product penicillin and streptomycin (Pen Strep, Norbrook Laboratories Ltd) being given to a sheep once daily for three days, despite being authorised at a dose rate of 1 ml per 25 kg and a maximum of 3 ml per injection site.

It was observed that while the vast majority of veterinary sales record included batch numbers and some withdrawal period information, there was a failure to document species-appropriate withdrawal periods on some records, particularly, but not exclusively, when products without an authorisation for use in sheep where prescribed. In addition, there was also illegal prescribing practice identified in that tilmicosin was sold by the bottle to one farmer, even though it is only authorised for administration by a veterinarian. This farmer, SF6, outlined how they had an arrangement with their veterinarian to hold a stock of tilmicosin on farm, for them to administer to sheep themself, which they were aware was illegal.

3.3. Semi-structured interviews

The demographics of the 27 interview participants are summarised in Table 2. Twenty-four interviews were electronically recorded, with contemporaneous written notes were taken for the remaining three interviews. Mean transcript length for the recorded interviews was 6675 words (range 3200–9900 words), and the mean interview duration was 46 minutes (range 20–74 minutes). Only information related to the purchase and use of antibiotics is reported here, with additional exemplar quotes available in Appendix B.

3.4. Overview of the economics of the NI sheep sector

To frame and contextualise the interview responses, participants were asked about their perception of the current economic state of their sheep enterprise. Overall, sheep farmers did believe that their sheep enterprise was profitable, although the majority made it clear that without subsidies from the state, it would not be sustainable to continue sheep farming as evidenced in these quotes:

Sheep leave a wee bit of profit behind, but state subsidies are essential to earn a living. (SF64)

I make about £10 per ewe – excluding state subsidies. (SF94)

3.4.1. Recording medicine use

Complete on-farm medicine records were rarely presented at the time of the record discussion or interview, and the farmers stated that time pressures and the practicalities of data capture meant they failed to maintain accurate, up-to-date records. In particular, they reported struggling around lambing time, and when individual sheep required unplanned treatments, such as a lame sheep, spotted, caught, and treated in the field there and then. The practicality of obtaining a perfect medicines record, including the individual identification of each animal to which the antibiotic was administered, was questioned by some interviewees:

You will probably find the veterinary practice records are showing a lot more bottles than are recorded in my records. (SF5)

We have used electronic recording. Everything has been EID-tagged at birth since 2010, so the potential is there to do it; the difficulty is not

Table 2
Demographic information about Northern Irish sheep farmers who took supplied medicine records for analysis and / or were interviewed about the medicine use in their flock. In all fields U indicated information the farmer chose not to disclosed (U). Farmers' ages were recorded as less than fifty year (-) or fifty years of age or more (+). To ensure anonymity of participating farmers, county names have been replaced by a letter A-F representing each of the six counties of Northern Ireland. Other enterprises: SC-B suckler cows through to beef; A -arable; N – no other farming enterprises; HR – dairy heifer rearing; SC – suckler cows; SC-S – suckler cows to store; S-B stores to beef; C-B calf to beef; B&B winter housing and feeding of cattle owned by another; P pigs; Po poultry.

Reference	Gender	Age	County where farm is located	Flock size (breeding females)	Farm size (hectares)	Other farming enterprises	Medicine records supplied	Semi-structured interview participant?
SF18	M	+	C	194	120	N	Both	Y
SF42	M	+	A	595	215	N	Both	Y
SF13	M	+	D	730	71	HR	Both *	Y
SF03	M	U	A	115	20	SC-B	Farm	Y
SF30	M	-	C	150	39	C, A	Farm*	Y
SF05	M	+	D	300	35	A	Veterinary	Y
SF28	M	+	C	100	49	S-B	Veterinary	Y
SF33	F	+	C	215	81	A	Veterinary	Y
SF38	M	+	D	350	39	A	Veterinary	Y
SF40	M	-	A	480	148	SC-B	Veterinary	Y
SF41	M	-	A	360	81	SC-B	Veterinary	Y
SF65	M	-	D	255	47	SC-B, S-B, A	Veterinary	Y
SF66	M	+	C	145	28	N	Veterinary	Y
SF72	M	U	A	640	51	P, S-B	Veterinary	Y
SF29	M	+	C	340	40	SC-S	Veterinary *	Y
SF51	M	+	B	130	49	SC-S	Veterinary *	Y
SF54	M	+	B	469	22	S	Veterinary *	Y
SF62	M	+	C	300	29	B&B	Veterinary *	Y
SF32	M	+	C	U	U	SC-B	None	Y
SF50	M	U	B	400	79	C	None	Y
SF52	F	-	B	290	31	N	None	Y
SF57	M	+	D	40	4	N	None	Y
SF61	M	+	C	350	79	SC-S	None	Y
SF63	M	-	A	615	748	SC-B	None	Y
SF83	M	-	E	450	U	N	None	Y
SF68	M	-	C	100	35	SC	None *	Y
SF69	M	+	B	520	217	SC-B	None *	Y
SF06	M	+	D	199	U	N	Both	N
SF07	M	+	C	230	26	N	Both	N
SF20	F	-	C	90	20	N	Both	N
SF10	M	+	C	165	40	N	Veterinary	N
SF16	M	-	C	365	22	SC	Veterinary	N
SF21	M	+	C	275	49	S-B	Veterinary	N
SF22	M	+	C	370	121	S-B	Veterinary	N
SF24	M	+	C	120	21	SC-B, C, A	Veterinary	N
SF25	M	+	C	210	90	SC-S, A	Veterinary	N
SF31	M	+	C	330	45	N	Veterinary	N
SF35	M	+	A	300	202	SC-B	Veterinary	N
SF37	F	-	D	35	9	SC-B	Veterinary	N
SF39	M	U	D	300	57	HR	Veterinary	N
SF55	M	+	C	600	U	U	Veterinary	N
SF67	M	U	C	240	19	N	Veterinary	N
SF70	M	U	A	420	40	N	Veterinary	N
SF71	M	U	C	45	30	S	Veterinary	N
SF73	M	U	D	400	170	N	Veterinary	N
SF74	M	+	C	650	141	SC-S	Veterinary	N
SF75	M	+	C	130	40	SC-B	Veterinary	N
SF76	M	+	C	235	34	N	Veterinary	N
SF77	M	+	C	153	16	N	Veterinary	N
SF79	M	U	D	165	28	Po	Veterinary	N
SF80	M	+	D	300	54	N	Veterinary	N
SF84	M	+	C	300	121	SC	Veterinary	N
SF85	F	-	A	30	4	N	Veterinary	N
SF88	M	+	C	170	28	A, Po	Veterinary	N
SF90	M	U	F	50	12	N	Veterinary	N
SF91	M	+	E	120	36	N	Veterinary	N
SF92	M	+	E	74	8	S	Veterinary	N
SF93	M	-	A	75	9	N	Veterinary	N
SF94	M	-	A	700	182	SC	Veterinary	N
SF95	M	-	A	80	12	N	Veterinary	N
SF96	M	-	B	480	40	C	Veterinary*	N

Farmers marked * provided medicine records from more than one veterinary practice or indicated during interview that they source medicines from more than one veterinary practice.

having the electronic tag reader at the point you are out in the field. (SF13)

So, there is a medicine book here, but it might not be complete. What goes in the book is not a record of all the medicine that is used. It is updated about a week before an inspector comes. Which is basically the way it is. One reason: time constraints. You never get around to it. (SF40)

When you have a sick animal or a sick sheep, especially at lambing

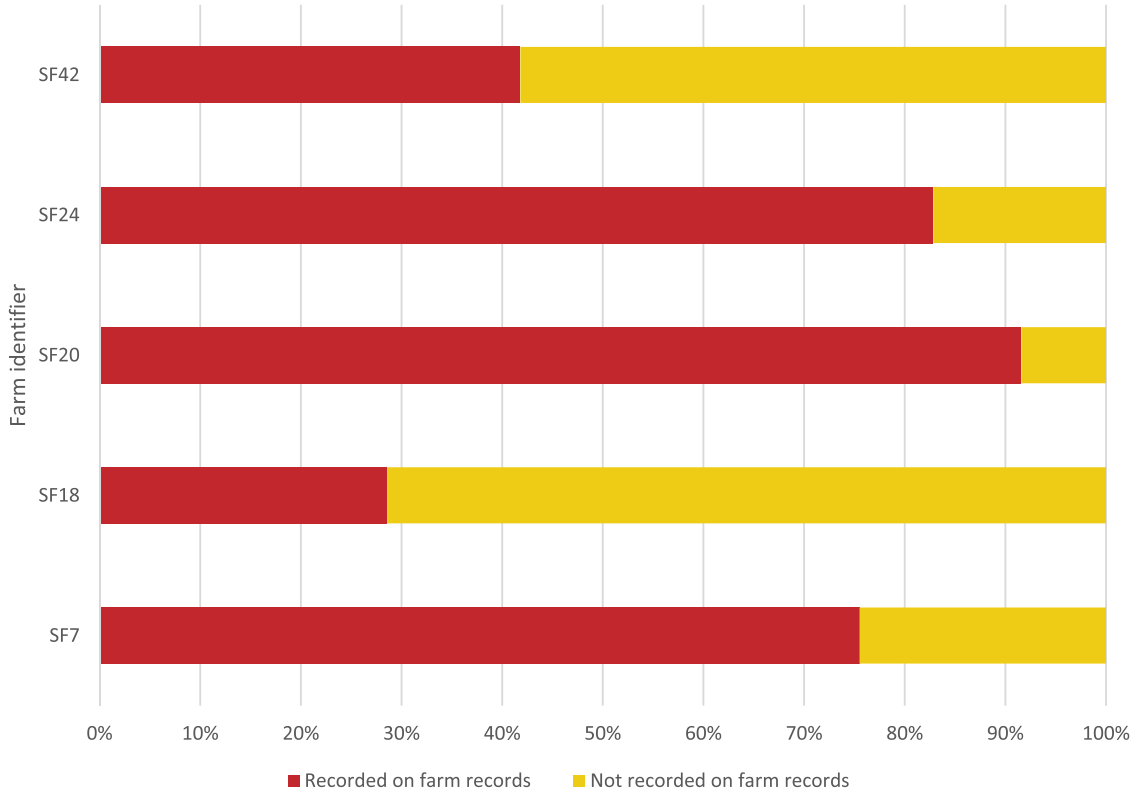

Fig. 3. The antibiotic purchases from the veterinary practice sales records and whether or not these were recorded in on farm records, displayed as a percentage of total antibiotic purchased, for the five (9.6% of the sample of 52) Northern Ireland sheep farms from which temporally matched paired records were obtained. On farm records recorded a mean of 44.9% less antibiotic than was recorded in veterinary sales records.

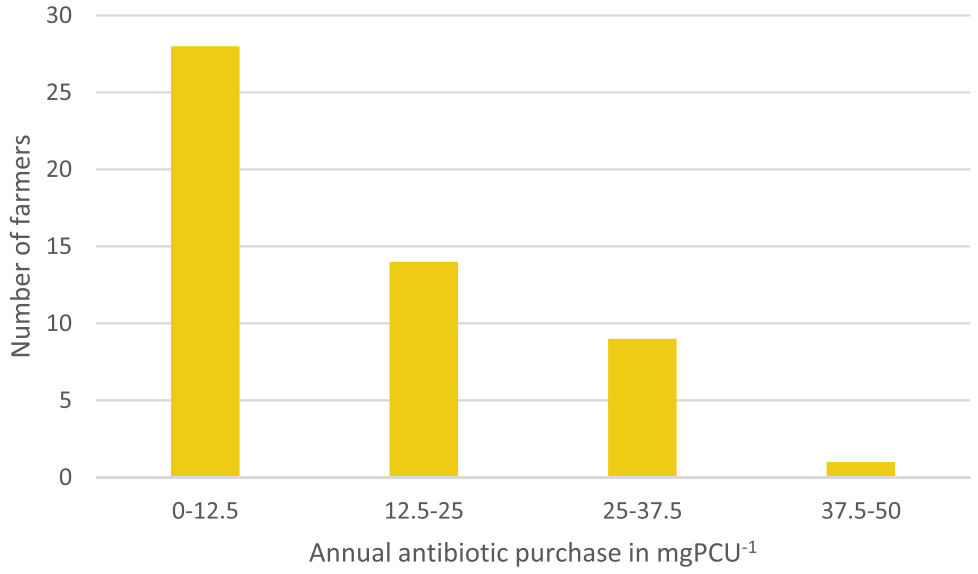

Fig. 4. Distribution of fifty-two Northern Irish sheep farmers' annual antibiotic purchase, measured in $mgPCU^{-1}$.

time, you are not really thinking 'I must record this', you are just hoping that it will get better and that is it. (SF52)

Two farmers reported being put off recording their medicines because of their inability to get the purchased medicines and used medicines to reconcile. This had then been criticised by inspectors auditing the records for quality assurance purposes. Others however, reported that participation in a quality assurance scheme was a driving factor in their attempt to record medicine use:

Probably Farm Quality Assurance [NI Beef & Lamb Farm Quality Assurance Scheme] maybe makes you slightly better, more accurate, how you keep records. (SF33)

The weaknesses come, Alamycin (oxytetracycline, Norbrook Laboratories Ltd) in particular. Dealing with footrot. I was actually pulled up on a Farm Quality [inspection] because the guy said, "Where are the individual tag numbers for your treatment of Alamycin?" And I am thinking "Who has time to record tag numbers when you are dealing with 34 cases of footrot on a January day in the middle of a field?" (SF69)

Table 3
The distribution of antibiotic purchased, by pharmaceutical class, and by the route of administration of the product by fifty-two Northern Irish sheep farmers.

Class of antibiotic		Route of administration	
Tetracyclines	40.1%	Injectable	89.20%
Beta lactams	29.5%	Topical – spray	7.58%
Aminoglycosides	19.3%	Oral	2.09%
Macrolide	7.4%	Ophthalmic ointment	1.11%
Phenicols	2.2%	Intramammary	0.03%
Sulphonamides	1.1%	Footbath	0.00%
Lincosamides	0.3%		
Quinolones	0.1%		

Poor recording of medicine use was often justified in the mind of the farmer by their belief that they could remember which sheep have been treated, and by the fact that they believed a treated sheep will not have recovered sufficiently to go for slaughter prior to any withdrawal period ending:

There is the odd sheep there, that needed treatment, but she wouldn't be going now, she probably would need the summer to get a bit of flesh on her after she had had a problem. (SF05)

A small subset of the farmers interviewed were both aware of the need for accurate records and claimed to be fully compliant with recording of medicine use. A range of techniques that assisted in the collection of the necessary information to update the medicine records were outlined:

If I'm in the shed, I'd gather it on the hand-held computer, but I've also got a book and a pen and record the same thing in the book. I will record any lamb, or any sheep that gets, for example, an antibiotic for any reason - difficult lambing, bad feet. (SF18)

You are legally required to keep your medicine book up to date. I will record it into a diary when I buy something and then you have all the expiry dates and codes on it. I would do it at the time, because it slips on, and you would forget about it. It is a nightmare. And then every 6 weeks or so I would write it into the medical book. If I do inject sheep at lambing time, that is written on the wee white board I have at the back of every small pen. With so many ewes lambing you forget, so you need something to [help you] memorise it. (SF50)

I put it in the phone or into a notebook and on a wet day then I transfer it across. I hate doing it, don't get me wrong. I detest doing it, but I do do it. (SF51)

Farmers who had some form of records recognised the potential benefits to their business from information within their records, but highlighted that the material needed to be accessible:

If you make the effort of doing it [recording medicine use in individual cases of infectious lameness], I am sure there are repeat cases that you can cull out of the flock because you have the information to do that. So, it is just having the discipline to do it. (SF69)

3.5. Production records

On-farm production records were of poor quality; for example, some farmers looked through paperwork on the kitchen table to try and tally up lamb sales using their flock movement records. Many simply estimated the numbers of ewes or lambs in round figures or using rounded lambing percentages. Scanning figures were the specific figures most commonly quoted:

Interviewer: How many lambs would you be expecting to sell this year, or how many did you sell after last year's lambing?

We finish everything. But I'd say it is roughly, it probably comes down to about 1.6 per ewe or something. Whatever that comes out at. (SF41)

Table 4
Data from four farmers' records are presented showing their relative ranking position for each of the three metrics studied (lowest user to highest) and data on their antibiotic use for the management of lameness in their flock. * Based on datasheet dose recommendations, or 10mgkg^{-1} for tylosin, for a 75 kg adult sheep as this product does not carry a licence indication for sheep usage in Northern Ireland.

Metric	Sheep farmer's unique identifier			
	SF74	SF92	SF29	SF6
mgPCU^{-1}	3.2	8.55	17.71	45.29
mgPCU^{-1} ranking	10th	20th	36th	52nd
DDDvet ranking	50th	48th	39th	52nd
DCDvet ranking	37th	39th	35th	52nd
Courses of injectable antibiotic purchased for lameness management*	493	65	107	232
Courses per adult ewe	2.05	0.88	0.31	1.66
Distribution of the classes of systemic antibiotic purchased for lameness control by each of the four farms as a percentage of total systemic antibiotic purchased for lameness control.				
	SF74	SF92	SF29	SF6
Oxytetracycline	25.0%	67.3%	42.5%	65.6%
Tilmicosin	0.0%	0.0%	0.0%	32.8%
Tulathromycin Tylosin	75.0%	32.7%	2.3%	1.6%
	0.0%	0.0%	55.2%	0.0%

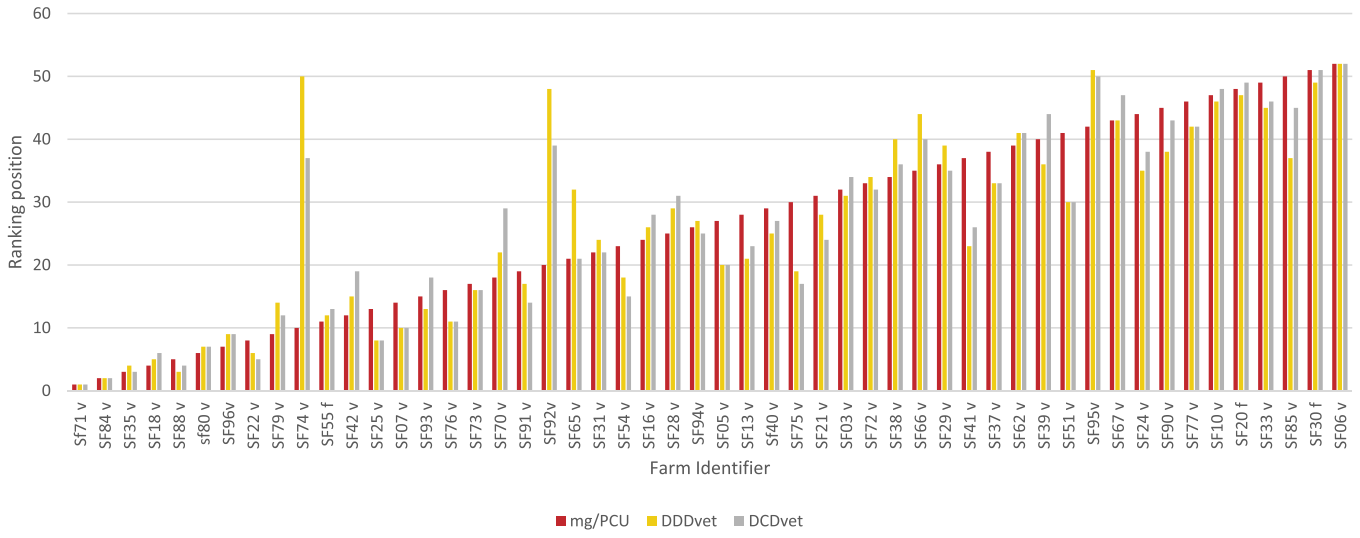

Fig. 5. The rankings of fifty-two Northern Irish sheep farmers based on differing metrics for antibiotic use: mgPCU-1, DDDvet and DCDvet. Results are displayed in increasing purchase volume, left to right, by the mgPCU-1 metric.

Lambs sold - I cannot put a figure on it, just off hand. (SF61)

Both the cost of investing in recording equipment and the practicality of integrating it with daily work on the farm were highlighted as barriers to further data collection:

No, I don't record anything, I would be watching for my sweeter ewe lambs for selection as a replacement ewe and put a mark on them. If you want to stay in sheep, you just have to move into technology too, make life simpler, and be weighing lambs, seeing what daily liveweight gain they are doing, so you know they are growing well or not. If I had a few pounds now next year now, I would get an app for your 'phone, an app, and when my weighbridge needs replaced the new one will be electronic, but until it needs replaced, I don't want to spend money on a new one. (SF51)

So, you see some of the EID jobs that are on the go, it is becoming more expensive to install these things, but the information that they can gather is fantastic, so it is. (SF61)

Other farmers did record a range of production-related traits and had identified positive benefits to this approach. Techniques for data capture ranged from simple paint marking on the sheep to alert the farmer to the need to cull a particular sheep, through to detailed paper-based and electronic recording. Despite this, most farmers undertaking recording indicated that their systems were inefficient at times:

We record the birth weight of everything, the date, any difficulties issues, any issues with the ewe, and the ear numbers of the lamb and corresponding with the ewe and what ram she was with. (SF62)

I am benchmarking with the business development group I've been in, but I haven't really compared our results with other flocks you know. (SF68)

If they are a bad mother, we haven't actually been that detailed in terms of saying, 'No, she has to go.' We haven't been efficient enough in keeping records. (SF69)

3.6. Drivers for antibiotic use

Farmers reported that they did not want to use antibiotics, or medicines in general. Overall, they considered that their medicine use was reasonable, and they maintained on-farm oversight of its usage. No participants reported being advised to reduce their usage or adopt an alternative strategy for disease control by their veterinarians, with the exception of prophylactic use of oral antibiotics in neonatal lambs:

To be honest, I'm not buying a vast amount of drugs or anything. (SF28)

In an ideal world there would be no bottles of anything needed, but that is not the way it is. I certainly am conscious of drug usage. Being more selective with your drugs and trying to target those that need it rather than just using a scattergun approach. (SF29)

Reasons for antibiotic use outlined in the interviews fell into two broad groupings: treatment and prevention. Lameness was the most frequently mentioned driver for antibiotic use. In particular, when a new disease, such as contagious ovine digital dermatitis (CODD), or a new strain of footrot entered a flock, farmers reported a sharp increase in antibiotic use, often over a prolonged period, sometimes years. Of those with an active lameness problem, little evidence was shared of any proactive plan to deal with the lameness that had been offered to them by their veterinarian. Instead, they relied on continual antibiotic treatments and seeking, and being provided with, alternative antibiotics where they felt the product they had been using was not working:

I've never used more antibiotics than the last six months trying to get the problem under control, because we've never really had a lot of lameness until this CODD outbreak. I didn't do it last year, but I think I will start to vaccinate against footrot now. (SF33)

We had a severe outbreak of digital dermatitis about 6, 7 years ago and we used a lot of Alamycin (oxytetracycline, Norbrook Laboratories Ltd) and it wasn't working and I went to the vet and discussed it and he said "Try Draxxin (tulathromycin 100 mg/m, Zoetis UK Ltd.)." We tried that recommendation, and it has been successful so far. (SF62)

Other conditions where antibiotics were used for treatment included mastitis, pneumonia, and laryngitis. Eye infections were treated by both topical and systemic antibiotics, with some farmers expressing frustration at not being able to bring an outbreak of infectious conjunctivitis to a rapid conclusion.

In neonatal lambs, joint ill (septic arthritis) was most commonly identified as a driver of therapeutic antibiotic use. Some farmers indicated that they were uncertain about the efficacy of the treatment prescribed for joint ill and slow recovery to health of treated animals. This included use of antibiotics without an authorisation for use in sheep. The poor response to treatment led some farmers to adopt a prophylactic approach of giving systemic antibiotics to newborn lambs in an effort to prevent joint ill:

I had a problem with joint ill in my lambs. They were just hobbling about, and their joints were getting swollen, and I had an issue there and thought I needed to address problems and we went back to jagging (injecting) lambs with Betamox (amoxycillin 150 mg/ml, Norbrook Laboratories Ltd.) in below the skin to prevent it. (SF68)

The use of antibiotics for other preventative purposes was widely described. The patterns of use described included both prophylactic and metaphylactic used of antibiotics. These farmers were open about their use of antibiotics as being purely precautionary or habitual rather than for managing an active, diagnosed, clinical problem such as watery mouth, enzootic abortion of ewes or uterine infection:

Eight weeks prior to lambing we would give a jag (injection) of long-acting Alamycin (oxytetracycline, Norbrook Laboratories Ltd.) to the ewes. Don't ask me why we were even doing it. I assume it was to prevent abortions if there is any wee thing that's wrong with her inside. (SF30)

We maybe had a watery mouth problem, once upon a time, not in my time, but in father's time, and I suppose it started and then we always used prophylactical oral antibiotics in newborn lambs, and we got into the habit of doing it. (SF63)

If I have to lamb a ewe, she gets Pen Strep (dihydrostreptomycin sulfate 250 mg/ml and procaine penicillin 200 mg/ml, Norbrook Laboratories Ltd), right away. In fact, I have got into the habit of, the wife is the same, to inject them even before we put a hand in, if we knew we were going to have to put our hand in. Just one dose, not a course. (SF72)

The withdrawal of the final oral antibiotic authorised for use in neonatal lambs in the UK occurred mid-way through the data collection period (SVS, 2021). A wide range of experiences of the use of these products were described, including fears for a future without them and experience of the first lambing season following their withdrawal from the market, were encountered (Appendix B).

Some farmers expressed concern that not all farmers were as careful with their medicine use as they considered themselves to be:

At lambing time some farmers would put stuff down young lambs when they are being born. Don't need it. You know, Scour Halt (spectinomycin 50 mg/ml, CEVA Animal Health) and all that all that carry on - Vitamin A, Vitamin E. Sorry, but just do it when you can see a problem. (SF38)

3.7. Purchase of antibiotics and maintaining an on-farm supply

Farmers expressed concern that any tightening of regulations might restrict their ability to ensure they have a suitable supply of medicines to hand. This, they said, was to allow prompt treatment of sick animals, without the need to go to the veterinary practice on each occasion, especially outside normal working hours, and was justified for practical and economic reasons. Farmers reported liking to stock up with medicine prior to lambing time, and this behaviour was noted in some of the sales records analysed:

The vet does not want you bothering them on a Sunday night, and they are going to charge you well if you do have to get hold of them. A farmer still needs to be able to keep a stock of drugs in his medicine

cabinet, I think. You know, your staples. (SF28)

Farmers reported using more than one veterinary practice to source their medicines, including antibiotics, for practical reasons, such as proximity to the farm or their place of work. Other farmers indicated that they sourced medicines from a number of veterinary practices for financial reasons. Information on which practices were cheaper was shared through their peer networks. Sourcing medicines from practices remote from the farm location mainly involved the purchase of higher-priced items such as vaccines, or where a discount could be obtained for paying for bulk purchases on the day. Not all farmers openly disclosed that they sourced medicines from more than one veterinary practice. Non-disclosure was identified during interview or on cross-checking inconsistencies identified between veterinary medicine records and information supplied during interview:

We tend to find that a second vet practice are cheaper, and another farmer told me about the better prices there. (SF18)

We buy in Spectam (spectinomycin 50 mg/ml, CEVA Animal Health). We do not buy it at the local veterinary practice. They are getting very expensive for it, so we buy it elsewhere. I would ring him up on dose and stuff, Heptavac P (multivalent clostridial and bacterial pneumonia vaccine, MSD), "You come over and I'll give you a good price on it" the vendor tells me. (SF54)

3.8. Veterinarian oversight on prescribing and use

Farmers reported that they were rarely challenged when seeking medicine from their prescriber. Some described their own medicine use may be dictated by prior on-farm practice or convenience rather than best veterinary advice:

Well, I send my father in, I'm in disguise, and then my wife and then someone else. I have it down to a fine art [to avoid a confrontation about my medicine use]. (SF29)

We just use our vets like a fire-brigade service. Last year we didn't see them, we managed everything ourselves. No caesareans, no lambings. It was just to get a bottle of antibiotics. (SF61)

Interviewer: Just to clarify that, you just go down to the veterinary practice, walk up to the counter and ask for a bottle of Pen and Strep (dihydrostreptomycin sulfate 250 mg/ml and procaine penicillin 200 mg/ml, Norbrook Laboratories Ltd) and they just hand you one. Is that correct? Yes (SF61).

3.9. Mixed messages

Farmers perceived a mixed message in the veterinary advice they were given about the need to reduce antibiotic use and, at the same time, guidance to treat sheep with infectious lameness with long-acting injectable antibiotics promptly. This was most clearly expressed by farmer SF28:

I believe the modern thinking now is 'Don't trim sheeps' feet', but give them an antibiotic, which is really what you are trying to get away from. (SF28)

3.10. Preventative approach to reduce antibiotic demand

Some farmers identified a financial benefit in developing a proactive, preventative approach to disease control, rather than relying on treating animals when they became ill:

It's not in a farmer's interest to be buying a lot of drugs, because they are expensive, and it is certainly a lot cheaper to vaccinate. (SF28)

Two or three years ago I think our Alamycin (oxytetracycline, Norbrook Laboratories Ltd) bill was £650 just dealing with foot problems and we vaccinated with Footvax (multivalent Dichelobacter nodosus vaccine, MSD) and it came down to £180 or something like that. (SF69)

Among those who had adopted a preventive, vaccine-based approach to infectious lameness or abortion control, some commented that there was a significant initial expense. This led them to fail to optimally implement the vaccine protocols across their flock, leaving partial reliance on antibiotics:

The advice to only vaccinate replacements and not the whole flock was based on the cost of doing so. I have continued with the injection [of antibiotic] 90 days into gestation. (SF32)

We only used Footvax (multivalent Dichelobacter nodosus vaccine, MSD) the one year, but we did notice at lambing time there were very few lame sheep, but it is just the cost of it. It's, you know, I don't know how much it was, maybe like £1.50 a sheep? (SF41)

4. Discussion

The online questionnaire results presented raise both hope and concern in equal measure with regard to making the NI sheep farmer-veterinarian relationship effective and sustainable for the future. Participating sheep farmers indicated that they had been able to develop trusting relationships with veterinarians, who they regarded as knowledgeable about both sheep husbandry and sheep disease, and over 60% of respondents felt that their veterinarian was in a position to help them increase production and profit. While veterinarians have been identified among farmers' most trusted advisors (Garforth, et al., 2013), English sheep farmers felt they were the best person to understand their own flock's needs (Kaler and Green, 2013) and did not think veterinarians were sufficiently knowledgeable about sheep diseases. The findings here also contradict the feelings expressed by some veterinarians to Bellet et al. (2015) that sheep farmers did not think veterinarians had expertise that could add value to their farm. However, despite expressing faith in their veterinarian, few of the NI sheep farming participants make use of them for regular, proactive advisory consultations regarding sheep, preferring instead to employ them only on an emergency basis. This is similar to the findings of previous work (Kaler and Green, 2013), and may in part be driven by the belief that sheep farmers should not have to pay for veterinary advice, as has been reported here. An additional strain on the relationship between sheep farmers and their veterinarians is that farmers will 'shop around' to get the best prices for prescription-only medicines, and share that information through their peer network, which was evidenced in the questionnaire data, and confirmed during interviews and analysis of medicine records. This raises a concern about the depth of the farmer-vet relationship and with that the true level of understanding the prescribing veterinarian has about both the on-farm situation and all medicines being supplied into that environment. The veterinarian's duty of care as laid out in the Royal College of Veterinary Surgeon's Code of professional conduct in the UK (RCVS, 2023) is to ensure they have a real, current, and personal knowledge of the condition of individual animals or flocks before prescribing.

The business model on which most farm animal veterinary practices are based relies heavily on income from medicine sales and routine clinical work (Remnant, 2021). If local practices lose income from medicine sales, and sheep farmers rarely seek or are willing to pay for advisory visits, the economic viability of the current network of local veterinary practices is diminished, and along with it the ability to develop and retain the skills to serve the sheep farmers. This has already been reported elsewhere in the UK, with some Scottish veterinary practices servicing farms 75 miles (120 km) from their clinic (Lowe, 2009). This pattern is likely to continue unless alternative income streams or external support is provided for rural veterinary services (Remnant, 2021). There continues to be a long-running debate about the sustainable funding of on-farm advisory work in the sheep sector (Osmond, 2009), particularly in light of the poor economic returns currently achieved by NI sheep farms (DAERA, 2020) and echoed in this study.

Obtaining medicine records from farmers was challenging, and none accurately matched veterinary practice sales records (Fig. 3), reflecting the reported difficulties encountered to date by RUMA in obtaining authoritative national figures on medicine use in the sheep sector in the UK (RUMA, 2022). The lack of on-farm records and the discrepancy

between the on-farm records that existed, and their corresponding veterinary sales records, paralleled the findings of Menéndez Gonzáleza et al. (2010) and suggests that veterinary practice sales data is the most practical approach to estimate antibiotic use at farm level. The median population-adjusted amount of antibiotic purchased by the sample of NI sheep farmers whose records were analysed, and reported in this study - 11.35 mgPCU^{-1} (mean 13.63 mgPCU^{-1}; sd 10.7; range 0–45.29 mgPCU^{-1}) - was comparable to the mean of 11.38 mgPCU^{-1} (sd 15.35; range 0–116.9 mgPCU^{-1}) reported by Davies et al. (2017) for sheep farms in Great Britain. The mean reported here was less than half the population-adjusted mean for all antibiotic UK sales in food-producing animals during 2021 (VARSS, 2022).

Given the similarity between the results from this study and the results obtained by Davies et al. (2017), and in the current study all medicine records analysed had population-adjusted antibiotic purchase or use lower than 50 mgPCU^{-1}, supports the view that the UK sheep industry is not only a low contributor to overall antibiotic consumption in the UK livestock sector (UK-VARSS, 2021) but a positive contributor to the livestock sector's attempts to reach the <50 mgkg^{-1} target.

The results reported here confirm the positive correlation between the three antibiotic metrics identified by Davies (2017). However, the ranking position between the matrices can vary significantly for an individual farm in certain circumstances (Fig. 5 and Table 4–5). For example, in the case of SF74, the farm was in the lowest quartile for antibiotic use the metric mgPCU^{-1}, but in the highest quartile using DDDvet. This discrepancy between rankings appears to occur when significant quantities of specific antibiotics are used, such as the long-acting macrolide tulathromycin. Where such products are used in preference to an equivalent duration course of oxytetracycline or amoxycillin, the mgPCU^{-1} metric could create a false impression of low antibiotic use. These findings parallel the findings and concerns of O'Neill et al. (2020) in their consideration of the effect of differing metrics to relative benchmark thresholds and ranking positions across Irish pig farms. Mills et al. (2018), O'Neill et al. (2020) and Craig et al. (2020) have questioned the influence of production system on the final output from each metric. Such consideration may be needed in the sheep sector also.

The production systems on farms participating in this study varied, thus significantly influencing the mass of livestock on farm at different times of year and so to be averaged over time. Thus, the use of these current metrics to rank farmers in benchmarking or for the purposes of setting antibiotic use thresholds, which trigger either bonuses or penalties, may require complex analysis. Selection of the ideal metric to measure and compare antibiotic use needs further consideration to allow representative and meaningful comparison between the range of livestock production systems and to ensure that the information is meaningful to farmers (Mills et al., 2018). If not, there may be a failure to identify farms where intervention is needed to improve health and welfare or veterinarians may come under pressure to prescribe certain antibiotics, for example macrolides, which may not reflect responsible use of antibiotics (Mills et al., 2018). The effect of product choice on benchmarking reinforces the concern expressed by Davies et al. (2017) that low antibiotic use does not always equate to good health and welfare, as seen in the current study with one farm (SF 74) having reported a significant and ongoing lameness problem while their overall antibiotic use was under 4 mgPCU^{-1}. Any benchmarking system must remain practical and adaptable, as antibiotic use patterns change over time and new products are developed which again change usage patterns at farm level and so the efficacy of the respective matrices. However, within any one farm, any metric may be used to track antibiotic use over time, provided no significant changes occur in the production system or classes of antibiotics used.

Previous industry guidelines have advocated better control of the use of both CIAs and use of soluble antibiotic powders (RUMA, 2019). Critically important antibiotic purchase in this study was less than half of the rate of the UK livestock sector as a whole (UK-VARSS, 2022). Only four farms, served by three veterinary practices, were using CIAs. This suggests many veterinarians in NI are following the advice to minimise their use (WHO, 2019; RUMA, 2021). Antibiotic powders have traditionally been used within the sheep sector in footbaths and topically to manage infectious lameness, despite not being authorised for use in sheep (Judson, 2010; Davies et al., 2017); nor is there substantive evidence for their efficacy (Lovatt, et al., 2019). Davies et al. (2017) reported that soluble antibiotic powder accounted for approximately six percent of all recorded antibiotic sales from their study sample of British sheep farms. None were detected in the records presented here and farmers, during interview, highlighted that they could no longer obtain such powders, despite some farmers expressing a belief in the effectiveness of such products. This suggests previous industry advice to stop the use of antibiotics in footbaths (RUMA, 2019) has also been acted upon by the veterinarians who service the sampled farms, as these products were still commercially available at the time of writing.

The use of antibiotics without an authorisation for use in sheep, but authorised in other food production species, was widespread (71% of farms in this sample). While some were only purchased for an individual animal, the majority of sales were of full or multiple bottles, supplied multiple times throughout the year, and exceeded 40% of total mass of injectable antibiotic purchased by eight farmers (15% of the sample). Previous work has highlighted those farmers with over 20 years' farming experience were more likely to be higher users of such unauthorised products (Gozdzielewska et al., 2020), suggesting a potential for repeated and habitual rather than case-by-case prescription, which is not condoned under the veterinary prescribing cascade (VMD, 2018). The extent of unauthorised antibiotic use in sheep should prompt veterinarians to reconsider their prescribing practices to ensure that they are prescribing the most suitable product (RUMA, 2019; RCVS, 2023). This can help ensure that a farmer does not develop a habitual preference for a particular antibiotic, where other authorised alternatives exist.

As farmers reported referring to their sales records to confirm withdrawal periods when making decisions regarding whether it was safe to slaughter livestock, it is critical veterinarians clearly record on these the relevant sheep withdrawal period, as these often vary between cattle and sheep and farmers may be unfamiliar with the statutory withdrawal period requirements for products not authorised in sheep.

The practice of some farmers to source medicines from two (or more) unrelated veterinary practices complicates the ability of a veterinarian treating livestock, or reviewing or certifying medicine use to fully comprehend what the medicine use on a farm is. While some farmers did disclose during interview that they obtained medicines from more than one practice, in other cases this information was only garnered by careful listening and cross-checking. This involved comparing the product use described during interview with products identified through analysis of the veterinary medicine records, and noting when farmers described using products which were not identified in the sales records from the same time-period. This triangulation and deduction, by examining objective records and assessing attitudes through both interview and reported behaviours, will be essential for any veterinarian wanting to fully understand the on-farm antibiotic use of their clients and provide appropriate veterinary advice or joint veterinary-farmer decisions making. A more robust prescribing and dispensing system with central recording or record sharing could benefit both veterinarians tasked with auditing medicine use and policy makers determining progress on antibiotic use at a national level. Examples include the Danish recording and reporting system, which is backed by Government enforcement (Craig et al., 2020), or the approach more recently announced for introduction into Ireland (DAFM, 2022). However, any change would need to be carefully negotiated with the industry to ensure that their concerns about the availability of medicines are addressed (Doidge et al., 2020), and that they see a benefit to the system by simplifying their medicine recording, not complicating it.

The conditions driving antibiotic use in sheep flocks reported here

are similar to those described by Davies et al. (2017), with ongoing or severe lameness being reported by farmers with the highest levels of antibiotic purchase. Thus, there remains considerable scope to reduce lameness through preventative approaches such as the 'Five-point-plan' (Clements and Stoye, 2014), improving sheep welfare, while reducing antibiotic use in the long-term. Despite the 'Five-point-plan' being in existence for nearly a decade, the apparent lack of a co-ordinated approach between farmer and veterinarian in many of the farms represented here is concerning, with one farm purchasing the equivalent of two antibiotic courses per breeding ewe over the 12 months for which records were provided (Table 4).

The administration of antibiotics to ewes around parturition, and in particular following assistance at lambing, was an area to which significant antibiotic usage was ascribed by farmers during interview. There were a range of beliefs described by farmers outlining when antibiotics should be used following assisted lambing, with some waiting for signs of infection, through to others giving a pre-emptive injection prior to assisting the ewe to lamb. Where antibiotics were administered, they tended to be as a single injection, but often the product administered was not designed or authorised to be used this way.

While not all farms reported mastitis as a condition driving antibiotic use, for those who were affected, it caused them considerable concern. Mastitis was also the single biggest driver for the use of the CIAs marbofloxacin and cefquinome. These products were prescribed by two different veterinary practices to manage the condition. As with antibiotic use following assisted lambing, farmers stated that they lacked access to clear guidance on mastitis management and prevention. For example, some farmers said they had been advised by their veterinarian that cold weather affected the udder following the pre-lambing dagging (removal of wool around the rear of the ewe), but they had previously been encouraged to undertake dagging to improve hygiene at lambing time (SVS, 2017), creating a mixed message in farmers' minds. Our findings suggest that further research and guidance are needed to assist both farmers and veterinarians control mastitis in sheep and to develop optimal treatment protocols which avoid the use of CIAs.

Interviewees described either using tactics to avoid being confronted by their veterinarian, or rarely being challenged over repeat antibiotic purchase. This may explain why medicine use has become habitual among some of the farmers who were interviewed, and this was something that they were cognisant of and admitted to. In particular, this applied to the use of oral antibiotics in neonatal lambs and the administration of antibiotics to ewes prior to lambing.

During the data collection period the sole remaining authorised oral antibiotic product for neonatal lambs (Spectam, 50 $mgml^{-1}$, CEVA Animal Health) was withdrawn from the market (SVS, 2021). This created three backdrops to conversations about the use of this product over the period: prior to the announcement; in the immediate aftermath, facing the upcoming lambing season; and following the first lambing season without the product. The change in interviewed farmers' attitudes over that period confirmed how habitual the use of the product had become, from a point where some were fearful of the consequences of lambing without it, to others describing a successful lambing season without it, leaving them questioning why they had previously relied on it. This positive outcome to lambing without the use of prophylactic antibiotics supports the findings of Lima et al. (2019) who found no difference in flock productivity between UK sheep flocks using or not using such products. When the lack of a production benefit is taken in conjunction with some farmers not understanding why they were using the product, this suggests potential lax, protectionist or defensive prescribing by the veterinarians. Veterinarians may have been fearful of the consequences of an outbreak of Watery Mouth, or loss of clients, if they declined a request for such products for prophylactic use year on year. A similar situation has been identified previously among farmers who were reluctant in advising peers to change an established behaviour, fearing they would feel to blame if the change went wrong (McKernan et al., 2021). Harnessing awareness among farmers that they may have become habitual in their medicine use, and that successful outcomes can be achieved without prophylactic antibiotic use, could be useful in getting them to consider improving other areas of poor medicine stewardship. Specifically, from the results presented in this study, the routine prophylactic treatment with antibiotics of ewes to prevent infectious abortion or lambs to prevent joint ill continue and are neither fully efficacious nor recommended (Lovatt, et al., 2019).

Many farmers were open and frank about the often-poor quality of their on-farm records. The lack of up-to-date, accurate medicine records that farmers were able to share, and the frankness with which they described the state of their on-farm medicine records, confirms that record-keeping on sheep farms remains suboptimal. This also extended to production figures, suggesting a wider problem around record-keeping. Accurate record-keeping as has been identified as an area that requires specific motivation, tools, and time in both agriculture (Escobar-Tello, 2015) and human health settings (Mutshatshi Takalani et al., 2018). Participants in this project identified that they lacked some or all these requirements for record keeping. Bellet et al. (2015) identified that there was a feeling among veterinarians that a lack of records on sheep farms was a key contributor to their failure to offer preventative services to sheep farming clients. The reasons given for poor record keeping echo previous findings in the sheep sector in Britain (Doidge et al., 2021) and focused on the logistics of capturing and recording data. While farmers did report strategies to enable them to capture medicine use throughout lambing, using aids such as white boards behind each lambing pen, the lack of willingness, or inability of these farmers to share both on-farm and veterinary sales records made claims about the effectiveness of these aids impossible to verify. The lack of tags in newborn lambs was identified by some as a reason why accurate records could not be achieved at lambing time. However, any drive to encourage farmers to tag lambs promptly after birth is an area where another mixed message could arise given the concern farmers already have about joint ill, and the association some authors have made between tagging young lambs and subsequent joint ill (Swinson, 2021).

In the five sets of paired medicine record received (Fig. 3), farm medicine records underestimated medicine use compared with veterinary medicine sales records in all cases. This occurred even when one of these farmers described a dual paper and electronic recording system (SF18). Together, these findings suggest that data capture may be a systemic problem on farm.

However, each farmer does have veterinary practice sales records, a set of authoritative data on the medicine use in their flock, to which the veterinarian has access, which could form the basis of a detailed discussion about the flock's current needs and past problems (Doidge et al., 2020). This does not provide detail at the animal level; however, the veterinary sales records could be interrogated by the veterinarian in the presence of their farming client to improve the resolution and accuracy of this data. Firstly, on mixed farms, the species to which the medication was administered should be confirmed (Craig et al., 2020) before determining the reason for antibiotic administration. This can focus the mind of the farmer on the use of antibiotics and extent of ongoing flock problems, as well as highlight to the prescriber where antibiotics are being used inappropriately. It is also important to check on the dose rate used, as the analysis described here has identified inappropriate dosage. Also, poor technique for vaccination in sheep has recently been highlighted (Hall, et al., 2022), therefore it is reasonable to extrapolate that poor technique will extend to the administration of antibiotics, so this too must be checked. Where metrics are calculated it is essential that the pattern of medicine use is reviewed as well, as significant antibiotic usage or welfare problems can be present in a flock despite low $mgPCU^{-1}$. Target setting is important to improve stewardship (Ritter, et al., 2017) and may have contributed to reductions in antibiotic use in Danish and Dutch dairy herds (Craig et al., 2020). However, debate continues around how these can be presented in a format that a farmer can understand and how they can be used to drive responsible use, rather than simply reduction in use at a cost to animal welfare (O'Kane,

et al., 2017; Mills et al., 2018; Doidge et al., 2021). This reduction versus responsibility conflict is highlighted by the management of lameness and by the interview participants reported here. The veterinarian has a central role in guiding farmers through this challenge, utilising a range of communication approaches (Bard, et al., 2019, Morgans, et al., 2019); promoting prompt efficacious treatment for clinically affected animals in the present, while creating a robust plan to prevent further disease in the future (Kleen, et al., 2011). Potentially, metrics based around the number of treatments purchased for a specific condition per sheep in the flock could highlight specific areas for focused attention by the farmer and their veterinarian (Doidge, et al., 2020). Additionally, prescribers should question their own habits during this process. The VMD (2018) states, and the RCVS code of professional conduct (2023) requires, that veterinarian must ensure that each antibiotic is prescribed for a reason, and not sold to the farmer without a prescriptive need. This applies, in particular, to the situations outlined in the findings where CIAs or other unauthorised antibiotics are prescribed (VMD, 2021). Similarly, careful consideration must also be given to the prescription of authorised antibiotics that are supplied to farms either in significant quantity, or frequently, throughout the year.

5. Study limitations

This study is limited in the number of medicine records that have been analysed (n=52) and farmers interviewed (n=27) out of a potential population of approximately 10,000 NI sheep farms/farmers (DAERA, 2020). While this sample size is low as a percentage of the overall sampling frame, the number of interviews conducted is well beyond the minimum of 12 that Guest et al. (2006) suggest are enough to reach data saturation. The approach of convenience sampling was the only practical option, as compliance with provision of medical records could not be ensured following any random sampling. The use of 'snowball' sampling, particularly following a semi-structured interview, may also bias observations. This may occur as the interview process could affect who the participant suggests to the interviewer as a potential participant. Additionally, the initial participant may discuss the interview with the person(s) they nominate, influencing their subsequent behaviour (Noy, 2008). Overall, these sampling effects create the potential to introduce bias, with possibly only farmers who felt confident that their antibiotic use would be viewed favourably, participating. However, the wide range of antibiotic use documented in the records obtained, and similarity between the median reported here and that of Davies et al. (2017), despite the differing methodical approach, suggest that the figures obtained by both studies provide a representative indication of the antibiotic usage within the wider UK sheep sector, irrespective of the quality and precision of recording by individuals. Farmers were also open in acknowledging issues such as: a) their medicine use was at times suboptimal; b) they omitted material from their records; c) they knew they should not have tilmicosin on farm. This suggests these results represent realistic and indicative on-farm medicine use and recording, and the prescribing patterns behind this.

The greatest potential source of error is the unknown-unknown – antibiotic used on farm that is not disclosed for analysis, and accuracy of the stock numbers each farmer provided. That similar proportions of farmers from both the online questionnaire and supplying medicine records indicated the use of more than one veterinary practice, and in the case of supplied medicine records, provided these, gives confidence that the majority of the antibiotic data for the farms sampled has been captured. While this provides insight into the range of antibiotic use across the sampled flocks, there were insufficient matched farms to create meaningful groupings to compare medicine use in different geographical situations and those managed under differing production systems. Additionally, there were insufficient farm records from individual veterinary practices to group them by practice and analyse the records to validate the relationship previously identified between the prescribing veterinarian and antibiotic use (Davies et al., 2017).

6. Conclusions

This study suggests that overall antibiotic use is low in this sample of NI sheep farms when compared to the industry-wide target set by O'Neill (2016) and reflects the levels of use recorded elsewhere in the UK by Davies et al. (2017). The wide range of antibiotic purchase quantities demonstrates there is scope to not only improve the responsible use of antibiotics, but to see clear reductions in volumes used, while maintaining or improving animal welfare in some flocks. Veterinarians are well placed to influence this change in their role as both trusted advisor to the sheep farmer and as the prescriber of antibiotics. Their influence is two-fold. Firstly, they need to carefully consider their own prescribing habits, ensuring that all antibiotics are appropriately prescribed, and that each prescription they authorise is utilised responsibly. Secondly, they can aim to improve stewardship through listening to farmers' concerns, rather than supplying antibiotics on request and unchallenged as farmers reported here. They could, instead, promote the development of an agreed preventative approach to flock health that the farmer feels competent to implemented, particularly through the increased use of vaccination, as some outline successfully having done, particularly in the area of infectious abortion control. Farmers, in turn, will need to adapt their expectations of receiving antibiotics without being challenged to engage in greater preventative approaches. Primary areas for consideration are the management of lameness and responsible use of antibiotics in the ewe and lamb during the periparturient period. However, to enable meaningful intervention to improve medicine stewardship, the individual veterinarians undertaking these conversations will need to have confidence that they are fully aware of all antibiotic and vaccine being used on farm, regardless of source. Further research, considering the barriers in accessing this data and solutions needed to permit veterinarians to utilise it may be necessary.

Co-development of solutions to the practical problems outlined here and previously regarding on-farm recording of medicine use in sheep flocks is also necessary. The elements of good medicine recording practice identified here may provide some starting points to engage farmers. However, as farmers participating here expressed, the current electronic tag readers and data-loggers remain either expensive or impractical to capture electronically capture medicine use in their flock contemporaneously and seamlessly in their on-farm environment.

Finally, given the high proportion of farmers indicating a reluctance to pay for veterinary advice, both partners need, with possible external state support, if available, to develop a sustainable funding basis, ensuring a fair return for veterinarians' professional advice, and an increase in the on-farm presence of veterinarians. Veterinary advice must be locally accessible and affordable to sheep farmers (and other livestock farmers facing similar economic challenges) if antibiotic stewardship is to be sustainably improved across all farmed species.

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CRediT authorship contribution statement

Fiona Lovatt: Writing – review & editing, Supervision, Methodology, Conceptualization. **Kim Hamer:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Paul E Crawford:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Philip Robinson:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Malgorzata Behnke:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics

Ethical approval was obtained from the Research Ethics Committee of Harper Adams University (approval number: 0010–202101-PGMPHD).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2024.106169.

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