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Abstract: A questionnaire was distributed electronically amongst sheep farmers in England; it aimed to provide a quantification of current anthelmintic practices, farmer awareness of the issue of anthelmintic resistance (AR) and the uptake, awareness and opinions surrounding conventional and alternative methods of nematode control. The majority of farmers relied on several anthelmintics and used faecal egg counts to identify worm problems. Although farmers were aware of the issue of AR amongst helminth parasites in the UK, there was a disconnection between such awareness and on farm problems and practice of nematode control. Grazing management was used by 52% of responders, while breeding for resistance and bioactive forages by 22 and 18% respectively. Farms with more than 500 ewes, and farmers who felt nematodes were a problem, had a higher probability of using selective breeding. Farmers who considered their wormer effective, had a qualification in agriculture and whose staff did not include any family members, were more likely to use bioactive forages; the opposite was the case if farmers dosed their lambs frequently. Amongst the alternatives, highest preference was for selective breeding and vaccination, if the latter was to become commercially available, with more respondents having a preference for breeding than actually using it. Several barriers to the uptake of an alternative were identified, the most influential factor being the cost to set it up and the length of time for which it would remain effective. The disconnection between awareness of AR and practice of nematode control on farm reinforces the need for emphasising the links between the causes of AR and the consequences of strategies to address its challenge.

Dear Editor

Thank you for forwarding the comments made by the second Reviewer on our paper. We have taken them into account and revised our paper accordingly. We trust that the revisions are now acceptable by Veterinary Parasitology.

Yours sincerely

Ilias Kyriazakis on behalf of all the co-authors

Reviewer #2:

The authors responded to my comment regarding the lack of discussion of the family connections, and how they influenced farming practices. I do not accept their response that they are unwilling to address this as it will make the discussion too long. If it is not important enough to be properly addressed in the Discussion, then it should not be mentioned in the manuscript at all.

We have now inserted a paragraph to accommodate for this request.

I obviously missed something first time round. The authors state in the M&M that they surveyed farmers in EBLEX, which farm in two regions (their words) - however, the results are not confined to these regions.

We indeed targeted two regions with the highest concentration of sheep in England but we received questionnaires from two additional regions (Midlands and SE). We believe that this was due to word of mouth and EBLEX function. We have now added a sentence to clarify what we did and what we considered in the statistical analysis.

There is still mention of 'anthelmintic with high levels of resistance'. This needs to be corrected.

We have reverted to 'high resistance anthelmintic'. This is the term used by numerous papers in Veterinary Parasitology.

*Highlights (for review)

- A questionnaire was distributed electronically amongst sheep farmers in England
- It aimed to identify views about nematode control methods, including alternatives.
- Farmers disconnected anthelmintic resistance from the practice of control.
- Barriers to the uptake of alternative controls were identified.
- Most influential barriers were the cost and time length it would remain effective.

**Familiarity with and uptake of alternative methods to control sheep gastro-
intestinal parasites on farms in England**

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Abstract

A questionnaire was distributed electronically amongst sheep farmers in England; it aimed to provide a quantification of current anthelmintic practices, farmer awareness of the issue of anthelmintic resistance (AR) and the uptake, awareness and opinions surrounding conventional and alternative methods of nematode control. The majority of farmers relied on several anthelmintics and used faecal egg counts to identify worm problems. Although farmers were aware of the issue of AR amongst helminth parasites in the UK, there was a disconnection between such awareness and on farm problems and practice of nematode control. Grazing management was used by 52% of responders, while breeding for resistance and bioactive forages by 22 and 18% respectively. Farms with more than 500 ewes, and farmers who felt nematodes were a problem, had a higher probability of using selective breeding. Farmers who considered their wormer effective, had a qualification in agriculture and whose staff did not include any family members, were more likely to use bioactive forages; the opposite was the case if farmers dosed their lambs frequently. Amongst the alternatives, highest preference was for selective breeding and vaccination, if the latter was to become commercially available, with more respondents having a preference for breeding than actually using it. Several barriers to the uptake of an alternative were identified, the most influential factor being the cost to set it up and the length of time for which it would remain effective. The disconnection between awareness of AR and practice of nematode control on farm reinforces the need for emphasising the links between the causes of AR and the consequences of strategies to address its challenge.

Key words: alternative controls; anthelmintics; attitudes; bioactive forages; breeding; gastrointestinal parasites; sheep

1 Introduction

Gastro-intestinal nematode (GIN) parasites are the single most pervasive challenge to the health and welfare of sheep worldwide (Morgan and Coles, 2010; Domke *et al.*, 2011), and a significant cause of economic loss to the relevant industries (Matika *et al.*, 2011; Burgess *et al.*, 2012). GIN infections are predominantly treated through the use of pharmaceuticals. However, an over reliance on these treatments has led to the evolution of anthelmintic resistance (AR) in GIN populations (Larsen, 2006; Papadopoulos *et al.*, 2012). Management strategies contributing to an increased rate of AR generation have been identified, including higher drenching frequency, under dosing (Lawrence *et al.*, 2007; Papadopoulos *et al.*, 2012; Laurenson *et al.*, 2013) and the previously recommended dose and move strategy (Morgan and Coles, 2010; Domke *et al.*, 2011). Monitoring current anthelmintic protocols is therefore important to ensure that farms are using anthelmintics in a way that does not promote AR (Kahn and Woodgate, 2012).

Alternatives to control GIN, such as breeding for resistance to parasites (Bishop, 2012), targeted nutrition and bioactive forages (Coop and Kyriazakis, 2001), have been considered as means of reducing the use of anthelmintics and by extension the rate of AR development, although their uptake by the UK sheep industry is currently unknown. Previously surveys have been used to quantify the extent to which of GIN management techniques on small ruminant farms are employed, and have served as useful determinants of how well AR awareness programmes are working (Morgan and Coles, 2010). The aim of this paper was three fold: 1) to develop a survey able to build upon previous surveys of UK sheep farms (Fraser *et al.*, 2006; Burgess *et al.*, 2012) and give an updated quantification of anthelmintic practices used on such farms in England, identify farmer awareness of the issue of AR and whether such awareness influences helminth control strategies. 2) The survey aimed to be the first in its field to quantify responder uptake, awareness and opinions surrounding alternative

methods of GIN control. This included both currently commercial available options and ones that may become available in the future, such as nematophagous fungi and vaccination. 3) Finally, as previous surveys have highlighted the lack of information on the best way to disseminate parasite management information to farmers (Fraser *et al.*, 2006; Woodgate and Love, 2012), the survey also focussed on how respondents received information on GIN management and AR control.

2 Materials and Methods

2.1 Study population

The population of the study consisted of sheep farmers who are registered as members of the English Beef and Lamb Executive (EBLEX) Ltd (now Agricultural and Horticultural Development Board Beef and Lamb), and have their farms located in the south west and north east and north west of England, as these regions have the highest numbers of sheep in England (EBLEX, 2014). All 1616 EBLEX sheep farmers located in these regions were asked to complete the survey on line. Survey distribution was split between two regions due to previous surveys finding regional differences in parasite exposure (Bennema *et al.*, 2010), AR (Burgess *et al.*, 2012) and chemo-prophylactic use (Bloemhoff *et al.*, 2014). The survey was incentivised through all completed surveys being entered into a prize draw to win an £100 Amazon voucher.

2.2 Questionnaire

The starting point was questions used in previous surveys that related to control of GIN in ruminants (Maingi *et al.*, 1996; Fraser *et al.*, 2006; Čerňanská *et al.*, 2008; Morgan and Coles, 2010; Domke *et al.*, 2011; Burgess *et al.*, 2012; Morgan *et al.*, 2012; Falzon *et al.*, 2013). The questionnaire was piloted and internally validated on a small number of farms, allowing determination of consistency of responses and ensuring the language used within the

survey could be easily understood by the target audience, and an estimation of how long the survey took to complete. After completion of the pilot survey aim, internal audit and further discussions took place, to test how accurate the responses were in terms of the quantitative data. This led to the inclusion of an extra option in the methods of communication section of the survey, that of choosing to get information from an agricultural merchant.

The final questionnaire consisted of 62 questions, divided into four sections, aimed at obtaining information on the following: section one (farm demographics), section two (anthelmintic use), section three (quarantine protocol), and section four (awareness of alternative strategies, barriers to using alternative strategies and preference of obtaining information on worm control strategies). The alternatives considered within the survey were based on reviews of possible alternative methods of GIN control research (Coop and Kyriazakis, 2001; Stear *et al.*, 2007). Questions on the following alternatives included: grazing management (GM), breeding for resistance (BR), vaccination, bioactive forage (BF), such as chicory, birdsfoot trefoil, and sainfoin, and fungal biocontrol agents. Regarding vaccination, it was clarified in the questionnaire that currently there were no commercially available vaccines against nematodes, so the question was based on the hypothesis that this may become available in the future. For each one a question on awareness and opinion on that alternative was asked. For GM, BR and BF an additional question was asked on whether farmers used any of the methods, as all three are recommended by EBLEX. Within the survey acronyms were used for the following organisations: NADIS (National Animal Disease Information Service) and SCOPS (Sustainable Control of Parasites in Sheep). Moreover, Faecal egg count was abbreviated to FEC. Questions about quarantine procedure were based on guidelines given in EBLEX literature. This allowed us to gauge the exactness of whether farms were implementing their quarantine procedure correctly, rather than eliciting just a simple yes or no answer to whether they quarantined their animals or not.

The questionnaire consisted of binary and multiple choice questions, with some questions providing a comment box for recipients to write their own responses to questions. Farmers that were contacted were given one month to complete the survey.

2.3 Statistical analysis

‘Google Forms’ software was used to create the online survey, making the survey available through the link provided in the distribution email. ‘Google Forms’ was automated to collate all answers into a ‘Google spreadsheet’ which could then be downloaded into a 2010 Microsoft Excel spreadsheet for statistical analysis. Most descriptive statistics were automatically produced by ‘Google Forms’ software; there being a constant live update of results in graphs and pie charts.

Survey responses were then imported into RStudio software (R version 2.15.1) where further analysis could be undertaken. Analysis was carried out on data relating to use of alternative strategies and use, and perception of anthelmintic protocols. Four binary and two multinomial regression models of association were created, as shown in Table 1. Categorization of resistance of anthelmintics used on farm was according to McMahon *et al* (2013).

Chi squared analysis was first carried out between all independent variables within the dataset with the function *chisq test* of the R package *stats*. A full list of variables classed as independent and used for the multinomial and binary models are listed in Table 2. When two variables were highly correlated in the Chi square test ($p < 0.001$) the variable not significant in the univariate analysis was removed from subsequent models to avoid confounding effects. If both variables were significant, the one judged susceptible to give the most interesting outcome for the study was kept. Subsequently, the function *glm* from the R package was used for the formation of binary models. Only univariate models giving a p value < 0.25 were used within the formation of the multivariate analysis. Final models were formed using an

automatic procedure through the function *stepAIC* on the R package *MASS*. The odds ratio, confidence interval, and p value were then extracted from each model.

For formation of the multi nominal models the function *multinom* from the R package *nnet* was used. All the univariate models were compared with the null model with an ANOVA using the function *anova* within R package *stats*. The function *anova* of the R package was used to compare the maximal models with different possibilities of minimal models. The final multivariate model was chosen based on the significance of the independent variables and the minimum AIC value.

3 Results

A total of 147 surveys were completed; 138 were filled in online and a further 9 were completed manually. It was thought that this occurred due to word of mouth amongst farmers and EBLEX employees. Of the 9 manually completed surveys, only 6 were able to be used as part of the final analysis, leaving a sample of 144 (~10% response rate). For data relating to anthelmintic use, three farms within the sample did not use anthelmintics. Although distributed directly through email to farms in the north and south west the responses in the survey had a more general geographical distribution throughout England, as shown in Table 3. We decided to use questionnaires from across the country, although the majority of the responders (56%) were from the south west, the region that has the highest number of sheep in England (EBLEX, 2014).

3.1 Current anthelmintic use

Ninety five per cent of respondents said they considered their current anthelmintic treatment to be effective. However, 70% thought GIN were a problem on their farm, 52% had perceived an anthelmintic they had used to be ineffective in the past and 92% said anthelmintic resistance is something that concerns them either now or in the future.

Sixty two per cent wormed their ewes once annually. There was a variation in when the ewes were wormed, with 36% worming pre-tupping, 32% worming before lambing, 58% worming just after lambing and 16% worming their ewes at weaning. Forty two per cent of farms said they wormed lambs 3 or more times, 43% wormed lambs twice , 14% once and 1.4% did not worm lambs at all. Forty nine per cent of farms changed the wormer they used on farm one to two times per year, 30% less than once per year and 20% more than twice a year. Thirty five per cent used three different types of wormer, 30% used two, 24% used four and 11% used only one wormer type. The relative uses of wormer classes are displayed in Table 4.

When respondents were asked what method they relied upon to recognise worm problems, the most popular method used was by FEC at 47%, 29% used scours, 13% general ill thrift, 9.7% reduced weight gain and 2.1% coat condition. It was found that 79% of farmers surveyed have used FEC at least once to assess the worm situation on their farm. When asked how they decided the quantity of wormer given, 47% of farms drenched all animals on the basis of the weight of the heaviest animal in their flock. When respondents who had not used FEC were asked why they had not adopted the technology, responses were distributed fairly evenly between the six available options. In response to this question 9% of farmers used the option of typing their own answer; this included a majority of responses similar to: 'I have not considered it before but now I am' or 'I am now going to ask my vet about it'. The second highest response was that 'FEC were too much hassle/ trouble' followed by it being too expensive.

Eighty eight percent of respondents said they quarantined all new sheep coming onto their farm premises. Out of those, 94% said they dosed these new sheep with an anthelmintic during their quarantine procedure. Of this 94%, 64 (54%) farmers used the anthelmintics monepantel or derquantel. Furthermore, of the 64, nearly half accompanied the use of the one of these classes of anthelmintic with a 1% moxidectin injection.

Results of multivariate model of association for the dependent variable: the number of classes of anthelmintic used on the farm is outlined in Table 5. Farmers concerned about anthelmintic resistance for the future tended to be more likely to use more than one anthelmintic. Moreover, the confidence intervals for ‘use of four different wormers’ were high, due to all the farmers using four wormers answering yes to whether they were concerned about resistance. Farms with more than 200 ewes were found to be more likely to use three or four types of anthelmintic. Farms that were aware of SCOPS were more likely to use three or four types of wormer compared to those who had not heard of SCOPS. Farms where all the staff was family members were less likely to use four types of anthelmintic. Binary logistic regression analysis found farmers who did think GIN were a problem on their farm were less likely to have felt their wormer to have been ineffective ($p < 0.05$).

Results of binary logistic regression for the dependent variable: the resistance status of anthelmintic product used, are displayed in Table 6. Farms located in the south west, south east and north west were all less likely to be using a high resistance anthelmintic, when compared to farms from the Midlands. On farms where anthelmintic resistance was something that concerned them for the future, they were more likely to use a high resistance anthelmintic. Moreover, farms that were aware of benefits of using an alternative method of worm control and the smallest farms in the sample (less than 50 hectares) were found to be less likely to be using a high resistance anthelmintic. When all the staff on the farm were family the farm was less likely to be using a high resistance anthelmintic compared to the farms where less than 50% of the staff were family members.

3.2 Methods for obtaining worm control information by farmers

To find out more information regarding worm control 74% said they would ask a vet, 76% said they would look on EBLEX, NADIS or SCOPS website (the farmers were able to answer more than one category). Thirty six per cent said they would use Google, 28% a

farming magazine, 24% would talk to an agricultural merchant or someone they considered to be more qualified than them, 20% would ask other farmers. Eight point three per cent filled in the 'other' category and the responses included: use an online forum, internet, Soil Association, ask lecturer and seminars or farm discussion groups. Furthermore, 71% said they received NADIS forecasts, and of the farms receiving NADIS forecasts, 71% said these sometimes caused them to change their worming routines.

3.3 Farmer awareness, preference and use of alternative method of worm control

Figure 1 has combined results for farmer awareness, use of alternatives and which ones they would prefer to use if all were available and worked. Grazing management (GM) was the method farms were most aware of. Targeted nutrition and nematophagous fungi showed very low preference by farmers. The highest preference was for breeding for resistance (BR) and vaccination, with more respondents having a preference for BR than were actually using it. In contrast more people were using GM than had a preference for it. It was also found that 84% of respondents would be interested in receiving more information on ingested nematophagous fungi as a worm control strategy. No significant difference was found between the awareness of one and awareness of several alternative methods. Farmers who were aware of several alternative methods were not more aware of SCOPS.

Anthelmintics were used by nearly all the farms surveyed. GM was used by 52% of responders, whereas BR and bioactive forages (BF) were used by 22% and 18% of responders respectively. Results of binary logistic regression for the dependent variable: use of BR, are in Table 7. Farms with more than 500 ewes were found to be more likely to use BR ($0.06 > p > 0.05$).

Results showed that the number of times lambs were wormed per annum on a farm did not have an effect on the use of BF (Table 8). Farms that had not felt their wormer be ineffective

were found to be more likely to use BF. Additionally farmers who had a qualification in agriculture were more likely to use BF and if none of the staff working at the farm were family members the farm was also more likely to use a BF.

3.4 Possible barriers to using alternative methods of nematode control

Forty one per cent of the responder said the most influential factor for their farm adopting a new control method would be the cost to set up the method on farm, 39% said it would be how long the treatment remained effective into the future and 21% used the 'other' box. 'Other' comments included: 25% of answers relating to the need to know whether the treatment was going to work effectively, 20% of answers relating to the method's practicality in application and 7.1% of farmers again citing their stewardship scheme as the main reason they would not adopt a new control strategy. One farmer cited the withdrawal period after the treatment as being an influential factor and one was concerned about new treatments affecting the farm's organic status.

Fifty eight per cent of farms surveyed said they had not considered reseeding their crop to BF. Of the 118 farms that said they did not currently graze BF, 29% said this was due to their lack of ground, 20% said they were unaware of this as a method, 6.8% said it was due to crop rotation, 7.6% that it was due to them perceiving it to be ineffective as a treatment and another 7.6% that it was due to the cost of using it. Twenty nine per cent of the 118 wrote their own response in the comment box. Of these twenty five per cent said the reason they had not reseeded was due to the type of ground they had rather than the lack of ground, 3.6% cited their stewardship scheme as not permitting a change in crop and 2.9% said they had tried BF but had had unsatisfactory results. Other responses included: the farm having a dairy as well as sheep, and that BF were not favourable to use as part of a dairy herd, lack of herbicides and the land being tenanted as grass pasture only.

4 Discussion

The first aim of this paper was to give an updated quantification of anthelmintic practices used on sheep farms in England and to identify whether farmer awareness of the issue of AR influences the current helminth control strategies. The survey targeted members of EBLEX, an organisation that aims to deliver services to all beef and lamb levy payers in England. Membership of EBLEX amongst sheep farmers is estimated at more than 70% (EBLEX, 2014); as such the survey was considered to be inclusive. The return rate of the survey was 10%, which is comparable to the rates achieved by previous exercises (e.g., Burgess *et al.*, 2012). However, as our survey was distributed electronically, the responses are likely to have been biased towards farmers who use technological innovation, or to have captured responders that were interested or concerned about the issue. The relationship between technological innovation and uptake of alternatives to anthelmintics is currently unknown (Woodgate and Love, 2012).

The survey found similar results to those reported previously on anthelmintic use in the UK (e.g., Burgess *et al.*, 2012), with benzamidazole and macrolytic lactones being the most widely used classes. However, a widespread use of amino-acetonitrile derivatives (monepantel) was also reported, despite this class being the one requiring prescription for its use, in order to reduce the rate at which AR is generated to this anthelmintic (EBLEX, 2013).

The survey also found higher awareness of, and concerns about, AR amongst farmers than in previous surveys conducted in the UK. This awareness is perhaps reflected in the higher use of FEC to recognise worm problems and to assess the effectiveness of the treatment, and the drenching of the flock on the basis of the weight of their heaviest animal, which is likely to decrease underdosing (Morgan and Coles, 2010). In addition the uptake of "quarantine drenching" was very high amongst responders. This is a useful yardstick of farmer engagement with extension messages, as it is an important, but often overlooked

recommendation (Kahn and Woodgate, 2012). In this survey, the response in the proportion that apparently implement introductory treatments was surprisingly good, but elsewhere this appears to have been poorly adopted (Lawrence *et al.*, 2007).

However, at the same time there seemed to be a disconnection between awareness of the issue of AR and GIN problems on farm. First of all, farmers with stated GIN problems were less likely to identify the wormer used as being ineffective; second, farmers who were more concerned about AR at the same time used a more resistant class of anthelmintic. In addition, although most farmers reported that they were using quarantine procedures on their farm, only a quarter of them were following the correct procedures recommended by EBLEX (2013) and SCOPS. Convincing sheep farmers to adopt best practices for worm control has been an obstacle in achieving sustainable worm control in other countries (Woodgate and Love, 2012).

Farmers relied on several classes of anthelmintics to control GIN. EBLEX (2013) and The BVA recommend avoiding frequent and repeated use of anthelmintics from the same class over extended periods of time. Indeed, farmers concerned about anthelmintic resistance, who were aware of SCOPS, and farms with more than 200 ewes, were more likely to use three or four classes of anthelmintic. The opposite was the case when all farm staff were family members; this issue is further addressed below. The choice of anthelmintic class was also affected by several factors: farmers who were concerned about resistance were more likely to use a high resistance anthelmintic, perhaps pointing towards a cause and effect. These findings point towards several factors influencing farmer decisions on anthelmintic use and type, and these decisions may be related to the higher concerns of the responders about anthelmintic resistance than were identified in previous surveys (Fraser *et al.*, 2006).

One of the consistent findings of our paper was that farm practices in relation to anthelmintics were affected by whether staff members were related: when this was the case, the farm was less likely to be using four types of anthelmintic and less likely to be using a high resistance anthelmintic. This is perhaps an area of research that merits further investigation, as it has been suggested that related staff are likely to influence farm practices (Garforth *et al.*, 2013); this in turn may influence the outcome of campaigns for control (see also below, when dealing with preference for using bioactive forages).

The second aim of the paper was to quantify farmer uptake, awareness and opinions surrounding alternative methods of GIN control. Given the increased concerns about AR, the expectation was that farmers would be aware of and more willing to use alternatives to control GIN. Here we investigated alternatives recommended by EBLEX (2013) and SCOPS, such as grazing management, breeding sheep for resistance to parasites, bioactive forages and targeted nutrition, and alternatives that may become available in the near future, such as vaccination and nematophagous fungi (Stear *et al.*, 2007; Arunkumar, 2012). Grazing management was associated with both very high awareness and usage – more than 50% of the responders said that they were already using it. This method has been in practice since 1960 and its benefits have been widely demonstrated (Coop and Kyriazakis, 2001). In the survey the term grazing management was used as an umbrella to encompass a number of alternatives, such as: alternating use of pasture, moving animals to clean pasture, rotational grazing and ‘dose and move’. Although there are benefits to be had from most grazing management applications, some of these practices, such as the ‘dose and move’ strategy, are now in fact associated with AR promotion (Sutherland *et al.*, 2002). Despite this, Morgan and Coles (2010) found that two thirds of farmers still use this strategy. In future it would be more appropriate to distinguish between which aspects of grazing management are practised.

330 Although breeding for sheep resistance to nematodes was preferred by a third of the
331 responders, only 20% of them were actually using it. These were mainly on farms with more
332 than 500 ewes, and farmers who thought that GIN were a problem on their premises.

333 Although breeding for resistance in sheep has been advocated for more than 25 years in the
334 UK, its uptake seems to have been relatively low. Bishop (2012) has identified some of the
335 barriers to the application of this method of control, including the relatively slow
336 manifestation of benefits, and concerns about its effectiveness both in the short and long term
337 (Stear *et al.*, 2007; Kemper *et al.*, 2013). Ensuring that breeding for resistance will be
338 associated with improvements in productivity also remains a major concern (Laurenson *et al.*,
339 2013). It is thus likely that these concerns are a bottleneck in the adoption of this alternative.

340 Despite the lower preference for bioactive forages as alternatives to control nematodes, a
341 similar percentage of farmers to those breeding for resistance were actually using them. Their
342 use, however, depended on several factors: surprisingly, farmers who felt their wormers to be
343 ineffective were not using this alternative control method more than the ones who did not feel
344 their wormer to be ineffective. This was another case of disconnection between awareness
345 and practice, as the identification of AR might not always be connected to the use of an
346 alternative. If farmers or their staff had a qualification in agriculture or no family members
347 were employed, these alternative control methods were more likely to be used. It is possible
348 that the latter two factors reflect the tendency for better educated farmers to be more aware of
349 novel trends in GIN control. It has been suggested by Garforth *et al.* (2013) that farms that
350 employ family members are less open to alternative options, as they are more likely to hold
351 entrenched beliefs. The main barriers associated with use of such forages were associated
352 with establishing and maintaining such crops, something that has been identified repeatedly
353 by advocates of the method (Coop and Kyriazakis, 2001). Ultimately, the uptake of an
354 alternative method to control GIN on farms will also depend on its (financial) returns (Torres-

Acosta *et al.*, 2012). This is perhaps one of the reasons that targeted nutrition was found to have such a low uptake, despite its well documented benefits in GIN control (Coop and Kyriazakis, 2001).

The disconnection between awareness of AR and practice of nematode control on farm reinforces the need for emphasising the links between the causes of AR and the consequences of strategies to address its challenge (Woodgate and Love, 2012). The survey also demonstrated relatively high awareness of the alternatives to control nematodes amongst farmers in England. However, at the same time it identified a relatively low uptake, due to a number of barriers, both real and perceived. Most of these barriers were associated with economic concerns and long term effectiveness. As the incidence of AR is increasing amongst UK farms, there is an imperative to apply controls that would reduce its rate of development. In order to achieve this, farmers need to be convinced of the value of the current alternatives to anthelmintics. As far as we are aware there has not been an economic assessment of the application of these alternatives, both in the short and the longer term, and this is perhaps where effort should be directed.

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458 **Figure legends**

459

460 **Figure 1.** *Farmer percentage awareness, use of alternative methods and the percentage of*
461 *farmers selecting each of the alternative methods as their preferred choice of worm control if*
462 *all were available and worked*

Familiarity with and uptake of alternative methods to control sheep gastro-intestinal parasites on farms in England

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Abstract

A questionnaire was distributed electronically amongst sheep farmers in England; it aimed to provide a quantification of current anthelmintic practices, farmer awareness of the issue of anthelmintic resistance (AR) and the uptake, awareness and opinions surrounding conventional and alternative methods of nematode control. The majority of farmers relied on several anthelmintics and used faecal egg counts to identify worm problems. Although farmers were aware of the issue of AR amongst helminth parasites in the UK, there was a disconnection between such awareness and on farm problems and practice of nematode control. Grazing management was used by 52% of responders, while breeding for resistance and bioactive forages by 22 and 18% respectively. Farms with more than 500 ewes, and farmers who felt nematodes were a problem, had a higher probability of using selective breeding. Farmers who considered their wormer effective, had a qualification in agriculture and whose staff did not include any family members, were more likely to use bioactive forages; the opposite was the case if farmers dosed their lambs frequently. Amongst the alternatives, highest preference was for selective breeding and vaccination, if the latter was to become commercially available, with more respondents having a preference for breeding than actually using it. Several barriers to the uptake of an alternative were identified, the most influential factor being the cost to set it up and the length of time for which it would remain effective. The disconnection between awareness of AR and practice of nematode control on farm reinforces the need for emphasising the links between the causes of AR and the consequences of strategies to address its challenge.

Key words: alternative controls; anthelmintics; attitudes; bioactive forages; breeding; gastrointestinal parasites; sheep

1 Introduction

Gastro-intestinal nematode (GIN) parasites are the single most pervasive challenge to the health and welfare of sheep worldwide (Morgan and Coles, 2010; Domke *et al.*, 2011), and a significant cause of economic loss to the relevant industries (Matika *et al.*, 2011; Burgess *et al.*, 2012). GIN infections are predominantly treated through the use of pharmaceuticals. However, an over reliance on these treatments has led to the evolution of anthelmintic resistance (AR) in GIN populations (Larsen, 2006; Papadopoulos *et al.*, 2012). Management strategies contributing to an increased rate of AR generation have been identified, including higher drenching frequency, under dosing (Lawrence *et al.*, 2007; Papadopoulos *et al.*, 2012; Laurenson *et al.*, 2013) and the previously recommended dose and move strategy (Morgan and Coles, 2010; Domke *et al.*, 2011). Monitoring current anthelmintic protocols is therefore important to ensure that farms are using anthelmintics in a way that does not promote AR (Kahn and Woodgate, 2012).

Alternatives to control GIN, such as breeding for resistance to parasites (Bishop, 2012), targeted nutrition and bioactive forages (Coop and Kyriazakis, 2001), have been considered as means of reducing the use of anthelmintics and by extension the rate of AR development, although their uptake by the UK sheep industry is currently unknown. Previously surveys have been used to quantify the extent to which of GIN management techniques on small ruminant farms are employed, and have served as useful determinants of how well AR awareness programmes are working (Morgan and Coles, 2010). The aim of this paper was three fold: 1) to develop a survey able to build upon previous surveys of UK sheep farms (Fraser *et al.*, 2006; Burgess *et al.*, 2012) and give an updated quantification of anthelmintic practices used on such farms in England, identify farmer awareness of the issue of AR and whether such awareness influences helminth control strategies. 2) The survey aimed to be the first in its field to quantify responder uptake, awareness and opinions surrounding alternative

methods of GIN control. This included both currently commercial available options and ones that may become available in the future, such as nematophagous fungi and vaccination. 3) Finally, as previous surveys have highlighted the lack of information on the best way to disseminate parasite management information to farmers (Fraser *et al.*, 2006; Woodgate and Love, 2012), the survey also focussed on how respondents received information on GIN management and AR control.

2 Materials and Methods

2.1 Study population

The population of the study consisted of sheep farmers who are registered as members of the English Beef and Lamb Executive (EBLEX) Ltd (now Agricultural and Horticultural Development Board Beef and Lamb), and have their farms located in the south west and north east and north west of England, as these regions have the highest numbers of sheep in England (EBLEX, 2014). All 1616 EBLEX sheep farmers located in these regions were asked to complete the survey on line. Survey distribution was split between two regions due to previous surveys finding regional differences in parasite exposure (Bennema *et al.*, 2010), AR (Burgess *et al.*, 2012) and chemo-prophylactic use (Bloemhoff *et al.*, 2014). The survey was incentivised through all completed surveys being entered into a prize draw to win an £100 Amazon voucher.

2.2 Questionnaire

The starting point was questions used in previous surveys that related to control of GIN in ruminants (Maingi *et al.*, 1996; Fraser *et al.*, 2006; Čerňanská *et al.*, 2008; Morgan and Coles, 2010; Domke *et al.*, 2011; Burgess *et al.*, 2012; Morgan *et al.*, 2012; Falzon *et al.*, 2013). The questionnaire was piloted and internally validated on a small number of farms, allowing determination of consistency of responses and ensuring the language used within the

survey could be easily understood by the target audience, and an estimation of how long the survey took to complete. After completion of the pilot survey aim, internal audit and further discussions took place, to test how accurate the responses were in terms of the quantitative data. This led to the inclusion of an extra option in the methods of communication section of the survey, that of choosing to get information from an agricultural merchant.

The final questionnaire consisted of 62 questions, divided into four sections, aimed at obtaining information on the following: section one (farm demographics), section two (anthelmintic use), section three (quarantine protocol), and section four (awareness of alternative strategies, barriers to using alternative strategies and preference of obtaining information on worm control strategies). The alternatives considered within the survey were based on reviews of possible alternative methods of GIN control research (Coop and Kyriazakis, 2001; Stear *et al.*, 2007). Questions on the following alternatives included: grazing management (GM), breeding for resistance (BR), vaccination, bioactive forage (BF), such as chicory, birdsfoot trefoil, and sainfoin, and fungal biocontrol agents. Regarding vaccination, it was clarified in the questionnaire that currently there were no commercially available vaccines against nematodes, so the question was based on the hypothesis that this may become available in the future. For each one a question on awareness and opinion on that alternative was asked. For GM, BR and BF an additional question was asked on whether farmers used any of the methods, as all three are recommended by EBLEX. Within the survey acronyms were used for the following organisations: NADIS (National Animal Disease Information Service) and SCOPS (Sustainable Control of Parasites in Sheep). Moreover, Faecal egg count was abbreviated to FEC. Questions about quarantine procedure were based on guidelines given in EBLEX literature. This allowed us to gauge the exactness of whether farms were implementing their quarantine procedure correctly, rather than eliciting just a simple yes or no answer to whether they quarantined their animals or not.

The questionnaire consisted of binary and multiple choice questions, with some questions providing a comment box for recipients to write their own responses to questions. Farmers that were contacted were given one month to complete the survey.

2.3 Statistical analysis

‘Google Forms’ software was used to create the online survey, making the survey available through the link provided in the distribution email. ‘Google Forms’ was automated to collate all answers into a ‘Google spreadsheet’ which could then be downloaded into a 2010 Microsoft Excel spreadsheet for statistical analysis. Most descriptive statistics were automatically produced by ‘Google Forms’ software; there being a constant live update of results in graphs and pie charts.

Survey responses were then imported into RStudio software (R version 2.15.1) where further analysis could be undertaken. Analysis was carried out on data relating to use of alternative strategies and use, and perception of anthelmintic protocols. Four binary and two multinomial regression models of association were created, as shown in Table 1. Categorization of resistance of anthelmintics used on farm was according to McMahon *et al* (2013).

Chi squared analysis was first carried out between all independent variables within the dataset with the function *chisq test* of the R package *stats*. A full list of variables classed as independent and used for the multinomial and binary models are listed in Table 2. When two variables were highly correlated in the Chi square test ($p < 0.001$) the variable not significant in the univariate analysis was removed from subsequent models to avoid confounding effects. If both variables were significant, the one judged susceptible to give the most interesting outcome for the study was kept. Subsequently, the function *glm* from the R package was used for the formation of binary models. Only univariate models giving a p value < 0.25 were used within the formation of the multivariate analysis. Final models were formed using an

automatic procedure through the function *stepAIC* on the R package *MASS*. The odds ratio, confidence interval, and p value were then extracted from each model.

For formation of the multi nominal models the function *multinom* from the R package *nnet* was used. All the univariate models were compared with the null model with an ANOVA using the function *anova* within R package *stats*. The function *anova* of the R package was used to compare the maximal models with different possibilities of minimal models. The final multivariate model was chosen based on the significance of the independent variables and the minimum AIC value.

3 Results

A total of 147 surveys were completed; 138 were filled in online and a further 9 were completed manually. It was thought that this occurred due to word of mouth amongst farmers and EBLEX employees. Of the 9 manually completed surveys, only 6 were able to be used as part of the final analysis, leaving a sample of 144 (~10% response rate). For data relating to anthelmintic use, three farms within the sample did not use anthelmintics. Although distributed directly through email to farms in the north and south west the responses in the survey had a more general geographical distribution throughout England, as shown in Table 3. We decided to use questionnaires from across the country, although the majority of the responders (56%) were from the south west, the region that has the highest number of sheep in England (EBLEX, 2014).

3.1 Current anthelmintic use

Ninety five per cent of respondents said they considered their current anthelmintic treatment to be effective. However, 70% thought GIN were a problem on their farm, 52% had perceived an anthelmintic they had used to be ineffective in the past and 92% said anthelmintic resistance is something that concerns them either now or in the future.

Sixty two per cent wormed their ewes once annually. There was a variation in when the ewes were wormed, with 36% worming pre-tupping, 32% worming before lambing, 58% worming just after lambing and 16% worming their ewes at weaning. Forty two per cent of farms said they wormed lambs 3 or more times, 43% wormed lambs twice , 14% once and 1.4% did not worm lambs at all. Forty nine per cent of farms changed the wormer they used on farm one to two times per year, 30% less than once per year and 20% more than twice a year. Thirty five per cent used three different types of wormer, 30% used two, 24% used four and 11% used only one wormer type. The relative uses of wormer classes are displayed in Table 4.

When respondents were asked what method they relied upon to recognise worm problems, the most popular method used was by FEC at 47%, 29% used scours, 13% general ill thrift, 9.7% reduced weight gain and 2.1% coat condition. It was found that 79% of farmers surveyed have used FEC at least once to assess the worm situation on their farm. When asked how they decided the quantity of wormer given, 47% of farms drenched all animals on the basis of the weight of the heaviest animal in their flock. When respondents who had not used FEC were asked why they had not adopted the technology, responses were distributed fairly evenly between the six available options. In response to this question 9% of farmers used the option of typing their own answer; this included a majority of responses similar to: 'I have not considered it before but now I am' or 'I am now going to ask my vet about it'. The second highest response was that 'FEC were too much hassle/ trouble' followed by it being too expensive.

Eighty eight percent of respondents said they quarantined all new sheep coming onto their farm premises. Out of those, 94% said they dosed these new sheep with an anthelmintic during their quarantine procedure. Of this 94%, 64 (54%) farmers used the anthelmintics monepantel or derquantel. Furthermore, of the 64, nearly half accompanied the use of the one of these classes of anthelmintic with a 1% moxidectin injection.

Results of multivariate model of association for the dependent variable: the number of classes of anthelmintic used on the farm is outlined in Table 5. Farmers concerned about anthelmintic resistance for the future tended to be more likely to use more than one anthelmintic. Moreover, the confidence intervals for 'use of four different wormers' were high, due to all the farmers using four wormers answering yes to whether they were concerned about resistance. Farms with more than 200 ewes were found to be more likely to use three or four types of anthelmintic. Farms that were aware of SCOPS were more likely to use three or four types of wormer compared to those who had not heard of SCOPS. Farms where all the staff was family members were less likely to use four types of anthelmintic. Binary logistic regression analysis found farmers who did think GIN were a problem on their farm were less likely to have felt their wormer to have been ineffective ($p < 0.05$).

Results of binary logistic regression for the dependent variable: the resistance status of anthelmintic product used, are displayed in Table 6. Farms located in the south west, south east and north west were all less likely to be using a high resistance anthelmintic, when compared to farms from the Midlands. On farms where anthelmintic resistance was something that concerned them for the future, they were more likely to use a high resistance anthelmintic. Moreover, farms that were aware of benefits of using an alternative method of worm control and the smallest farms in the sample (less than 50 hectares) were found to be less likely to be using a high resistance anthelmintic. When all the staff on the farm were family the farm was less likely to be using a high resistance anthelmintic compared to the farms where less than 50% of the staff were family members.

3.2 Methods for obtaining worm control information by farmers

To find out more information regarding worm control 74% said they would ask a vet, 76% said they would look on EBLEX, NADIS or SCOPS website (the farmers were able to answer more than one category). Thirty six per cent said they would use Google, 28% a

farming magazine, 24% would talk to an agricultural merchant or someone they considered to be more qualified than them, 20% would ask other farmers. Eight point three per cent filled in the 'other' category and the responses included: use an online forum, internet, Soil Association, ask lecturer and seminars or farm discussion groups. Furthermore, 71% said they received NADIS forecasts, and of the farms receiving NADIS forecasts, 71% said these sometimes caused them to change their worming routines.

3.3 Farmer awareness, preference and use of alternative method of worm control

Figure 1 has combined results for farmer awareness, use of alternatives and which ones they would prefer to use if all were available and worked. Grazing management (GM) was the method farms were most aware of. Targeted nutrition and nematophagous fungi showed very low preference by farmers. The highest preference was for breeding for resistance (BR) and vaccination, with more respondents having a preference for BR than were actually using it. In contrast more people were using GM than had a preference for it. It was also found that 84% of respondents would be interested in receiving more information on ingested nematophagous fungi as a worm control strategy. No significant difference was found between the awareness of one and awareness of several alternative methods. Farmers who were aware of several alternative methods were not more aware of SCOPS.

Anthelmintics were used by nearly all the farms surveyed. GM was used by 52% of responders, whereas BR and bioactive forages (BF) were used by 22% and 18% of responders respectively. Results of binary logistic regression for the dependent variable: use of BR, are in Table 7. Farms with more than 500 ewes were found to be more likely to use BR ($0.06 > p > 0.05$).

Results showed that the number of times lambs were wormed per annum on a farm did not have an effect on the use of BF (Table 8). Farms that had not felt their wormer be ineffective

were found to be more likely to use BF. Additionally farmers who had a qualification in agriculture were more likely to use BF and if none of the staff working at the farm were family members the farm was also more likely to use a BF.

3.4 Possible barriers to using alternative methods of nematode control

Forty one per cent of the responder said the most influential factor for their farm adopting a new control method would be the cost to set up the method on farm, 39% said it would be how long the treatment remained effective into the future and 21% used the 'other' box. 'Other' comments included: 25% of answers relating to the need to know whether the treatment was going to work effectively, 20% of answers relating to the method's practicality in application and 7.1% of farmers again citing their stewardship scheme as the main reason they would not adopt a new control strategy. One farmer cited the withdrawal period after the treatment as being an influential factor and one was concerned about new treatments affecting the farm's organic status.

Fifty eight per cent of farms surveyed said they had not considered reseeding their crop to BF. Of the 118 farms that said they did not currently graze BF, 29% said this was due to their lack of ground, 20% said they were unaware of this as a method, 6.8% said it was due to crop rotation, 7.6% that it was due to them perceiving it to be ineffective as a treatment and another 7.6% that it was due to the cost of using it. Twenty nine per cent of the 118 wrote their own response in the comment box. Of these twenty five per cent said the reason they had not reseeded was due to the type of ground they had rather than the lack of ground, 3.6% cited their stewardship scheme as not permitting a change in crop and 2.9% said they had tried BF but had had unsatisfactory results. Other responses included: the farm having a dairy as well as sheep, and that BF were not favourable to use as part of a dairy herd, lack of herbicides and the land being tenanted as grass pasture only.

4 Discussion

The first aim of this paper was to give an updated quantification of anthelmintic practices used on sheep farms in England and to identify whether farmer awareness of the issue of AR influences the current helminth control strategies. The survey targeted members of EBLEX, an organisation that aims to deliver services to all beef and lamb levy payers in England. Membership of EBLEX amongst sheep farmers is estimated at more than 70% (EBLEX, 2014); as such the survey was considered to be inclusive. The return rate of the survey was 10%, which is comparable to the rates achieved by previous exercises (e.g., Burgess *et al.*, 2012). However, as our survey was distributed electronically, the responses are likely to have been biased towards farmers who use technological innovation, or to have captured responders that were interested or concerned about the issue. The relationship between technological innovation and uptake of alternatives to anthelmintics is currently unknown (Woodgate and Love, 2012).

The survey found similar results to those reported previously on anthelmintic use in the UK (e.g., Burgess *et al.*, 2012), with benzamidazole and macrolytic lactones being the most widely used classes. However, a widespread use of amino-acetonitrile derivatives (montepantel) was also reported, despite this class being the one requiring prescription for its use, in order to reduce the rate at which AR is generated to this anthelmintic (EBLEX, 2013).

The survey also found higher awareness of, and concerns about, AR amongst farmers than in previous surveys conducted in the UK. This awareness is perhaps reflected in the higher use of FEC to recognise worm problems and to assess the effectiveness of the treatment, and the drenching of the flock on the basis of the weight of their heaviest animal, which is likely to decrease underdosing (Morgan and Coles, 2010). In addition the uptake of "quarantine drenching" was very high amongst responders. This is a useful yardstick of farmer engagement with extension messages, as it is an important, but often overlooked

recommendation (Kahn and Woodgate, 2012). In this survey, the response in the proportion that apparently implement introductory treatments was surprisingly good, but elsewhere this appears to have been poorly adopted (Lawrence *et al.*, 2007).

However, at the same time there seemed to be a disconnection between awareness of the issue of AR and GIN problems on farm. First of all, farmers with stated GIN problems were less likely to identify the wormer used as being ineffective; second, farmers who were more concerned about AR at the same time used a more resistant class of anthelmintic. In addition, although most farmers reported that they were using quarantine procedures on their farm, only a quarter of them were following the correct procedures recommended by EBLEX (2013) and SCOPS. Convincing sheep farmers to adopt best practices for worm control has been an obstacle in achieving sustainable worm control in other countries (Woodgate and Love, 2012).

Farmers relied on several classes of anthelmintics to control GIN. EBLEX (2013) and The BVA recommend avoiding frequent and repeated use of anthelmintics from the same class over extended periods of time. Indeed, farmers concerned about anthelmintic resistance, who were aware of SCOPS, and farms with more than 200 ewes, were more likely to use three or four classes of anthelmintic. The opposite was the case when all farm staff were family members; this issue is further addressed below. The choice of anthelmintic class was also affected by several factors: farmers who were concerned about resistance were more likely to use a high resistance anthelmintic, perhaps pointing towards a cause and effect. These findings point towards several factors influencing farmer decisions on anthelmintic use and type, and these decisions may be related to the higher concerns of the responders about anthelmintic resistance than were identified in previous surveys (Fraser *et al.*, 2006).

One of the consistent findings of our paper was that farm practices in relation to anthelmintics were affected by whether staff members were related: when this was the case, the farm was less likely to be using four types of anthelmintic and less likely to be using a high resistance anthelmintic. This is perhaps an area of research that merits further investigation, as it has been suggested that related staff are likely to influence farm practices (Garforth *et al.*, 2013); this in turn may influence the outcome of campaigns for control (see also below, when dealing with preference for using bioactive forages).

The second aim of the paper was to quantify farmer uptake, awareness and opinions surrounding alternative methods of GIN control. Given the increased concerns about AR, the expectation was that farmers would be aware of and more willing to use alternatives to control GIN. Here we investigated alternatives recommended by EBLEX (2013) and SCOPS, such as grazing management, breeding sheep for resistance to parasites, bioactive forages and targeted nutrition, and alternatives that may become available in the near future, such as vaccination and nematophagous fungi (Stear *et al.*, 2007; Arunkumar, 2012). Grazing management was associated with both very high awareness and usage – more than 50% of the responders said that they were already using it. This method has been in practice since 1960 and its benefits have been widely demonstrated (Coop and Kyriazakis, 2001). In the survey the term grazing management was used as an umbrella to encompass a number of alternatives, such as: alternating use of pasture, moving animals to clean pasture, rotational grazing and ‘dose and move’. Although there are benefits to be had from most grazing management applications, some of these practices, such as the ‘dose and move’ strategy, are now in fact associated with AR promotion (Sutherland *et al.*, 2002). Despite this, Morgan and Coles (2010) found that two thirds of farmers still use this strategy. In future it would be more appropriate to distinguish between which aspects of grazing management are practised.

330 Although breeding for sheep resistance to nematodes was preferred by a third of the
331 responders, only 20% of them were actually using it. These were mainly on farms with more
332 than 500 ewes, and farmers who thought that GIN were a problem on their premises.

333 Although breeding for resistance in sheep has been advocated for more than 25 years in the
334 UK, its uptake seems to have been relatively low. Bishop (2012) has identified some of the
335 barriers to the application of this method of control, including the relatively slow
336 manifestation of benefits, and concerns about its effectiveness both in the short and long term
337 (Stear *et al.*, 2007; Kemper *et al.*, 2013). Ensuring that breeding for resistance will be
338 associated with improvements in productivity also remains a major concern (Laurenson *et al.*,
339 2013). It is thus likely that these concerns are a bottleneck in the adoption of this alternative.

340 Despite the lower preference for bioactive forages as alternatives to control nematodes, a
341 similar percentage of farmers to those breeding for resistance were actually using them. Their
342 use, however, depended on several factors: surprisingly, farmers who felt their wormers to be
343 ineffective were not using this alternative control method more than the ones who did not feel
344 their wormer to be ineffective. This was another case of disconnection between awareness
345 and practice, as the identification of AR might not always be connected to the use of an
346 alternative. If farmers or their staff had a qualification in agriculture or no family members
347 were employed, these alternative control methods were more likely to be used. It is possible
348 that the latter two factors reflect the tendency for better educated farmers to be more aware of
349 novel trends in GIN control. It has been suggested by Garforth *et al.* (2013) that farms that
350 employ family members are less open to alternative options, as they are more likely to hold
351 entrenched beliefs. The main barriers associated with use of such forages were associated
352 with establishing and maintaining such crops, something that has been identified repeatedly
353 by advocates of the method (Coop and Kyriazakis, 2001). Ultimately, the uptake of an
354 alternative method to control GIN on farms will also depend on its (financial) returns (Torres-

Acosta *et al.*, 2012). This is perhaps one of the reasons that targeted nutrition was found to have such a low uptake, despite its well documented benefits in GIN control (Coop and Kyriazakis, 2001).

The disconnection between awareness of AR and practice of nematode control on farm reinforces the need for emphasising the links between the causes of AR and the consequences of strategies to address its challenge (Woodgate and Love, 2012). The survey also demonstrated relatively high awareness of the alternatives to control nematodes amongst farmers in England. However, at the same time it identified a relatively low uptake, due to a number of barriers, both real and perceived. Most of these barriers were associated with economic concerns and long term effectiveness. As the incidence of AR is increasing amongst UK farms, there is an imperative to apply controls that would reduce its rate of development. In order to achieve this, farmers need to be convinced of the value of the current alternatives to anthelmintics. As far as we are aware there has not been an economic assessment of the application of these alternatives, both in the short and the longer term, and this is perhaps where effort should be directed.

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458 **Figure legends**

459

460 **Figure 1.** *Farmer percentage awareness, use of alternative methods and the percentage of*
461 *farmers selecting each of the alternative methods as their preferred choice of worm control if*
462 *all were available and worked*

1 *Table 1. Dependent variables for each of the four binary and the two multinomial models*
2 *regression created for the Parasite management survey response dataset*

Binary models	Variable categories
Genetics use	Yes No
Bioactive forage use	Yes No
Resistance status of anthelmintic products used	Using 2 or more high resistance anthelmintics Using 1 or 0 high resistance anthelmintics (See Table 1c)
Farmer felt anthelmintic be ineffective	Yes No
Multi nominal models	
Number of types of anthelmintics used on farm	1
	2
	3
	4
Number of alternatives farmers are aware of	1
	2
	3
	4
	5
	6

3

4

5 Table 2. Full list of variables classed as independent and tested in Chi squared analysis

Independent variable	Level
Ineffective	Yes, No
Lowland	Lowland, upland/hill
Both	Yes, No
Indoors	Yes, No
Staff	1-2, 3-5, more than 5
Family	Yes all, less than 50%, none
Qualification	Yes, No
SCOPS	Yes, No
Vet advice	Yes No
AR problem	Yes, No
Conventional	Conventional, Organic
Concern	Yes, No
Region	North East, North West Midlands, South East South West
Frequency of dosing	1 or less, 2, 3 and more
No of ewes on farm	Less than 200, 200-500, more than 500
Hectares	Less than 50, 50-200, more than 200
Any benefits	Yes, No

6
7 *Ineffective = for the question: have you ever felt your wormer be ineffective?*

8 *Lowland = for the question: what is the nature of the habitat?*

9 *Both = for the question: do you graze sheep and cows on your farm?*

10 *Indoors = for the question: do your ewes lamb indoors or outdoors?*

11 *Staff = for the question: how many staff do you have working at the farm?*

12 *Family = for the question: how many of the staff on your farm are family?*

13 *Qualification = for the question: does anyone on your farm have a qualification in agriculture?*

14 *SCOPS= for the question: Have you heard of SCOPS?*

15 *Vet **advice**= for the question: Do you ask your vet for advice about worm treatment?*

16 *AR problem = for the question: Is worm resistance to treatment a problem on your farm?*

17 *Conventional = variable of whether farm was: conventional or organic*

18 *Concern = for the question: are you concerned about worm resistance?*

19 *Region = regional location of the farm*

20 *Frequency of dosing= number of times lambs on the farm are wormed per annum*

21 *No of Ewes on farm= number of ewes on the farm*

22 *Hectares = number of hectares of the farm*

23 *Any benefits = Are you aware of any benefits to using an alternative method of worm control?*

24

25

26 *Table 3. Regional distribution of survey responses for the Parasite management survey*

Region	Number of responses	Responses as percentage(%) of total sample
North East	23	16.0
North West	14	9.5
Midlands	22	15.0
South East	5	3.5
South West	80	56.0

27

28

***Table 4.** Number of responses (and percentage responders) given to the question: ‘Which classes of wormer do you use on your farm?’ The respondents were able to select more than one answer. The resistance status of the anthelmintic according to McMahon et al. (2013) is also given; high implies high levels of resistance amongst worms.*

Class of Anthelmintic	Number of respondents using this anthelmintic class on their farm	% of respondents using this class of anthelmintic on their farm
Benzimidazole (High)	108	76.6
Levamisole(Medium)	82	58.2
Macrocyclic Lactones (High)	125	88.7
Amino Acetonitrile derivative (Montepantel) (Low e)	59	41.8
Derquantel (Low)	11	12.1

Table 5. Multivariate model of association between independent ('number of breeding ewes', 'how many of your staff are family?', 'have you heard of SCOPS?', 'How many times do you normally worm the lambs born on your farm?', 'Is worm resistance to treatments something that concerns you either now or for the future?') and dependent 'the number of different classes of anthelmintic used on the farm' variable

		Use two different classes of anthelmintic on their farm				Use three different classes of anthelmintic on their farm			Use four different classes of anthelmintic on their farm				
		Odds ratio	Confidence interval	P value		Odds ratio	Confidence interval	P value	Odds ratio	Confidence interval	P value		
Number of breeding ewes	(Intercept)	0.064	0.001	2.81	0.154	0.027	0.001	1.39	0.072	0.000	0.000	0.000	0.000
	200-500	11.3	0.883	146	0.062	19.3	1.47	254	0.024	20.9	1.39	314	0.028
	More than 500	6.55	0.41	105	0.184	33.1	2.08	527	0.013	45.9	2.54	832	0.01
How many of your staff are family?	None of them are	3.40	0.083	138	0.518	0.886	0.022	35.8	0.949	0.294	0.007	13.3	0.529
	All of them	0.607	0.031	11.7	0.741	0.162	0.009	2.85	0.213	0.048	0.002	0.924	0.044
Have you heard of SCOPS?	Yes	5.30	0.776	36.2	0.089	14.2	1.616	125	0.017	48200000	15800000	147000000	0.000
How many times do you normally worm the lambs born on your farm?	2 times	0.470	0.089	2.47	0.372	0.580	0.093	3.62	0.560	0.293	0.038	2.278	0.240
	3 or more times	9.49	0.676	133	0.095	13.7	0.857	220	0.064	11.9	0.648	217.936	0.095
Is worm resistance to treatments something that concerns you either now or for the future?	Yes	11.9	1.31	107	0.028	21.2	1.96	228	0.012	59100000	19400000	180000000	0.000

Table 6. Binary logistic regression analysis model of association between independent (region, 'is worm resistance something that concerns you?', 'are you aware of any benefits to using an alternative', hectares, 'how many of your staff are family?') and dependent 'the resistance status of anthelmintic product used' variable

		Odds ratio	Confidence interval		P value
Region	(Intercept)	27.7	1.70	450	0.020
	North East	0.372	0.065	2.14	0.268
	North West	0.164	0.025	1.08	0.060
	South East	0.034	0.002	0.595	0.021
	South West	0.211	0.048	0.922	0.040
Is worm resistance to treatments something that concerns you either now or for the future?	Yes	7.93	1.59	39.4	0.011
Are you aware of any benefits of using an 'alternative method of worm control' rather than an anthelmintic?	Yes	0.333	0.118	0.938	0.038
Hectares	Greater than 200 hectares (494 acres)	0.888	0.255	3.10	0.852
	Less than 50 hectares (123 acres)	0.380	0.144	1.00	0.050
How many of your staff are family or related to you in any way?	None of them are	0.291	0.040	2.09	0.220
	Yes, all of them	0.110	0.019	0.627	0.013

Table 7. Binary logistic regression analysis model of association between independent (type of farm, 'are both sheep and cattle present on your farm?', number of ewes, 'do you think worms are a problem on your farm?') and dependent 'use of breeding for resistance' variable.

		Odds ratio	Confidence interval		P value
Type of farm	(Intercept)	0.168	0.044	0.642	0.009
	Upland/ Hill	0.384	0.128	1.16	0.089
Are both sheep and cattle present on your farm?	Yes	0.480	0.198	1.16	0.104
Number of ewes	Less than 200	1.10	0.355	3.40	0.871
	More than 500	3.07	0.985	9.57	0.053
Do you think worms are a problem on your farm?	Yes	2.57	0.877	7.52	0.085

Table 8. Binary logistic regression analysis model of association between independent (number of times lambs wormed per annum, 'have you ever felt your wormer be ineffective?', 'Do you or any of your staff have a qualification in agriculture?', 'How many of your staff are family or related to you in any way?') and dependent 'use of bioactive forage' variable

		odds	Confidence interval		P value
	(Intercept)	0.094	0.010	0.853	0.036
Number of times lambs wormed per annum	lambs 2 times	0.456	0.125	1.67	0.236
	lambs 3 or more times	0.364	0.088	1.50	0.162
Have you ever felt wormer ineffective?	ineffective Yes	0.415	0.153	1.12	0.083
Do you or nay of your staff have a qualification in agriculture?	Qualification Yes	4.24	1.140	15.7	0.031
How many of your staff are family or related to you in any way?	family None of them are	6.19	1.09	35.0	0.039
	family Yes, all of them	1.62	0.312	8.382	0.567

Figure 1. Farmer percentage awareness, use of alternative methods and the percentage of farmers selecting each of the alternative methods as their preferred choice of worm control if all were available and worked