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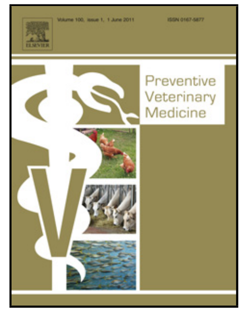
Cornelius, M.P., Jacobson, C. and Besier, R.B. (2015) Factors likely to influence the adoption of targeted selective treatment strategies by sheep farmers in Western Australia. Preventive Veterinary Medicine, 121 (3-4). pp. 325-331.

Accepted Manuscript



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Author: M.P. Cornelius C. Jacobson R.B. Besier

PII: S0167-5877(15)00268-8
DOI: http://dx.doi.org/doi:10.1016/j.prevetmed.2015.08.004
Reference: PREVET 3854

To appear in: *PREVET*

Received date: 23-4-2015
Revised date: 5-8-2015
Accepted date: 6-8-2015

Factors likely to influence the adoption of targeted selective treatment strategies by sheep farmers in Western Australia

M.P. Cornelius[ab]*, C. Jacobson[a] and R.B. Besier[c]

[a]School of Veterinary and LifeSciences, Murdoch University, WA 6150, Australia.

[b]Department of Agriculture and Food Western Australia, Katanning, WA 6317, Australia.

[c]Department of Agriculture and Food Western Australia, Albany, WA 6330, Australia.

*Corresponding author. Tel: +61477748430. Email: meghan.cornelius@agric.wa.gov.au

Abstract

The investigation aimed to assess factors affectingthe uptake of novel targeted selective treatment (TST) strategies by sheep farmers in Western Australia wherethe most common nematode species present were *Teladosagiacircumcincta*,*Trichostrongylus*spp. and *Nematodirus*spp. ("scour worms"). The study used a questionnaire format with questionsconcentrated on current worm control practicesand farmers' current understanding and adoption of putative TST strategies. Participants represented a range of environments (derived from four farming regions) and sheep management situations, and it is therefore likely that the results of this investigation will apply in other locations where scour worms predominate. Sixty-five percent of participants were aware of the TST concept and 25% had implemented it in some form.The awareness of the TST approach was greatest where sheep farmers were concerned about anthelmintic resistance, where tools such as worm egg counts and faecal worm egg count resistance tests were employed, and where professional advisers were consulted regarding worm control. Respondents that sought advice chiefly from rural merchandise retailerswere considerablyless (0.1-0.6 times) likelyto be aware of these management tools or to be aware of TST approaches. The findings indicated that the adoption of TST strategies will require greater use of professional advisers for worm control advice by sheep farmers, and that advisers are conversant with TST concepts.

nematodes; anthelmintic resistance; refugia; adoption

Introduction

Resistance by sheep nematodes to anthelmintics (drenches) is a major problem for sheep industriesglobally (Kaplan and Vidyshankar, 2012). Factors including nematode biology,environment, and sheep management affect the occurrence of anthelmintic resistance, and the rate at which anthelmintic resistance develops depends on the selection pressure exerted by these factors to favour resistant genes in the nematode population (Kaplan, 2010).

A key concept in the management of anthelmintic resistance is the provision of "refugia" for a population of parasites not exposed to anthelmintic treatment, thusserving to dilute resistant individualssurviving anthelmintics so they do not become a significant part of the total population (Van Wyk, 2001).Parasite control strategies that maintain significant levels of refugia by limiting exposure of parasites to treatments aim to decrease the development of resistance by reducing the frequency of resistant genes in the parasite population (Kenyon et al., 2009; Leathwick et al., 2009; Leathwick and Besier, 2014). However, in some situations even relatively infrequent anthelmintic treatments are associated with a high resistance prevalence, due to environmental or animal management factors (Besier and Love, 2003; Leathwick and Besier, 2014).Targeted Selective Treatment (TST) is a refugia-based approach to worm controlthat restricts anthelmintic treatment to animals judged likely to suffer significant production loss or health effects if not treated, while avoiding treatment for individuals less likely to benefit from the treatment(Kenyon et al., 2009; Leathwick et al., 2009; Besier, 2012; Kenyon and Jackson, 2012). However, apart from the FAMACHA system,that identifies individual animals in need of treatment against *Haemonchuscontortus* from an indication of anaemia based on the conjunctival membrane colour, according to a standardised colour chart(Van Wyk and Bath, 2002), TST strategieslargely remain at a validation stage andthere are few examples where the concept has been translated into practicable recommendations for non-haematophagous species (Cabaret et al 2009; Besier, 2012).

Sustainable worm control strategies are essential in sheep producing environments such as the Mediterranean climatic regions of Western Australia (WA) where a high prevalence of anthelmintic resistance is associated with the heavy selection pressure imposed bycommonly-used summer treatment strategies (Besier and Love, 2003). Alternative strategies based on refugia principles have been developed (Woodgate and Besier, 2010), but the need for significant changes to traditional control programs are believed to explain limited adoption of the modified strategiesto date (Besier, 2012). In this context, the relative simplicity of TST-based programs may be considered by sheep farmers to be more practicable, with consequent greater uptake and adoption. However, local anecdotal information suggests that many farmers find it difficult to accept the concept of deliberately withholding anthelmintics to a proportion of sheep because it appears counter to long-held views that effectiveness of drenching may be compromised unless all animals in the flock aretreated. Whether this reflects a lack of awareness or acceptance that anthelmintic resistance is a significant constraint on sheep productivity,and therefore the need for more sustainable control practices,is not clear. A recent national survey by the Sheep Cooperative Research Centre(M.Curnow, unpublished) indicated that whilst some practices recommended as elementsof sustainable worm control programs, including use of worm egg counting (WEC) as the basis of drenching decisions,have been well-adopted, other practices such as faecal worm egg count reduction tests (FWECRT) to assess anthelmintic efficacy, have not.There is consequently a need to investigate factors likely to influence the likely uptake (or otherwise) of TST and other sustainable practices as the basis of efforts to promote wider adoption.

This investigation aimed to identify factors associated with the acceptance of sustainable worm control practices, especially those likely to facilitate the adoption of TST strategies by farmers in Western Australia, as the strategies may initially appear counter intuitive to farmers. More specifically, the study aimed to determine whether farmer demographics, current worm control practices and sources of animal health advice are likely to impact the awareness of TST strategies and attitudes towards adoption. The results of this investigation will act as the basis for the development of communicationstrategies of TST to farmers, which can be varied appropriately to suit the complexity of such strategies as suggested by Woodgate and Love (2012).

Materials and methods

Study design

The study conforms to the international reporting guidelines for strengthening the reporting of observational studies in epidemiology (STROBE) (von Elm et al., 2008) and was approved by the Murdoch University Human Research Committee.

The study used a questionnaire that could be completed using a paper format or in a personal interview. The questionnaire included 14 short-answer questions, four of which included specific options from which respondents could select an answer, and five of which required Yes/No answers. Questions focussed on farmer demographics included age of the respondent(s), farm location, farm size, area cropped and number of sheep. Questions focused on current worm control practices included examined respondent utilisation use of WEC and FWECRT for treatment decisions, timing and the number of drenches given in the past year to adult ewes, sources of worm control advice and perception of severity of drench resistance in their district. Questions focussed specifically on TST examined their current understanding and adoption of putative TST strategies. For this purpose, participants were asked whether they were aware of or had implemented strategies whereby some sheep were deliberately left untreated when a flock treatment was given, and whether they would consider implementing TST strategies in the future.

Colleagues from Murdoch University'sSchool of Veterinary and Life Sciences and the state department of agriculture were recruited for pre-testing during the development of the questionnaire to ensure questions were clear and unambiguous with no bias. Modifications to question design were made in response to feedback.

Data collection

Data were obtained from 106 sheep farmers that were individually recruited to participate in the survey at five different field days throughout regional WA, from July to September 2012, giving a sample of respondents equivalent to a focus group.

Farmers were approached at random at the field days where the interviewer explained the purpose of study and invited the farmer to participate in the survey. To be eligible for the study, participants needed to be commercial sheep producers (running more than 200 sheep, for a commercialincome) within the major sheep producing regions of Western Australia.Following recruitment,questionnaires were completed either in a short interview (n=72) or by the farmer in written format (n=34)and returned to organisers. The questionnaire was identical in both formats and responsesfrom both formats (written or interview response) and all five field days were analysed together.

All responses were collected from farmers in regions in Western Australia where the major worm species of clinical significance were *Teladosagiacircumcincta*,*Trichostrongylus*spp. and *Nematodirus*spp., with *Haemonchuscontortus* absent or only occasionally of significance (Woodgate and Besier 2010). No follow up was required.

The validity of the size of the final study group was assessed following recruitment of 106 respondents at the five field days to confirm that the geographical distribution of respondents was approximately representative of the distribution of sheep in Western Australia and that statistical differentiation between the relative importance of factors included in the questionnaire could be achieved.

Statistical analysis

Data analyses were conducted using the software SPSS Statistics Standard Version 22.0 (IBM Corporation, Armonk NY). The experimental unit was respondent (farmer). There was no non-response as all farmers recruited to the focus group completed the questionnaire.

Respondents were allocated to a region based on farm location, categorised according to agricultural regions of WA representing production areas for sheep, cattle and crops in the state (Figure 1). Drench timing was categorised by season; summer (December-February), autumn (March-May), winter (June-August) and spring (September-November). Respondents were categorised into seven age categories. Responses from age groups <20 and >70 were excluded due to lack of responses in these groups for analyses where age category was an independent variable.

Categorical data (utilisation of WEC and FWECRT, perception of relevance of resistance in the district, awareness and adoption of TST, source of worm control advice) were analysed using Chi square analysis (two-tailed probability) to confirm statistical differences between categorical data, and odds ratioswith relative risk used to quantify relationships between factors.Continuous data (for example, rainfall, farm size, area cropped, proportion of farm cropped, number of sheep and farmer age) were analysed using univariate general linear modelsor linear regression. Annual rainfall data was derived from the Australian Government Bureau of Meteorology based on the farm location given by the respondent.

Results

Respondent demographics and farm characteristics

All respondents were fromthe AgriculturalRegion of south-west WA where sheep are grazed intensively:Great Southern, Wheatbelt South, Wheatbelt North HR (High Rainfall), Wheatbelt North LR (Low Rainfall), Esperance Region and South West/Perth(Figure 1).

Properties were smallest, with the lowest sheep numbersand the percentage area cropped,in the South West/Perth region, and thelargest sheep numbers per farm were in the Great Southern region (Table 1).The annual rainfall on individual properties varied between regions ($P<0.001$; Table 1) with weak but significant associations identified whereby lower annual rainfall was associated with larger farms ($P<0.001$, $R^2=0.12$) and a greater proportion of farm cropped per respondent ($P=0.001$, $R^2 =0.27$).Weak but significant associations were also identified for farm size and theproportion (%) of farm area cropped($P<0.001$, $R^2=0.15$) and number of sheep ($P=0.001$, $R^2=0.30$) with a larger proportion of area cropped and more sheepon larger farms.

Sources of worm control advice

Respondents received advice from rural merchandisers (40%), veterinarians (31%), state agricultural department (Department of Agriculture and Food Western Australia; 31%), private consultant(s) (10%) and friends/neighbours (9%) (Table 2). The majority of respondents (69%) reported using a single source of advice on worm control, some more than one source (24%) and a smallproportion indicated no sources for advice (7%), although it is possible that some respondents indicated only the source most commonly used, even though they were told that multiple categories could be selected.

Worm control practices

Sixty-one percent of respondents drenched ewes once within the last year, 15% twice, 6% three times, and 18% didnot drench ewes at all in the last year. There was an association between rainfall and the number of drenches given per year (P=0.010), with drenching three times per year associated with higher rainfall.There was also an association between number of drenches per year and the proportion of farm cropped (P=0.004) whereby respondents that cropped larger areas drenched less frequently. There was an association between drenching frequency and advicesource with farmers that drenchedewes at least once a year being 7 times (95% CI 1.6-33.2) more likely to source advice from rural merchandisers than those that didnot drench (P=0.003). For drench timing, 38% of respondents drenched in summer, 41% in autumn, 13% in winter and 8% in spring.

Overall,57% of respondents had used WEC at some time to aid treatment decisions (Table 2). Sheep flock sizes were larger for respondents that used WEC to aid treatment decisions (P=0.014) than for respondents that did not use WEC, and respondents in the Great Southern region utilised WEC more often than the other regions(P<0.01). Respondents that sourced advice from a veterinarian or the state agricultural department were 4(95% CI 1.5-10.4, P=0.002) and 2.5 (1.1-6.3, P=0.027) times (respectively)more likely to have used WEC to aid treatment decisions than respondents who didnot.Respondents that used advice from rural merchandisers were less likely to have used WEC (relative risk 0.3, 95% CI 0.1-0.7; P=0.004).

Overall,37% of respondents had used FWECRTat some time to aid treatment decisions (Table 2). There was an association with use of FWECRT and region (P=0.022) with respondents in the South West, Wheatbelt South and Wheatbelt North LR regions less likely to have used FWECRT. Respondents with more sheep were more likely to have used FWECRT (P<0.001).Respondents sourcing advice from a veterinarian (P=0.01) or the state agricultural department (P=0.03) were 3(1.3-7.0) and 2.5 (1.1-5.7) times (respectively) more likely to have used FWECRT to aid treatment decisions than others, in contrast tothose nominating rural merchandisers as the main advisory sourcethat were significantly less likely to have used FWECRT (relative risk 0.16,95% CI 0.05-0.4; P<0.001).

Perceptionof drench resistance

Drench resistance was perceived to be a problem in their districts by 66% of respondents (Table 2).All respondents that used a private consultant statedresistance to be an issue (P=0.008), but there was no association with other sources ofadvice and perception of anthelmintic resistance.

Respondents that utilised WEC were 2.2 times (1.0-5.1;P=0.04)more likely to consider resistance to be important, with 74% of these respondents statingresistance to be important in their district. Similarly, respondents that utilisedFWECRT (79%) were 2.8 times (1.1-6.9; P=0.02)more likely to consider resistance important in their district. However, 56% of respondents thatconsidered resistance to beimportant in their district had not conducteda FWECRT.

Respondent awareness and adoption of the targeted selective treatment concept (TST)

Sixty-five percent of respondents were aware of the TST concept (ie, leaving a proportion of sheep untreated), and 25% of all respondents had utilised TST strategies (Table 2). Respondents that had heard of TST (including those that also used TST) had greatersheep numbers (2999 sheep) than respondents that had not heard of TST (1837 sheep; P=0.003). Furthermore, respondents that were aware of TST more commonly utilised veterinarians, private consultants and the state agricultural department for worm control advice, while respondents using rural merchandisers were less likely to be aware of TST (Table 3). Eighty percent of respondents that had utilised WEC (P<0.001) and 90% that had utilised FWECRT (P<0.001) were aware of TST.

Similarly to the patterns observed for TST awareness, the 26 respondents that had implemented TST also had greater sheep numbers (3785 sheep) than those which had not (2202 sheep; P<0.001), and were mostly from the Great Southern and Wheatbelt North HR regions (P=0.025), reflecting the association between farm size and location. Respondents that perceived drench resistance to be an issue in their district were 2.7 (0.9- 7.8) times more likely to have used TST than those that did not perceive drench resistance to be an issue.Respondents that had utilised WEC (57.5% respondents) or FWECRT (36.8% respondents) were also more likely to have used TST (P<0.001 and P=0.001, respectively) then those that had not utilised WEC or FWECRT. Respondents that utilised veterinarian and private consultants for advice were more likely to have used TST compared to those that used rural merchandisers for advice which were much less likely to have used TST (Table 3).

Of the 75% of all respondents that had not implemented TST on their farms (whether or not they were aware of the concept), 48 answered the question “would you consider implementing this idea in the future?” (Table 2). Tenof the 48 respondents answering this question indicated that they would consider implementing TST and a further 12 answered that they may be interested, while 26 said they would not. A comparison of respondents that had implemented TST or were prepared to consider it (n=49) versus those that would not (n=26), indicated that respondents that used WEC (P=0.035) and FWECRT (P<0.001) were 2.8 (1.0-7.3) and 7.1 (1.9-26.7) times (respectively) more likely to use or have an interest in using TST. Similarly,respondents thatobtained advice from a veterinarian (P=0.018) or private consultant (P=0.009) were 3.9 (1.2-13.2) and 1.3 (1.1-1.5)times (respectively) more likely to use or have an interest in using TST. Although there was no statistically-significant association with the belief that anthelmintic resistance is important in their district and TST implementation, 77% of the 48 respondents who considered drench resistance to be important and had heard of TST either would consider or have implemented the strategy.

Discussion

The complexity of sheep worm control has increased considerably with the widespread occurrence of anthelmintic resistance, in many instances requiring modifications to ensure that worm control programs are sustainable in the longer term. The refugia concept has been shown to be an effective basis for sustainable worm control recommendations (Leathwick and Besier, 2014), but the implementation of refugia-based approaches often requires a departure from routine practices. As TST strategies require the deliberate withholding of treatments to some animals in a flock, a potential barrier to their adoption is the perception that failing to treat some individuals may be detrimental to sheep production, and could impair the effectiveness of epidemiologically-based pre-emptive control programs. In WA, the high level of anthelmintic resistanceinvolving several drug classes (Playfordet al., 2014) is believed to justify refugia strategies but the new practice is likely to appear counter-intuitive to many sheep farmers, and therefore require targeted communication approaches for their adoption (Kahn and Woodgate 2012).

This investigation was therefore intended to provide direction for communication activities aimed at gaining TST adoptionin an environment with a high prevalence of anthelmintic resistance. The distribution of responses included an appropriately representative range of respondents in terms of sheep manager profile, location, scale of sheep enterprise and the adoption of various worm control recommendations. Of the 106 responses, the majority were derived from four sheep farming regions which together account for 91% of the WA sheep population, and withrelatively large mean sheep flock sizes(1900per farm). This suggests that sheep enterprises are economically significant on the individual properties of most respondents, although the relative importance compared to cereal cropping (the main competitor for farmland in WA) varied between regions and respondents. The recruitment of farmers at non-specific agricultural field days as participants in a focus group provides a good distribution of respondents, reflecting the distribution of sheep production enterprises in the different regions. A strength of collecting data via short interview is that there is no non-response rate, and a personal approach ensures that all questions are completed without misunderstandings.It is possible that the method of completion (written versus interview) could impact repeatability of answers by respondents. Given that the questions and options for answering questions were identical between written and interview formats, there was no reason to suspect that the format method would alter responses to any great extent. Future studies could test agreement between methods of survey completion to confirm this and if significant differences are identified, then the questionnaire could be modified or method of questionnaire completion could be included as a factor in statistical analyses of responses.

The finding that the majority (65%) of respondents were aware of the TST concept, and that 25% had implemented it in some form, was unexpected as the TST concept has not yet been developed into generally recommended strategies by advisory agencies in Australia. However, interest by Australian farmers in TST strategies was confirmed by a national survey of over 1000 sheep farmers in 2014, in which 14% reported that they had trialled the strategy (M. Curnow, unpublished). This reflects awareness of the high and increasing prevalence of anthelmintic resistance in sheep worms in Australia (Playfordet al., 2014), including in WA where resistance has been a significant problem on the majority of sheep farms for many years (Edwards et al., 1986;Overendet al., 1994). In this environment, resistance is believed to result largely from the routine use of strategic anthelmintic treatments in summer in a Mediterranean climate (Besier and Love, 2003), and recommendations have been developed to reduce this selection pressure by drenching adult sheep in autumn rather than in summer (Woodgate and Besier, 2010). The results from the present investigation confirm wide interest in drench resistance management strategies in WA, as more respondents had drenched ewes in autumn, which is a change in recent years from the majority of farmers drenching ewes in summer (Curnow unpublished). Investigations to develop TST as an alternative approach have been under investigation for some years as field trials (Besier et al., 2010) and computer modelling studies (Dobson et al., 2011) with reports in the scientific literature and rural media. These presumably account for the wide awareness of TST by farmers, and the implementation of TST in some form by many of them.These producers may have an ‘early adopter’ attitude that could account for them being aware of TST before the population majority. Further investigations that determine how respondents became aware ofTST and their general attitude to innovation could be used to guide the direction of extension programmes and maximise adoption rates according to attitude categories.

The investigation results provide a clear indication of factors associated with the awareness and attitudes towards TST by sheep farmers in an environment where anthelmintic resistance is prevalent.This will provide the basis for communication efforts to gain its adoption as a routine strategy. The characteristics of respondents who were either aware of the TST concept or had implemented it in some form included: larger flock sizes, use of WEC and/or FWECRT, utilisation of professional advisory sources, and anthelmintic resistance stated to be an issue in their district. Acceptance of the importance of anthelmintic resistance for continued sheep productivity is an obvious key requirement for interest in TST strategies. While 66% of respondents in this investigation considered drench resistance to be a problem, this appears surprisingly low in contrast with survey figures from countries where anthelmintic resistance is less advanced than in Australia. For example, other studies showed57% of surveyed farmers in New Zealand (Lawrenceet al., 2007) and 51% in the United Kingdom (Morgan et al., 2012) rated drench resistance as a serious problem. It would be expected that interest in worm control and drench resistance would reflect the relative economic importance of sheep production.

The greater awareness of, and interest in, TST of respondents in the Great Southern region with larger flocks (mean, 3500 ewes per farm) contrasted with that of respondents with smaller – although significant – flock sizes (mean, 1958 ewes per farm) in the drier regions(Wheatbelt South and Wheatbelt North LR) where cereal cropping generally provides a greater proportion of farm income. This association between larger flocks and TST awareness may be linked to economic motivation, with farmers who manage larger flocks likely to have a greater incentive to reduceparasite management costsor prolong the life of effective drenches for continued profitability. Of all respondents, only 55% thatroutinely cropped more than 50% of the farm area considered drench resistance to be important, compared with 75% for those cropping smaller proportions of farm area. This is confounded by the associationof larger cropping areas with lower annual rainfall and shorter pasture growing seasons, hence a lower risk of significant worm parasitism due to shorter periods of the year where environmental conditions (particularly moisture) in a Mediterranean climate are favourable for persistence of free living stages. This was consistent with the finding that fewer drenches were given to sheep annually in the lower rainfall regions. Despite this, FWECRT results over many years indicate the prevalence of drench resistance to be similar in both high and low rainfall regions of WA (B.Besier, personal observations). The heavy selection pressure for resistance associated with anthelmintic use in highly seasonal environments such as WA (Besier and Love, 2003) is especiallyapplicable in the lower rainfall regions, and the need for sustainable worm control strategies therefore warrants greater recognition by sheep farmers in these locations. However, of the WA respondents, 77% of farmers who considered drench resistance to be a problem and who had also heard of TST, had either trialled the strategy or stated that they would consider the strategy.

As expected, the use of WEC and FWECRTs was associated with the perception of the importance of anthelmintic resistance and with larger flock sizes, again consistent with the relative significance of sheep enterprises. As recommendations for the use of these measurement tools are aimed at ensuring efficient worm control as much as at drench resistance management, interest in TST-based strategies is likely to require convincing sheep owners that TST can be implemented with minimal risk of disease or production loss, and are practical to apply.

In field trials in WA(Besier et al.,2010) and subsequent investigations in South Australia and Victoria (I. Carmichael, personal communication), and supported by computer simulation modelling (Dobson et al., 2011), leaving a proportion of sheep untreated resulted in no significant loss of production in flocks of adult ewes, which show a greater resilience to worm infections than lambs. Concerns over the practicality of implementation (particularly labour and time requirements) can also be allayed as investigations have demonstrated the effectiveness of a simple protocol using body condition score to identify individual animals that may safely be left untreated in regions where *Haemonchuscontortus* is not the predominant parasite (Besier et al., 2010; Besier, 2012; Cornelius et al., 2014).Other indicators that have been investigated for selecting animals to leave untreated include target weights and weight change (Greer et al 2009; Kenyon et al 2013; Busin et al 2014). Encouragingly, the use of WECs and FWECRTs was highly correlated with the implementation of TST or willingness to consider it, so that extension measures to increase the adoption of these management tools is also likely to increase the interest in sustainable approaches. It is of interest that the proportion of respondents who utilised WECs and FWECRTs was higher than indicated by some recent surveys (M.Curnow personal communication;Reeve and Walkden-Brown, 2014), as TST is most efficiently implemented with prior knowledge of worm burdens and anthelmintic efficacy. However, most who considered drench resistance to be important had never conductedFWECRTs, although the uptake of resistance testing is universally low (Lawrenceet al., 2007; Morgan et al., 2012;Playfordet al., 2014).

The investigation findings also highlighted the significant role of professional advisers in worm control planning and the willingness to follow sustainable control recommendations. Respondents who utilised veterinarians, private consultants and the state agricultural agency for worm control advice were significantly more likely to consider drench resistance to be a problem, to drench on fewer occasions and to use WECs and FWECRTs, compared with those who sought advice chiefly from rural merchandisers. However, the responses indicated that individual professional services (private veterinarians and consultants) and rural merchandisers were of similar rank as advisory sources (nominated in 41% and 40% of replies, respectively), which is consistent with the figures from a large national survey (Reeve and Walkden-Brown, 2014). This indicates the need to ensure that merchandisers' staff are sufficiently informed regarding worm control and anthelmintic resistance, as well as TST, and that private professional advisers are conversant with the TST concept. Although the prospect of reduced drench sales may be seen as a potential barrier to the promotion of TST by merchandisers, this could be offset by the positive perception by farmers of a more informed service. The ranking of advisory sources used in Australia also contrasts with that in countries such as the UK (Morgan et al., 2012) and New Zealand (Lawrenceet al., 2007), where veterinarians are the dominant worm control source, suggesting that there is a need to better promote the availability of informed livestock management advice from consultants and veterinarians in Australia.

Although this investigation was conducted in a Mediterranean climatic zone where selection pressures from anthelmintic treatments are high, TST has been proposed as the basis of sustainable worm control in more temperate environments (Kenyon et al., 2009; Leathwick et al., 2008), as well as in regions where *Haemonchuscontortus* is the major helminth parasite. It is likely that similar potential barriers to the adoption of sustainable strategies apply globally, especially the requirement of an awareness of the significance of anthelmintic resistance in particular locations and whererelatively complex solutions are required(Woodgate and Love, 2012; Kahn and Woodgate, 2012). Demonstrations of the potential economic loss due to reduced anthelmintic efficacy will increaseawareness (Besier et al., 1996;Sutherland et al., 2010; Miller et al., 2011), and demonstrations that TST is an appropriate approach for a particular environment (Larsen, 2014) and does not entail significant animal production loss will increase interest. The initial uptake of TST will be greatest by farmers who are clients of private livestock advisory services, and who have already implemented recommendations for the use of measurement tools such as WEC and FWECRT. Although the awareness of the potential cost of anthelmintic resistance may be lower where resistance is less advanced than in Australia, this may be offset by the closer involvement of farmers with veterinarians and agricultural advisers in some countries.

Conclusion

Conceptual barriers to the adoption of TST by sheep farmers are likely to apply in all locationsdue to concerns over potential losses of sheep production and worm-related disease, and an understanding of the factors associated with the strategies will aid in their adoption. This investigation confirmed that awareness of the TST approach was greatest where sheep farmers are concerned about anthelmintic resistance, where tools such as WEC and FWECRT are employed, and where professional advisers are consulted regarding worm control. The wider than expected awareness of TST and implementation by some of theparticipants supports the relevance of the strategy in this environment, and indicates that leaving some sheep untreated is likely to be seen by many farmers as an acceptable strategy to manage anthelmintic resistance, provided that they are convinced that resistance is of sufficient importance.

Conflict of interest statement

Corresponding author was employed by pharmaceutical company Jurox Animal Health from January 2013 to February 2014 but the company had no input or influence on the investigation.

Acknowledgements

This work was funded by the Sheep Cooperative Research CentrethroughMurdoch University. The authors would like to thank all of the respondents for their participation; Becky Townsend, Grace Clifford, Sara Burt, and Rachel Walmsleyfor their assistance in collecting responses;and to Andrew van Burgel from the Department of Agriculture and Food Western Australia for his contribution in reviewing the manuscript.

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Figure 1. Map of agricultural regions

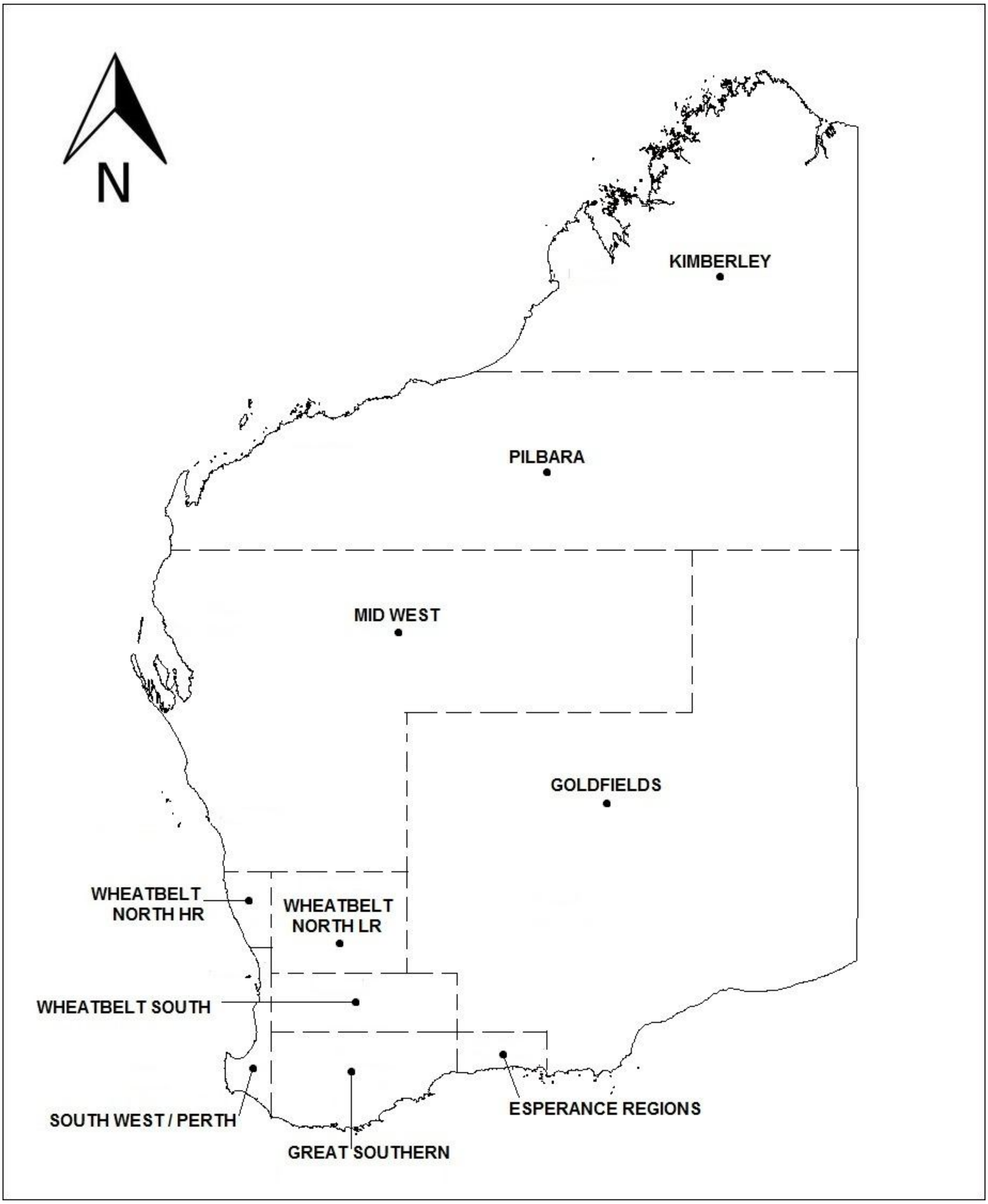

Table 1. Number of responses and proportion (%) of Western Australian sheep population per region

Region:	**Great Southern**	**Wheatbelt South**	**Wheatbelt North LR**	**Wheatbelt North HR**	**Esperance Region**	**South West/Perth**
Responses (n)	36	19	23	16	5	6
% of total responses	34	18	22	15	5	6
WA sheep farms (n)*	1762	935	1129	440	297	588
WA sheep population /region (%)*	41	19	15	8	6	2
Mean rainfall/respondent (mm/annum)	529^{b}	419^{cd}	389^{d}	550^{b}	501^{bc}	737^{a}
Mean sheep/ respondent (n)	3500^{a}	2896^{ab}	1913^{bc}	2133^{bc}	1600^{bc}	1047^{c}
Mean farm size/ respondent (Ha)	2920^{a}	3407^{a}	3468^{a}	2638^{a}	3367^{a}	329^{b}
Mean proportion farm cropped (%)	38^{a}	49^{a}	46^{a}	38^{ab}	43^{ab}	19^{b}

*Based on Australian Bureau of Statistics data, Department of Agriculture and Food Western Australia analysis

Values within rows with different superscript are significantly different ($p<0.05$)

Table 2. Percentages of respondents who identified 'yes' or 'no' to having heard of and/or utilised specific worm control tools and strategies, andtheir most common sources of worm control advice

	Respondents indicating each response		Response rate (%)
	%	95% CI	
Is resistance an issue in your district?			100
Yes	66.0	56.98, 75.02	
No	34.0	24.98, 43.02	
Have used WEC in the past			100
Yes	57.5	48.09, 66.91	
No	42.5	33.09, 51.91	
Have used FWECRT in the past			99.1
Yes	36.8	27.58, 46.02	
No	62.3	53.03, 71.57	
Source of worm control advice*			100
Vet	31.1	22.29, 39.91	
Private consultant	10.4	4.59, 16.21	
State Department	31.1	22.29, 39.91	
Rural merchandiser	39.6	30.29, 48.91	
Relative/Friend	9.4	3.84, 14.96	
None	7.5	2.49, 12.51	
Heard of TST (including those who had implemented)			100
Yes	65.1	56.03, 74.17	
No	34.9	25.83, 43.97	
Have used TST in the past			99.1
Yes	24.5	16.27, 32.73	
No	74.5	66.16, 82.84	
Haven't used TST but would consider it			45.3
Yes	47.9	33.77, 62.03	
No	52.1	37.97, 66.23	

*Percentages do not add to 100 as respondents could nominate more than one option

CI = confidence interval

Table 3. Relative risk for respondents' awareness and implementationof TST from different sources of advice

	Relative risk (95% confidence interval) p-value for 2-sided Pearson Chi-square test				
	Veterinarian	Private Consultant	DAFWA	Rural merchandiser	Friend/Neighbour
Heard of TST (including had implemented)	4.4 (1.5, 12.6) P=0.003	1.2 (1.1, 1.3) P=0.007	3.3 (1.2, 9.0) P=0.012	0.28 (0.1, 0.6) P=0.002	ns
Used TST	4.7 (1.8, 12.0) P=0.001	20.6 (4.1, 104.3) P<0.001	ns	0.37 (0.1, 1.0) P=0.037	ns

DAFWA: Department of Agriculture and Food Western Australia (state agricultural agency)
ns = non-significant