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Prevalence and on-farm risk factors for diarrhoea in meat lamb flocks in Western Australia

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Abstract

Diarrhoea is a widespread problem for sheep enterprises worldwide. A cross-sectional epidemiological study was conducted using a questionnaire to determine the prevalence of diarrhoea and associated risk factors where there was evidence of recent diarrhoea (active diarrhoea or fresh faecal soiling of breech fleece), for meat lambs on farms in southern Western Australia during 2010. The response rate was 41.4% (139/336).

Evidence of recent diarrhoea was reported on 64.8% of farms, with a mean of 6.9% lambs affected per farm. Location of a farm and a higher annual rainfall were associated with an increased diarrhoea prevalence. Binary logistic regression analysis suggested that the drinking water source was associated with the incidence of diarrhoea, as lamb flocks supplied with dam water were 117 times (95% CI: 18.2, 754.8) more likely to have observed diarrhoea or fresh breech fleece faecal soiling. Faecal worm egg counts (WECs) were utilised by 65% of respondents to determine if an anthelmintic treatment was warranted and 74% of respondents administered an anthelmintic treatment to their meat lambs. Regardless of the diarrhoea scenario presented to respondents (5%, 25% and 50% of their flock with evidence of recent diarrhoea), 15.1% elected to administer an anthelmintic treatment to their flock.

*Keywords***:** Survey; Diarrhoea; Meat lambs; Water; Anthelmintic

Introduction

Diarrhoea is a significant economic and welfare problem for sheep enterprises worldwide (Larsen et al., 1999; Sargison, 2004; Jacobson et al., 2009). Diarrhoea poses a major risk factor for the accumulation of faeces on fleece at the breech (perineal region) of sheep and outbreaks of cutaneous myiasis ('blowfly strike') (Morley et al., 1976; French et al., 1994; Hall and Wall, 1995; Snoep et al., 2002; Bisdorff and Wall, 2008). Furthermore, breech fleece faecal soiling increases the risk of carcase contamination with enteric microbes associated with meat spoilage and human food poisoning (Greer et al., 1983; Hadley et al., 1997). In addition, faecal contamination of carcases is associated with trimming of effected carcase tissues, that in turn limits abattoir productivity (Hadley et al., 1997).

Despite the widespread nature of diarrhoea in sheep enterprises and the serious economic and animal welfare consequences, little information on diarrhoea prevalence and potential farm management risk factors have been reported. A large number of infectious and non-infectious agents have been associated with diarrhoea in naive lambs, including strongylid nematodes (Taylor et al., 1993; Eerens et al., 1998; Sargison, 2004), protozoan (*Cryptosporidium, Giardia*) and coccidian (*Eimeria*) parasites (Olson et al., 1995; Causapé et al., 2002; Aloisio et al., 2006). Apart from diarrhoea, strongylid nematodes and protozoa adversely affect lamb meat productivity, through reduced growth rates and subsequent carcase weights of infected lambs (Sackett et al., 2006; Sutherland et al., 2010).

Control of strongylid nematodes is a major challenge for sheep enterprises, due to widespread anthelmintic resistance, particularly in Western Australia where resistance to several anthelmintic treatment groups has been reported (Palmer et al., 2001; Besier and Love, 2003; Suter et al., 2005). Sheep producers commonly administer anthelmintic treatments to flocks following diarrhoea outbreaks and an increased anthelmintic treatment frequency has been linked with an increased risk in the development of anthelmintic resistance in worm populations (Besier and Love, 2003; Woodgate and Besier, 2010).

The aims of this study were: to investigate the reported prevalence of diarrhoea in meat lamb enterprises in Western Australia, determine the observed proportion of meat lambs effected with diarrhoea, report sheep management practices relevant to conditions associated with diarrhoea (including strongylid nematode control), identify risk factors for diarrhoea, examine producer awareness of internal parasites and assess producer responses to different, defined diarrhoea scenarios.

Materials and Methods

Study population

In a recent financial performance report of the sheep industry in Australia, 7,100 farms in Western Australia were reported to run a sheep enterprise (wool or meat production) with a reported 14.7 million sheep at the end of 2010. Of these, a total of 1,316 farms were reported to have a specialised lamb meat enterprise that sent lambs for slaughter to commercial abattoirs (ABARE, 2010; Athas, 2011). A total of 139 lamb meat enterprises responded to the questionnaire in this current study, accounting for 10.6% of Western Australia's specialised lamb meat farms.

Questionnaire design

This research conforms to the international reporting guidelines of strengthening the reporting of observational studies in epidemiology (STROBE) (Vandenbroucke et al., 2007; von

Elm et al., 2007) and was approved by the Murdoch University Human Research Committee approved the questionnaire (HREC permit number 2009/222). The questionnaire consisted of a cover note which explained the aims of the study, followed by 20 questions relating to the prevalence of diarrhoea observed in meat (slaughter) lambs during 2010, sheep management, internal parasite control and awareness and response to different diarrhoea outbreak scenarios. Questions included; time of lambing, whether respondents observed diarrhoea in meat lambs, the proportion of lambs affected, the month diarrhoea was first observed, administration of anthelmintics to pregnant ewes (before lambing) or lambs, presence of cattle on the property, utilisation of faecal worm egg counts (WECs) to determine if anthelmintic treatment was warranted, sources of livestock drinking water, awareness of internal protozoan and coccidian parasites (*Cryptosporidium*, *Giardia* and *Eimeria*) and knowledge as to whether these parasites were known to cause disease in sheep flocks within a district.

"Evidence of recent diarrhoea" was defined in the questionnaire as active diarrhoea (loose or liquid faeces) or fresh faecal soiling of the breech fleece, where the breech fleece faecal soiling scores ranged from score three to score five using standard breech fleece faecal soiling scores (Australian Wool Innovation et al., 2007). A graphical representation of standard breech fleece faecal soiling scores was included in the survey (Fig. 1).

Scenarios were presented whereby 5%, 25% or 50% of the respondent's meat lamb flock were affected with diarrhoea and the response options included; doing nothing, monitor flock to see if the incidence of diarrhoea becomes worse, conduct flock WEC, administer an anthelmintic treatment only to lambs with evidence of diarrhoea, administer an anthelmintic treatment to the entire flock or have the problem investigated by a veterinarian. More than one response could be selected for each scenario. These scenarios were included to assess meat lamb producers' management and anthelmintic treatment responses to different, defined diarrhoea scenarios described above.

The questionnaire was trialled with 13 sheep farmers at the Muchea Livestock Saleyards (Muchea, Western Australia) in November 2010. Then 336 surveys were distributed by post (n=264) or electronic-mail (n=72) to sheep enterprises throughout south-west Western Australia via a Merino breeding alliance, two sheep meat processors, a livestock exporter and an agricultural lobbying group. A postage paid return-addressed envelope was included with the questionnaire. No follow up telephone contact or extra incentives were utilised to increase the reply rate.

Agricultural zones

Responses were categorised into six agricultural zones, depending on where they were located in (Fig. 2) (Garlinge, 2005). These agricultural zones were developed from statistical analyses of crop performances, average annual rainfall and length of the growing season. Region cells were coded by location ranging from 1 (north) to 5 (south) and by annual rainfall categorised as being very high (>700mm), high (451–700mm), medium (325–450mm) and low (<325mm) (VH, H, M and L) (Fig. 2) (Garlinge, 2005). Generally, moving north shortens the length of the growing season and moving east (inland) reduces the average annual rainfall. Quantum GIS mapping software (Quantum Geographic Information System, Version 1.6.0) was used to map the locations of survey farm respondents as presented in Fig. 3.

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Statistical analysis

Statistical analysis was performed using SPSS Statistics 17.0 (Statistical Package for the Social Sciences) for Windows (SPSS inc. Chicago, USA). Reported diarrhoea prevalences (including 95% confidence intervals) were calculated using the exact binomial method for all respondents and for individual agriculture zones (Thrusfield, 2007). Pearson’s chi-squared test or Fisher’s exact two-sided test for independence were used to determine if management practices were associated with differences in the reported prevalence of diarrhoea.

Binary logistic regression (multivariable analysis) model was conducted to examine the association of reported diarrhoea (outcome variable) with covariate variables including; winter or autumn lambing, an anthelmintic administered to pregnant ewes, an anthelmintic administered to lambs, WEC utilised to determine if anthelmintic treatment is warranted (yes or no), presence of cattle on property and if the property was located in agricultural zone 5 or 6. In addition, the sources of livestock water (dam, river/creek, bore, or scheme water) were included as covariate factors. Backward elimination was used to determine which covariate factors were removed from the binary logistic regression model, until only significant factors remained. The likelihood-ratio test statistic was calculated to determine the significance at each regression step of the model, followed by building and testing the goodness-of-fit for the logistic regression models. The level of significance for a factor to remain in the final model was set at 5%, with variables that were included in the final model checked for collinearity as described by Stern (2010). Variables with tolerance values >0.1 were considered not to be correlated with other variables and therefore retained in the final model (Stern, 2010).

Univariable analyses (ANOVA) were conducted with least significant difference post-hoc tests to determine if the observed diarrhoea, proportion of lambs effected with diarrhoea or utilisation of WEC, were associated with farm average annual rainfall (mm/annum) or the agricultural zone location.

Results

Response rate

Of the 336 questionnaires distributed to farmers, 164 (49%) replies were received, of which 139 (41.1%) valid, with their distribution across southern Western Australia illustrated in Fig. 3. The response rate was 139/264 (53%) for mailed questionnaires, 11/59 (19%) for e-mailed questionnaires and 13/13 (100%) for personally distributed questionnaires.

Meat lamb enterprise characteristics

Farm characteristics, number of producer responses, annual rainfall and other farm information is outline in Table 1, with meat lamb respondents grouped by agricultural zones.

Reported diarrhoea prevalence in meat lambs

The reported diarrhoea prevalence in meat and lamb flocks during 2010 is detailed in Table 2. The reported diarrhoea prevalence in agricultural zone 6 (100%) was different to all other agriculture zones (P<0.05), except to zone 5.

Proportions of meat lambs per enterprise reported with diarrhoea

The proportion of meat lambs per enterprise reported with diarrhoea ranged between 2–30%, with the highest mean proportion of lambs reported with diarrhoea recorded in agricultural zone 6 (10.6%) and this was higher than all other zones (*P*=0.043) (Table 2).

Diarrhoea was most commonly first observed in the months of August (48.9%) or September (27.8%). The proportion of respondents reporting diarrhoea first observed in these months was different to June (3.3%), July (10.0%) and October (10.0%) (*P*<0.05).

Mean annual rainfall was higher on farms that reported observing diarrhoea in meat lambs (453 ± 12mm per annum) compared to those farms where no diarrhoea was reported (403 ± 10mm per annum; *P*=0.002).

Diarrhoea risk factor analyses

Six management factors were significantly (*P*<0.05) associated with the risk of diarrhoea using univariable analyses. These were; property location in agricultural zone 5 or 6, an anthelmintic treatment administered to lambs, protozoa or coccidia known to cause disease in sheep farms within enterprise district, livestock water sourced from a dam, livestock water sourced from a scheme or livestock water sourced from a bore (Table 3).

Multivariable analyses by binary logistic regression identified four factors that were significantly (*P*<0.05) associated with the risk of diarrhoea. Livestock water sourced from a dam and property location in either agricultural zone 5 or 6, both increased the risk of reporting diarrhoea (Table 4). Livestock water sourced from either scheme or bore, decreased the risk of diarrhoea (Table 4).

Sheep management practices relevant to diarrhoea

A total of 71/139 (51.1%) respondents administered an anthelmintic treatment to pregnant ewes before lambing and 103/139 (74.1%) administered an anthelmintic treatment to meat lambs. Respondents that administered an anthelmintic treatment to lambs, reported a higher proportion of lambs with diarrhoea (7.5 ± 0.66%) compared to respondents that didn't administer an anthelmintic treatment (4.4 ± 1.36%; P=0.041).

Overall, 34.5% of respondents reported never using WECs, 39.6% occasionally used WECs, 21.6% usually used WECs and 4.3% of respondents always used WECs, to determine if an anthelmintic treatment was warranted. Increased utilisation of WECs was associated with an increased farm average annual rainfall, whereby average annual rainfall for those respondents, reporting to never (402 ± 12.2mm), occasionally (432 ± 11.4mm), usually (477 ± 15.4mm) and always (536 ± 24.9mm) utilise WECs, were all different to one another (P<0.001).

Respondent awareness of protozoan and coccidian parasites

Overall, 47.5% respondents were not aware and 32.4% respondents were unsure about protozoan or coccidian parasites (*Cryptosporidium*, *Giardia* and *Eimeria*) being a contributing cause of sheep disease within their district. Specifically, 18/139 (12.9%) were aware of *Eimeria*, 14/139 (10.1%) were aware of *Cryptosporidium* and 20/139 (14.4%) were aware of *Giardia*, with

11/139 (8.0%) being aware of two or more of these above parasites and 6/139 (4.3%) aware of all three parasites.

Respondent responses to defined diarrhoea scenarios

Across the three diarrhoea scenarios presented (5%, 25% and 50% of respondent meat lamb flock affected by diarrhoea), 21/139 (15.1%) respondents elected to administer an anthelmintic treatment to the entire lamb flock for all of the three scenarios; 63/139 (45.3%) elected to administer an anthelmintic treatment to the entire lamb flock for only one scenario; and 15/139 (10.8%) never elected to administer an anthelmintic treatment for any scenario (Table 5). Overall, 64/139 (46.0%) and 90/139 (64.7%), elected not to conduct a flock WEC and not to consult a veterinarian respectively, regardless of the scenario presented (Table 5). A total of 23/139 (16.6%) respondents made additional comments indicating that they would either provide oaten hay supplementation or move the flock to a different paddock, if 25% or 50% of their lamb flock was effected with diarrhoea.

Discussion

This is the first epidemiological investigation of diarrhoea reported for meat lamb flocks on-farm in southern Australia. A novel finding in this study was the association between livestock water sources and the reported prevalence of diarrhoea, whereby lambs which drank water sourced from a dam were more than a 100 times more likely to experience diarrhoea compared to other water sources (Table 3 and Table 4). It is possible that the lambs drinking from open water sources (dams, rivers or creeks) had increased risk of exposure to faecal pathogens (including protozoa, bacteria and viruses), compared to lambs drinking water supplied from either a bore or the scheme. Faecal material, fertilisers and pesticide residues can be washed from pastures into open water sources following moderate to high rainfall events and this has potentially deleterious effects on livestock water quality (Coddington, 1992; Sharpley and Withers, 1994; Hooda et al., 2000; Smith and Frost, 2000; Bodley-Tickell et al., 2002; Delin and Landon, 2002; Chadwick et al., 2008; Edwards et al., 2008).

In contrast, bore and scheme water are protected to a greater extent from contaminants by storage in underground aquifers or via managed catchments, tanks and troughs. With respect to ground water (bore or scheme), surface water movement through the soil has been reported to filter some impurities (fertiliser and pesticide residues) and pathogens as the water passes through different soil layers and pores in the infiltration process. The distance and speed that water travels through a soil profile depends upon soil structure, soil particle size, soil pore size and the depth of the aquifer supplying either the bore or scheme water source and all these factors influence the filtration of pathogens and residues (Stevik et al., 1999; Unc and Goss, 2004; Mosaddeghi et al., 2009; Schinner et al., 2010).

Diarrhoea was most commonly reported to have been first observed in meat lambs in late winter (August) and early spring (September). Rainfall events reported across the south-west land division in early July, mid and late August 2010 (Australian Bureau of Meterology, 2011b), were likely to have contributed to increased pasture growth, increased distribution of strongylid nematode larvae over pasture and increased surface water run-off from pastures into dams, rivers and creeks. Climatic conditions during August and September are also favourable for the survival of infectious parasite stages, including strongylid nematode third stage larvae (Dobson et al., 1990; Marley et al., 2006; Moss and Bray, 2006) and *Cryptosporidium*, *Giardia* and *Eimeria* (oo)cysts (Robertson et al., 1992; Fayer et al., 1996). The actual (observed) annual rainfall across the survey region was below average during the 2010 survey period (Fig. 4), with winter rainfall being the second driest on record and spring rainfall the fifth driest on record for the region (Australian Bureau of Meterology, 2011b). Agriculture zones 5 and 6 were not as severely impacted by the reduced annual rainfall when compared to the other agriculture zones (particularly zones 2 and 3) in 2010 (Fig. 4), and this is potentially why farming properties located in zones 5 and 6 had an increased risk of reporting diarrhoea in meat lambs.

The majority of respondents had administered an anthelmintic treatment to lambs and respondents whoobserved diarrhoea were 2.7 times more likely to have administered an anthelmintic treatment to lambs, than respondents that did not. It was likely that for those respondents located in districts where internal parasites are a well recognised disease risk in sheep, that they would be more likely to implement strategic (preventive) or tactical (in response to suspected helminthosis) anthelmintic treatments. It is also possible that that these same respondents elected to administer an anthelmintic to lambs in response to an outbreak of diarrhoea and/or fresh breech fleece faecal soiling (Besier and Love, 2003; Coles et al., 2006; Besier, 2008; Woodgate and Besier, 2010). This suggestion was supported by the finding that 16-82% of respondents reported that they would elect to treat the whole lamb flock, where 5%, 25% or 50% of the flock were observed with diarrhoea. However, an investigation of slaughter lambs at abattoirs showed that observation of active diarrhoea or fresh faecal soiling was a poor predictor, as to which consigned groups had high flock WECs (Jacobson et al., 2009).

Over a third of respondents reported never using WECs to determine if an anthelmintic treatment was warranted and nearly half of respondents reported that they wouldn’t elect to conduct a flock WEC where 5%, 25% or 50% of the flock was effected with diarrhoea (Table 5). Farmers that occasionally, usually or always used WECs for planning parasite control (determining if an anthelmintic treatment was warranted), were from districts with higher average annual rainfall and therefore likely to have a higher risk of helminthosis, compared to those districts with lower average annual rainfall. Anthelmintic resistance poses an ongoing challenge to sheep enterprises (Besier and Love, 2003; Gilleard, 2006; Beraldi et al., 2008; Greer et al., 2009; Jackson et al., 2009; Mitchell et al., 2010; Sargison et al., 2010; Sutherland et al., 2010) and an increased utilisation of WEC testing by farmers, as a means of determining if anthelmintic treatments are justified, may aid in reducing treatment frequency, increasing refugia and delaying resistance development to treatments (Dobson et al., 2001; Besier and Love, 2003; Besier, 2008; Woodgate and Besier, 2010).

Less than 2% of respondents reported that they would elect to consult a veterinarian if 5% or 25% of their lambs were effected by diarrhoea and only 35% of respondents reported that they would elect to consult a veterinarian if 50% of their lambs were effected by diarrhoea (Table 5). Respondents were 4.1 times more likely to report diarrhoea in their lamb flocks, when they were aware that protozoa and/or coccidia were known causes of disease in sheep within their district. This suggests that respondents reporting diarrhoea in their flocks are potentially more aware of the infectious agents that are associated with diarrhoea. Strengthening communication between farmers and veterinarians may be one way to improve the uptake of sustainable parasite control programmes, which incorporate utilising flock WECs and improving the probability of detecting other infectious agents associated with diarrhoea and reduced sheep productivity.

A survey questionnaire was considered the most practical method to obtain the information, with the questionaries designed to communicate clearly to respondents what the researchers are asking for and allow accurate retrieval of data. Although a graphical representation of recent evidence of diarrhoea was included in the questionnaire, data in this research was quite subjective depending upon the different experiences of respondents with respect to the detection of active or recent evidence of diarrhoea and the proportion of lambs they observed with diarrhoea.

This study accounted for ~11% of the 1,316 farms reported to have a meat lamb enterprise. The questionnaire was designed with the aim of maximising response rate, by making it concise and limiting the complexity of questions. As a result, limitations of this study included not clarifying the type of anthelmintic treatment administered to ewes and lambs and not determining the causes of diarrhoea, as a large number of infectious and non-infectious agents have been associated with diarrhoea in lambs: strongylid nematodes, *Cryptosporidium*, *Giardia* and *Eimeria* (Gregory and Catchpole, 1990; Olson et al., 1995; Sargison, 2004; Aloisio et al., 2006), bacteria (*Campylobacter spp.*, *Yersinia spp.* and *Salmonella spp.*) , as well as viruses (Skirrow, 1994; Belloy et al., 2009) and fungal endophytes (Eerens et al., 1998).

Conclusions

Diarrhoea was reported in 65% of the surveyed meat lamb enterprises from southern Western Australia in 2010, with the source of livestock drinking water identified as an important diarrhoea risk factor. An increased anthelmintic treatment frequency was observed in those flocks with diarrhoea and this practice increases the risk of anthelmintic resistance development. Improving the availability of cost-effective diagnostic tools may strengthen our understanding of the risk factors associated with diarrhoea in lambs and reveal if there are more options to limit both flock welfare and productivity consequences associated with diarrhoea.

Conflict of Interest

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the paper.

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Appendix A Supplementary material

Supplementary data associated with this article can be found in the online version of this manuscript, at.

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Table 1

Meat lamb farm information from survey respondents across different agricultural zones in Western Australia.

Agricultural zone*			**Average annual rainfall, area cropped and grazed, ewes mated and farms grazing cattle (± SE)**						
Number	Name	Number of farms	Annual rainfall per year (mm)	Area cropped (hectares)	Area grazed (hectares)	Ewes mated (n)	Number of ewes mated to terminal sires	Percentage of ewes mated to terminal sires (%)	Farms grazing cattle (n)
1	North West	8	439 ± 29	3095 ± 1127	2088 ± 870	3163 ± 1082	1863 ± 638	64.2 ± 11.1	4
2	Central	49	393 ± 9	1656 ± 224	1335 ± 190	2236 ± 267	1402 ± 194	65.6 ± 3.7	7
3	South West	57	470 ± 9	678 ± 75	940 ± 58	2401 ± 232	1018 ± 98	49.9 ± 3.2	10
4	North East and Central	8	296 ± 7	3067 ± 991	597613 ± 35544	3350 ± 512	1850 ± 329	61.7 ± 12.2	3
5	Lakes/Mallee	8	428 ± 34	1631 ± 507	1925 ± 333	2863 ± 407	1394 ± 151	54.3 ± 8.5	1
6	South Coast	9	578 ± 26	972 ± 293	1158 ± 197	2656 ± 353	1389 ± 185	58.1 ± 9.2	3
	Mean	-	436 ± 8	1374 ± 138	4620 ± 2244	2485 ± 154	1296 ± 92	57.7 ± 2.3	0.20
	Total	139	-	190,919	642,164	345,340	180,112	-	28

* Agricultural zone boundaries are shown in Fig. 2.

Table 2

Survey replies from meat lamb farms by agricultural zones, with diarrhoea prevalence and proportion of their lamb flocks that experienced active or recent evidence of diarrhoea.

Agricultural zone*		Number (n)	Respondents reporting diarrhoea in lambs				Average proportion of lamb flock with evidence of diarrhoea (%)
Number	Name		n		%	95% CI	
1	North West	8	4		50.0^{A}	(15.7, 84.3)	4.3^{A}
2	Central	49	30		61.2^{A}	(46.2, 74.8)	6.6^{A}
3	South West	57	38		66.7^{A}	(52.9, 78.6)	6.8^{A}
4	North East and Central	8	3		37.5^{A}	(8.5, 75.5)	6.7^{A}
5	Lakes/Mallee	8	6		75.0^{AB}	(34.9, 96.8)	5.5^{A}
6	South Coast	9	9		100.0^{B}	(66.4, 100.0)	10.6^{B}
	Total	139	90	**Mean**	64.8	(56.2, 72.7)	6.9

* Agricultural zones and their boundaries are shown in Fig. 2.

^{AB} Values in columns with different superscripts are significantly different (P<0.05).

Table 3

Univariable associations between management practices and the risk of diarrhoea in meat lamb farms from Western Australia.

Management variable	**Percentage of respondents that observed diarrhoea**	**Odds ratio (95% CI)**	***P*-value**
Farm property located in agricultural zone 5 or 6			
Yes	88.2	4.70 (1.03, 21.49)	0.030*
No	61.5	1.0	
Lambing season			
Autumn	62.3	1.19 (0.58, 2.43)	0.630
Winter	66.3	1.0	
Anthelmintic treatment administered to pregnant ewes			
Yes	66.2	1.14 (0.57, 2.28)	0.715
No	63.2	1.0	
Anthelmintic treatment administered to lambs			
Yes	70.9	2.72 (1.25, 5.93)	0.011
No	45.2	1.0	
Faecal worm egg count used to determine if anthelmintic treatment is warranted			
Yes	67.4	1.40 (0.68, 2.90)	0.361
No	59.6	1.0	
Cattle grazed on farm			
Yes	57.1	0.67 (0.29, 1.55)	0.346
No	66.7	1.0	
Protozoa or coccidia known to cause disease in sheep or lambs in nearby district.			
Yes	85.7	4.09 (1.33, 12.59)	0.009
No/Unsure	59.5	1.0	
Livestock water from a dam			
Yes	88.9	152.0 (32.1, 719.0)	<0.001 *
No	5.0	1.0	
Livestock water from a river or creek			
Yes	83.3	2.82 (0.32, 24.88)	0.330*
No	63.9	1.0	
Livestock water from a bore			
Yes	43.8	0.32 (0.14, 0.72)	0.005

No	71.0	1.0	
Livestock water from a scheme			
Yes	42.3	0.14 (0.06, 0.34)	<0.001
No	75.5	1.0	

* Fisher’s exact test (two-sided significance).

Table 4

Binary logistic regression model of management factors associated with the risk of active diarrhoea in meat lamb flocks in Western Australia.

Covariate variables	***β* - estimates**	**Odds Ratio (95% CI)**	***P*-value**
Farm property from agricultural zone 5 or 6	2.07	7.92 (1.82, 45.27)	0.020
Livestock water from a dam	4.73	117.1 (18.19, 754.79)	<0.001
Livestock water from a bore	- 1.98	0.45 (0.16, 0.89)	<0.001
Livestock water from a scheme	- 3.04	0.28 (0.08, 0.46)	<0.001
Constant	2.19		

Note: Hosmer and Lemeshow statistic = 0.831, Cox and Snell r^2 value = 0.295 and Nagelkerke r^2 value = 0.406.

All variables had tolerance values >0.1

Table 5

Farmer responses towards different diarrhoea scenarios, whereby 5%, 25% and 50% of a meat lamb flock had active diarrhoea or evidence of recent diarrhoea (n=139 responses).

	Response options available to farmers (n)					
Percentage of lamb flock with diarrhoea (%)	*Monitor to see if diarrhoea incidence become worse*	*Conduct flock WEC*	*Administer anthelmintic treatment*		*Veterinary investigation*	*Do nothing*
			Entire flock	*Diarrhoeic or fleece soiled lambs only*		
5	94	13	22	3	1	10
25	31	60	69	26	2	0
50	1	30	114	6	49	0

Figure Legends

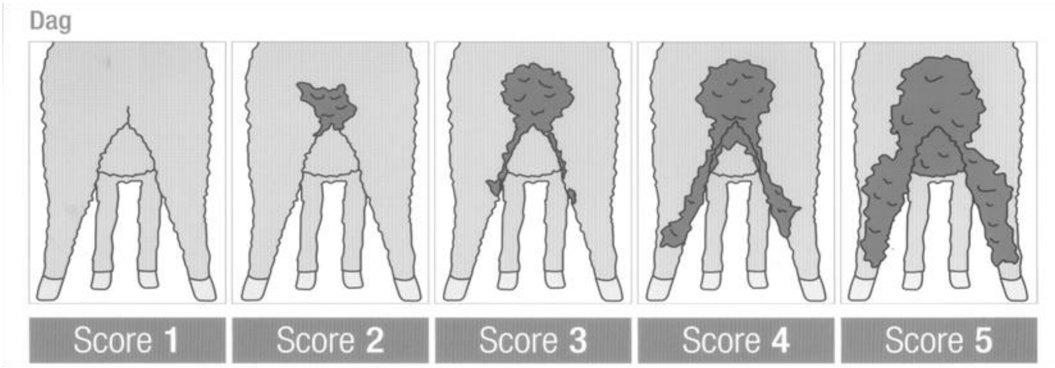

Fig 1. A graphical representation of the different breech fleece faecal soiling scores ('dag') utilised as an illustration for surveyed meat lamb farmers. (Australian Wool Innovation et al., 2007).

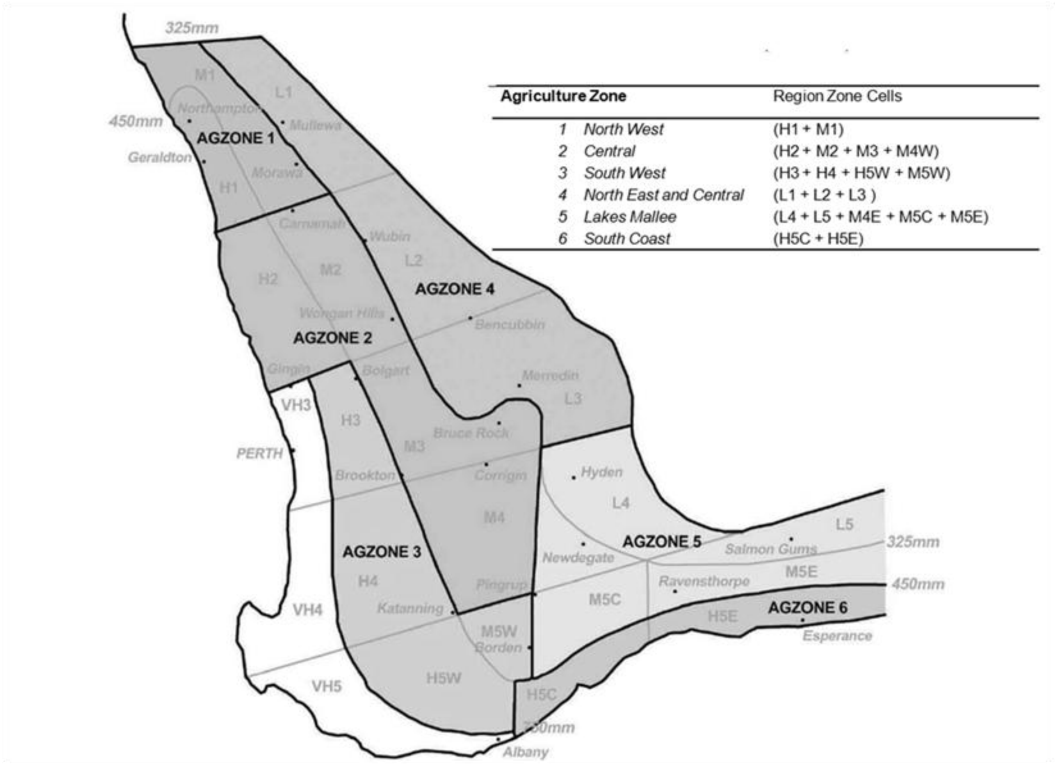

Fig. 2. Agricultural zones and boundaries of southern Western Australia (Garlinge, 2005).

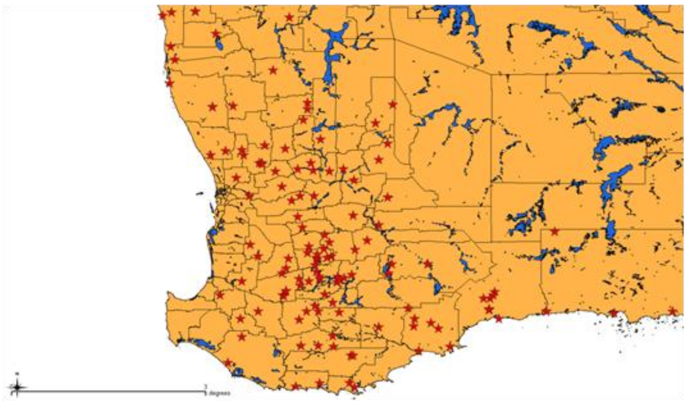

Fig. 3. Distribution of meat lamb farms surveyed (red star labels) in the southern Western Australia.

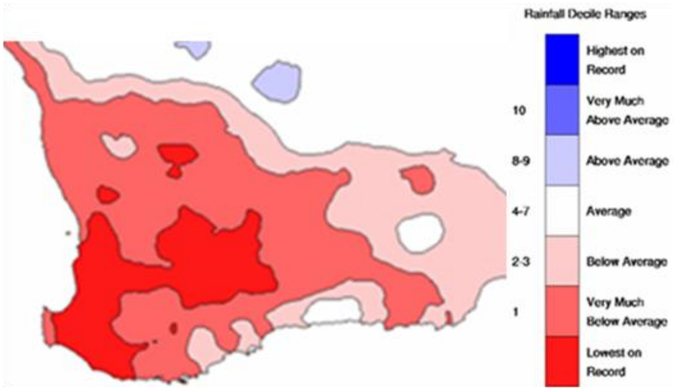

Fig. 4. Annual rainfall decile ranges across southern Western Australia from January 1st to December 31st 2010 (Australian Bureau of Meterology, 2011a).