Final Report

Project code: B.AHE.0043

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Date published: July 2012

Published by
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Foot abscess in tablelands sheep: Evaluation of risk factors and management options

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Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Foot abscess occurs sporadically in sheep flocks depending on pasture conditions, but during the wet winter/spring of 2010 on the tablelands of NSW foot abscess was common resulting in considerable financial loss. Consequently, in 2011 we conducted a two part study designed to i) determine whether supplementing pre-lambing ewes with iodine would reduce the prevalence of foot abscess, and ii) identify environmental and management risk factors associated with foot abscess expression. In the iodine response trial, twin bearing crossbred ewes from 3 flocks (N=900) were either treated with an iodine drench within 2 weeks of the start of lambing or were left untreated. Every sheep had its feet inspected pre-lambing and at marking when foot lesions were recorded. During lambing flocks were inspected weekly and lame ewes recorded. Pre-lambing around 20% of the ewes had old foot abscess lesions and post-lambing, following a dry late winter period, only 1.9% of ewes had active foot abscess and there was no affect of iodine treatment.

For the risk factor trial we conducted a cross-sectional observational study involving 115 tablelands sheep flocks by telephonic interview. Multivariable logistic regression analyses were conducted using two outcome variables: i) the presence of foot abscess, and ii) low (< 1%), medium (1% to 5%) or high (> 5%) levels of foot abscess. We found that moving sheep during lambing, having more than four months of wool growth at lambing, having boggy areas within the paddock or a wet season, and having greater than 30% clover in the paddock were all associated with increased foot abscess expression. The findings from this study will be used to provide updated extension advice to producers.

Keywords: Foot abscess, sheep, iodine, risk factors

Executive Summary

Foot abscess in sheep occurs only sporadically when wet environmental conditions prevent hooves from drying out for extended periods. Because of this irregular expression FA was considered as only a disease of medium economic importance in the most recent analysis of nationally important endemic sheep diseases. However in the high altitude, high rainfall Tablelands region of NSW, FA has been shown, particularly during 2010, to cause ewe and lamb deaths and serious financial loss, particularly in heavy crossbred meat sheep.

Consequently, in 2011 we conducted a two part study designed to i) determine whether supplementing pre-lambing ewes with iodine would reduce the prevalence of foot abscess, and ii) identify environmental and management risk factors associated with foot abscess expression amongst local producers.

The investigation into the impact of iodine was conducted because i) some local lamb producers were treating ewes with iodine following anecdotal reports that this was beneficial; ii) iodine treatment was reported to reduce FA in cattle, and iii) there was a need to scientifically determine whether iodine was of benefit in Tablelands sheep so that appropriate advice could be provided to local industry.

The investigation into risk factors associated with FA was conducted because i) there was little specific objective information available on risk factors for FA in high rainfall Tablelands region, and ii) producers were facing what appeared to be a second year of high FA prevalence.

Because of the sudden onset of dry conditions during winter and early spring of 2011, and the consequent reduction in the prevalence of FA, only 2% of the trial ewes developed FA over lambing and we were unable to adequately test the value of supplementing pregnant ewes with iodine for reducing the impact of FA. However, because there continues to exist a growing anecdotal belief amongst producers that iodine is beneficial for controlling FA it remains important to test this hypothesis. Given the sporadic nature of FA we propose to conduct a simplified low cost opportunistic trial that could be applied at short notice should the environmental conditions arise for FA expression. Several producers have already offered their flocks for this study.

The risk factor investigation comprised a cross-sectional, observational study of 115 producers in the Tablelands region of NSW by telephonic interview. Multivariable logistic regression analyses were performed to identify significant predictors of foot abscess presence and prevalence level after adjusting for potential confounders. Detrimental risk factors identified were moving sheep during lambing, having more than four months of wool growth at lambing, having any level of boggy areas within the paddock, a wet season, and having greater than 30% clover in the paddock. A favourable risk factor was having shale/slate soils. In terms of changed management producers should be prepared for an increased risk of FA when wet seasons are predicted, and consider lambing in the autumn, not moving sheep during lambing, moving shearing to within four months before lambing, running pregnant ewes in a paddocks with no higher than 30% clover, or containing boggy

areas. However because most of the associations identified are not consistent with maximising productivity, management changes such as lambing earlier, lambing on paddocks of low fertility with low clover content, are likely to reduce lamb turnoff and reduce profitability. At best producers should be prepared for an increased risk of foot abscess when wet seasons are predicted. By being more vigilant in these periods and making sure that the precursor condition, interdigital dermatitis (OID), is absent or controlled, they may be able to reduce losses.

Contents

1 Background

Foot abscess (FA) in sheep is an acute infection of the interphalangeal joint of the ovine foot with *Arcanobacter pyogenes*, usually following the development of interdigital dermatitis caused by *Fusobacterium necrophorum* which gains access to the skin following water maceration and mechanical damage caused by muddy wet pastures, particularly in heavy pregnant ewes and in rams (West et al., 2009). FA is a serious animal welfare issue and can drastically reduce animal productivity in affected animals. Overall the incidence of FA in Australian sheep flocks is usually sporadic and variable between years depending on pasture conditions. However in specialist lamb producing flocks joining heavy crossbred ewes, up to 15% of the flock may be affected.

Following observations of high ewe losses during 2010, the Tablelands LHPA conducted a survey of sheep producers with more than 1000 sheep to quantify losses and identify the main causes of ewe deaths (Watt et al., 2011). Mortality rates averaged 5.7% and 4.8% for adult and maiden ewes, respectively, but ranged from negligible to 28.6%. The most common causes of ewe deaths in descending order were: FA leading to pregnancy toxaemia; during parturition; and FA alone, suggesting that the costs associated with FA are very significant, given current sheep values.

Extension advice on the control of FA concentrates on avoiding risk factors such as over-fatness and wet, muddy ground conditions (Allan, 2010). Other than these, little objective information is available about the risk factors for the disease. Knowledge of risk factors is essential for developing objective and science-based control programs and extension advice. As a result a major aim of this project was to utilise producers who had responded to the 'ewe loss' survey to conduct a more detailed FA risk factor investigation.

In addition, anecdotal reports from local lamb producers suggested that treating ewes with an iodine drench prior to lambing can reduce the incidence of FA. This concept is supported by 2 reports in the scientific literature (Berg et al, 1984; Maas et al 1984) of reduced foot infection in cattle treated with ethylenediamine dihydriodide (EDDI), an iodide salt. In these reports serum iodine concentrations were elevated 10-fold on Day 46 after the commencement of treatment and associated with this, the proportion of cattle with foot infections fell from 21% in untreated cattle to 8% in EDDI-treated cattle. A second objective of this project was to measure the effect of iodine supplementation on FA expression, including a literature review on the potential role of iodine on immune competence and FA expression.

2 Project objectives

The objectives of the project are presented below:

1. Compare the prevalence of FA in untreated ewes with ewes treated pre-lambing with iodine in 3 meat sheep flocks.
2. Prepare a review of possible roles of iodine on FA expression.

3. Conduct an epidemiological risk factor investigation to determine management and environmental factors related to the high prevalence of FA in tablelands flocks
4. Conduct a preliminary survey of the bacteria present in FA lesions on trial sheep as a pilot study for further investigations to characterise the disease with a view to identify antigens for possible vaccine development.

3 Methodology

3.1 Iodine response trial

Review of the possible role of iodine in preventing FA

A literature review was conducted and is presented in Appendix 8.1.

Flocks Three specialist prime lamb producing flocks running approximately 3000 first cross or composite ewes near Blayney (altitude of 900 m) were used in the study. Two of these flocks were selected because they experienced a high prevalence of FA during lambing in August – September of the previous year, while the owner of the third flock has drenched his ewes with iodine pre-lambing over the past two decades and considered that he had fewer cases of FA consequently. All flocks grazed similar improved perennial pastures on volcanic derived soils (andesite or basalt) that had been top dressed regularly with superphosphate. This trial was approved by the Orange Animal Ethics Committee (ORA 11/14/005).

Design Multiple bearing, 4 year old ewes were identified at pregnancy scanning six weeks after the completion of joining for use in the trial. Approximately 10 days before the expected onset of lambing, the trial ewes were tipped and had their feet inspected for lesions. Concurrently, each ewe was fitted with a numbered neck tag to enable identification from a distance during lambing. Half of the ewes, selected at random, were drenched with a solution containing 237 mg of ethylenediamine dihydriodide (EDDI, equivalent to 213 mg of iodine) and all ewes were weighed and condition scored. The ewes had their feet inspected again at lamb marking approximately 8 weeks later. Following the first foot inspection, the ewes were moved to their lambing paddocks in mobs of approximately 100. In one flock, 10 ewes from each treatment group were bled 7 days after the EDDI drench and again at the final foot inspection at marking. The blood samples were assayed for free T3 and free T4 levels.

Foot lesion scoring Each inspected foot was examined for the presence and degree of active FA, evidence of previous old foot abscess (OFA), overgrown hooves (OG), shelly toe (ST), interdigital dermatitis (OID) and interdigital fibromas (corns). No previously published scoring system for these foot conditions (other than OID) could be found in the literature so we developed a system for use in this study. Active FA was diagnosed when sheep presented with one or more hot, swollen digits with a purulent discharge. OFA was diagnosed when one or more digits were abnormally thick and sometimes deformed and the phalanges ankylosed but without evidence of current infection. Feet were scored as OG when the hoof projected beyond the end of the toe more than 1-2 cm. ST as described by Egerton (2007) was recorded when more than about one third of the lateral hoof wall was separated from the underlying hoof. OID, an acute infection of the interdigital skin has been previously described (Parsonson et al 1967). Interdigital fibromas (corns) were recorded when a firm swelling of otherwise normal tissue between the toes was observed. Each week during the lambing period, the ewes were inspected from a vehicle that was driven slowly through each paddock ensuring that each ewe was required to walk. Neck tag numbers and affected feet were recorded for all lame sheep. To avoid mismothering, lame ewes were not caught for closer inspection so no information was collected on the cause of lameness.

Statistical analyses Data on the proportion of ewes exhibiting feet conditions were compared using chi-squared analysis, while data on peripheral T3 and T4 concentrations were analysed by ANOVA using Genstat.

3.2 Foot Abscess risk factor study

An observational cross-sectional study was carried out using a telephone interview. The target population was sheep producers on the Central and Southern Tablelands of NSW (Figure 1) with a sheep flock numbering over 1000.

Sample size required to provide 95% confidence of detecting a significant difference for odds ratios of 3 has been calculated to be 128 and 150, assuming that 15% and 20% of flocks in the low-prevalence group have the factor of interest, respectively, and that there are equal numbers of low- and high-prevalence flocks.

Case definition was FA in one or more sheep within the selected mob of sheep, diagnosed by the producer.

Selection of sheep flocks*:* A previous survey of producers on the Central Tablelands of NSW in 2010 was sent to 700 producers with over 1000 sheep listed on their stock returns to the Central Tablelands LHPA (Watt, Eppleston & Dhand 2011). A total of 260 producers responded to this survey. Each of these respondents was sent a letter in July 2011 asking them if they would be willing to participate in a further study regarding FA in their sheep. A simple recording sheet for observing one mob of sheep in their lambing period was also included.

A follow up phone call was made to see if they had received the letter and whether they would participate in a phone interview in November. A total of 200 producers responded that they would be interested in doing so.

Survey design and implementation: A questionnaire was developed from the literature review on possible risk factors of FA. Local District Veterinarians and Livestock Officers were also consulted in developing the questionnaire. The questionnaire was trialled with two people and modified in accordance with their suggestions to improve clarity and interpretation.

A professional company, Kaliber Professional Research, was used to conduct the phone interviews with producers in November 2011. They conducted the telephone interview using Computer Aided Telephone Interview (CATI) software. The questionnaire was approved by the University of Sydney Human Ethics Committee. All 200 producers were called during November 2011 with 115 questionnaires being completed.

Data*:* Data were collected in an Excel spreadsheet then imported to GenStat (13th version) and SAS (SAS statistical software, release 9.3, 2002–10, SAS Institute Inc., Cary, NC, USA) for further analyses.

Outcome variables: Two outcome variables were created based on a question in the questionnaire about percentage of sheep with foot abscess: (a) presence or absence of FA (binary); and (b) level of FA prevalence: low (<1%), medium (1-5%) and high (>5%). These outcomes were used in binary and ordinal logistic regression analyses, respectively, to determine significant risk factors for FA.

Explanatory variables: Risk factors were determined from the questionnaire. Most continuous variables were categorised using medians, quartiles or based on biological plausibility.

Producers who moved their sheep were asked about the variables within the new paddock(s). Since their answers for all of the variables (pasture type and height, stubble, thistle, clover, rocks, bogginess and dry area) were rarely different for the old and new paddock, it was decided to analyse data just for the first paddock.

Figure 1. Map of the Tablelands LHPA showing the region that properties selected for the survey are located within.

Data analysis*:* Data were analysed to identify and quantify risk factors for both outcome variables. Descriptive analyses were first conducted to determine the distribution of variables and to allow a preliminary evaluation of their association with the outcomes.

Univariable logistic regression analyses were then conducted to evaluate unconditional association of each risk factor with each outcome using GenStat and UniLogistic SAS macro (Dhand, NK 2010). Explanatory variables with a large number of missing observations (>10%) were excluded from further analyses and those with p-values <0.25 in univariable models were tested in pairs to check for collinearity using Spearman correlation coefficient and chi-square test. Only one of the pair of highly correlated variables (Spearman correlation coefficient >0.8; p-value <0.05) was used for further multivariable modelling.

Multivariable models were fitted by forward manual stepwise approach using SAS MultiLogistic macro (Dhand, N. 2010) retaining variables with P-value <0.05. All biologically plausible interactions were tested for the variables in the final model and retained if significant (<0.05).

The goodness-of-fit of the final binomial model was evaluated using The Hosmer-Lemeshow Goodness-of-Fit Test. The proportional odds assumption of the ordinal model was evaluated using Score test in SAS. Linearity of continuous variables was evaluated using splines; the variables were categorised if not found to be linear.

Odds ratios and 95% confidence intervals along with likelihood ratio chi-square P-values are reported. All p-values reported in this report are 2 sided.

4 Results

4.1 Iodine response trial

At the pre-lambing inspection the mean (standard deviation) live weight and condition score of the twin bearing trial ewes were 78.3 ± 0.3 kg and 3.30 ± 0.02, respectively, (73.5 ± 0.4 kg and 3.0 ± 0.03, 75.0 ± 0.4 kg and 3.2 ± 0.02 and 85.8 ± 0.43 kg and 3.6 ± 0.03 for Flocks A, B and C respectively). The proportion of ewes at the pre-lambing inspection with at least one foot affected by each foot lesion type monitored is presented in Table 1.

Table 1. The proportion of ewes before lambing with one or more feet affected by FA, OFA, ST, OG, OID and Corns.

Flock	Ewes inspected	FA	Old FA	Shelly Toe	Overgrown	OID	Corns
A	351	0 (0%)	41 (12% ^{A})	78 (22%)	86 (25%)	0 (0%) ^{A}	8 (2% ^{A})
B	296	0 (0%)	65 (22%) ^{B}	54 (18%)	78 (26%)	13 (4%) ^{B}	6 (2%) ^{A}
C	353	0 (0%)	88 (25% ^{B})	80 (23%)	80 (23%)	0 (0%) ^{A}	28 (8%) ^{B}

Means within columns with different superscript are different at the 5% level.

No cases of FA were detected at the pre-lambing inspection, however lesions remaining from previous, healed FA (OFA) were found in 194 of the 1000 (19.4%) ewes inspected. The prevalence of OFA varied between flocks (X^2_2 = 21.52; P<0.001) with the prevalence in Flock A being lower than in the other 2 flocks.

The prevalence of shelly toe and overgrown hooves averaged 21.2% and 24.4 % and was not different between flocks. Interdigital dermatitis was observed in Flock B only where 4.4% sheep were affected, while 4.2% of sheep were identified with corns and the level was greater in Flock C compared with the other 2 flocks.

Post-lambing prevalence of active foot abscess

The effect of iodine treatment on the prevalence of active FA is shown in Table 2. At the second inspection 4/370 (1.1%) iodine-treated ewes developed FA compared to 10/360

(2.9%) untreated ewes (X^2_1 = 3.26; P=0.20; NS). There was no difference between flocks in the prevalence of FA (X^2_1 = 2.79; P=0.10; NS).

Table 2. The effect of iodine drenching on the prevalence of FA at the post-lambing foot inspection in three flocks.

Iodine treatment	A	B	C	Total
No	5/137 (3.7%)	4/119 (3.4%)	1/104 (1.0%)	10/360 (2.8%)
Yes	2/141 (1.4%)	2/123 (1.6%)	0/106 (0.0%)	4/370 (1.1%)
Total	7/278 (2.5%)	6/242 (2.5%)	1/210 (0.5%)	14/730 (1.9%)

Of the 14 feet identified with FA at the second inspection, two had been identified with an OFA, two with OG and one with OID at the first inspection, suggesting that these other conditions do not predispose feet to the development of FA. However, the 2 feet that had previously been identified with OFA suggests the possibility that in some instances FA could develop from bacteria resident in OFA lesions.

Lameness

During the lambing period, 146 ewes were assessed as lame (Table 3). Only 2 of the 14 ewes observed with FA at the second inspection were not recorded as lame during the lambing period. The reason for lameness in the balance of the ewes could not be determined.

Table 3. The prevalence of lameness during the lambing period

Flock	Proportion of lame ewes (%)	Duration of lameness (weeks)			
		1	2	3	4
A	70/351 (20%)	46	16	6	2
B	48/296 (16%)	38	8	0	2
C	28/353 (8%)	28	0	0	0
Total	146/1000 (15%)	112	24	6	4

Peripheral plasma thyroxin response to iodine drenching

The mean peripheral concentrations (pmol/L) of free T3, free T4 and T3/T4 ratio before and after lambing were 5.02 and 6.89, 13.4 and 14.3, 0.41 and 0.55, , respectively. There was no significant interaction between iodine treatment and time for any thyroxin measure, indicating that drenching with EDDI had no impact on circulating thyroxin levels.

4.2 Foot Abscess risk factor study

Study flocks and outcome variables

The survey achieved a response rate of 57.5% (115 out of a possible 200 farmers completed the questionnaire). However 42 of the non-responders were either not contactable by phone or no longer ran sheep making the response rate to be 115 of 158, or 73%. The respondents were overwhelmingly male (114/ 115) and mostly over 45 years of age (108/ 115). The respondents in total managed approximately 100,000 hectares and ran over 325,000 sheep. Foot abscess occurred on 79 of the 115 properties at a level ranging from 0.03% up to 28%.

There were 64 low prevalence (≤ 1% of mob) properties, 32 medium prevalence (>1% and ≤ 5% of mob) and 19 high prevalence (>5% of mob) properties.

Descriptive and univariable analyses

Detailed descriptive and univariable results are presented in Appendix 8.3 but some of the associations are discussed below.

Comparison to previous year (2010): Because the local District Veterinarian reported that FA incidence was lower during 2011 than in 2010, questions were included in the questionnaire to allow comparison between the two years. In total, 69 respondents reported a higher prevalence, 32 reported a similar prevalence, and 14 reported a lower prevalence in 2010 compared to the surveyed year of 2011.

Timing of FA occurrence***:*** Six properties experienced their first cases of FA in January and the remainder had their first case in the following months through to September with a peak of 18 properties in July. There were no new cases in October or November. The peak of FA on some properties commenced as early as March but the overall numbers didn't peak until August.

Mortalities: Thirty six producers reported mortalities due to FA. The number of deaths in the selected mob varied from one to 60 sheep. The highest mortality rate reported was 30/180 sheep (16.7%).

Environmental factors

Soil types***:*** Responses of 'loam', 'sandy loam' and 'pipeclay' were classified as granite-derived while 'clay' was classified as basalt- derived (Belinda Hackney, Research Agronomist Bathurst, pers. comm.). While granite and basalt-derived soil types were fairly evenly represented in the FA cases, producers who had only slate or shale type soils had no infection in their flocks. Producers with basalt-derived soils were 100 times more likely to have a mob of sheep with some FA compared to those with shale/ slate soils (p = 0.001, binary analysis). Soil type did not converge in the ordinal model because shale/slate type soils had zero counts in the medium and high categories. Therefore it couldn't be used in the multivariable analysis, although it was significant in Fisher's exact test (P = 0.05).

Soil deficiencies***:*** Most respondents reported deficiencies (50/115 - 43.4%) in their soils. However the reported presence of a soil deficiency was not significantly associated with the presence of FA (p = 0.79).

Fertilisers***:*** Fertilisers had been used on 92 out of the 115 properties with some producers using multiple types. Types of fertiliser used were: single superphosphate (80), triple superphosphate (2), molybdenum (18), DAP (7), MAP (2), urea (4), and various organic or manure-type ones (10). However using fertiliser, at any rate, was found to not be significant (p= 0.17 for its use, in binary analysis).

Weather***:*** The peak of rainfall in 2011 was in November/ December with a lower peak in February/ March. June was a relatively dry month. There was a clear difference between the winter of 2010 and 2011. Winter rainfall was below the long term average for most areas on the Tablelands in 2011, while rainfall for the same period in 2010 was well above average with many stations experiencing double the rainfall of 2011 in 2010. The respondents opinion on whether 2011 was a wet season was significantly associated with FA in the ordinal analysis (p= 0.0005).

Pasture***:*** Sheep grazing on paddocks with 30% or more clover content were 2.8 times more likely to have higher levels of FA than those grazing on pastures with less than 30% clover (p = 0.009). However the type of pasture (improved or native) was not significantly associated with FA (p= 0.16). In addition some respondents reported high levels of boggy, water logged paddocks and having any of these areas within the paddock was significantly related to the presence of FA (p = 0.028).

Husbandry and animal factors

Supplementary feeding and water source: Supplementary feeding was carried out by 39 (34%) respondents. Of these, 23 fed various grains, 7 fed pellets, 5 fed hay, and 4 supplemented with mineral/salt blocks. Neither supplementary feeding nor water source was significantly associated with presence of FA (p = 0.33 and 0.61, respectively).

Yarding of sheep***:*** A total of 89 producers yarded their sheep in the pre-lambing period, 77 (67%) of these within a month of the onset of lambing. Reasons for yarding the sheep included vaccination, drenching and crutching or shearing. Yarding sheep was not significantly associated with having FA on the property (p= 0.58).

Lambing***:*** Having a lambing percentage greater than 100% (the median) was not significantly associated with having FA compared with less than 100% (p= 0.165). However FA was significantly associated with lambing season in the ordinal analysis (p= 0.047). There was a rise in the level of FA around the time that sheep started lambing on properties in the Tablelands, peaking in the winter. Twenty six (23%) respondents reported they moved their sheep during the lambing period and flocks that were moved were 12.4 times more likely to be associated with having at least one case of FA (p= 0.003).

Length of wool: There was considerable spread of shearing dates throughout the year with some ewes carrying up to a full year of wool at the start of lambing. Greater than four months wool was a significant factor associated with having FA on properties in the survey (p= 0.024).

Other sheep affected on the property: Just over half (60 of the 115) of producers had FA in sheep other than the trial mob on their property; 52 of whom had FA in the ewes in the study. The other sheep involved were: rams (43), other ewes on the property besides the selected mob (22), wethers (5) and a small number of lambs (3).

Management changes: Only 20 (17%) of producers said they had changed their management between 2010 and 2011 to address FA. The changes included using a drier lambing paddock shorter pasture, changing lambing time, foot-bathing, providing supplementary iodine and not yarding the sheep when it was wet.

Control and treatment methods: Of the 115 respondents, 82 (71%) culled sheep with poor foot or leg conformation and 66 (57%) culled sheep that develop FA. To treat FA, 70 (61%) producers said they use antibiotics while 70 (61%) pared the feet.

Logistic regression analyses for the presence of foot abscess (binary outcome)

Of the 42 variables analysed, 22 were associated with presence of FA at P<0.25 (Appendix 8.3, Table 6). Significant correlations were not detected in pairs of variables at Spearman correlation > 0.8, therefore, none of the variables was excluded from further analyses. Finally, 22 variables were tested in multivariable analyses and 5 were significant in the final model (Table 4). The Hosmer-Lemeshow goodness-of-fit test was not significant indicating that the model fit was appropriate.

The properties with shale or slate soil type were less likely to have foot abscess. In contrast, farmers who moved sheep during lambing, had sheep with >4 months wool at the beginning of lambing, had >5% of the paddock boggy or used foot bath had greater odds of having foot abscess.

Table 4. Final model logistic regression analyses for the binary outcome variable (any foot abscess on property) based on 110 observations in the dataset.

Variables	Categories	b	SE(b)	Adjusted odds-ratios	95% confidence interval	P-value
Intercept		-0.94	0.60			
Soil type						0.001
	Basalt-derived	0.00		1.00		
	Granite-derived	0.15	0.59	1.17	0.36, 3.75	
	Shale/ slate	-4.46	1.82	0.01	<0.001, 0.21	
	Mixed	0.77	0.70	2.16	0.57, 8.92	
Sheep moved during lambing						0.003
	No	0.00		1.00		
	Yes	2.52	1.09	12.42	2.14, 239.12	
Months wool at beginning of lambing						0.024
	≤ 4 months wool	0.00		1.00		
	> 4 months wool	1.17	0.53	3.22	1.17, 9.60	
Percentage of paddock boggy						0.028
	0%	0.00		1.00		
	≤ 5%	1.29	0.57	3.63	1.25, 11.74	
	> 5%	1.49	0.89	4.45	0.91, 33.71	
Use foot-bathing						0.03

to prevent	No	0.00		1.00	
	Yes	1.45	0.73	4.28	1.14, 21.80

Logistic regression analyses for the level of foot abscess (ordinal outcome)

Of the 42 variables analysed, 22 were associated with presence of FA at P<0.25 (Appendix 8.3, Table 7). Some variables had a Spearman correlation > 0.7 (yard sheep and in last month, area of property and sheep number, and breed of sheep and lambing percentage) but none of them were > 0.8. Finally, 22 variables were tested in multivariable analyses and 4 were significant in the final model (Table 5).

Farms that had a wet season, had clover in ≥ 30% of the paddock, used antibiotics, or lambed in winter had greater odds of having high levels of foot abscess.

Table 5. Final model logistic regression analyses for the ordinal outcome variable (low, medium and high levels of foot abscess on a property) based on 114 observations in the dataset.

Variables	**Categories**	**b**	**SE(b)**	**Adjusted odds-ratios**	**95% confidence interval**	**P-value**
	Intercept high	-1.24	0.67			
	Intercept medium	0.55	0.67			
Wet season, producer view	Wetter	0.00		1.00		0.0005
	Same	-1.90	0.59	0.15	0.05, 0.45	
	Drier	-2.02	0.57	0.13	0.04, 0.39	
Percentage of clover in paddock	< 30% of paddock	0.00		1.00		0.009
	≥30% of paddock	1.04	0.41	2.83	1.29, 6.40	
Use antibiotics to treat	Yes	0.00		1.00		0.010
	No	-1.08	0.43	0.34	0.14, 0.78	
Lambing season	Autumn	0.00		1.00		0.047
	Spring	0.85	0.64	2.35	0.68, 8.05	
	Winter	1.12	0.47	3.05	1.25, 7.88	

5 Discussion

5.1 Iodine response trial

Two of the three properties used in this study had a high prevalence of FA in the winter and spring of 2010. The owner of the third property routinely uses iodine pre-lambing and so had an interest in its efficacy. However, in the winter and spring of 2011, a wet autumn was followed by a dry winter. Prevalence of FA in the ewe flocks studied were therefore low (14 new cases in 730 ewes examined at the marking visit or 1.9%). An examination of ewes at marking may under estimate the prevalence of FA as some cases may have healed quickly (Egerton J pers. comm.). It is also possible that the high prevalence of FA in previous years may have induced some immunity providing protection in 2011. On all properties, the prevalence of FA was lower in the treated than the control ewes but this difference was not significant. Therefore, no conclusions can be drawn on the effect of parenteral prelambing iodine on FA from this study.

The presence of a range of other feet conditions of sheep was recorded. The ewes were also weighed and condition scored. It was intended to determine the relationship between bodyweight, these feet conditions and FA. However, the prevalence of FA was low during this trial and so it was considered pointless to attempt to correlate FA with these conditions. However, it is interesting to note that OFA was detected in from 12-25% of the ewes examined pre-lambing in 2011. These findings support the observation that FA was a major problem in the past and presumably mainly in 2010. These prevalence figures may also underestimate the true prevalence of previous FA, as some cases will presumably have healed without permanent deformities (Egerton J, pers. comm.). A finding that was not anticipated was that two ewes with OFA developed active FA in the same foot. It is possible that these were new cases that progressed from IOD as is usual with FA (Parsonson et al 1967, West 1983). However, the lesions appeared to be unusually extensive and chronic suggesting that recurrence from bacteria harbouring within chronically infected tissues is a possibility.

Bovine interdigital necrobacillosis (footrot) is a similar condition in cattle to FA in sheep. It is a synergistic invasion of *Fusobacterium necrophorum* and *Porphyromonas levii* into the deeper structures of the foot originating from an interdigital dermatitis (Vermunt et al 2010). While Berg et al (1984) and Maas et al (1984) found that iodine supplementation (as EDDI) was effective in reducing experimentally induced or naturally occurring bovine footrot, it was administered daily and presumably achieved therapeutic blood levels. In this trial, iodine was administered as a single dose about two weeks before the commencement of lambing. It is doubtful that this regimen would have been sufficient to maintain therapeutic levels of iodine but an equivalent quantity of potassium iodide (280 mg equivalent to 213 mg of iodine) has been shown to be adequate to alleviate iodine deficiency in perinatal lambs and kids (Caple 1990). No difference was found in T3 and T4 levels between the treated and control ewes.

Foot abscess remains a challenge to manage. It occurs under conditions otherwise consistent with good management and productivity (fecund ewes in good body condition on abundant winter pastures or forage crops). Some of the management recommendations that would alleviate FA therefore risk compromising productivity and profitability. However, allowing high-risk sheep (especially mature twin bearing ewes) access to dry areas can sometimes be managed. Foot bathing with zinc sulphate can also reduce interdigital dermatitis but mustering sheep and putting them through wet yards is usually counterproductive. It is intriguing that FA, while a common problem in young rams in New Zealand is much less of a problem in lambing ewes under circumstances that would otherwise appear conducive to FA (D West pers. comm.).

Foot abscess occurs sporadically associated with favourable seasons although it can be a common problem for some producers. Egerton (1981) commented that there was (at least in 1981) no evidence that *F. necrophorum* vaccines are of any value in sheep. However, vaccines have been shown to reduce *F. necrophorum* infections in cattle (Clark et al 1986) but generally vaccination has not afforded satisfactory protection against *Fusobacterium* infections (Tan et al 1996). However it is encouraging that while vaccination against *D Nodosis* was initially not effective against foot rot in sheep, recent research has shown that control and even eradicated can be achieved using antigen-specific vaccines (Egerton, et al 2002; Dungyel et al 2008).

5.2 Foot Abscess risk factor study

The study population in this survey was 200 farmers that had previously responded to a survey on ewe mortality during 2010. The response rate of 73% of those that could be contacted and still ran a sheep enterprise was very high for a telephonic study and would have helped reduce non-response bias. However there may have been some bias towards producers with high ewe losses in those responding to the initial mortality survey.

The study identified four environmental and five management factors associated with the occurrence of FA in tablelands sheep flocks. The environmental factors identified were soil type, rainfall, and the proportion of clover and wet boggy areas in the lambing paddocks, while the management factors were: changing paddocks during lambing, length of wool, use of antibiotics, use of a footbath and the time of lambing.

Environmental factors

Soil type: The absence of FA in farms with shale/slate type soils is probably due the lower productive capacity of this soil type. Pasture growth is generally lower resulting in less dense, shorter pastures so sheep feet may be drier than those of sheep grazing pastures on more productive soil types. Shale/ slate soils are often in steeper landscapes allowing rapid water run-off and less water holding than level granite and basalt soils. It is also possible that hoof wear will be greater on shale soil types. However it is unlikely that producers will be able to utilise this finding as the majority of them have either basalt-derived or granite-derived soils and lambing pregnant ewes on pastures on shale/ slate type soils will limit nutrition at a time of greatest demand.

Rainfall: FA expression has been shown to increase after periods of heavy rainfall (Roberts et al., 1968; West, D 1983). The producers view on whether 2011 was wetter than average, although subjective, was significantly associated with FA in the ordinal analysis ($p= 0.0005$). This agrees with other reports that higher rainfall is associated with increased levels of FA. With the current level of weather prediction available, it may be possible to be more prepared for FA when climate risks are greater. However, further investigation could be done by collecting and comparing meteorological data from weather stations closer to the farms.

Clover content: The recommended pasture legume content for lambing ewes is around 30% (Hatcher 2006). However in this study increased FA was associated with pastures with more than 30% clover in the ordinal analysis (p= 0.009). Other reports have identified a higher incidence of OID on legume pastures (Healy 1971; West, D, Bruere & Ridler 2009), and as FA is a possible sequel to OID and wet conditions, it may be prudent to graze pregnant and lambing ewes in paddocks with 20- 30% clover, particularly in a wet season.

Percentage of paddock boggy: The proportion of lambing paddocks with boggy areas was positively associated with the outcome in the binary analysis (p= 0.028) and agrees with other reports indicating that wet, muddy conditions are a risk for developing FA (West, 1983; West, Bruere & Ridler 2009). In high risk wet seasons it may be advisable to not graze ewes on the wettest paddocks.

Management factors

Sheep moved during lambing: The association between FA and moving sheep during the lambing period was unexpected. It may have been that pastures in the new paddocks were longer and therefore exposed feet to wetter conditions than if they were left in the initial paddocks. Drift lambing is a common management procedure and if this was done through sheep yards may have increased FA expression.

Further analyses could be done by including characteristics of the second paddock in the analysis, although it was not considered necessary initially as most of the responses for the two paddocks were similar.

Lambing: The range in lambing percentage was large with one flock having only 35% lambs and at the other extreme, one with 177%. Number of twinning ewes (when extrapolated from lambing percentage) was not associated with higher incidence of FA in this study.

The weight of a lamb and associated membranes at birth may be 8 to 10 kilograms, with twin lambs adding a further 4 to 5 kilograms. In a 50 kilogram animal this is a considerable extra weight on the feet. Twinning sheep are thought to be at higher risk of FA (Phil Graham, Sheep Livestock Officer, pers comm.) and they will certainly be at higher risk of secondary complications with their high nutritional requirements in late pregnancy meaning it is easier for them to be tipped into pregnancy toxaemia with this condition.

Moving lambing to the autumn would be recommended if FA was the only factor to decide when it should occur. In reality the decision is made on a combination of factors including when peak of pasture production is, meeting a specific target market, condition of ewes at joining, best conditions for lamb survival, and occurrence of other enterprise activities on the property (Hatcher 2006).

Months of wool at beginning of lambing: The observed association between wool growth and FA could be related to the extra live weight it contributes as a full fleece may weigh as much as six kilograms at twelve months, depending on breed and age of the sheep. This is in addition to the extra weight associated with pregnancy. This may be an additional consideration for producing when deciding on the optimum time of shearing.

FA control methods: Producers utilise a number of methods to try and prevent FA and treat it if it is present in their sheep. Ideally at-risk sheep should be on shorter pastures that will dry out quicker in wet conditions. This may be a problem if they are lambing ewes as they will require a high plane of nutrition in the later stage of pregnancy and lactation. Moving them soon after lambing may lead to mis-mothering problems, particularly with Merinos. Using zinc sulphate or formalin footbath is fairly common in the treatment of OID and to prevent it progressing onto footrot or FA under the right conditions. It is therefore unsurprising that we have found the footbath to be associated with the presence of FA on properties ($p = 0.03$ in binary analysis). This is probably a management response to presence of OID and a consequence of presence of disease, not a cause. Reverse causation is a limitation of a cross-sectional study as both exposure and outcome are measured at the same time and the investigator cannot determine whether the exposure preceded the outcome or vice versa.

Similarly, producers who have stated they will use antibiotics in the treatment of FA are much more likely to have experienced it. Producers with low levels or no FA may not have needed to use them for this problem.

Study validity

A cross-sectional, observational study was performed, which was reliant on producer's memory if records were not available. Therefore, some recall bias might have occurred, as in most other observational studies. However reliance on their recall was minimised by sending a pre-interview explanatory letter prior to the start of the lambing season, which included a record sheet. However, as in most other observational studies some recall bias may have occurred.

Some confounding bias is possible, but we collected data on many variables, tested their associations with the outcome and included them in the multivariable model, if they had a significant association. However, as we tested a large number of variables, it is possible that we might have detected some spurious associations.

We achieved a good response rate which would have reduced the selection bias in our study but our initial sampling frame was opportunistic and based on those who responded in a previous survey. If response to the initial survey was somehow biased, this would have resulted in selection bias in our study. This also means that our sample is not a representative sample of the target population. Therefore, the results should be generalised or extrapolated to other populations with caution.

In extensive grazing systems, particularly during lambing, it is often not possible to inspect individual sheep to improve the accuracy of diagnosis of lame sheep. Hence while producers have been shown to be capable of identifying FA in at least one study (Kaler & Green 2008), misclassification bias may have occurred if the disease status was incorrectly determined by the producer. The main differential diagnosis for lameness in Australia is virulent footrot however the prevalence of this notifiable disease has fallen considerably in NSW following a successful eradication program. The possibility of misclassification bias was further reduced by categorising the outcome into binary and ordinal outcomes.

6 Conclusions

Because of the sudden onset of dry conditions during winter and early spring of 2011, and the consequent reduction in the prevalence of FA, we were unable to adequately test the value of supplementing pregnant ewes with iodine for reducing the impact of FA. However, because there continues to exist a growing anecdotal belief amongst producers that iodine is beneficial for controlling FA it is more important than ever to test this hypothesis. Given the sporadic nature of FA we propose to conduct a simplified low cost opportunistic trial that could be applied at short notice should the environmental conditions arise for FA expression. Several producers have already offered their flocks for this study.
In the risk factor study, detrimental risk factors identified were moving sheep during lambing, having more than four months of wool growth at lambing, having any level of boggy areas within the paddock, a wet season, and having greater than 30% clover in the paddock. A favourable risk factor was having shale/slate soils. In terms of changed management producers should be prepared for an increased risk of FA when wet seasons are predicted, and where practical consider lambing in the autumn, not moving sheep during lambing, moving shearing to within four months before lambing, running pregnant ewes in a paddocks with no higher than 30% clover, or containing boggy areas.

7 Acknowledgements

Meat and Livestock Australia funded this trial. For the on-farm study we acknowledge the assistance of graziers Bob Stanbridge, Tony Gordon and Bruce Gordon, farm manager Tim Jamieson and TLHPA rangers Colin Somerset, Neville Collins and John Foran. Murray Grant from Chemvet Australia Pty. Ltd. kindly donated the EDDI used and John Egerton made valuable suggestions both prior to the conduct of the trial and subsequently.

8 Appendices

8.1 Review of the possible role of iodine in preventing FA

A case of apparent Iodine-responsive foot abscess in crossbred sheep
Penny Browne, Undergraduate, Veterinary Science Student, University of Sydney

The ‘inspiration’ for this report
A prime lamb producer in the tablelands district has been supplementing potassium iodine in his pre-lambing ewe drench for the last 20years. There is anecdotal evidence on this property that the incidence of foot abscess has decreased. This producer has been using a supplement mixture in his drenches, which includes Cobalt, Zinc and Iodine as well as Selenium. There are limited publications that investigate or discuss the use of iodine to prevent foot abscess. An extensive literature search revealed that there have only been a small number of studies performed in cattle during the 1980’s and there have been no studies performed in sheep. The Tablelands Livestock Health and Pest Authority (TLHPA) are looking to undertake a trial of iodine supplementation and its correlation to foot abscess prevalence. The use of a number of mineral supplements in these sheep may confound the true efficacy of the iodine alone and so the trial will have to be tailored accordingly.

Pathogenesis of foot abscess in sheep

Foot abscess is a serious disease of sheep that is characterised by a necrotising or purulent infection involving the distal interphalangeal tissues and sometimes the joint (Merck Veterinary Manual, 2010). It has an effect on productivity and welfare and can be as serious as virulent footrot. Acute lameness, swelling of one digit and discharging sinuses distinguish foot abscess from footrot (Merck Veterinary Manual, 2010). A foot abscess can cause lameness in one of more feet, which leads to a reduction in mobility of the animal and subsequent loss of condition (Allan, 2010). Both heel and toe abscesses are common in fat, heavy sheep, meat sheep are more predisposed but twinning merino ewes also suffer frequently (Allan, 2010). Foot abscess is more common in good seasons, where the rainfall is high and when conditions are favourable for footrot (Allan, 2010). In these good conditions, sheep are usually fat and grazing on high biomass pastures and the ground is warm and moist.

Foot abscess is a bacterial infection caused by organisms that are normally found in the gut and faeces and only cause disease when the normal healthy skin and hoof wall of the foot is damaged (Allan, 2010). These organisms commonly include *Fusobacterium necrophorum* and *Arcanobacterium (Actinomyces) pyogenes*. The majority of isolates of *F. necrophorum* belong to the biotype AB and produce a variety of toxins such as exotoxin, leucotoxin and haemolysin (Emery et al, 1985). It has been shown that experimentally induced lesions can be created in sheep with the inoculation of suspensions of *F. necrophorum* biotype AB into the interdigital skin, previously devitalised with liquid nitrogen (Corner et al, 1995). In the study by Corner et al (1995), it was found that to produce foot abscess in devitalised tissue required between 10^3 and 10^6 fewer bacteria that were necessary to produce similar lesions in healthy tissue.

In foot abscess, bacteria from the ground colonise the damaged epithelial surface either interdigitally or from damage to the lamellae of the hoof. The bacteria then invade the deeper soft tissues of the foot and begin to cause an abscess below the subcutaneous tissue layer. Extension of the necrotic process into the distal interphalangeal joint can occur as this joint is particularly vulnerable to infection on the interdigital aspect where the joint capsule protrudes above the coronary border as the dorsal and volar pouches (Merck, Veterinary Manual 2010). At these two sites, the joint capsule is protected only by the interdigital skin and a minimal amount of subcutaneous tissue (Merck Veterinary Manual, 2010). As infection progresses the abscess grows and pressure within the foot increases resulting in significant pain.

A guide to distinguishing foot abscess from footrot

Footrot	**Foot abscess**
Usually affects more than one foot	Usually affects one foot which is carried
No swelling	Swelling – usually spreading the toes
No pus, but a black-grey slime may be present	Pus present, often green and/or creamy

No heat	Hot to touch the digit especially at the site of swelling
Putrid odour	Slight odour – often not fly blown
Spreads rapidly through the flock affecting all ages	Usually seen only in heavy sheep
No break in the coronet (hoof-skin junction) but separation of the sole of the foot with underrunning	Abscess usually breaks out near the coronet, but sometimes in the heel or toe

(Allan, 2010)

Iodine and thyroid function

The primary function of iodine is to control the rate of cellular oxidation through its presence in the biosynthesis of iodated thyroid hormone (Ettinger & Feldman, 2009). Iodine is a constituent of the thyroid hormones 3,5,3',5'-tetraiodothyronine (thyroxine, T4) and 3,5,3'-triiodothyronine (T3). Thyroid hormones have an active role in thermoregulation, intermediary metabolism, reproduction, growth and development, circulation and muscle function (Hand et al, 2010). Thyroid hormones also: 1) influence physical and mental growth and differentiation and maturation of tissues, 2) affect other endocrine glands, especially the hypophysis and gonads, 3) influence neuromuscular functioning and 4) have an effect on the integument, hair and fur (Hand et al, 2010).

Hypothyroidism

In domestic ruminants, there are two common causes of hypothyroidism under normal management conditions. The first cause is grazing in areas where soil is naturally low in available iodine in conjunction with provision of minimal supplementary feed (Villar et al, 2002). The second is ingestion of plants containing goitrogenic compounds, especially member of the Brassica family such as turnips, cabbage, rape and kale (Villar et al, 2002). Since thyroid hormones are involved in many metabolic processes, in tissues, the clinical signs of a thyroid deficiency are variable and involve most organ systems (Villar et al, 2002). The classical syndrome of hypothyroidism in ruminants is usually one or more of a wide range of reproductive performance problems such as weak neonates, stillbirths, abortions, increased neonatal mortality, prolonged gestation and reduced fertility (Villar et al, 2002). Thyroid impairment can also result in poor growth and impaired neurological development of offspring (similar to cretinism in humans) (Villar et al, 2002). Other, less specific clinical signs reported include anaemia, lethargy, anorexia, poor growth, alopecia, dry hair coat, thickened skin, Hyperpigmentation of the skin, cold intolerance, myxoedema, bone deformity and muscle weakness (Villar et al, 2002).

The rate of peripheral glucose utilisation is decreased during hypothyroidism, and there is a greater accumulation of lactic acid in muscles, accounting for poorer work efficiency with rapid onset of fatigue (Villar et al, 2002).

Selenium and the thyroid gland

Elements such as selenium, iron and zinc affect the thyroid gland metabolism and thus also affect the levels of thyroid hormones in the organism (Pavlata et al 2005). Selenium deficiency can cause a decrease in the concentration of T3 and take part in the development of the signs related to disorders of the thyroid gland and hormone metabolism (Pavlata et al, 2005). After supplementation of animals with selenium, there appears to be an increase in the concentration of T3 (Pavlata et al, 2005). Selenoproteins involved in cellular anti-oxidative defence systems and redox control, such as glutathione peroxidase (GPx), are involved in protection of the thyroid gland from excessive hydrogen peroxide and reactive oxygen species produced by the follicles for biosynthesis of thyroid hormones (Kohrle & Garter, 2009). In addition, there are three key enzymes involved in the activation and inactivation of thyroid hormones and these are all selenoproteins (Kohrle & Garter, 2009). The first clinical evidence that severe Se deficiency in combination with other environmental factors is deleterious for the thyroid was in Central Africa (Kohrle & Garter, 2009). Here, the supplementation of iodine alone was ineffective in restoring thyroid function (Kohrle & Garter, 2009). Excessive iodine supplementation may have a negative effect on selenium metabolism and/or selenium status in kids (Pavlata et al, 2005). Selenium deficiency is accompanied by loss of immune competence (Kohrle & Garter, 2009). Both cell mediated immunity and B-cell immunity can be impaired (Kohrle & Garter, 2009). Serum Se behaves as a negative acute-phase reactant, it appears reasonable to correct a developing deficit and to strengthen the immune system by Se supplementation (Kohrle & Garter, 2009).

Ovine thyroid gland and its relevance to human medicine

The sheep has attracted attention as an animal model for studying the thyroid gland because of a close resemblance of thyroid hormone metabolism in the foetal sheep to that in the human foetus (Potter et al, 1980). Because of this close resemblance it would seem reasonable to expect the sheep to behave similarly to the human in the manner in which iodine also it metabolised in the foetus (Potter et al, 1980). In humans the relationship between thyroid disease and rheumatic disease is significant (Anwar & Gibofsky, 2010). Muscle symptoms may manifest in 25-79% of adult patients with hypothyroidism (Anwar & Gibofsky, 2010). The symptoms are often reported as pain, cramps, stiffness, easy fatigability and weakness (Anwar & Gibofsky, 2010).

Iodine usage in animal species

The primary use for iodide is as Sodium Iodine administered intravenously in the treatment of Actinobacillus (Woody tongue) and Actinomycosis (Lumpy Jaw) in cattle. In horses, dogs and cats it has been used in the treatment of sporotrichosis. The antifungal mechanism of iodides is not known (Ettinger & Feldman, 2009). They are rapidly and completely absorbed orally, distributed to the extracellular fluid, and concentrated in the thyroid gland (Ettinger & Feldman, 2009). While the exact mode of action for its efficacy in treating actinobacillosis is unknown, iodides probably have some effect on the granulomatous inflammatory process (Plumb, 2010).

Is there evidence that iodine supplementation can prevent foot abscess?

There is minimal published data on the exact mechanism of iodine’s germicidal action when used topically and although it is an essential trace element, its role in animal health is more of a general one. The production of thyroid hormones are essential for metabolism and maintenance of homeostasis but as described above, in animals signs of iodine insufficiency are numerous and non-specific.

There is evidence in cattle that iodine supplementation can prevent both experimentally and naturally occurring foot rot (Berg et al, 1984; Maas et al, 1984). In two separate studies, Berg et al (1976 & 1984) demonstrated that ethylenediamine dihyriodide (EDDI) could not prevent bovine foot rot experimentally induced with high dosages of *F. necrophorum* and *P. melaningenicus* but did have efficacy against a challenge with a low dose innoculum. In a study performed by Maas et al (1989) serum iodine concentrations were measured and a linear dose-response curve was generated to oral supplementation, which could be helpful in predicting dosage rates for iodine supplementation if the serum iodine concentration was known. There is a steep rise in total serum iodine concentration after the first 3 hours following oral administration, then a slow decline to a baseline at 24hrs (Berg et al, 1984). Therefore once daily administration of EDDI would be adequate to maintain serum iodine concentrations (Maas et al, 1989). When administration of 0.111mg/kg/day was stopped, the total serum iodine concentration of the cattle, returned to baseline in about 8 days (Berg et al, 1984). Serum iodine concentrations of 20ug/dl or greater were associated with protection in studies where supplementation with EDDI decreased the incidence and severity of foot rot (Berg et al, 1984 & Maas et al, 1984). *Fusobacterium necrophorum* is a known pathogen involved in bovine footrot and ovine foot abscess and so it would be easy to extrapolate this data on iodine supplementation in cattle to sheep.

The farmer who inspired the investigation into a possible connection between iodine and foot abscess prevention in sheep has been routinely supplementing Selenium at every drench. Selenium has an important role in cellular immunity and so it could be assumed that it is this producer's routine Selenium supplementation is having more of an effect on reducing the prevalence of foot abscess than the iodine supplementation. More recently the addition of Zinc and Cobalt to the pre-lambing drench has occurred and the farmer reports a decreased number of sheep with foot abscess. Zinc has been shown to be important in the healthy growth of skin and horn/hoof.

There is merit in undertaking an iodine response trial in sheep to see if there really is a connection between iodine supplementation and a decrease in the prevalence of foot abscess. But the anecdotal evidence of its success from this one farmer may be due to a multifactorial change in ewe management. If the results of the trial were to be relevant and significant then three trial groups would need to be used, a group that didn't receive any mineral supplementation, a group that received iodine only and a group that received the iodine/selenium/cobalt/zinc mix.

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8.3 Foot lesion scoring system

Figure 1. Foot lesions recorded at foot inspection.

Overgrown hoof

Old foot Abscess showing thickening of digit

Current foot abscess

Shelley toe

8.4 Risk factor tables for univariable analyses

Table 6. Parameter Estimates and odds ratios for the unconditional association between explanatory variables and the binary outcome, with p < 0.25

Variables	Categories	b	SE(b)	Odds-ratios	95% confidence interval	P-value
Soil type						0.007
	Intercept	0.96	0.37			
	Basalt-derived	0.00		1.00		
	Granite-derived	-0.04	0.51	0.96	0.35, 2.59	
	Shale/ slate	-2.90	1.13	0.06	0.00, 0.36	
	Mixed	0.20	0.60	1.22	0.38, 4.12	
Sheep moved during lambing						0.008
	Intercept	2.04	0.61			
	Yes	0.00		1.00		
	No	-1.51	0.65	0.22	0.05, 0.70	
Minimum age of sheep						0.011
	Intercept	0.34	0.26			
	≤ to 3yrs age	0.00		1.00		
	> 3 yrs age	1.05	0.43	2.86	1.26, 6.80	
Use antibiotics to treat						0.015
	Intercept	1.22	0.28			
	Yes	0.00		1.00		
	No	-0.99	0.41	0.37	0.16, 0.83	
Percentage of paddock with clover						0.019
	Intercept	0.33	0.27			
	≤ 30% paddock	0.00		1.00		
	> 30% of paddock	0.96	0.42	2.60	1.17, 6.00	
Use foot-bathing to prevent						0.026
	Intercept	1.75	0.54			

	Yes	0.00		1.00		
	No	-1.19	0.59	0.30	0.08, 0.88	
Percentage of paddock boggy						0.033
	Intercept	0.34	0.26			
	0% of paddock	0.00		1.00		
	≤ 5% of paddock	0.93	0.46	2.54	1.06, 6.51	
	> 5% of paddock	1.46	0.81	4.29	1.05, 29.11	
Months wool at beginning of lambing						0.043
	Intercept	0.39	0.27			
	≤ to 4 months	0.00		1.00		
	> 4 months	0.83	0.42	2.29	1.03, 5.28	
Producer pares feet						0.045
	Intercept	1.12	0.27			
	Yes	0.00		1.00		
	No	-0.83	0.41	0.44	0.19, 0.98	
Area of paddock(s)						0.073
	Intercept	1.14	0.30			
	≤ 100 hectares	0.00		1.00		
	> 100 hectares	-0.74	0.41	0.48	0.21, 1.07	
Breed of sheep						0.077
	Intercept	0.53	0.25			
	Merino	0.00		1.00		
	Merino x British or British	0.77	0.45	2.17	0.92, 5.46	
Wet season, producer view						0.086
	Intercept	2.08	0.75			
	Wetter	0.00		1.00		
	Same	-1.57	0.82	0.21	0.03, 0.87	
	Drier	-1.39	0.80	0.25	0.04, 1.00	

	Intercept	-2.19	1.77			
% of property grazed		0.03	0.02	1.03	1.00, 1.07	0.088
Lambing season						0.146
	Intercept	0.27	0.33			
	Spring	0.00		1.00		
	Autumn	0.52	0.63	1.68	0.50, 6.22	
	Winter	0.87	0.45	2.39	1.00, 5.78	
	Intercept	1.13	0.33			
Area of property (hectares)		0.00	0.00	1.00	1.00, 1.00	0.150
Type of pasture						0.160
	Intercept	1.24	0.34			
	Improved	0.00		1.00		
	Native	-0.95	0.56	0.39	0.13, 1.16	
	Improved native	-0.70	0.48	0.50	0.19, 1.27	
Frequency sheep checked						0.163
	Intercept	1.12	0.30			
	Daily	0.00		1.00		
	Every 2-3 days	-0.43	0.51	0.65	0.24, 1.80	
	Weekly - fortnightly	-0.67	0.57	0.51	0.17, 1.61	
	Rarely or never	-1.63	0.79	0.20	0.04, 0.89	
Lambing percentage						0.165
	Intercept	0.62	0.27			
	≤ 100%	0.00		1.00		
	> 100%	0.58	0.43	1.80	0.79, 4.23	
Fertiliser used						0.168
	Intercept	0.93	0.23			
	Yes	0.00		1.00		
	No	-0.67	0.48	0.51	0.20, 1.34	
	Intercept	0.01	0.71			

Lambing period		0.02	0.01	1.02	0.99, 1.05	0.205
Number of times fertilised in last 5 years						0.229
	Intercept	0.61	0.24			
	≤ 3 times in 5 yrs	0.00		1.00		
	> 3 times in 5 yrs	0.52	0.44	1.68	0.73, 4.10	
Cull sheep with bad feet/ leg conformation						0.241
	Intercept	0.94	0.25			
	Yes	0.00		1.00		
	No	-0.51	0.43	0.60	0.26, 1.42	
	Intercept	1.00	0.27			
Number of sheep in mob		0.00	0.00	1.00	1.00, 1.00	0.246

Table 7. Parameter Estimates and odds ratios for the unconditional association between explanatory variables and the ordinal outcome, with $p < 0.25$

Variables	**Categories**	**B**	**SE(b)**	**Odds-ratios**	**95% confidence interval**	**P-value**
Wet season, producer view	Intercept high	-0.29	0.45			0.001
	Intercept medium	1.27	0.47			
	Wetter	0.00		1.00		
	Same	-1.72	0.56	0.18	0.06,0.51	
	Drier	-1.79	0.53	0.17	0.06, 0.46	
Soil type	Intercept high	-1.30	0.36			0.003
	Intercept medium	0.17	0.33			
	Basalt-derived	0.00		1.00		
	Granite-derived	-0.79	0.45	0.45	0.18, 1.10	
	Shale/ slate	-14.29	410.70	<0.001	0, 0.25	
	Mixed	0.12	0.49	1.13	0.43, 2.94	

Percentage of paddock with clover	Intercept high	-2.22	0.35			0.007
	Intercept medium	-0.76	0.29			
	< 30% paddock	0.00		1.00		
	≥ 30% clover	0.99	0.38	2.70	1.30, 5.77	
Area of paddock (hect)	Intercept high	-1.33	0.29			0.024
	Intercept medium	0.13	0.25			
	≤ 100 hectares	0.00		1.00		
	> 100 hectares	-0.85	0.38	0.43	0.20, 0.90	
Percentage of paddock boggy	Intercept high	-2.05	0.33			0.028
	Intercept medium	-0.57	0.27			
	0% of paddock	0.00		1.00		
	≤ 5% of paddock	0.52	0.40	1.69	0.77, 3.72	
	> 5% of paddock	1.47	0.57	4.36	1.45, 13.48	
Lambing season	Intercept high	-2.37	0.42			0.034
	Intercept medium	-0.91	0.36			
	Spring	0.00		1.00		
	Autumn	0.80	0.60	2.22	0.70, 7.04	
	Winter	1.09	0.43	2.96	1.30, 7.12	
Use footbathing to prevent	Intercept high	-1.86	0.29			0.039
	Intercept medium	-0.41	0.22			
	No	0.00		1.00		
	Yes	0.87	0.42	2.39	1.04, 5.50	
Use antibiotics to treat	Intercept high	-1.35	0.28			0.043

	Intercept medium	0.08	0.24			
	Yes	0.00		1.00		
	No	-0.77	0.39	0.46	0.21, 0.98	
Paddock boggy	Intercept high	-0.45	0.66			0.045
	Intercept medium	1.01	0.67			
	Very/ a lot boggy	0.00		1.00		
	Sometimes boggy	-0.59	0.79	0.56	0.11, 2.69	
	Fairly dry/ all the time	-1.44	0.69	0.24	0.06, 0.91	
Months wool at beginning of lambing	Intercept high	-2.02	0.34			0.073
	Intercept medium	-0.56	0.27			
	≤ to 4 months	0.00		1.00		
	> 4 months	0.66	0.37	1.93	0.94, 4.03	
Minimum age of sheep	Intercept high	-1.97	0.33			0.077
	Intercept medium	-0.54	0.27			
	≤ to 3yrs age	0.00		1.00		
	> 3 yrs age	0.64	0.37	1.91	0.93, 3.95	
Breed of sheep	Intercept high	-1.91	0.31			0.089
	Intercept medium	-0.43	0.24			
	Merino	0.00		1.00		
	Merino x British or British	0.65	0.38	1.91	0.91, 4.04	
Altitude of property	Intercept high	-3.01	0.92			0.089
	Intercept medium	-1.62	0.88			
		0.00	0.00	1.00	1.00, 1.00	

Number of times fertilised in last 5 years	Intercept high	-1.86	0.30			0.092
	Intercept medium	-0.44	0.24			
	≤ 3 times in 5 yrs	0.00		1.00		
	> 3 times in 5 yrs	0.63	0.37	1.89	0.90, 3.96	
Fertiliser used	Intercept high	-1.48	0.26			0.101
	Intercept medium	-0.06	0.21			
	Yes	0.00		1.00		
	No	-0.78	0.49	0.46	0.17, 1.16	
Frequency sheep checked	Intercept high	-1.36	0.29			0.105
	Intercept medium	0.12	0.25			
	Daily	0.00		1.00		
	Every 2-3 days	-0.61	0.46	0.55	0.21, 1.33	
	Weekly - fortnightly	-0.68	0.54	0.51	0.17, 1.38	
	Rarely or never	-1.96	1.12	0.14	0.01, 0.87	
Producer pares feet	Intercept high	-1.43	0.28			0.169
	Intercept medium	-0.02	0.23			
	Yes	0.00		1.00		
	No	-0.52	0.38	0.59	0.28, 1.24	
Sheep moved during lambing	Intercept high	-1.76	0.28			0.169
	Intercept medium	-0.34	0.21			
	No	0.00		1.00		
	Yes	0.59	0.42	1.81	0.77, 4.19	

Topography	Intercept high	-1.74	0.31			0.170
	Intercept medium	-0.33	0.25			
	Undulating	0.00		1.00		
	Hilly	0.12	0.52	1.12	0.39, 3.07	
	Flat & undulating	2.05	0.85	7.75	1.29, 62.47	
	Undulating & hilly	0.09	0.47	1.09	0.44, 2.68	
Sheep supplementary fed	Intercept high	-1.29	0.34			0.199
	Intercept medium	0.13	0.31			
	Yes	0.00		1.00		
	No	-0.50	0.38	0.61	0.29, 1.30	
Lambing period (days)	Intercept high	-2.20	0.53			0.225
	Intercept medium	-0.78	0.49			
		0.01	0.01	1.01	0.99, 1.03	
Pasture height	Intercept high	-1.97	0.58			0.228
	Intercept medium	-0.55	0.54			
	0 - 5cm	0.00		1.00		
	5-10cm	0.61	0.59	1.84	0.59, 6.44	
	>10cm	-0.03	0.63	0.97	0.28, 3.65	
Lambing percentage	Intercept high	-1.78	0.32			0.245
	Intercept medium	-0.36	0.26			
	≤ 100%	0.00		1.00		
	> 100%	0.43	0.37	1.53	0.75, 3.16	

8.5 Presentations and publications resulting from project

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