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16 **Abstract**

17 From observational studies, farmers who use parenteral antibacterials to promptly treat all sheep  
18 with footrot (FR) or interdigital dermatitis (ID) have a prevalence of lameness of <2% compared  
19 with a prevalence of 10% lameness reported by farmers who treat lame sheep by trimming  
20 affected feet. We tested the hypothesis that prompt treatment of sheep lame with naturally  
21 developing FR or ID with parenteral and topical antibacterials reduces the prevalence and  
22 incidence of lameness with these conditions compared with less frequent treatment by trimming  
23 hoof horn and applying topical antibacterials. A further hypothesis was that reduction of ID and  
24 FR would improve productivity. A lowland sheep flock with 700 ewes was used to test these  
25 hypotheses in an 18-month within farm clinical trial with four groups of ewes: two intervention  
26 and two control. The duration and severity of lameness was used to categorise sheep into three  
27 weighted scores of lameness (WLS): never lame (WLS0), lame for a maximum of six days with  
28 locomotion score 2 (WLS1) and lame for more than six days or a higher locomotion score  
29 (WLS2). The intervention reduced the prevalence of lameness due to FR and ID in ewes and  
30 lambs and the incidence of lameness in ewes. The WLS was significantly lower in sheep in the  
31 intervention groups. Ewes with a higher WLS were subsequently significantly more likely to  
32 have a body condition score (BCS) <2.5 and have lame lambs. Significantly more ewes lambed  
33 and successfully reared more lambs that were ready for slaughter at a younger age in the  
34 intervention versus control groups. There was an increase in the gross margin of £630 / 100 ewes  
35 mated in the intervention group, including the cost of treatment of £150 / 100 ewes mated. We  
36 conclude that prompt parenteral and topical antibacterial treatment of sheep lame with ID and FR  
37 reduced the prevalence and incidence of these infectious conditions and led to improved health,  
38 welfare and productivity.

39

40 *Keywords:* sheep; footrot; clinical trial; parenteral antibiotics; foot trimming; welfare;

41 productivity

42

### 43 **1. Introduction**

44 Lameness is one of the greatest concerns for poor welfare in sheep (Goddard et al., 2006;

45 Fitzpatrick et al., 2006). It has been estimated to cost the UK industry £24 million / annum

46 (Nieuwhof and Bishop, 2005). More than 90% of farmers in the UK report lameness in their

47 sheep, with a farmer-estimated prevalence of 10% with more than 80% of lameness caused by

48 footrot (FR) and interdigital dermatitis (ID) (Grogono-Thomas and Johnston, 1997; Kaler and

49 Green, 2008a). In a study of 209 sheep farmers, those treating all sheep with FR with parenteral

50 antibacterials and foot sprays reported a significantly lower peak prevalence of FR of 2%

51 compared with the 9% reported by farmers who treated FR by paring the hoof horn and spraying

52 disinfectant on to the foot (Wassink et al., 2003). In addition, farmers who reported prompt

53 treatment of mildly lame sheep also reported a lower prevalence of lameness than those treating

54 groups of lame sheep (Kaler and Green, 2008). Further evidence for the benefits of parenteral

55 antibiotics comes from a prospective longitudinal study of 160 sheep on one farm where the

56 treatment of sheep with FR and ID with parenteral and topical antibacterials was associated with

57 a lower incidence of lameness in the subsequent 4 weeks (Green et al., 2007).

58 *Dichelobacter nodosus* is the necessary pathogen to cause FR (Beveridge, 1941) and is present in

59 the majority of cases of both ID (inflammation of the interdigital skin) and FR (separation of

60 hoof horn from the underlying tissue) (Moore et al., 2005). As a consequence, ID and FR are

61 often a continuum of the same disease. The terms that are equivalent to ID and FR in Australia

62 are benign and virulent FR (Depiazzi et al., 1991). *D. nodosus* is an anaerobic bacterium that has  
63 no known resistance to antibacterials. Parenteral antibacterial treatment of FR leads to recovery  
64 from lesions in over 90% of sheep (Sterk, 1960; Egerton et al., 1968; Grogono-Thomas et al.,  
65 1994) and in a recent factorial design study, over 90% of sheep with FR treated with long acting  
66 oxytetracycline recovered from lesions and lameness within 10 days whilst <30% sheep treated  
67 with foot trimming recovered in this time period (Kaler et al., 2010). This, together with the  
68 evidence above and biological reasoning, led to the hypothesis that prompt treatment of lame  
69 sheep with ID or FR with parenteral and topical antibacterials would reduce the prevalence  
70 (because of a reduced duration of lameness) and incidence (because a reduced infectious period  
71 would decrease the probability of transmission of *D. nodosus* between sheep) of lameness caused  
72 by these diseases compared with the traditional treatment of trimming hoof horn and applying a  
73 topical bactericide. Consequently, the health, welfare and productivity of the flock should  
74 increase. To test these hypotheses, a within flock clinical trial comparing these two treatments  
75 was set up on a convenience-selected farm in Oxfordshire with a commercial lowland spring-  
76 lambing flock of approximately 700, mainly North Country mule ewes. The objective was to  
77 compare prompt treatment of FR and ID with parenteral and topical antibacterial with a typical  
78 farmer's management of FR and ID (Wassink et al., 2003; 2004) which includes less frequent  
79 treatment of lame sheep with ID and FR by trimming hoof horn and applying a topical  
80 bactericide. The study lasted from March 2005 to December 2006.

81

## 82 **2. Materials and Methods**

83 2.1 *Study design March to September 2005*

84 A sample size calculation was used to estimate the number of ewes required per treatment to test  
85 a reduction in lameness of 50% assuming a prevalence of lameness of 10%, 80% power and 95%  
86 significance. A total of 147 ewes were required per treatment.

87 Ewes lambed from the second week of March 2005. Ewes and lambs were identified with both  
88 ear tags and flank markings. The age (dentition), body condition score (BCS) (MAFF, 1994) and  
89 conformation of feet of ewes were recorded. All foot lesions were also ([www.footrotinsheep.org](http://www.footrotinsheep.org))  
90 recorded. Ewes with triplets were excluded from the trial. After the ewes lambed they were  
91 allocated by researchers to one of two fields with similar pasture type and stocking density using  
92 stratified random sampling on age, BCS, foot conformation and presence of existing footrot  
93 lesions. Once the first two matched fields were stocked, two further fields with similar pasture  
94 type were filled. Each group consisted of approximately 175 ewes and their lambs (Table 1). The  
95 matched groups were moved between fields simultaneously and to similar pasture types and  
96 stocking densities throughout the trial period. In May 2005, when the youngest lamb in each  
97 group was four weeks old, one group from each pasture type was selected to be an intervention  
98 treatment group by tossing a coin; the other became the matched control group, thus giving two  
99 intervention and two control groups. Six observers collected data on age, BCS, locomotion and  
100 foot lesions over the 18-month study. All observers were trained by GJW who attended one day  
101 of data collection each week to check that observers remained consistent in their scoring.

102 A locomotion scoring system (Kaler et al., 2008b) was used by these trained researchers to score  
103 the locomotion of all sheep in all four groups each day for 5 weeks and then each weekday until  
104 October 2005. The identity, locomotion score and the limb or limbs that were observed lame  
105 were recorded for every sheep that had a locomotion score  $\geq 1$  in each group.

106 Treatments

107 Intervention groups: In the intervention groups, sheep with a locomotion score  $\geq 2$  were caught  
108 for diagnosis and treatment within 1-3 days of becoming lame. Their feet were inspected and the  
109 type and severity of lameness recorded. Sheep with FR or ID were treated with parenteral  
110 antibacterials (Terramycin LA 200 mg/ml, Pfizer Ltd; 20mg per kg bodyweight for ewes; and  
111 Engemycin LA 200 mg/ml, Intervet/Schering-Plough Animal Health; 15mg per kg bodyweight  
112 for lambs) and an antibacterial spray (Terramycin Aerosol Spray, 150ml pack, 4g  
113 Oxytetracycline Hydrochloride 3.92% w/w, Pfizer Ltd.). Other foot lesions were treated using  
114 standard protocols (Winter, 2004). When a sheep in an intervention group had a locomotion  
115 score  $\geq 2$  ten days after treatment it was re-caught, re-examined and re-treated.

116 Control groups: Lame sheep in the control groups were treated by the farm shepherd who had  
117 managed the flock for over 10 years. He inspected each group of sheep as part of his usual  
118 routine and was blind to the locomotion scores. When he elected to treat a sheep he was assisted  
119 by the research team who recorded the foot affected and cause of lameness. If ID was present,  
120 the shepherd trimmed the hoof horn wall and sprayed the feet with the topical spray above. If FR  
121 was present the hoof horn over lesions was trimmed away and the exposed lesions were sprayed  
122 with the topical spray. Other foot lesions were treated using standard protocols (Winter, 2004).

123

## 124 2.2 *Changes to the study design after September 2005*

125 Lambs were weaned on 20/08/2005. One month after weaning, one intervention group was  
126 selected by tossing a coin (solid grey line, Figure 1) and swapped with its matched control group  
127 in a cross over design. As a result, approximately 25% of the sheep were always in an  
128 intervention and 25% always in a control group, with the other 50% crossing over. Some ewes

129 (Table 1) were culled from all four groups and replacement ewes were added to the groups to  
130 balance the number of sheep per group. Both replacement ewes and rams used for mating were  
131 examined and if necessary treated. These sheep were not put with their group until sound. From  
132 October 2005, the treatments above were carried out twice each week in the intervention group  
133 rather than every week-day. No lame sheep were treated during early pregnancy (between 24<sup>th</sup> of  
134 October 2005 and the 9<sup>th</sup> of January 2006) except when sheep were gathered on 8<sup>th</sup> and 18<sup>th</sup>  
135 November and 12<sup>th</sup> December. The intervention groups were combined to facilitate housing on  
136 the 10<sup>th</sup> of February 2006. The control groups were also combined. Ewes were housed in several  
137 large straw-bedded solid-floored pens until they lambed. Straw was added to the pens each day  
138 and was 30 – 40 cm deep. Ewes were moved to individual pens after they had lambed.

139

### 140 2.3 *Study design from May to September 2006*

141 Two intervention groups and two control groups were re-formed from the merged intervention  
142 group and merged control group, respectively (Table 2). No ewes were put out to pasture until  
143 sound. Treatments for lameness started when the youngest lamb in a group was four weeks old.  
144 The intervention and control groups were treated as for the first lamb production season (2005)  
145 with the exception that lambs with ID were treated with topical antibacterials but not parenteral  
146 antibacterials.

147

### 148 2.4 *Monitoring health and production in the flock*

149 Ewe age, BCS and foot conformation and foot lesions were scored again at weaning in 2005 and  
150 at lambing and weaning 2006. The number of lambs born alive and dead, and the sex, birth



151 weight and adoption details of all lambs were recorded in 2005 and 2006. Ewe and lamb deaths  
152 and the date lambs left the farms as finished or store lambs were also recorded in 2005 and 2006.

153

#### 154 2.5 *Data storage and analysis*

155 Data were entered into a database (Access 2003, Microsoft) and checked for errors before  
156 statistical analysis in Stata SE 10, (Statacorp) and MLwiN 2.0 (Rasbash et al., 1999). Ewe body  
157 condition was categorised into below recommended ( $<2.5$ ) and at or above recommended ( $\geq 2.5$ ),  
158 birth weights were categorised by a good vs less good birth weight of  $<5.5\text{kg}$  and  $\geq 5.5\text{ kg}$  and  
159 ewe age at a median of  $<4$  years and  $\geq 4$  years. Breed was categorised into mule and other cross-  
160 breeds. Parametric and non-parametric tests were used to investigate univariable associations as  
161 appropriate for the data distributions.

162 Ewes at pasture with lambs from May – August 2005 and May – September 2006 were analysed  
163 separately from weaned ewes were at pasture; September 2005 to housing in February 2006.

164 Data during housing were not used in the analysis because deep litter straw restricted observation  
165 of the ewes' legs.

166 The groups compared were intervention and control groups in 2005 and 2006 and also the sub  
167 group of ewes that were always in an intervention group or always in a control group ( $n = 176$ ).

168 These ewes were dispersed within the two intervention and two control groups in 2006.

169

170 The mean prevalence and incidence of lameness were plotted to visualise the effects of the  
171 intervention and the cross-over design. The prevalence and incidence of lameness in matched  
172 groups were compared using t tests. The prevalence was calculated from the number of sheep  
173 with locomotion score 2 or above at an observation divided by the number of sheep in the group

174 divided by the number of days that observations occurred in a period. The incidence was  
175 calculated in the same way except that the denominator was the group size minus the number of  
176 non-susceptible sheep (those lame within the last 10 days).

177 Sheep had up to four episodes of lameness in a time period. To test the hypothesis that duration  
178 and severity of lameness affected production an weighted lameness score (WLS) was calculated  
179 where  $d$  = duration of an episode of lameness,  $m$  = maximum locomotion score during the  
180 episode of lameness,  $\Sigma$  = summed for all episodes of lameness in a time period

$$181 \quad \text{WLS} = \Sigma (d*m)$$

182 an episode of lameness started on the day the locomotion score was first observed  $\geq 2$  and ended  
183 on the day midway between the last observation of locomotion score  $\geq 2$  and next observation of  
184 locomotion score  $< 2$ , unless a sheep was observed lame again within 10 days in which case this  
185 was part of the current episode.

186 The WLS was then categorised into WLS0, sheep that never had a locomotion score  $\geq 2$ , WLS1,  
187 sheep with a weighted lameness score  $\leq 12$  (e.g. a sheep lame over 2 episodes, one with 3 days of  
188 locomotion score 2 and another with 2 days of locomotion score 3) and WLS2, sheep with a  
189 weighted lameness score  $> 12$ . This three level categorical variable was used in an ordinal  
190 multilevel multinomial regression analysis (Goldstein, 2003) to investigate impact of treatment  
191 on duration and severity of lameness. A multilevel binomial logistic regression analysis was used  
192 to investigate factors associated with ewe body condition ( $< 2.5$  or  $\geq 2.5$ ). Cox proportional  
193 survival analysis with robust estimates of variance using the cluster-option in Stata (Williams,  
194 2000) was used to investigate the age at finishing for lambs.

195 A cost-benefit analysis of the intervention treatment vs control treatment was done using  
196 production figures from sheep that were in the intervention or control groups for the whole 18-  
197 month trial period and other existing data.

198

### 199 **3. Results**

#### 200 *3.1 Prevalence and incidence of lameness in ewes and lambs*

201 Descriptive statistics are presented in Tables 1 and 2. The four groups started with similar  
202 numbers of ewes by BCS, foot conformation, FR and ID. Although there were fewer treatments  
203 in the control groups (Tables 1 and 2) there were significantly more episodes of lameness with a  
204 maximum locomotion score >2 compared with the intervention groups in both ewes and lambs  
205 (Tables 3 and 4) over the trial period. Ewes and lambs in the intervention groups were lame for  
206 significantly fewer days for each episode of lameness: 4.3 (CI: 4.0 – 4.6) and 4.0 (CI: 3.6 – 4.3)  
207 compared with ewes and lambs in the control groups 7.9 (CI: 7.2 – 8.7) and 7.3 (CI: 6.4 – 8.2)  
208 respectively.

209 The prevalence and incidence of lameness in ewes in the intervention groups fell in the first 4 – 8  
210 weeks each time the intervention was introduced in 2005 and in 2006 (Figure 1). The mean  
211 prevalence and incidence of lameness in ewes was significantly lower in intervention vs control  
212 groups the both production seasons (Tables 1 and 2). In 2005, the mean prevalence of lameness  
213 in lambs was significantly lower in the intervention groups compared with the control groups  
214 from week 8 onwards (Figure 2, Table 1) but there was no significant difference in the mean  
215 incidence of lameness.

216 Over the intervention period, 35 isolates of *D. nodosus* cultured from ewes treated with  
217 parenteral antibacterials at least twice were tested for antibacterial resistance to oxytetracycline  
218 using a modified MIC test. All isolates were sensitive to oxytetracycline (DEFRA, 2008).

219

### 220 3.2 *Factors associated with lameness*

221 The intervention treatment significantly reduced the number and / or severity of lameness events:  
222 ewes and lambs in the control groups were more likely to have a WLS2 than ewes and lambs in  
223 the intervention groups (Table 1). WLS2 was also more likely in ewes > 4 yrs old (Table 5) and  
224 in lambs which were single born, male or their mother was lame, especially if the ewe had had a  
225 WLS2 (Table 5). Ewes were less likely to become lame between September 2005 and housing in  
226 February 2006 if they had been in the intervention group in 2005. A ewe was significantly more  
227 likely to become lame in this period if she had been lame in the previous lamb production period  
228 (Table 1).

229

### 230 3.3 *Factors associated with ewe body condition*

231 At the start of the intervention there were 73% sheep in the intervention and 77% sheep in  
232 control groups with BCS  $\geq 2.5$  ( $P > 0.05$ ). There were significantly more ewes with a BCS  $\geq 2.5$  in  
233 the intervention groups at weaning 2005 (62%), 2006 (76%) and lambing 2006 (83%) compared  
234 with ewes on the control groups with 26%, 62% and 61% with BCS  $\geq 2.5$  respectively at these  
235 times ( $P < 0.01$ ). BCS  $\geq 2.5$  at weaning 2005 was associated with a previous WLS of 0 or 1 than  
236 WLS2, a BCS  $\geq 2.5$  at lambing 2005, rearing one lamb, less than 4 years of age and mule breed

237 (Table 7). Ewes with a  $BCS \geq 2.5$  at lambing 2006 were more likely to have had a WLS 0 or 1  
238 than WLS2 in 2005, a  $BCS \geq 2.5$  at weaning 2005 and produced a single lamb in 2006.

239

#### 240 3.4 *Cost-benefit analysis of the intervention*

241 The cost of reducing the prevalence of lameness in the first six weeks of the study in 2005 was  
242 £45 and £278 per 100 ewes in the two intervention groups; the prevalence of lameness fell more  
243 rapidly in one intervention group than the other (Figure 1).

244 There were 167 ewes that were either in intervention or control groups for the whole project.

245 From week 8 until the end of the project the mean prevalence and incidence of lameness in ewes  
246 that were always in intervention groups (solid black line, Figure 1) were significantly lower than  
247 in ewes that were always in control groups (dashed black line, Figure 1) (2.4 (95% CI: 1.7 – 3.1)  
248 vs. 5.6 (CI: 4.6 – 6.6) and 1.4 (CI: 1.0 – 1.8) vs. 2.5 (CI: 1.9 – 3.1), respectively). These ewes  
249 were used to estimate the impact of the intervention on productivity because they remained under  
250 the same treatment for two seasons.

251 There were fewer barren ewes and ewes that died among ewes always in the intervention group  
252 than always in the control group, resulting in more productive ewes per 100 ewes put to the ram  
253 and lower replacement costs (Table 9). There were 17 more lambs reared per 100 ewes put to the  
254 ram. In 2006, one year after the intervention was started, a significantly higher percentage of  
255 lambs born to ewes always in the intervention group were finished before weaning compared  
256 with lambs born to ewes in the control group; 18% versus 6%, respectively (Table 8).

257 The additional cost of the intervention was calculated as £150 per 100 ewes put to the ram (Table  
258 4). The intervention improved the gross margin by £630 in 2006 (Table 9), more than 50%  
259 higher than the gross margin in the control group.

260

## 261 **4. Discussion**

### 262 *4.1 Impact on prevalence and incidence of footrot and interdigital dermatitis*

263 We have demonstrated that prompt treatment of individual lame sheep with parenteral and  
264 topical antibacterials given to those with FR or ID significantly reduced the prevalence and  
265 incidence of lameness in ewes compared with delayed treatment of individual lame ewes with  
266 FR/ID treated with foot trimming and topical antibacterials. This latter management is used by  
267 the majority of sheep farmers in the UK and elsewhere in the world and so was an ideal control  
268 to provide useful results to farmers and to compare with a new practice. It is clear from our  
269 results that prompt treatment of FR/ID with parenteral and topical antibacterials was not only  
270 beneficial to sheep health and welfare but also cost effective, in that the ewes in the intervention  
271 groups were in better body condition, produced more lambs and reared them more rapidly,  
272 presumably because of their better body condition.

273 The reduction in prevalence of lameness occurred in ewes and lambs on each occasion that the  
274 intervention was started (May 2005, September 2005, May 2006). The reduction in incidence of  
275 lameness suggests that the treatment reduced re-occurrence in the same sheep; this could suggest  
276 that transmission of *D. nodosus* was reduced or foot health was improved. This might explain  
277 why there was no reduction in incidence of FR or ID in lambs; very few lambs were treated more  
278 than once. Alternatively, it might have been lack of power in the study because few lambs were  
279 lame.

280 All ewes with ID (as well as those with FR) were treated with parenteral antibacterials because in  
281 Moore et al., (2005) ID lesions were infected with *D. nodosus*, the cause of footrot on 60% of  
282 occasions. Lambs with ID were treated with parenteral antibiotics in 2005 but not 2006 because  
283 the farm shepherd was concerned about meat withdrawal times.

284

#### 285 4.2 *Impact on productivity*

286 The impact of footrot lesions on bodyweight, lamb growth rates and wool growth in untreated  
287 sheep has been reported previously (Stewart et al., 1984; Marshall et al., 1991; Nieuwhof et al.,  
288 2008). This is the first paper to report the impact of duration and severity of lameness on  
289 production in meat sheep. It is useful to know that treating sheep lame with FR or ID promptly  
290 will make them more productive. The reduction in severity and duration of lameness in  
291 intervention groups was statistically associated with a higher body condition score (BCS) and  
292 greater lamb production. This is probably because low BCS affects fertility and fecundity (Rhind  
293 and McNeilly, 1986; Forcada et al., 1992; Abecia et al., 2006). Low BC in ewes also leads to  
294 high mortality in lambs (Binns et al., 2002), probably because of low birth weights (Christley et  
295 al., 2003; Everett-Hincks and Dodds, 2008) and insufficient production of colostrum and milk  
296 (Mellor and Murray, 1985; O'Doherty et al., 1997).

297 Significantly more lambs were finished before weaning in the intervention groups than in the  
298 control groups. This is a very important component of the cost effectiveness of the treatment  
299 because one of the main factors determining profitability of lowland flocks is the percentage of  
300 lambs finished (MLC, 2001). This is because supplementary feed to lambs after weaning is  
301 expensive and so impacts on profits. This, together with the production benefits from the current

302 intervention (Table 4), indicates that it was cost effective to put in the extra time (approximately  
303 two treatments per 100 ewes per week) and drug resources needed to treat individual lame sheep.  
304 Rapid treatment of lame sheep might also prevent hyperalgesia that is reported in chronically  
305 lame sheep (Fitzpatrick et al., 2006) and so ensure that energy is put into body condition,  
306 reproduction and milk production.

307

#### 308 *4.3 Concerns regarding the development of antibiotic resistance*

309 In this trial there was no evidence that the parenteral treatments led to bacterial selection for  
310 resistance to oxytetracycline. This might be because although there were many treatments they  
311 were staggered over time with 1 – 8 treatments per group per week, so there was no selective  
312 pressure for development of resistance. Whilst the use of parenteral antibiotic to treat infectious  
313 lameness might not be considered the ideal, it is highly efficacious as a treatment and, as this  
314 trial has clearly shown, of considerable benefit to animal welfare and production. It is the best  
315 current treatments, the alternatives, trimming and spraying individuals and the whole flock  
316 methods of footbathing and footrot vaccination are less effective treatments and in many sheep  
317 flocks in the UK do not lead to acceptable levels of lameness control (Kaler and Green, 2009;  
318 Kaler et al., 2010; Schwartzkoff et al., 1993).

319

#### 320 *4.4 Study design*

321 This within farm clinical trial testing two treatments was carried out on one lowland spring-  
322 lambing flock with a compliant farm management team. This approach enabled us to make  
323 detailed observations and collect a comprehensive, reliable dataset. We are uncertain whether the  
324 improvements that occurred through the intervention would be quantitatively similar on other



325 lowland sheep farms with similar management and prevalence of FR and ID in the UK and  
326 worldwide, but we would expect the qualitative results to be generalisable. The distribution of  
327 age, BCS, foot conformation (Hawker, 2007) and prevalence of lameness in ewes at the start of  
328 the study were similar in all four groups, suggesting that the random stratification was successful.  
329 The prevalence of lameness (8%) was also similar to that reported by farmers in previous studies  
330 (Grogono-Thomas and Johnson, 1997; Wassink et al., 2003; Kaler and Green, 2009). The group  
331 of ewes that moved from intervention to control came from the intervention group with the most  
332 rapid reduction in lameness in 2005 (grey solid bar Figure 1). The cross over in 2006 was used to  
333 demonstrate that lameness patterns followed the treatment regimes. The incidence and  
334 prevalence of lameness rose when sheep were moved from intervention to control groups and  
335 vice versa. This suggests that lameness was a correlate for control of FR and ID. The time to a  
336 stable prevalence of lameness of 1 – 2%, and the number of treatments required varied between  
337 intervention groups. This might have occurred because of differences in the environment in the  
338 fields within treatments or that some sheep in intervention group 2 were more infectious.  
339 Treatments were matched by field type to minimise the potential impact of climate and soil.  
340 Sheep were not in sufficient numbers of fields to test a treatment field interaction. Climate is  
341 important in clinical impact of *D. nodosus* (Green and George, 2008) and is one explanation for  
342 the difference in incidence of lameness between 2005 (a very wet, cool year) and 2006 (a hot,  
343 dry year). We used groups with the same treatments rather than individuals within groups  
344 because we wanted to test whether the treatment of lame sheep reduced transmission between  
345 sheep.  
346 To minimise observer bias, all observers (n=6) were trained by GJW who also observed the  
347 observers once each week to prevent drift in scoring of sheep. In addition, observers regularly

348 discussed scores to confirm continued agreement. A validated locomotion scoring system (Kaler  
349 and Green, 2008b) was used to assess the quantity and severity of lameness with paired groups  
350 inspected on the same day. The scales for scoring ID, FR lesions and foot integrity have not yet  
351 been evaluated and consequently might introduce error. Every effort was made to ensure that all  
352 sheep in each field were observed at each observation. Sheep were marked on their flank and had  
353 large ear tags. Despite this, sheep that were being observed after a lameness event were  
354 occasionally missed for one observation. There were no further feasible improvements that could  
355 be made to the design to reduce these reporting errors.

356 The farmer was blind to locomotion scores to prevent the possibility of him altering his usual  
357 management. He was an experienced stock person who had managed the flock for over 10 years  
358 and his treatment of FR is typical of that used by many farmers in GB (Wassink et al., 2003,  
359 2004; Kaler and Green, 2008, 2009). This makes the results from this study highly relevant to  
360 many farmers and was the ideal baseline control for this clinical trial. It does mean that this study  
361 does not compare a treatment alone but time to known good treatment. There is a wealth of  
362 evidence that antibacterials lead to recovery from FR (Sterk, 1960; Egerton et al., 1968;  
363 Grogono-Thomas et al., 1994; kaler et al., 2010) and the aim of this study was more than  
364 repeating such research. Our results highlight that it is the duration and severity of lameness that  
365 affects sheep health and productivity and that is why we see an improved performance in sheep  
366 in the intervention groups. Rate of treatment is essential as well as appropriate treatment.

367

## 368 **5. Conclusions**

369 We conclude that prompt individual treatment of all lame sheep with ID and FR with parenteral  
370 and topical antibacterials reduced the prevalence of FR and ID in ewes and lambs and the

371 incidence of these conditions in ewes. The reduced duration and severity of lameness improved  
372 the production of the flock through increased body condition in ewes which led to higher  
373 lambing rates, fewer deaths in ewes and lambs and earlier finishing of lambs. The cost-benefit  
374 was an increase in gross margin of £630 (€932) per 100 ewes put to the ram.

375

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381

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471

472 **Figure 1.** Two-week mean prevalence and incidence of lameness in ewes between May 2005  
473 and September 2006

474 Key: solid black line = always intervention, dashed black line = always control, solid grey line =  
475 intervention then intervention crossed over from control, dashed grey line = control then control  
476 crossed over from intervention

477 **Figure 2.** Two-week mean prevalence and incidence of lameness in lambs over two lamb  
478 production seasons, May – August 2005 and May – August 2006

479 Key: solid black line = dam always intervention, dashed black line = dam always control, solid  
480 grey line = dam intervention (2005) then intervention crossed over from control (2006), dashed  
481 grey line = dam control (2005) then control crossed over from intervention (2006)

482



483 **Table 1. Descriptive statistics 2005**  
 484

|                               | Intervention<br>Group 1 | Intervention<br>Group 2 | Control<br>Group 1   | Control<br>Group 2 |
|-------------------------------|-------------------------|-------------------------|----------------------|--------------------|
|                               | Control yr 2            |                         | Intervention<br>yr 2 |                    |
| No. ewes                      | 175                     | 177                     | 181                  | 177                |
| No. lambs                     | 364                     | 323                     | 357                  | 312                |
| Date first ewe lambed         | 7/03/2005               | 17/03/2005              | 11/03/2005           | 17/03/2005         |
| % FR foot exam March 2005     | 26.1                    | 20.5                    | 19.4                 | 20.9               |
| % ID foot exam March 2005     | 44.9                    | 43.8                    | 38.9                 | 50.3               |
| No. treatments for FR & ID    | 78                      | 232                     | 20                   | 18                 |
| No. treatments other lameness | 5                       | 4                       | 2                    | 0                  |
| Prevalence (95% CI)           | 1.9                     | 1.1                     | 4.6                  | 5.3                |
| lame ewes                     | (1.1 – 2.6)             | (0.6 – 1.7)             | (2.6 – 6.7)          | (3.5 – 7.1)        |
| Incidence (95% CI)            | 1.3                     | 0.8                     | 2.3                  | 2.5                |
| lame ewes                     | (0.7 – 1.8)             | (0.4 – 1.2)             | (1.4 – 3.1)          | (2.0 – 3.0)        |
| Prevalence (95% CI)           | 0.8                     | 1.41                    | 2.5                  | 1.45 (1.2 –        |
| lame lambs                    | (0.65 – 0.95)           | (CI: 0.9 – 1.8)         | (CI: 1.7 – 3.3)      | 1.7)               |
| Incidence (95% CI)            | 0.4                     | 1.1                     | 1.1                  | 0.6                |
| lame lambs                    | (CI: 0.2 – 0.6)         | (0.8 – 1.4)             | (CI: 0.8 – 1.4)      | (0.4 – 0.8)        |
| No. (%) culled 2005           | 49 (28)                 | 31 (18)                 | 52 (29)              | 54 (36)            |
| % FR foot exam Sept. 2005     | 5 (3)                   | 10 (6.1)                | 22 (13)              | 18 (11)            |
| % ID foot exam Sept. 2005     | 5 (3)                   | 31 (19)                 | 20 (12)              | 66 (39)            |

485 **No. number, % percent**  
 486

487 Table 2. **Descriptive statistics 2006**  
 488

|                                | Intervention<br>Group 3 | Intervention<br>group 4 | Control<br>Group 3  | Control<br>Group 4  |
|--------------------------------|-------------------------|-------------------------|---------------------|---------------------|
| No. ewes                       | 147                     | 147                     | 144                 | 132                 |
| No. lambs                      | 265                     | 278                     | 267                 | 240                 |
| Date first ewe lambed          | 13/03/2005              | 22/03/2006              | 12/03/2006          | 20/03/2006          |
| No. (%) FR at exam March 2006  | 5 (3.4)                 | 6 (4.1)                 | 3 (2.0)             | 7 (5.3)             |
| % ID at first exam March 2006  | 31 (21)                 | 15 (10.2)               | 31 (21.5)           | 13 (9.8)            |
| No. treatments FR&ID           | 102                     | 76                      | 23                  | 49                  |
| No. treatments other lameness  | 8                       | 2                       | 5                   | 1                   |
| Prevalence (95% CI) lame ewes  | 1.87<br>1.39 – 2.55     | 0.81<br>0.51 – 1.11     | 1.69<br>1.31 – 2.07 | 7.65<br>6.65 – 8.65 |
| Incidence (95% CI) lame ewes   | 1.33<br>0.83-1.83       | 0.55<br>0.27 – 0.83     | 1.06<br>0.68 – 1.44 | 3.72<br>2.88 – 4.56 |
| Prevalence (95% CI) lame lambs | 1.55<br>1.09 – 2.01     | 0.46<br>0.22 – 0.70     | 1.03<br>0.75 – 1.35 | 4.29<br>3.59 – 4.99 |
| Incidence (95% CI) lame lambs  | 1.01<br>0.59 – 1.43     | 0.21<br>0.07 – 0.35     | 0.72<br>0.12 – 1.32 | 1.84<br>0.44 – 2.24 |
| No. (%) culled 2006            | 32 (22.0)               | 36 (24.4)               | 33 (22.9)           | 28 (21.2)           |
| No. (%) FR foot exam Oct. 2006 | 0 (0)                   | 0 (0)                   | 7 (5)               | 20 (16)             |
| No. (%) ID foot exam Oct. 2006 | 66 (44)                 | 29 (20)                 | 51 (38)             | 28 (22)             |

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 491

492 Table 3. Number of episodes of lameness by maximum locomotion score in ewes and lambs ; 2005 and  
 493 2006 data combined.  
 494

| Maximum locomotion score <sup>a</sup> | Intervention ewe episodes (n=628) | Control ewe episodes (n=622) | Intervention lamb episodes (n=1047) | Control lamb episodes (n=1029) |
|---------------------------------------|-----------------------------------|------------------------------|-------------------------------------|--------------------------------|
| 2                                     | 271                               | 257                          | 306                                 | 262                            |
| 3                                     | 45                                | 85                           | 43                                  | 94                             |
| 4                                     | 46                                | 85                           | 56                                  | 89                             |
| 5 or 6                                | 7                                 | 26                           | 5                                   | 26                             |

495 <sup>a</sup> Kaler et al., 2008b

496

497 Table 4. Number, percent, median and IQ range of weighted lameness score (WLS) for ewes and  
 498 lambs in intervention and control groups; 2005 and 2006 data combined  
 499

|              | Intervention groups combined |       |         | Control groups combined |       |          |
|--------------|------------------------------|-------|---------|-------------------------|-------|----------|
|              | WLS 0                        | WLS 1 | WLS 2   | WLS 0                   | WLS 1 | WLS 2    |
| <b>Ewes</b>  |                              |       |         |                         |       |          |
| Number       | 398                          | 143   | 86      | 390                     | 95    | 136      |
| percent      | 63                           | 23    | 14      | 63                      | 15    | 22       |
| WLS Median   | 0                            | 6     | 27      | 0                       | 6     | 63       |
| WLS IQ range | –                            | 4 – 8 | 18 – 48 | –                       | 4 – 9 | 29 – 137 |
| <b>Lambs</b> |                              |       |         |                         |       |          |
| Number       | 754                          | 217   | 76      | 755                     | 142   | 132      |
| percent      | 72                           | 21    | 7       | 73                      | 14    | 13       |
| WLS Median   | 0                            | 6     | 24      | 0                       | 6     | 52       |
| WLS IQ range | –                            | 4 – 8 | 18 – 40 | –                       | 4 – 8 | 28 – 98  |

500  
501

502 **Table 5.** Multilevel multinomial logistic regression models of factors associated with weighted  
 503 lameness score (WLS) 1 and 2 versus 0 in lactating and dry / pregnant ewes

|   |                    | WLS 1<br>(n=238) |                 | WLS 2<br>(n=221) |                 |
|---|--------------------|------------------|-----------------|------------------|-----------------|
|   | No. (%)<br>exposed | OR               | 95% CI          | OR               | 95% CI          |
| <b>Lactating ewes (n = 1245)</b>  |                    |                  |                 |                  |                 |
| Intervention vs control   | 626 (50)           | 1.47             | 1.10 – 1.96     | 0.62             | 0.46 – 0.84     |
| ≥4 yrs vs <4 yrs age  | 652 (52)           | 1.17             | 0.88 – 1.55     | 1.37             | 1.02 – 1.84     |
| Random effects  |                    | Var.             | SE              | Var.             | SE              |
| Variation between years   |                    | 0.05             | 0.21            | 0.09             | 0.22            |
| Covariance with score   |                    |                  |                 |                  |                 |
| Ewe   |                    | -0.01            | 0.16            |                  |                 |
| <b>Ewes dry / pregnant always<br/>intervention or control (n = 174)</b> |                    |                  |                 |                  |                 |
|   |                    |                  | WLS 1<br>(n=60) |                  | WLS 2<br>(n=41) |
| Intervention vs control   | 98 (56)            | 0.63             | 0.31 – 1.26     | 0.19             | 0.08 – 0.43     |
| Ewe WLS>0 May - Sept<br>2005  | 79 (45)            | 1.98             | 1.00 – 3.93     | 4.01             | 1.80 – 8.96     |

504 No. number, % percent, OR: odds ratio, CI, confidence interval, Var.: variance, SE: standard  
 505 error

506

507

508 Table 6. Multilevel multinomial logistic regression model of factors associated with higher  
 509 weighted lameness score (WLS) in lambs in both 2005 and 2006

|                                  | No. (%)<br>exposed | WLS1<br>(n=355) |             | WLS2<br>(n=207) |             |
|----------------------------------|--------------------|-----------------|-------------|-----------------|-------------|
| Intervention vs control<br>group | 1033 (50)          | 1.54            | 1.21 – 1.96 | 0.62            | 0.45 – 0.84 |
| Ewe WLS>0                        | 754 (37)           | 2.49            | 1.96 – 3.16 | 3.54            | 2.60 – 4.80 |
| Single vs twin                   | 420 (20)           | 1.45            | 1.10 – 1.92 | 1.44            | 1.02 – 2.05 |
| Male vs female                   | 1058 (51)          | 1.28            | 1.01 – 1.63 | 1.73            | 1.28 – 2.36 |
| Random effects                   |                    | Var.            | SE          | Var.            | SE          |
| Variance within litters          |                    | 0.24            | 0.18        | 0.44            | 0.27        |
| Variance between litters         |                    | 0.00            | 0.00        | 0.00            | 0.00        |
| Covariance with score            |                    |                 |             |                 |             |
| Litter                           |                    | 0.40            | 0.16        |                 |             |
| Ewe                              |                    | 0.00            | 0.00        |                 |             |

510 **No. number, % percent**

511

512 **Table 7.** Multilevel multivariable binomial logistic regression model of factors associated with  
 513 ewe body condition  $\geq 2.5$

| At weaning 2005 and 2006   |                    |      |              |                     |
|--|--------------------|------|--------------|---------------------|
| Variable   | No. (%)<br>exposed | OR   | 95% CI       | <i>P</i> -<br>value |
| Ewe body condition at previous lambing $\geq 2.5$ vs $< 2.5$                       | 880 (77)           | 2.83 | 2.09 – 3.83  | <0.01               |
| Rearing single lamb vs twin  | 390 (34)           | 1.80 | 1.38 – 2.36  | <0.01               |
| WLS2 compared with WLS0 or WLS1 before weaning                                     | 218 (19)           | 0.54 | 0.39 – 0.75  | <0.01               |
| Ewe age $< 4$ vs $\geq 4$ yrs  | 543 (47)           | 1.59 | 1.23 – 2.05  | <0.01               |
| Mules vs other crossbreeds   | 814 (71)           | 1.52 | 1.14 – 2.02  | <0.01               |
| Random effects   | Var.               | SE   |              |                     |
| Variation between years  | 0.13               | 0.16 |              |                     |
| Lambing 2006 - Ewes always in the intervention or always in control groups (n=167) |                    |      |              |                     |
| Ewe body condition at weaning 2005 $\geq 2.5$ vs $< 2.5$                           | 90 (54)            | 7.63 | 3.30 – 17.65 | <0.01               |
| WLS2 between Sept 2005 and Feb 2006 compared with WLS0 or WLS1                     | 39 (23)            | 0.31 | 0.13 – 0.73  | <0.01               |
| Single vs multiple litter  | 42 (25)            | 2.73 | 1.02 – 7.26  | <0.05               |

514 WLS weighted lameness score, No. number, % percent, OR: odds ratio, CI confidence interval,  
 515 Var.: variance, SE: standard error  
 516

517 **Table 8.** Performance and cost-benefit analysis of the intervention from weaning 2005<sup>a</sup> to  
 518 weaning 2006 per 100 ewes put to the ram.

| Performance                 | Intervention<br>(No./100<br>ewes) | Control<br>(No./100<br>ewes) | Financial results                    | Intervention<br>(£) | Control<br>(£) |
|-----------------------------|-----------------------------------|------------------------------|--------------------------------------|---------------------|----------------|
| Empty ewes                  | 4                                 | 7                            | Slaughter lamb sales<br>@ £35 / lamb | 1098                | 331            |
| Ewe deaths                  | 3                                 | 5                            | Store lamb sales<br>@£25 / lamb      | 3572                | 3701           |
| Productive ewes             | 93                                | 88                           | Wool                                 | 140                 | 132            |
| Total lambs born            | 186                               | 176                          | Gross receipts                       | 4809                | 4165           |
| Lambs born<br>dead          | 7                                 | 10                           | Replacement costs<br>@£48.50 per ewe | 811                 | 1055           |
| Lambs born<br>alive         | 179                               | 166                          | <b>Total output</b>                  | <b>3998</b>         | <b>3109</b>    |
| Lambs deaths<br>after birth | 5                                 | 9                            | Feed costs £13.50 /<br>ewe           | 1201                | 1136           |
| Lambs reared                | 174                               | 157                          | Vet & medicine @£5<br>/ ewe          | 465                 | 440            |
| Lambs finished              | 31                                | 10                           | Intervention cost <sup>a</sup>       | 150                 | 0              |
| Lambs sold as<br>stores     | 143                               | 148                          | Other costs £3.80                    | 356                 | 337            |
|                             |                                   |                              | <b>Total variable costs</b>          | <b>2173</b>         | <b>1914</b>    |
|                             |                                   |                              | <b>Gross Margin</b>                  | <b>1825</b>         | <b>1195</b>    |

519 <sup>a</sup> Cost of treatment parenteral antibacterial £1, antibacterial spray £0.30, Time 5.6 min  
 520 (unpublished data, The University of Warwick); Minimum wage cost (per hour): £5.05  
 521



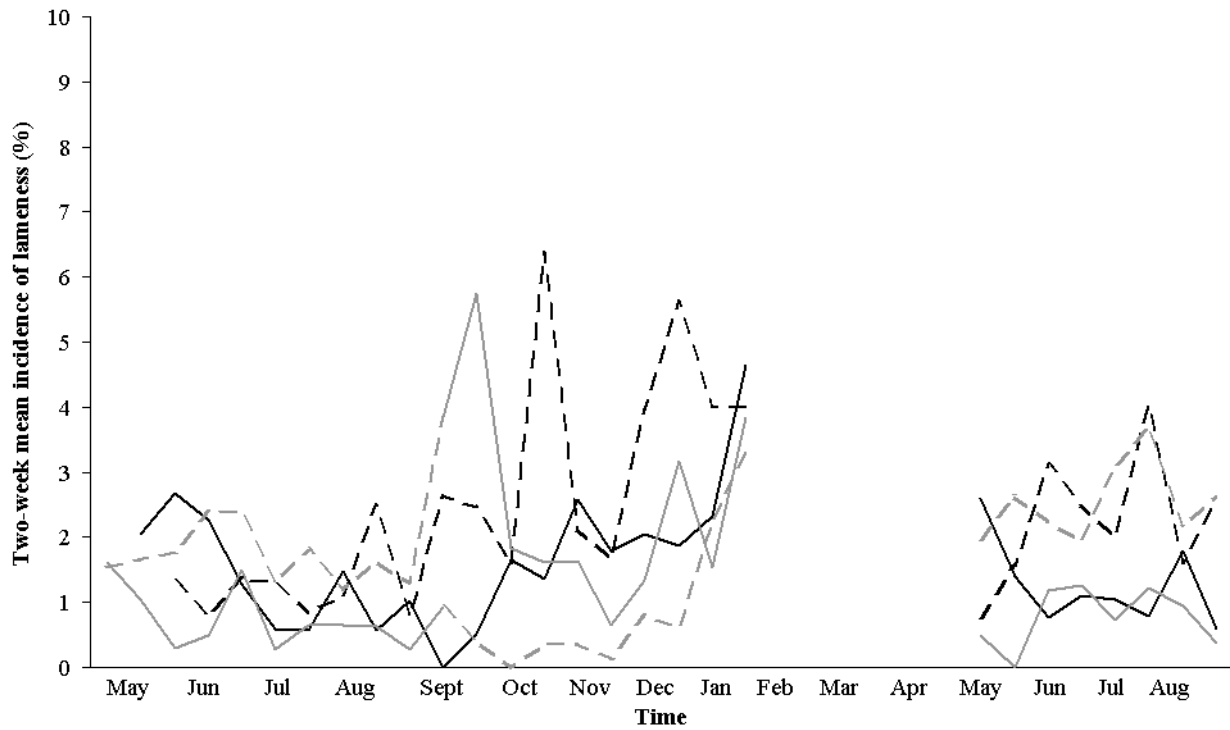
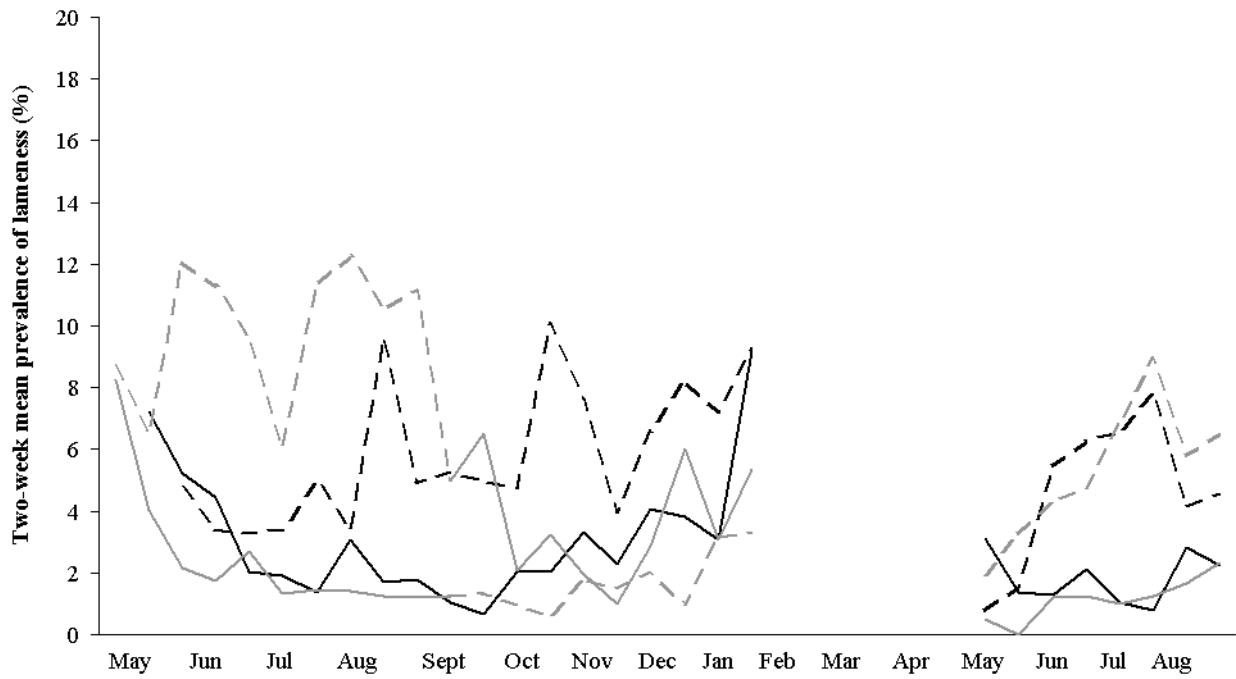
522 **Table 9.** Cox proportional survival model of time to finishing of lambs.

| Among 182 lambs finished before 140 days of age                    | No. (%) exposed | Hazard ratio    | 95% CI <sup>a</sup> | Wald $\chi^2$ | $\chi^2$ P-value |
|--|-----------------|-----------------|---------------------|---------------|------------------|
| In intervention vs control group                                   | 162 (89)        | 2.91            | 1.92 – 4.42         | 14.91         | <0.01            |
| Birth weight $\geq 5.5$ vs <5.5kg                                  | 121 (66)        | 1.75            | 1.24 – 2.47         | 27.78         | <0.01            |
| Single vs twin lamb  | 98 (54)         | 1.44            | 1.07 – 1.94         | 30.71         | <0.01            |
| Proportional-hazards assumption test based on Schoenfeld residuals |                 | $\chi^2 = 2.21$ | $P > 0.1$           |               |                  |
| Among 188 lambs finished between 140 and 163 days of age           |                 |                 |                     |               |                  |
| Dam body condition score at lambing $\geq 2.5$ vs <2.5             | 145 (77)        | 1.69            | 1.28 – 2.24         | 11.56         | <0.01            |
| In intervention vs control group                                   | 128 (68)        | 1.48            | 1.06 – 2.06         | 16.79         | <0.01            |
| Birth weight $\geq 5.5$ vs <5.5kg                                  | 111 (59)        | 1.41            | 1.07 – 1.84         | 22.06         | <0.01            |
| Proportional-hazards assumption test based on Schoenfeld residuals |                 | $\chi^2 = 6.24$ | $P > 0.1$           |               |                  |

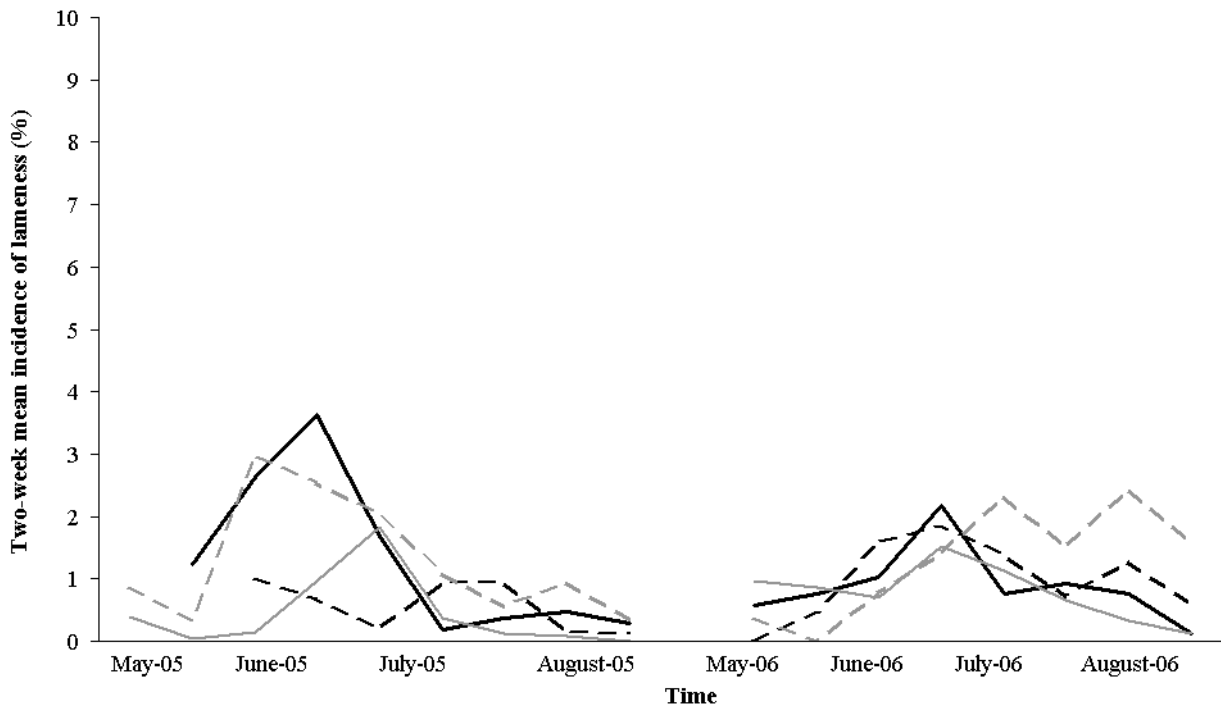
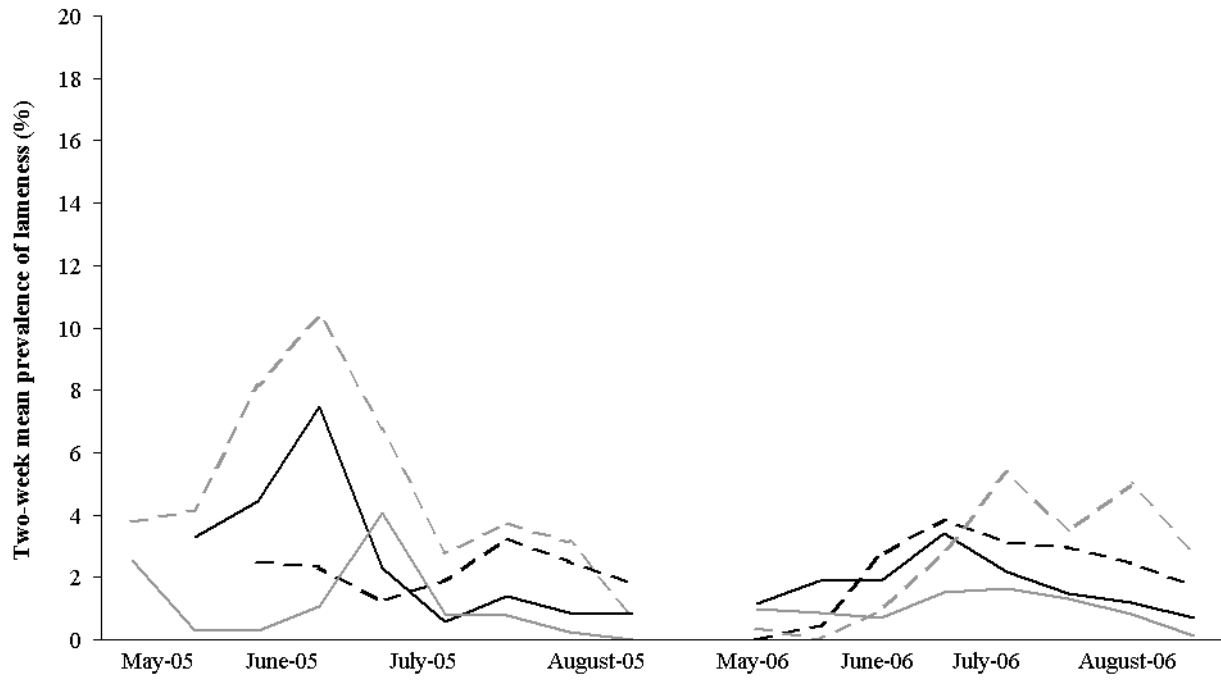
523 <sup>a</sup> Robust 95% confidence intervals, No. number, (%) percent

524

525



526  
527 **Figure 1**



528  
529 **Figure 2**