**Prevalence, risk factors and vaccination efficacy of contagious ovine ecthyma (orf) in England**

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**Abstract**

Orf is a viral disease found in English sheep flocks which can cause economic losses. It is a zoonosis with limited epidemiological research available in the UK. In 2012, 3000 questionnaires were sent to English sheep farms in order to: 1) investigate the prevalence of orf, 2) determine vaccination efficacy, 3) identify some of the potential risk factors. The overall response rate was 30% with a usable response rate of 25.4%. The usable farms (*N*=762 in the years 2011 and 2012) were used to model the percentage of animals affected on the farm, and the probability of a farm being found with the disease. The disease prevalence (DP) was standardised for the year and calculated as 1.9% for ewes and 19.53% for lambs. The disease risk (RR) ratios for the use of the vaccine were calculated as 2.04 for ewes and 0.75 for lambs, and therefore the study found that lamb vaccination was beneficial (RR<1). Weed infestation and increased number of orphan lambs were associated with increased cases of orf. We conclude that the DP in both ewes and lambs affect each other, though the impact is higher in lambs with an increased prevalence in ewes. A short lambing season lowers the probability of a farm experiencing cases of orf. Vaccination was effective in lambs but not in ewes, even though lambs benefitted when ewes were vaccinated (reduced orf prevalence in lambs born from vaccinated ewes), likely because any unvaccinated ewes may have been carriers that could spread the virus to the new-born lambs.

**Key words:** contagious ovine ecthyma; risk factors; orf; England;epidemiology; sheep

**Introduction**

Contagious ovine ecthyma is also known as orf, sore mouth, contagious pustular dermatitis, infectious labial dermatitis or scabby mouth (de la Concha-Bernejillo et al., 2000; Abrahao et al., 2009) is a viral disease caused by the sheep pox virus belonging to the *Poxviridae* family, *Chordopoxvirinae* subfamily Genus *Parapoxvirus* and Species *Orf virus* (Buller et al., 2005; Abrahao et al., 2009). Several other viruses of the same genus are the aetiological agents of similar diseases in other mammals such as cattle, goats, camels, red deer, squirrels and seals (Haig and Mercer, 1998; Haig and McInnes, 2002). The disease has a worldwide distribution, with a high incidence in Africa, the Middle East, Central Asia and the Indian subcontinent (Babiuk et al., 2008; Yogisharadhya et al., 2011), as well as being found in the United Kingdom (UK) (Buchan, 1996; Bennett, 1999; Bennett and Ijpelaar, 2003). Orf is classified as a notifiable disease by the World Organization for Animal Health, and as a zoonosis is also an occupational hazard (Nadeem et al., 2010; Scagliarini et al., 2012). The disease has been documented as one of the most common viral zoonoses (Gilray et al., 1998; Buchan, 1996) but as it is not classified as notifiable in the UK, less than three cases per year on average have been officially reported in the last ten years (DEFRA, 2012).

Some literature suggests that during grazing the exposed sensitive areas of skin around the animal’s mouth may be subject to abrasion from fibrous plant stalks, allowing the virus to access and replicate in the epidermal cells (Haig and Mercer, 1998; Nandi et al., 2011). Infected animals transmit the disease either by direct contact or through aerosol transmission (Bowden et al., 2008). Biting insects have also been identified as potential vectors (Bhanuprakash, 2006; Babiuk, 2008).

Clinical signs start with erythematous papules (3-5 mm in diameter) developing around the lips, nares and buccal cavity (McElroy and Bassett, 2007). In more severe cases, these lesions can also be seen on the skin, udder, eyes, feet and vulva (de la Concha-Bernejillo et al., 2000). These lesions enlarge a few days later with a verrucose appearance being observed also on the tongue and dental pad, which finally becomes ulcerated producing an exudate (McElroy and Bassett, 2007), thus creating highly infective pustules and scabs (Nandi et al., 2011). These lesions start to regress after one week and should heal between three weeks to two months leaving no scar (McElroy and Bassett, 2007). However, wounds may become complicated if secondary bacterial infection occurs through opportunistic agents such as *Staphylococci*, *Streptococci* or *Corynebacteria* (Haig, 2006; Nandi et al., 2011). Internal infection can also occur, with the lungs and rumen developing pox-like lesions (Babiuk et al., 2008; Bawden et al., 2008).

Orf is a cause of economic losses to the British sheep industry (Bennett and Ijpelaar, 2003), resulting in poor growth rates in lambs and mastitis in ewes (Burriel, 1997; Lovatt et al., 2012). Morbidity can be as high as 100% and mortality is occasionally observed e.g. Gumbrell and McGregor (1997) reported 10% mortality in lambs transported between Wiltshire (England) and Aberdeenshire (Scotland). In the UK, orf has not been identified as a disease with a high mortality rate (Binns et al., 2002), but the estimated National costs of the disease (which include production losses and treatment costs), in the best scenario and with 2.167 million sheep affected (as described by Bennett and Ijpelaar, 2005), can reach £10 million (a cost of £4.62 per head).

The host immune response to the virus involves CD4+ T cells, CD8+ T cells, the cytokinine IFN-γ (interferon-γ) and antibodies (Haig and Mercer, 1998; Haig, 2006). In addition, immune-modulatory virulence factors have been identified to disturb host immunity (Haig, 2006). Vaccination is available through attenuated live vaccines, but its efficacy is incomplete (Babiuk et al., 2008; Yogisharadhya et al., 2011; Zhao, 2011) due to strain variations, short duration of the protection period and a low level of antibody induction. The virus has been known to develop evasive strategies against the immune response of the host and therefore can repeatedly cause reinfection, despite immune response build-up, with milder, shorter subsequent infections (Haig et al., 1997). DNA vaccines have recently been tested in mice with promising results but these are not yet available at market (Zhao, 2011). Treatment should concentrate on controlling bacterial infection (Lewis, 1996) with topical formulations containing cidofovir and phosphate (Sonvico et al., 2009).

Studies have so far focused on the nature of the orf virus with very limited research on the effect of vaccination and the possible potential risk factors associated with orf in England. This study therefore aimed to identify some of the potential risk factors contributing to the prevalence of orf as well as the efficiency of the vaccination programmes in English sheep farms.

**Material and methods**

***Animals, sampling and variables***

A total of 3000 farms, registered with the English Beef and Lamb Executive (EBLEX) were targeted for collection of data. Questionnaires, together with a covering letter explaining their purpose, and a stamped addressed envelope were posted out in September 2012. No reminders were sent out and a total of 1000 farmers responded by February 2013. Out of 1000 responses 762 complete questionnaires were included in data analysis, the rest discounted as incomplete.

The data collected from the farms contained several variables considered to be relevant to the study of orf epidemiology as previously describe by other researchers (Lewis, 1996, Scalgliarini et al., 2012). The data contained a replication (referring to the years 2011 and 2012) and included the following variables: location of the farm, main activity, area of pasture, and number of ewes and lambs; biosecurity measures; infestation with weeds (thistle, nettle, dock and ragwort); sheep breeds; lambing start and end month; lambing management (indoors, outdoors); presence of orphan lambs and orf prevalence (%); vaccination of ewes and / or lambs against orf, month of vaccination, vaccine ID, and personnel who administered it (farmer, vet, shepherd); percentage of lambs and ewes in the flock affected with orf; numbers of new stock; and type of farming (sheep only or mixed). Area and number of animals were used to calculate stocking rates. The degree of weed infestation on the farm was scored as 0 to 5 each for nettle, thistle, dock and ragwort, and these scores used to derive an overall score for weeds (0 to 15), with ragwort being discarded as preliminary analysis found it had no significant impact. Lambing start and end month was used to create the variable ‘lambing season’ (warm for month 6 to 9 and cool for the others), and lambing season duration. The other variables were left as originally collected.

***Statistical analysis***

The disease risk ratio (RR), defined as the ratio of the risk of disease for animals with the risk factor (without vaccine or exposed) to the risk of disease for those without the risk factor (vaccinated or not exposed), was calculated for both ewes and lambs, using (1) (Woodward, 2005):

(1)

where *a* are the non-vaccinated animals developing the disease, *b* the non-vaccinated animals not developing the disease, *c* the vaccinated animals developing the disease and *d* the vaccinated animals not developing the disease.

Using the animal (ewes and lambs) as the subject of analysis, two multivariable regression models were created exploring disease prevalence (DP, percentage of animals affected). The dependent variables were ‘percentage of ewes with disease in the flock’ and ‘percentage of lambs with the disease in the flock’. A backwards stepwise procedure for selection of variables was implemented, with the significance level set to *P* < 0.05.

Using the farm as the subject of analysis, generalised linear models from the binomial family were tested to model the dichotomic dependent variable ‘presence or not of orf disease on the farm’. Two different models (one for ewes and another for lambs) were tested for goodness of fit using the likelihood ratio chi-square test, and evaluated through the Akaike’s information criterion. Two way interactions between factors were also entered into the models. A type III sum of squares was chosen, as the analysis had an unbalanced design. The variables were entered into the model with a forward stepwise procedure and were tested using the Wald Chi-square statistic, with the significance level set to *P* < 0.05.

The analysis was done respectively via the regression and the generalised linear models routine, using the software IBM® SPSS® Statistics 21.

**Results**

Table 1 Descriptive data regarding the different disease prevalence outcomes function of the different vaccination protocols.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| vaccine protocol | | % farms / protocol | DP | | DP (%) |
| ewe | lamb | ewe | lamb |
| Yes | Yes | 8 | Yes | Yes | 4 |
| Yes | No | 8 |
| No | Yes | 13 |
| No | No | 75 |
| Yes | No | 1 | Yes | Yes | 13 |
| Yes | No | 7 |
| No | Yes | 13 |
| No | No | 67 |
| No | Yes | 36 | Yes | Yes | 1 |
| Yes | No | 4 |
| No | Yes | 12 |
| No | No | 83 |
| No | No | 55 | Yes | Yes | 5 |
| Yes | No | 2 |
| No | Yes | 18 |
| No | No | 75 |
| DP: disease prevalence | | | | | |

The prevalence rate of the disease standardised for the year and defined as the number of cases per population number, was calculated as 1.9% for ewes and 19.5% for lambs. With regard to the different vaccination protocols, the majority of the farms either did not vaccinate ewes or lambs (55%), or only vaccinated lambs (36%). The majority of responding farms did not experience cases of orf, regardless of vaccination protocol. Full descriptive figures can be seen in Table 1.

The RR was calculated as 2.04 for ewes and 0.75 for lambs, and therefore the vaccine was effective in the control of the disease when given to lambs (RR < 1) but not when given to ewes (RR > 1).

Two multivariate regressions were found to be significant (F = 20.59, 2, *P* < 0.001; F = 29.15, 2, *P* < 0.001) for DP in lambs and ewes respectively. These have the following equations:

*l%DP* = 1.180 + 0.634*DWI* + 0.497 *e%DP* (2)

*e%DP* = 0.099*DWI* + 0.037 *l%DP* (3) where *l%DP* is the percentage of lambs in the flock with the disease, *DWI* is the degree of weed infestation on the farm and *e%DP* is the percentage of ewes in the flock with the disease. Therefore, the DP in ewes and lambs is positively correlated and increases in both models with the degree of weed infestation on the farm. By analysing the regression coefficients, we can also observe that the impact of ewes with disease, on lambs with disease is much higher than the opposite [the coefficient 0.497 taken from (2) being higher than the coefficient 0.037 taken from (3)]. Again, the impact of the degree of weed infestation is also higher in lambs 0.634 (2), than in ewes 0.099 (3). These relationships can be observed in Figure 1 and Figure 2 representing respectively the fitted regressions (2) and (3).

Approximate location of figure 1

Approximate location of figure 2

Two generalised linear models for the presence or absence of disease on the farm in both lambs and ewes were also fit to the data. The first with a complementary log-log link function modelling the probability of finding diseased lambs on a farm (Likelihood ratio chi-square 237, 9, *P* < 0.001), and the second with a negative log-log link modelling the probability of finding diseased ewes on a farm (Likelihood ratio chi-square 121, 6, *P* < 0.001).

The probability of finding diseased lambs on a farm was modelled by the variables presented in Table 2, where the parameters of the complementary log-log equation and respective confidence intervals can also be found. Probabilities can, therefore be obtained from the equation:

*lPD* = 1 - exp( - exp(*β1X1 + β2X2 + β3X3 + β4X4 + β5X4X5*) (4) where *lPD* is the probability of finding diseased lambs on a given farm; *β1* to *β5* are the parameters of the equation for each one of the variables found significant; *X1* is the ‘disease prevalence in ewes (percentage)’ (*e%DP*); *X2* is the ‘degree of weed infestation’ (*DWI*); and *X3*, *X4* and *X5* are the dummy variables associated with the inclusion of the different levels of the factors, respectively ‘lambing period’ (*LP*) (short < 5 month, long > 5 month), ‘lamb vaccination’ (*lV*) (yes, no), ‘orphan incidence’ (*OI*) (no, low, moderate, high) and interaction between ‘ewe vaccination’ (*eV*) and ‘lamb vaccination’ (no \* no, no \* yes, yes \* no, yes \* yes).

From this model it can be read that the probability of a farm having lambs with orf increases with the *e%DP* and the *DWI*. An increase in *OI*, long *LP* and lack of *lV* also increases this probability. The *eV* on its own does not impact on this probability but, in combination with *lV*, has a significant impact on reducing the probability when given to both ewes and lambs. The higher probability of finding orf on a farm is when the ewes are vaccinated but not the lambs (equation parameter value 1.45). This probability is close if both lambs and ewes are not vaccinated (equation parameter value 1.36). The probability decreases if only the lambs are vaccinated (equation parameter value 0.86), but a lower risk is found when both ewes and lambs are vaccinated (equation parameter value 0). It must be noted that the higher the equation parameter in the equation, the higher the probability of the dependent variable (in this model, the probability of finding lambs with orf on a given farm).

Table 2 Parameters of the complementary log-log equation modelling the probability of finding lambs with orf on a given farm. The 95% confidence intervals and the level of significance are also stated.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | *Β* | SE | 95% CI (*β*) | | P-value |
| *e%DP* | 1.38 | 0.15 | 1.09 | 1.67 | <0.001 |
| *DWI* | 0.08 | 0.02 | 0.04 | 0.12 | <0.001 |
| *LP* |  |  |  |  | <0.01 |
| short | -1.23 | 0.39 | -1.98 | -0.47 |  |
| long | 0 |  |  |  |  |
| *lV* |  |  |  |  | <0.001 |
| no | 1.45 | 0.41 | 0.66 | 2.24 |  |
| yes | 0 |  |  |  |  |
| *OI* |  |  |  |  | <0.001 |
| no | -1.34 | 0.33 | -1.98 | -0.69 |  |
| low | -1.16 | 0.33 | -1.80 | -0.51 |  |
| meddle | -0.05 | 0.35 | -0.74 | 0.63 |  |
| severe | 0 |  |  |  |  |
| *eV \* lV* |  |  |  |  | <0.05 |
| no \* no | 1.34 | 0.24 | 0.87 | 1.81 |  |
| no \* yes | 0.86 | 0.35 | 0.18 | 1.54 |  |
| yes \* no | 1.45 | 0.30 | 0.86 | 2.04 |  |
| yes \* yes | 0 |  |  |  |  |
| Akaike’s Information Criterion: 1583; SE standard error, CI confidence interval, *e%DP* disease prevalence (%) in ewes, *DWI* degree of weed infestation, *LP* lambing period, *lV* lamb vaccination, *eV* ewe vaccination, *OI* orphan incidence | | | | | |

Figure 3 illustrates the variability of the probabilities function of the 2 covariates (*e%DP* and *DWI*), and with the more favourable factors for a lower probability (short *LP*, no *OI*, *lV* given and *eV* given). The same figure for the higher probability (long *LP*, severe *OI*, *lV* not given and *eV* not given) would show the probability of a farm to have lambs with orf close to 1 even for a *DWI* and *e%DP* both close to 0.

Approximate location of figure 3

The probability of finding diseased ewes on a farm was modelled by the variables presented in Table 3, where the parameters of the negative log-log equation and respective confidence intervals can also be found. Probabilities can, therefore be obtained from the equation:

*ePD* = exp( - exp( - (*β0* + *β1X1 + β2X2 + β3X3 + β4X4*))) (5) where *ePD* is the probability of finding diseased lambs on a given farm; *β0* is the intercept; *β1* to *β4* are the parameters of the equation for each one of the variables found significant; *X1* is the ‘disease prevalence in lambs (percentage)’ (*l%DP*); *X2* is the *DWI*; and *X3* and *X4* are the dummy variables associate with the inclusion of the different levels of the factors, respectively ‘ewe vaccination’ (*eV*) (yes, no) and *OI* (no, low, moderate, high).

Table 3 Parameters of the negative log-log equation modelling the probability of finding ewes with orf on a given farm. The 95% confidence intervals and the level of significance are also stated.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | *Β* | SE | 95% CI | | P value |
| Intercept | -1.32 | 0.35 | -2.01 | -0.63 | <0.001 |
| *l*%DP | 0.81 | 0.10 | 0.62 | 1.00 | <0.001 |
| DWI | 0.05 | 0.02 | 0.01 | 0.09 | <0.05 |
| OI |  |  |  |  | <0.05 |
| no | -0.12 | 0.33 | -0.76 | 0.53 |  |
| low | 0.14 | 0.33 | -0.50 | 0.78 |  |
| middle | 0.24 | 0.34 | -0.43 | 0.92 |  |
| severe | 0 |  |  |  |  |
| *e*V |  |  |  |  | <0.05 |
| no | -0.36 | 0.16 | -0.67 | -0.06 |  |
| yes | 0 |  |  |  |  |
| Akaike’s Information Criterion: 659; SE standard error, CI confidence interval, *l*%DP disease prevalence (%) in lambs, DWI degree of weed infestation, LP lambing period, *l*V lamb vaccination, *e*V ewe vaccination, OI orphan incidence | | | | | |

From this model it can be read that the probability of a farm to have ewes with orf increases with the *l%DP* and the *DWI*, similar to the previous model. Long *LP* and higher *OI* also increase this probability, again similarly to the previous model. The main difference in this model is the lack of impact of *lV* and the adverse effect of *eV*, with the interaction of these last two not being significant. Ewe vaccination is shown to impact negatively, and farms that vaccinated ewes have a higher probability of having ewes with orf.

Figure 4a illustrates the variability of the probabilities function of the 2 covariates *(l%DP* and *DWI*), and with the more favourable factors for a lower probability (no *OI* and *eV* not given). Figure 4b illustrates the same variability with the less favourable factors for a lower probability (middle *OI* and *eV* given). As can be seen in this last scenario a lower *l%DP* is enough for the same probability.

Approximate location of figure 4

**Discussion**

Vaccination against orf virus is still not fully effective and there have been no major developments in this area for decades (Zhao et al., 2011). Doubts about efficacy, function of the strain variability and virus evasive capabilities against immune response, have sustained an interest in testing new vaccines. The rationale behind the use of the vaccines refers to the fact that the recovery from the disease is quicker in vaccinated sheep, allowing a fuller and quicker recovery, and therefore attenuating losses promoted by the disease. New vaccines tested vary only in the strains used and in the way the virus is attenuated. Current vaccines do not offer long lasting protection and therefore annual vaccination has been recommended (Lewis, 1996). Adult sheep should be vaccinated not less than eight weeks before lambing and lambs from day two after birth (Lewis, 1996).

The prevalence rate of orf in England was calculated as 1.9% for ewes and 19.53% for lambs. This leads to a considerable figure of 206,800 ewes and 14,256,900 lambs infected per year based upon DEFRA figures of over 11 million ewes and over 73 million lambs for the sheep population in England, as reported by Gloom (2010). The majority of the farms in England were found not to vaccinate their sheep against orf, but the disease was present in 25% of these farms (see Table 1). It has been reported that the vaccination is commonly missed (NADIS, 2013) and one of the reasons for this may be due to a shortage of vaccines (Anonymous, 2011).

This study established that the majority of the English farms do not follow the advised protocol of vaccinating both ewes and lambs (8% of total farms and 18% of those vaccinating), with 1% of the farms (2% of those vaccinating) vaccinating ewes only and 36% of the total (82% of those vaccinating) vaccinating lambs only. Looking at the disease prevalence using the different protocols we can see that the higher disease prevalence occurs when only ewes are vaccinated. The finding can be supported by Gilbray et al., (1998) who showed that vaccinating adult animals is not the best practice given that the live attenuated vaccines will themselves be responsible for the spread of disease to the young. The current study shows a clear higher prevalence of the disease in lambs if the ewes are vaccinated but not the lambs, when compared with neither ewes nor lambs being vaccinated. In addition, vertical transmission of the disease is very likely due to the close contact and lack of humoral protection in the lamb.

In ewes vaccinated six to eight weeks before parturition, orf antibodies are passed onto the lamb via colostrum, but no protection effect is noted against challenge with the disease (Buddle and Pulford, 1984; Mercer et al., 1994). There is no evidence to suggest that humoral response has a correlation with response to disease (Lloyd et al., 2000); as this response is mainly mediated by cell-mediated immune mechanisms (McKeever et al., 1987). This is why our model shows a higher degree of efficiency in protection of lambs if both the ewe and the lamb are vaccinated with less efficient results achieved following vaccination of adult animals. Also, the fact that lambs are naive to the disease and ewes may have been exposed, may be one of the explanations for a higher impact of diseased ewes in promoting disease in lambs compared with vice versa. A high morbidity has been found in lambs, yearlings and immunologically naive sheep where the disease incidence is also higher (Mariner et al., 1991; Banuprakash et al., 2006; Scagliarini, 2012).

The current study also found that orf prevalence decreases in flocks where the lambing season was more concentrated with a probable explanation that stock tasks are carried out within a short time frame. In a short lambing season the vaccination schedule tends to occur exactly six to eight weeks before lambing as required. However, if lambing season is extended, lamb vaccinations become asynchronous and vaccinated animals will need to be kept separate from non-vaccinated, with increased management difficulties. As Lewis (1996) suggests mixing of vaccinated and unvaccinated animals would be a “recipe for disaster”. As a result, the concentration of lambing allows a better vaccination schedule improving preventive protection.

Orf has for some time been related to abrasion in the mouth, ventral area and legs of sheep (Lewis, 1996) and this is commonly cited as a factor promoting the disease (Keever et al., 1988; Banuprakash et al., 2006; Rodriguez et al., 2011; Scagliarini, 2012); therefore it is not surprising that the models in this study incorporate this variable. The weeds identified in the English farms were potential risk factors as thistles, for example, can cause small lacerations in the skin allowing the virus to enter the body and replicate. This is in agreement with Lewis (1996) and Scalgliriani et al., (2012) that pastures that have spiky plants or rough fibrous vegetation, such as thistles, tend to cause damage on the muzzle during grazing thus providing entry for the orf virus.

The models in this study also showed that a higher prevalence of the disease was found to be related to an increased orphan incidence. Orphan lambs may be more prone to the disease due to compromised immunity. It may also be that it was the presence of orf in the dam that resulted in the lamb becoming orphaned. It has been shown that with instances of orf infection on the udder, both with and without the presence of mastitis, ewes tend to reject their lambs as a result of pain inflicted during suckling (Lewis, 1996; Lovatt, 2012), thus increasing orphan numbers.

The variable lambing season (warm and cool) was not included in the regression models but was found to be significant (P < 0.05) as a stand-alone variable. It was observed that for the warmer season (from June to September) the probability of disease increases. Dry weather has been identified before, as a factor for higher incidences of orf (Lewis, 1996; Rodriguez et al., 2011) due to easier propagation of aerosols and also because biting insects will be more active. Finally, the introduction of new animals, which can be carriers of the orf virus (Nettleton et al., 1996), has been identified as the main cause of disease spread between some flocks, but was found to have no significant impact (P > 0.05) on DP of both ewes and lambs within this study.

**Conclusion**

From this study it can be concluded that there are factors that can be managed to decrease the prevalence of orf in sheep farms across England. The vaccination protocols must be followed as recommended, not after eight weeks before lambing in ewes and from day two after lambing in lambs. Ideally both ewes and lambs should be vaccinated but in cases of vaccine shortage, lamb vaccination should be prioritised. Control of orf should also account for eradication of the three important weeds identified in English sheep farms. Since a high disease prevalence was associated with a higher number of orphan lambs it would be advisable as a management routine to foster such lambs where possible. A short lambing season favours the prevention of orf since the husbandry tasks can be programmed to occur within a shorter time period therefore vaccinations should occur at the same time, thus avoiding the need to separate vaccinated from non-vaccinated animals.

**Conflict of interest statement**

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Captions to figures

Figure 1 Percentage of lambs infected as a function of percentage of ewes infected and degree of weed infestation. The percentage of lambs infected increases as the other variables increase.

Figure 2 Percentage of ewes infected as function of percentage of lambs infected and degree of weed infestation. The percentage of ewes infected increase as the other variables increase.

Figure 3 Graphic representation of the complementary log-log model for estimation of the probability of finding a diseased lamb on a given farm as a function of the 2 covariates (percentage of disease incidence in ewes, and degree of weed infestation), considering the levels of the factors favouring the lowest probability (short lambing period, no orphan incidence, lamb vaccination and ewe vaccination both given).

Figure 4 Graphic representation of the negative log-log model for estimation of the probability of finding a diseased ewe on a given farm as a function of the 2 covariates (percentage of disease incidence in lambs, and degree of weed infestation): 4a considers the levels of the factors favouring the lowest probability (no orphan incidence, ewe vaccine not given); 4b considers the levels of the factors favouring the highest probability (middle orphan incidence, ewe vaccine given).