Risks associated with preweaning mortality on 39 commercial outdoor pig farms in England

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Abstract

A prospective longitudinal study was carried out on 39 outdoor breeding pig farms in England in 2003 and 2004 to investigate the risks associated with mortality in liveborn preweaning piglets. Researchers visited each farm and completed a questionnaire with the farmer and made observations of the paddocks, huts and pigs. The farmer recorded the number of piglets born alive and stillborn, fostered on and off and the number of piglets that died before weaning for the next 20 litters born following the visit. Data were analysed from a cohort of 9424 liveborn piglets from 855 litters. Overall, 1274 liveborn piglets (13.5%) died before weaning. A mixed effect binomial model was used to investigate the associations between preweaning mortality and farm and litter level factors, controlling for litter size and number of piglets stillborn and fostered. Increased risk of mortality was associated with fostering piglets over 24 hours of age, organic certification or membership of an assurance scheme with higher welfare standards, farmers' perception that there was a problem with pest birds, use of medication to control coccidiosis and presence of lame sows on the farm. Reduced mortality was associated with insulated farrowing huts and door flaps, women working on the farm and the farmer reporting a problem with foxes.

Keywords: piglet mortality, outdoor pig production, risk analysis, longitudinal study

Introduction

Preweaning mortality is a major cause of economic loss and poor welfare in the pig industry (Mellor and Stafford, 2004). In all farrowing systems, piglet mortality is affected by litter size (Wolf et al., 2008), fostering practice (Robert and Martineau, 2001), sow parity (Tubbs et al., 1993), disease status and treatment and vaccination regimes (Wittum et al., 1995). Provision of assistance by farm workers to new born piglets, such as drying the piglet or moving it to the teat, has also been reported to reduce preweaning piglet mortality (Andersen et al., 2009).

In England, approximately 43% of piglets are born and reared outdoors to weaning (Defra, 2010). Outdoor pig production offers the possibility of higher welfare because sows and piglets have greater opportunities to express natural behaviours than those housed indoors. Sows are typically kept as individuals or in groups in paddocks. Each sow has a hut in which to farrow. Huts are bedded with deep straw and have sloping sides to provide a space for piglets to avoid being crushed as the sow lies down. Despite this, crushing, predation and hypothermia are potential risks for preweaning piglets born and reared outdoors (Edwards et al., 1994) .

In a cross sectional postal study of 67 British pig herds there was a trend for higher mortality in outdoor systems (14%) compared with indoor systems where sows were kept in farrowing crates (10%), although the difference was not statistically significant (O'Reilly et al., 2006). In a cohort study of 112 English pig farms there was again a non-significant difference in preweaning mortality of liveborn piglets by system (KilBride et al., 2012); mortality was 11.7% in piglets born to sows housed in crates and 12.8% in piglets housed outdoors. There was, however, a significantly higher risk of crushing of healthy live born piglets and a lower risk of death from other causes in outdoor housed piglets compared to piglets born to sows housed in farrowing crates indoors.

Researchers have reported that insulated farrowing huts reduce fluctuations in internal hut temperature by keeping the interior of huts warmer in winter and cooler in summer compared with non-insulated huts (Edwards et al., 1995; Randolph et al., 2005). This has been reported to have mixed effects on preweaning piglet mortality. Randolph et al. (2005) reported lower mortality levels in insulated huts compared with non-insulated huts on one English farm, particularly in winter, however, a study carried out in the USA by Johnson and McGlone (2003) and Edwards et al. (1995) in the UK reported no association between preweaning mortality and whether or not farrowing huts were insulated.

In this paper we present factors associated with preweaning piglet mortality in liveborn piglets on 39 outdoor commercial pig farms in England. These farms are a subset from the sample used in the KilBride et al. (2012) paper.

Materials and methods

Development of data collection tools

A Delphi study was conducted to identify factors that might affect outdoor reared preweaning piglet mortality. Questionnaires were sent to 72 veterinarians, scientists, farm workers and other pig industry experts, asking for their opinions about important factors contributing to piglet mortality and stillbirths. Twenty five (35%) questionnaires were returned. Answers were collated and summarised, and the ranked answers were returned to the experts to allow them to confirm their top five factors associated with piglet mortality; 24 of the 25 experts returned the questionnaires for the second phase. Wherever possible, factors suggested by experts as associated with piglet mortality were incorporated into the data collection tools. Published literature was also reviewed and data on significant factors were incorporated into the data collection tools.

Selection of farms

The sample was recruited as part of a larger study comparing preweaning piglet mortality across farrowing systems (KilBride et al., 2012). The study farms were convenience sampled using industry contacts, word of mouth and advertising in the farming press.

Data collection

Each farm was visited once during 2003 or 2004 by two researchers. During the farm visit, the researcher completed a structured questionnaire with the farmer. Questions covered farm type, size and location, disease, vaccination and biosecurity, paddock and farrowing hut management, breeding, dry sow, farrowing and piglet management, feed and water, demographics and training of farm workers. See supplementary information Table 1 for a list of variables collected.

During the visit researchers recorded observations of the dry and lactating sow paddocks and each type of farrowing hut used on the farm. A paddock of dry sows was randomly selected and a 'walk through' test was performed to assess the sows' fear of humans. The test consisted of the researcher walked slowly and calmly across the paddock and the proportion of sows in the paddock alert, approaching and withdrawing from the researcher was recorded. Ten lactating sows were randomly selected and observations on their locomotion (according to Main et al. (2000) and body condition (according to (DEFRA, 1998) were recorded. These sows were not in all cases the mothers of the piglets in the cohort because at the time of the visit these sows had not been identified. The next twenty litters to farrow after the farm visit were recruited into the cohort. These measures provide farm level estimates of lameness and fear of humans in the breeding herd.

Farmers were asked to record data on the next 20 litters born following the farm visit. They recorded the parity of the sow, date of farrowing, number of piglets born alive, born dead, fostered onto and off the sow and date of weaning. Farmers were provided with a decision tree to assist with differentiation between stillborn and liveborn dead piglets. Piglets were not individually identified and fostering occurred, therefore some piglets in the study were not the offspring of the sow that reared them and no data were available on the birth sow of fostered piglets. Farmers posted data collection sheets back to the researchers once complete.

Data checking and analysis

Data were entered into Microsoft Access 2003 databases. The data were checked for errors and outliers and obviously incorrect codes were re-checked against the raw data and impossible values (n=9) were coded as missing. Variables with more than 90% of the data in one category were excluded from further analyses.

Statistical analysis

The outcome was the proportion of liveborn piglets per litter that died before weaning.

A binomial mixed effects model was used to account for the clustering of piglets within litters and litters within farms. Paddock was not included as a random effect because some sows were housed individually. All analyses was carried out in MLwiN version 2.1 (Rasbash et al., 2009). The binomial model took the form;

$$\text{Logit}\ (p_{ijk}) = \beta_0 + \sum\beta x_{jk} + \sum\beta x_{k} + v_k + u_{jk}$$

Where p_{ijk} = is the proportion of liveborn piglets that died in the litter, investigated with a logit link function, and litter size after fostering as the denominator. β_0 = constant, βx is a vector of fixed effects varying at level 2 (jk) or level 3 (k), j is litters and k is farms, $v_k + u_{jk}$ are the residual variances at farm and litter level respectively. Level 1 variance is constrained to a binomial distribution.

Variables were screened and those with a univariable association with the outcome where $p<0.2$ were taken forward to the multivariable model (see additional information for univariable results). Variables remained in the final model if $p<0.05$. All variables were tested back into the final model to check for residual confounding (Cox and Wermuth, 1996). The Hosmer Lemeshow statistic was used to check model fit. Given the sample size and the large number of predictor variables it was considered beyond the scope of this study to investigate interactions between variables. Spearmen's rho correlation was used to investigate associations between variables that were associated ($p<0.2$) with the outcome at univariable level.

Results

Descriptive summary of the sample of farms and litters

Data were analysed from a cohort of 9424 piglets from 855 litters on 39 outdoor farms. Herd size varied from 75 to 1200 breeding sows; median 497 (IQR 240-723). On all study farms, pigs were commercial crosses; breedlines were Large White and Landrace cross often with a small proportion of Duroc. Full information on the genetic composition of commercial breedlines was not available. Overall 13.5% (1274 / 9424) of liveborn piglets died before weaning. Mortality by farm ranged from 5.1 to 24.0%. The mean litter size after fostering was 11.0 (SD 2.0) and a mean of 9.5 (SD 2.0) piglets were weaned per litter.

On 31% (n = 11) of farms all fostering of piglets was completed before piglets were 24 hours old, on 52% (n = 21) of farms piglets were fostered up to 71 hours old and on 16.7% (n = 7) of farms piglets were fostered when over 72 hours old. There was a positive correlation between live born litter size at birth and the number of piglets fostered out of the litter ($r = 0.5$, $p<0.05$). There were women working on 10% (n=4) of the farms. All but one farm were members of a farm assurance scheme; 46% (n = 17) of farms were additionally certified organic and /or members of an assurance scheme with higher welfare standards.

Information on the farrowing hut was missing for 139 litters. Where information on the farrowing hut was known; 61% of litters had insulation in the farrowing hut and 15% had a flap covering the farrowing hut door. All farrowing huts in the current study were bedded with straw. Provision of additional bedding partway through lactation was not significantly associated with piglet mortality. See Table 1 for descriptive statistics.

Factors associated with preweaning mortality on outdoor farms

In the final multivariable model there was an increased risk of mortality in litters with 12 or more piglets after adjusting for fostering, compared with litters with ten piglets. There was also a non-significant trend for the risk of mortality to be higher in litters with nine or fewer piglets. There was an increased risk of mortality in liveborn piglets in litters where two or more piglets were stillborn compared with litters where no piglets were stillborn. There was an increased risk of mortality when four or more piglets were fostered from the litter compared with litters where no piglets were fostered out of the litter. There was an increased risk of mortality in litters on farms where fostering was carried out when piglets were 25-71 or > 72 hours of age compared with farms where the policy was for fostering to be carried out only when piglets were < 25 hours of age (Table 1).

There was a reduced risk of mortality in litters housed in farrowing huts with a door flap compared with huts without a door flap and in litters in huts that were insulated compared with litters in huts without insulation (Table 1). In the 139 litters for which information on the farrowing hut was missing, percentage mortality was 12.6% and not significantly different from mortality for piglets where the hut construction was known.

There was a reduced risk of mortality when at least one woman worked on the farm compared with farms where all the staff were male. There was an increased risk of mortality in litters from farms that were members of organic or higher welfare schemes compared with those that were only members of a baseline assurance scheme (Table 1).

There was an increased risk of mortality on farms where piglets were medicated to control coccidiosis compared with farms that were not using this medication. There was an increased risk of mortality when lame lactating sows (not the mothers of the piglets in the cohort) were observed on the farm by the research team compared with litters from farms where none of the sows observed were lame (Table 1).

There was an increased risk of mortality on farms where the farmer interviewed reported that they had a problem with birds on the farm and a reduced risk where they reported that they had a problem with foxes, compared with a reference category of farms where these were not reported as problems (Table 1).

Model fit indicated that the observed values did not differ significantly from the expected values, Hosmer Lemeshow $\chi 2 = 13.2$, df = 9, p=0.15.

Variables in the final model were correlated with other variables that were associated with piglet mortality in the univariable analysis (p<0.2 level). When women worked on the farm sows were less likely to retreat from the researcher and piglets were more likely to be dried at birth. Drying piglets at birth was also associated with insulated farrowing huts. Where a problem with birds was reported, farms had been run by the same workers for a longer time and were more likely to report Porcine Reproductive and Respiratory Syndrome (PRRS) present in the herd then those in the baseline category. On farms where a problem with foxes was reported, workers were more likely to give assistance at birth. Organic or higher welfare scheme farms were newer farms, more likely to breed their own replacement gilts and more likely to report PRRS present in the herd. However, they did not differ significantly from those not in these schemes in herd size (Organic / Welfare = 479 vs. 515), in median weaning age (Organic / Welfare = 27 vs. 28) or average sow parity (Organic / Welfare = 3.5 vs. 4). (Table 2 and supplementary information).

Discussion

This is the first study to investigate housing, management and litter risk factors associated with mortality in preweaning piglets born and reared outdoors on commercial farms in the UK. Some factors are similar to those reported in litters reared indoors whilst others are specific to outdoor breeding herds.

Among factors specific to outdoor breeding of pigs, there was a reduced risk of mortality in litters housed in insulated huts. This was similar to the findings of Randolph et al. (2005) and different from Edwards et al. (1995) and Johnson and McGlone (2003) who reported no effect of insulation on outdoor reared preweaning piglet mortality. In the current study insulated farrowing huts were associated with drying piglets at birth (Table 2), which would further protect against heat loss. Providing sufficient bedding is also likely to be important to keep piglets within their thermal comfort zone and it might be that in the Edwards et al. (1995) and Johnson and McGlone (2003) studies sufficient bedding was present and that overshadowed any benefit provided by insulated huts.

The significant reduction in risk of piglet mortality when a flap of plastic covered the hut door might also have been associated with maintaining a stable temperature inside the hut, or it might have acted as a physical barrier that prevented young piglets straying from the hut, or it might have deterred predators.

Pests and predators are often thought to be a cause of preweaning piglet deaths in outdoor herds. In the current study, preweaning piglet mortality was higher on farms where farmers reported that there was a problem with pest birds but it was actually lower when farmers reported a problem with foxes. Birds and foxes may predate on young piglets (Edwards et al., 1994) or introduce infectious disease. It is not clear in the current study why one pest should appear protective and another a risk for higher preweaning mortality. It might be that the apparent risk from pests was a correlate of other risks. A problem with birds was associated with farms that had been run by the same workers for a long time and that had previous evidence of PRRS. In contrast, farmers that reported a problem with foxes were more likely to assist piglets at birth. To understand these associations better, objective data on presence of wildlife on the farm are needed. In the current study, the variable refers to the farmers' perception of a problem and the validity is unknown. Further information on how this related to an objective measure of the number of birds or foxes or the effectiveness of actions taken to control these pests is required to understand this further.

Among factors common to preweaning mortality in all systems, as previous work has reported (Van der Lende and de Jager 1991, Daza, Evangelista et al. 1999, Hogberg and Rydhmer 2000, Koketsu, Takenobu et al. 2006, Cecchinato, Maretto et al. 2007, Su, Lund et al. 2007, Wolf, Zakova et al. 2008), there was an increased risk of piglet mortality in larger litters. Associations between litter size and mortality are thought to occur because parturition is longer, piglets are smaller and competition for food is increased. However, in the current study litter size was measured after fostering, rather than at birth. Therefore the increased risk of mortality in larger litters is likely to be associated most strongly with postnatal factors such as milk provision or the risk of being crushed verses gaining warmth from the sow when there are more piglets in the hut. The trend for increased risk of mortality in litters with nine or fewer piglets after fostering may occur because these small litters arise from poor health or poor mothering ability in the sow, which also affects the remaining piglets. When two or more piglets in the litter were stillborn, there was an increased risk of live born litter mates dying before weaning. This association was evident in analysis that included litters farrowed indoors (KilBride et al., 2012), has previously been reported by Friendship et al. (1986) and maybe indicative of a shared aetiology. There was an increased risk of mortality in piglets from litters where four or more piglets had been fostered out of the litter, a situation that occurs most frequently in large litters or when the litter is failing to thrive. Increased mortality in the remaining piglets may be associated with the risks for piglets born in large litters, discussed above, or as a consequence of problems such as the sow's milk provision that necessitated the removal of piglets.

The practice of fostering piglets at over 24 hours of age was associated with an increased risk of mortality. Fostering older piglets may increase the risk of mortality because the established teat order is disrupted (Robert and Martineau, 2001) or because piglets are exposed to pathogens against which they are not adequately protected (McCaw, 2000).

In the current study there was significantly lower mortality on farms where at least one woman worked with the pigs, although this was only 4 / 39 farms. This may be linked to the greater empathy for pain in animals and more positive attitudes towards animal welfare reported in women (Capner et al., 1999; Huxley and Whay, 2006; Väisänen et al., 2008; Kielland et al., 2009; Laven et al., 2009). However, recent studies of farmers reported no difference in attitudes between men and women (Kielland et al., 2010; Kauppinen et al., 2012). Attitudes were not measured in the current study. However, when women worked on the farm, piglets were more likely to be dried after birth and sows were less likely to retreat from the researcher. This might be an indication that good stockmanship was associated with women working on the farm which in turn led to reduced mortality.

It is unclear why in the current study piglet mortality was higher on farms that were organic or a member of a higher welfare farm assurance scheme. It might be associated with the higher likelihood of presence of PRRS on these farms, although current level of disease associated with PRRS infection was unknown, in addition, these farms had been in business for a shorter time than the base line group and may have still been developing skills and experience. However, there was no significant difference between these and other farms in the level of training or experience of farm workers, the time spent caring for sows and piglets, herd size, sow parity or weaning age. Higher piglet mortality in organic pig production compared with conventional production systems has been reported elsewhere (Wallenbeck et al., 2009; Leenhouwers et al., 2011). However, in those studies there were greater differences in housing with non organic systems using farrowing crates whereas sows were loose housed on the organic farms.

Piglet mortality was higher on farms where piglets were medicated to control coccidiosis, a protozoal infection that causes diarrhoea. Coccidiosis transmission occurs in faeces and the disease is difficult to control in outdoor herds where it is difficult to prevent contact with faeces (Skampardonis et al., 2012). This was the only vaccination or medication variable that was significantly associated with piglet mortality in the final model.

As reported in previous papers (Anil et al., 2009) there was an increased risk of preweaning mortality associated with farms where lame lactating sows were observed. This association might occur because sows that are lame are less agile and are at greater risk of crushing their piglets, or because a sow's wellbeing is compromised in other ways, for example, poor body condition that could reduce milk production or reduce other mothering abilities. In the current study, because the cohort was not recruited at the time of the visit, it was not the dams of the recorded litters that were lameness scored, but a random sample of lactating sows on the farm prior to the study of mortality that provide an estimate of lameness levels on the farm. To investigate whether there is a direct association between lameness and piglet mortality, detailed data on locomotion and health status of sows and their litters and preweaning mortality are needed.

Using farmer recorded data on mortality, rather than data recorded by researchers, might have increased error in the dataset. However, previous studies have reported that farmers record numbers of piglets born and stillborn accurately (Christensen and Svensmark, 1997). In our previous paper using these data, variability in the farmer reported data was investigated by comparing the farmer's mortality estimate over the telephone at first contact, computerised records (6 month rolling average), records observed by the researcher at the farm visit and prospective records collected for the purpose of this study (see KilBride et al. (2012) for more detail). These four measures were highly correlated suggesting that farmers were consistent in reporting preweaning mortality percentages in the data collected for the current study.

Collecting data on piglet mortality is more difficult in piglets housed outdoors compared with those housed indoors, particularly compared with sows in farrowing crates. Seclusion in the individual farrowing hut, free movement of the sow and provision of deep bedding means that dead piglets are more likely to be concealed in the bedding or eaten by the sow. These events might have affected the accuracy of the estimated number of piglets stillborn that was included in the model. However, the outcome used in the analysis, liveborn piglet mortality, was calculated from the number of piglets observed by the farmer alive at the first observation and the number of piglets recorded weaned. These two figures were not dependent on the farmer recording stillborn piglets.

The farms in the current study were not randomly selected. Therefore self-selection bias may have affected the estimates of preweaning mortality, if farmers that prioritise health and welfare were more, or less, likely to participate in the research. However, there was a wide range of mortality on the farms in the study (5-24%) and the mean preweaning mortality (13.5%) was similar to estimates from the UK pig levy body of 13.9% (BPEX, 2012) suggesting that the sample may be a reasonable representation of the population.

Conclusions

This prospective longitudinal study of the risks associated with mortality in outdoor reared preweaning piglets is the first of this size and scope in the UK. Preweaning mortality was 13.5% of liveborn piglets. The sample is thought to be a reasonable representation of the population. Increased risk of mortality was associated with fostering piglets more than 24 hours of age, organic certification or higher welfare assurance scheme membership, perception by farmers of a problem with pest birds, use of medication to control coccidiosis and presence of lame sows. Reduced mortality was associated with insulated farrowing huts and door flaps, women working on the farm and the farmer reporting a problem with foxes. Whilst some of these factors, such as litter size, fostering management, hut construction and sow lameness, have been reported in previous work, clinical trials to investigate the novel associations such as gender of the farm worker and membership of welfare assurance or organic certification scheme would be informative to elucidate cause.

Conflict of interest

The authors have no conflicts of interest to declare.

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Table 1. Univariable binomial regression for variables significantly associated with preweaning mortality at p<0.2

Variable	Categories	Litter n value	OR	CI	
Number of piglets fostered into the litter	None	674	Ref		
	One	79	1.18	1.03	1.35*
	Two	69	0.80	0.68	0.93*
	Three or more	79	0.92	0.80	1.07
Number of piglets fostered out of the litter	None	610	Ref		
	One	94	0.83	0.73	0.96*
	Two	85	0.92	0.80	1.05
	Three or more	112	1.27	1.12	1.44*
Litter size after adjusting for fostering	Seven or less	32	2.21	1.66	2.95*
	Eight	40	1.03	0.78	1.35
	Nine	64	1.00	0.81	1.24
	Ten	209	1.00		
	Eleven	208	1.20	1.05	1.37*
	Twelve or more	348	2.23	1.98	2.50*
Parity of the sow	One	134	Ref		
	Two	187	0.96	0.83	1.12
	Three	159	0.94	0.81	1.09
	Four	126	1.14	0.98	1.34
	Five	81	1.25	1.06	1.48*
	More than five	204	1.29	1.13	1.48*
Gestation length (days)	<114 days	241	Ref		
	115 days	188	0.93	0.83	1.04
	116 days	164	0.97	0.87	1.09
	117 days	81	0.79	0.68	0.92*
	>117 days	99	0.76	0.65	0.89*
Number of years farm run under the current ownership	<5 years	237	1.30	1.08	1.57*
	5-10 years	250	Ref		
	11-15 years	192	1.14	0.93	1.40
	>15 years	222	1.44	1.19	1.75*
Organic / higher welfare scheme membership	No	462	Ref		
	Yes	393	1.18	1.00	1.39
Pigs raised to slaughter weight on the farm	No	597	Ref		
	Yes	304	1.18	1.02	1.38*
Farm breeds its own replacement gilts	No	434	1.18	1.02	1.36*
	Yes	467	Ref		
Number of sows in the herd	<100 sows	77	Ref		
	100-399 sows	179	0.97	0.73	1.29
	400-599 sows	235	0.68	0.51	0.90*
	600-750 sows	173	0.84	0.63	1.12
	>750 sows	214	1.01	0.76	1.33
Women worked on the farm	All men	817	Ref		
	Men and women	84	0.59	0.46	0.76*

Variable	Categories	Litter n value	OR	CI	
Mean number of years the workers have worked on the farm	<2 years	187	1.17	0.97	1.42
	3-5 years	344	Ref		
	6-10 years	188	1.00	0.82	1.22
	Over 10 years	>10	1.31	1.08	1.60*
Proportion of workers with formal training in pig production	None	130	Ref		
	<50%	306	1.09	0.87	1.35
	>50%	278	1.48	1.19	1.85*
	All	187	1.06	0.84	1.35
Proportion of workers that read pig information and press	None	68	Ref		
	<50%	209	1.73	1.29	2.33*
	>50%	157	2.02	1.49	2.73*
	All	443	1.55	1.18	2.05*
Proportion of workers undergoing training in pig production	None	524	Ref		
	Some	126	0.86	0.69	1.08
	All	251	0.78	0.65	0.94*
Bonus pay scheme for farm workers	No	543	Ref		
	Yes	338	1.82	1.15	2.88*
Most important characteristic for pig a farm worker, as determined by the farm manager	Good with pigs / good stock person	274	Ref		
	Other	554	1.24	1.06	1.44*
Farmers reported bird problem	No	214	Ref		
	Yes	687	0.86	0.72	1.02
Farmers reported fox problem	No	528	Ref		
	Yes	373	1.15	0.99	1.34
Sows sometimes given oxytocin	No	283	1.30	1.13	1.51*
	Yes	618	Ref		
Inter birth interval monitored	Never	755	Ref		
	Sometimes	146	0.71	0.53	0.94*
Assistance sometimes given at birth	No	390	1.17	1.01	1.36*
	Yes	485	Ref		
Mucus cleared from piglets' nose and mouth	Never	342	Ref		
	Sometimes	519	1.20	1.02	1.40*
Piglets dried after birth	Never	570	Ref		
	Sometimes	331	0.89	0.76	0.99*
Piglets directed to the sow's teat	Never	411	Ref		
	Rarely	320	0.90	0.77	1.05
	Sometimes	170	0.73	0.59	0.91*
Number of times per day that sows and litter and checked	Once	446	1.17	1.02	1.36*
	More than once	455	Ref		
Latest fostering of piglets	<24 hours	267	Ref		
	25-71 hours	472	1.19	1.00	1.41
	>72 hours	162	1.62	1.30	2.00*
Percentage of litters in which fostering takes place	<10%	98	Ref		
	11-25%	270	0.61	0.48	0.77*

Variable	Categories	Litter n value	OR	CI	
	26-50%	293	0.79	0.62	0.99*
	>50%	167	0.93	0.72	1.20
Insulated farrowing hut	No	306	Ref		
	Yes	453	0.90	0.79	1.03
Door flap on hut	No	635	Ref		
	Yes	122	0.79	0.66	0.95*
Number of sows in the group	3	79	0.84	0.64	1.12
	4	81	0.71	0.54	0.94*
	5	232	1.15	0.88	1.51
	6	60	Ref		
	7	60	0.78	0.57	1.06
	8	158	1.05	0.84	1.31
	>8	103	0.88	0.68	1.14
Percentage of sows alert when observer enters paddock	<60%	224	Ref		
	60-70%	245	1.02	0.82	1.26
	70-99%	317	0.80	0.65	0.99*
	100%	115	0.90	0.68	1.18
Percentage of sows that retreat from observer in the paddock	<5%	263	Ref		
	5-20%	184	1.36	1.12	1.66*
	21-40%	200	1.46	1.20	1.77*
	>40%	254	1.09	0.91	1.31
Percentage of sows that approach an observer in the paddock	<5%	250	Ref		
	5-20%	147	1.07	0.85	1.36
	21-40%	229	0.96	0.78	1.19
	>40%	275	0.80	0.65	0.98*
Mean body condition score	Less than three	312	0.85	0.73	1.00
	Three	460	Ref		
	More than three	129	0.95	0.76	1.18
Lame lactating sows observed on the farm by the researcher	No	80	Ref		
	Yes	775	1.0	0.75	1.32
Ever had flu	No	632	Ref		
	Yes	250	0.77	0.64	0.92
Ever had PRRS	No	518	Ref		
	Yes	380	1.36	1.16	1.59
Boar has been vaccinated against E coli	No	858	Ref		
	Yes	40	1.65	1.14	2.37
Gilt vaccinated against Erysipelas	No	80	Ref		
	Yes	818	1.44	1.09	1.92
Boar vaccinated against PRRS	No	715	Ref		
	Yes	183	1.41	1.17	1.70
Piglets medicated to control coccidiosis	No	822	Ref		
	Yes	60	1.16	0.84	1.60

Ref = reference category, OR = odds ratio, CI = confidence interval.

* category significantly different from the reference at p<0.2

Table 2. Number and percent mortality, odds ratio and confidence interval from the multivariable logistic regression model for 9424 piglets from 855 litters on 39 outdoor farms

		Sample size by variable					Piglet mortality (%)	Odds ratio	Lower 95% CI	Upper 95% CI
		Farms[1]	Litters		Piglets					
		n	%	n	%	n				
Litter size after fostering	Nine or less		14.9	127	10.5	993	11.28	1.32	0.99	1.41
	Ten		22.7	194	20.6	1940	9.59			
	Eleven		22.9	196	22.9	2156	11.22	1.18	0.95	1.47
	Twelve		20.2	173	22.0	2076	13.05	**1.46**	**1.17**	**1.81**
	Thirteen or more		19.3	165	24.0	2259	20.50	**2.63**	**2.12**	**3. 72**
Number of piglets stillborn / litter	None		67.8	580	67.9	6402	12.86			
	One		18.1	155	18.1	1703	14.91	1.14	0.96	1.37
	Two or more		14.0	120	14.0	1319	14.94	**1.29**	**1.06**	**1.57**
Number of piglets fostered from the litter	None		67.6	578	67.2	6330	13.57			
	One		10.3	88	10.5	994	10.87	0.80	0.63	1.03
	Two		9.5	81	9.9	929	12.06	0.78	0.61	1.00
	Three		5.8	50	6.2	581	14.29	0.96	0.72	1.28
	Four or more		6.8	58	6.3	590	18.98	**2.11**	**1.64**	**2.70**
Latest fostering of piglets	< 25 hours	11	31.2	267	30.2	2845	11.60			
	25-71 hours	21	52.0	445	52.7	4964	13.28	**1.27**	**1.05**	**1.54**
	>72 hours	7	16.7	143	17.1	1615	17.65	**1.86**	**1.45**	**2.37**
Farrowing hut insulated	No		38.6	277	38.5	3080	15.10			
	Yes		61.4	441	61.5	4917	12.77	**0.83**	**0.70**	**0.99**
Door opening covered with a flap	No		84.6	606	84.6	6751	13.81			
	Yes		15.4	110	15.4	1225	13.06	**0.73**	**0.57**	**0.93**
Women worked on the farm	No	35	90.2	771	89.7	8453	14.08			
	Yes	4	9.8	84	10.3	971	8.65	**0.58**	**0.24**	**0.80**
Organic / higher welfare scheme membership	No	22	54.0	462	55.2	5202	12.86			
	Yes	17	46.0	393	44.8	4222	14.33	**1.34**	**1.14**	**1.57**
Piglets medicated to control coccidiosis	No	36	93.0	795	93.0	8769	13.39			
	Yes	3	7.0	60	7.0	655	15.27	**1.40**	**1.01**	**1. 39**
Lame lactating sows observed on the farm by the researcher	No	4	9.4	80	9.3	878	11.62			
	Yes	38	90.6	775	90.7	8546	13.71	**1.52**	**1.14**	**2.03**
Farmer reported bird problem	No	9	22.8	195	23.7	2236	11.99			
	Yes	30	77.2	660	76.3	7188	14.00	**1.64**	**1.34**	**2.01**
Farmer reported fox problem	No	22	56.5	483	56.2	5300	14.30			
	Yes	17	43.5	372	43.8	4124	12.51	**0.75**	**0.62**	**0.91**
		Var.		SE						
Random effects	Farm	0.003		0.014						
	Litter	0.471		0.063						

[1]Cells are blank in this column where the variable varies within farm. Bold values are different from the reference category at Wald statistic, $P<0.05$. Var = variance. SE = standard error. Intercept coefficient for the model = -3.07.

Table 3. Spearman's rho values for correlations between variables where p<0.2 at univariable level (rows) and variables in the final model (columns)

	Litter size adjusted for fostering	Number of piglets still born	Number of piglets fostered out of the litter	Latest fostering of piglets	Organic / higher welfare scheme membership	Women work on the farm	Lame lactating sows observed	Door opening covered with a flap	Farrowing hut insulated	Farmer reported bird problem	Farmer reported fox problem	Piglets medicated to control coccidiosis
Number of piglets fostered into the littler			-.264									
Mean number of years the workers have worked on the farm				-.088	-.161		.366	.143	-.178	.350	.174	
Parity of the sows				-.102	-.145	-.119				.149	.112	
Gustation length in days												.123
Number of years farm run under the current ownership					-.355		.234		-.110	.366	.196	.147
Pigs raised to slaughter weight on the farm		.095		.266		.093		.136	-.135		.190	.391
Farm breeds its own replacement gilts				-.392	.317	.127	-.136	-.130	-.238	.149	.218	
Number of sows in the herd		-.097		-.288		-.120	.148	-.263	-.153	.158		
Percentage of workers who have received formal training					.218		.182		-.356	.096	-.115	
Percentage of workers who read pig information	.119			.140	.218		-.296				.258	.131
Bonus pay scheme for farm workers						-.250				-.175	.208	
Most important characteristic for a pig farm worker, as determined by the farm manager						.157	-.136			.095		.215
Percentage of workers currently undergoing formal training				-.264	.217	-.093		-.149		-.294		-.227
Number of sows in the group					-.120		-.175	-.180	-.238	.233		.156
Inter birth interval monitored			.089	-.203	.201	-.114	-.111		.119		.222	-.113
Mucus cleared from piglets'					.106	.235			.112		.290	

nose and eyes											
Piglets directed to the sow's teat	-.128		-.176					.298		.117	
Number of times per day that the sows and litter are checked			-.211	.211		-.223	-.102	-.161	-.114		.091
Oxytocin is sometimes given to sows				.101	.129	.152		.201		.161	-.147
Assistance sometimes given at birth			.151		.261					.441	
Percentage of litters in which fostering takes place		.233		.167	-.219		-.173	-.162		.150	.264
Piglets dried after birth				-.150	.361	.236		.338			-.208
Percentage of sows alert when observer enters paddock			-.192	-.218	.261	.365	.318		-.187	-.139	-.103
Percentage of sows that approach an observer in the paddock			.145		.214	.160	.123	.187	-.265		-.301
Percentage of sows that retreat from observer in the paddock				-.237	-.322	.110	.206	-.126	.264	-.191	.114
Ever had swine flu			-.151	-.181	.139				.121	.195	.227
Ever had PRRS				.326	-.120	0.110		.098	.320		-.236
Boar has been vaccinated against E coli			.192	.233		-.311	-.104	.193	-.133	-.182	
Gilt vaccinated against Erysipelas					-.168	.177		-.150	.376		
Boar vaccinated against PRRS			.094	.180					.283	.264	-.139

R values reported where association was significant at $p<0.001$