ORIGINAL RESEARCH

Herd- and litter-level factors associated with the incidence of diarrhea morbidity and mortality in piglets 4–14 days of age.

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Summary: *We used National Swine Survey data collected by the National Animal Health Monitoring System to identify litter and herd factors associated with the risk of diarrhea morbidity and mortality in 4- to 14-day-old piglets. A total of 29,843 litters from 708 herds monitored for producer-observed health events were included. The rate of diarrhea among 4- to 14- day-old pigs was one case per day per 250 piglets. Diarrhea mortality averaged one death every 2–4 days for 250 pigs. Diarrhea increased with: herd size, sow health problems, deworming sows in the farrowing crate, and routine use of supplemental milk for piglets. Diarrhea decreased with: all-in–all-out farrowing rooms, washing sows, TGE-free herd status, and vaccinating sows against* Escherichia coli. *Diarrhea mortality increased with: litter size, sow health problems, fostering piglets at 4–14 days of age, and sow mange/lice treatment while in the farrowing crate. Diarrhea mortality decreased with: fostering piglets out of the litter at 1–3 days, using supplemental iron, using a hired manager in the farrowing facility, and* E. coli *vaccination. The factors not associated with diarrhea morbidity and mortality included: vaccinating piglets, clipping teeth, docking tails, feeding the sow antibiotics, farrowing problems, operation type, supplemental creep feed, vaccinating sows against TGE or rotavirus, treating navels, facility type, and using a consultant such as a veterinarian, nutritionist, or extension agent. We conclude that vaccinating sows for* E.coli *and fostering piglets off sick sows are expected to decrease preweaning losses due to diarrhea in 4- to 14-day-old pigs.*

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Published as journal series article number 10854 of the University of Nebraska Agricultural Research Division.

A survey conducted by the United States Department of Agriculture (USDA): Animal and Plant Health Inspection Service (APHIS) National Animal Health Monitoring System (NAHMS) Veterinary Service (VS), found piglet diarrhea to be an important disease problem on United States swine farms.[1]

The causes of piglet diarrhea are multifactorial, and the simple presence of enteric pathogens is not always sufficient to produce clinical disease. Diarrhea in piglets is typically caused by host-environment-pathogen interactions. We hypothesized that differences in specific management practices and environment, as well as animal and herd characteristics, may greatly influence the risk of disease. Factors that may increase preweaning diarrhea morbidity and mortality include:

- pigs of low birth weight,
- large litter sizes,
- low-viability piglets that don't receive sufficient nursing care,
- low environmental temperature leading to cold stress,
- poor hygiene of the farrowing crate,
- inadequate milk supply and/or intake,
- inadequate numbers of functional nipples, and
- inattention to the individual needs of the piglet or the sow.[2-9]

During the first 3 days of life, enterotoxigenic *Escherichia coli* is the most common causative agent associated with diarrhea.[10] From 4 –14 days of age, piglet diarrhea may be associated with various enteric pathogens. These agents include: *E. coli*, *Clostridium perfringens* type C, transmissible gastroenteritis virus (TGE), other corona viruses, *Isospora suis*, rotavirus, strongyloides, and occasionally *Serpulina hyodysenteriae*.[11] Although usually there is one primary causative agent, piglets can have mixed infections.

The purpose of this study was to identify factors associated with piglet diarrhea from 4–14 days of age. Because the agents and conditions associated with piglet diarrhea differ between two age groups (0-3 days and 4-14 days) we have examined these two periods separately. A companion study investigates similar risk factors among 1- to 3-day-old piglets (see page 99-104 in this issue).[12]

Methods

Source of the data

A total of 29,843 litters in 708 herds were monitored at 4–14 days of age for disease events as part of the USDA:APHIS:NAHMS National Swine Survey.[13] Swine producers voluntarily participated in the program after they were selected using the multiple-frame sampling technique of the National Agricultural Statistics Service. Due to the sampling scheme, the 18 states from which our study population was selected represented 84% of swine operations and 95% of the hogs in the United States. A detailed description of the study population and selection process is presented elsewhere.[1,13]

The NAHMS National Swine Survey monitored each participating herd for a 3-month period. The surveys were administered between December 1989 and March 1991. A random selection of farrowing rooms was used for farms with more than 100 expected farrowings. State and federal Veterinary Medical Officers visited the farms monthly during the monitoring period to collect data and administer four questionnaires to the producers to obtain information regarding general characteristics of the herd. Producers also recorded litter information onto standardized diary cards for each sow that farrowed during the 3-month monitoring period. Detailed descriptions of the producer questionnaires and the diary cards are presented elsewhere.[1,13]

Outcomes of interest for this analysis included producer-reported diarrhea and mortality due to diarrhea among piglets aged 4–14 days. A case was defined as the first observed sign of diarrhea in a piglet. The producers were directed to identify each pig that had diarrhea so that it would not be counted as a case twice. The duration of the clinical symptoms was not recorded. For analysis, these outcomes were expressed as an incidence density, i.e., the number of piglets in the litter or herd with diarrhea morbidity or mortality divided by the total number of piglet days at risk of diarrhea in the litter or herd. Using incidence densities to analyze our data allowed us to account for changes in population sizes of individual litters and herds that resulted from fostering activity and death losses between farrowing and weaning.

Table 1

Litter-level variables among 29,843 sows and their litters: descriptive statistics

Variable	Description	Categories of response	% of litters
Vaccinate piglets	Age piglets received a vaccination	1–3 d	6.4
		4-14 d	18.4
		Not done	75.2
Clip teeth	Age when teeth of piglets were clipped	1–3 d	70.3
		4-14 d	9.8
		Not done	19.9
Dock tails	Age when piglets' tails were docked	1–3 d	55.1
		4-14 d	24.5
		Not done	20.4
Castrate	Age piglets were castrated	1–3 d	61.4
		4-14 d	24.3
		> 14 d	14.3
Iron	Age when supplemental iron was given to piglets	1–3 d	14.8
		4-14 d	36.5
		Not done	48.7
Foster in (1–3 d)	At least one piglet fostered in between birth and 3 days	No	79.6
		Yes	20.4
Foster in (4–14 d)	At least one piglet fostered in between 4 and 14 days	No	97.1
		Yes	2.9
Foster out (1–3 d)	At least one piglet fostered out between birth and 3 days	No	83.9
		Yes	16.1
Foster out (4–14 d)	At least one piglet fostered out between 4 and 14 days	No	94.3
		Yes	5.7
Vaccinate sow	Any vaccination of the sow up to 14 d after farrowing	No	83.4
		Yes	16.6
Deworm sow	Deworm the sow in the crate up to 14 days postfarrowing	No	81.3
		Yes	18.7
Treat sow for mange/lice	Mange/lice treat sow up to 14 days postfarrowing	No	83.5
		Yes	16.5
Feed sow antibiotics	Antibiotics fed to the sow	No	91.6
		Yes	8.4
Farrowing problems	Sow had problems farrowing the litter	No	98.1
		Yes	1.9
Sow health problems	Health problems of the sow up to 14 d postfarrowing	None	95.3
		Milk problems	3.1
		All other[a]	1.6

[a] The category of "all other" sow health problems includes producer reported health problems classified as respiratory system, lameness, diarrhea, other known, or unknown.

Litter-level risk factors were developed from the sow diary cards that producers used to record litter information (Table 1). Herd-level risk factors that measure herd management decisions were developed from the four producer questionnaires (Table 2). The distribution of factors may differ from Table 1 to Table 2. Each herd contributed only one observation to the summary data in Table 2. But each litter contributed one observation to the data in Table 1. Therefore, herds with a large number of litters had more influence on the data in Table 1 than did small herds.

Variables were included as putative causes if we believed there was a plausible biological relationship prior to analysis. These risk factors generally apply to all animals in the herd or litter, and therefore, any inferences regarding risk also apply to the herd or litter rather than the individual animal.

Statistical analysis

Odds ratios[14] obtained from multiple logistic regression analysis[15] were used to identify and quantify associations between the risk factors and the outcomes of interest. We conducted separate analyses for herd-level and litter-level data. Management variables

Table 2

Herd-level variables among 708 swine herds indicating the overall herd management

Variable	Description	Categories of response	% of herds
Decision maker	Primary decision maker for the swine operation	Operator	71.3
		Hired manager	7.6
		Partners	21.0
Operation type	Type of swine operation	Farrow to finish	78.4
		Feeder pig	18.5
		Breeding stock	2.8
All-in–all-out	All-in–all-out management of farrowing facility	No	45.6
		Yes	54.4
Wash sows	Wash sows prior to entry into farrowing facility	No	62.6
		Yes	37.4
Supplement milk	Provide supplemental milk to piglets	No	95.9
		Yes	4.1
Supplement creep	Provide supplemental creep feed to piglets	No	17.8
		Yes	82.2
TGE-free herd	Herd is considered to be free of TGE	No	83.6
		Yes	16.4
Vaccinate TGE	Breeding herd vaccinated for TGE	No	72.0
		Yes	28.0
Vaccinate *E. coli*	Breeding females vaccinated for *E. coli*	No	48.4
		Yes	51.6
Vaccinate Rotavirus	Breeding females vaccinated for rotavirus	No	82.3
		Yes	17.7
Clip teeth	Routinely clip teeth of piglets	No	13.8
		Yes	86.2
Dock tails	Routinely dock tails of piglets	No	14.5
		Yes	85.5
Iron	Supplemental iron given to piglets	No	7.9
		Yes	92.1
Treat navels	Navels of piglets treated with iodine	No	67.9
		Yes	32.1
Consultant	Operation uses the services of a consultant: veterinarian, nutritionist, or extension agent	No	52.3
		Yes	47.7
Farrowing facility	Type of farrowing facilities utilized	Total confinement	85.3
		Other building	15.1
		Hut	5.5

that had simple associations ($P < .10$) with diarrhea morbidity and mortality were used to develop the logistic regression models. We constructed the models using a backward elimination procedure with criteria to leave the model set at $P < .01$. Similarities of animals within herds and litters result in a violation of the independence of observations assumption required by the model. We attempted to account for the resulting underestimate of variability of animals within herds and litters by using intraherd correlation coefficients[16] to adjust the model test statistics.[17,18] The intraherd correlation coefficient measured the clustering of morbidity and mortality within the herd and allowed us to determine which factors were associated with the outcome after we removed the clustering. The adjusted test statistics were used to determine variables to remain in the final models. We adjusted for the state in which the herd was located and the time of year in which the herd was monitored in all analyses. Biologically reasonable interactions were tested for the variables in the final model.

Incidence densities are measured in animal-time units. For example; a denominator of 100 piglet-days could represent 100 piglets observed for 1 day or 4 piglets observed for 25 days. As another example, six pigs each living for 3 days would contribute 18 pig days to the denominator for mortality; so would 9 pigs each living for 2 days. Incidence densities express the reality that not all piglets present at the start of the study period will be alive and well throughout the observation period.

Herd-level variables are management decisions that are made to apply to the entire herd (e.g., the producer decides to vaccinate the herd for TGE). They are also factors that can only be applied at the herd level (e.g., the herd is considered free of TGE).

Litter-level variables are management decisions that are made to apply within a herd only to certain litters (e.g., only parity-one sows are vaccinated for *E. coli*) or they may represent variations from the herd-level decision (e.g., the producer usually castrates at 1 day of age but this litter didn't get castrated until day 5 of age). For factors that can be measured at the herd and litter level, the litter-level variable will be more accurate.

Results

Diarrhea morbidity averaged 0.4 cases per 100 piglet-days at risk (Table 3). This ranged from 0–100 at the litter level and 0–29 at the herd level. Diarrhea mortality among litters averaged 0.2 per 100 piglets at the litter level and 0.1 cases per 100 piglet-days at risk herd level. The mortality ranged from 0–100 cases per 100 piglet days at the litter level and 0–3.5 cases at the herd level. The average litter size was 9.9 pigs, and the average parity of the sows in the sample was 3.1 (Table 4). Sows were in the farrowing facility for 5.7 days prior to farrowing. Sixteen percent of all litters had at least one piglet fostered out, and 20% had at least one piglet fostered in during the first 3 days after farrowing. At 4–14 days after farrowing, 5.7% of all litters had at least one pig fostered out and 2.9% of litters had at least one piglet fostered into the litter. Sow health problems in the farrowing facility were reported for 4.7% of the litters (Table 1). The mean and median herd size among the monitored farms were 228 and 100 females, respectively.

Table 3

Mean, median, and range of incidence densities[a] (%) of diarrhea[b] morbidity and mortality among 4–14 day old piglets born in 29,843 litters in 708 herds

	Mean	Median	Range
Diarrhea morbidity			
Litter level	0.4	0	0 to 100
Herd level	0.4	0	0 to 29
Diarrhea mortality			
Litter level	0.2	0	0 to 100
Herd level	0.1	0	0 to 3.5

a Incidence density is defined as the number of piglets in the litter or herd with diarrhea divided by the total number of piglet days at risk of the event in the litter or herd. The result is multiplied by 100 and expressed as a percentage. Incidence densities account for the movement of pigs due to fostering and death.

b As observed and reported by the participating producers.

Table 4

Distribution of breeding herd variables among 29,843 litters

Variable	Mean	Median	Range
Herd size	228	100	0 to 32,770
Litter size	9.9	10	0 to 21
Sow parity	3.1	3	1 to 19
Days in facility prefarrow	5.7	5	0 to 125

The final litter-level risk factor models are presented in Table 5. Piglets born to sows with milk-related problems were 1.6 times more likely to have diarrhea than piglets born to healthy sows. Similarly, piglets born to sows with other health problems were 4.4 times more likely to have diarrhea than piglets nursing healthy sows. An increased risk of diarrhea was also found in piglets nursing sows treated with anthelmintics while in the farrowing facility (OR=1.3). Castrating male piglets before 14 days of age was associated ($P < .05$) with a lower risk of diarrhea morbidity.

For continuous risk factor variables, the odds ratio is the multiplicative change in the odds of disease for each one unit increase in the risk variable.[3] In the litter-level model, as litter size increased by one pig, the risk of death due to diarrhea increased 1.07 times. Litter-level factors associated ($P < .01$) with a greater risk of diarrhea mortality included:

- larger litter size,
- sow health problems in the farrowing facility,
- fostering pigs into the litter at 4–14 days after farrowing, and
- treating the sow for mange or lice while in the farrowing facility.

The risk of diarrhea mortality was lower ($P < .01$) when:

- fostering pigs out of the litter occurred at 1–3 days following farrowing,
- piglets were castrated at 4–14 days of age,
- iron supplementation was given between 1–3 days of age, and
- sows were vaccinated while in the farrowing facility.

The final herd-level risk factor models are presented in Table 6. The risk of diarrhea morbidity in 4- to 14-day-old piglets was greater ($P < .01$) in:

- larger herds, and
- herds that routinely provided supplemental milk to piglets.

Diarrhea morbidity was lower ($P < .01$) in herds that:

- used all-in–all-out management of the farrowing facility,
- routinely washed sows prior to farrowing,
- were considered free of TGE, and
- routinely vaccinated sows against *E. coli*.

Diarrhea mortality in 4- to 14-day-old piglets was lower ($P < .05$) when:

- the primary decision maker for the operation was a hired manager rather than the owner/operator, and
- sows were routinely vaccinated against *E. coli* ($P < .01$) compared with herds that did not include *E. coli* in their sow vaccination program.

Discussion

Diarrhea is the primary cause of preweaning piglet morbidity.[2,13] Christison et al. (1987) found the rate of diarrhea morbidity to be 31% during the first 21 days of life.[3] Diarrhea affects at least 16% of all litters,[2] but the morbidity rate varies considerably among and within farms. Although this study is subject to the producer's willingness to recognize and record morbidity events, we believe that diarrhea is easily recognized by the producer. Hence, we do not expect any false positive cases.[12] In our study, diarrhea morbidity and mortality among litters averaged 0.4 and 0.2 cases per 100 piglet-days at risk, respectively. Most researchers record mortality during the first week of life or for the entire preweaning period. The crude preweaning mortality rate is reported at between 13% and 21%.[3,5,6] Twenty-five percent to 48% of this mortality occurs from 4–14 days of age.[15,16] The average mortality rate due to diarrhea in the preweaning period is between 0.2% and 7.6%.[3,5,19,20,21] Svendsen et al[7] found 1.1% of piglets die of diarrhea from 4–14 days of age. The proportional mortality rate due to diarrhea ranges from 5%–16%.[3,8,21]

Odds ratios: The odds of a litter having diarrhea if it was also subjected to that particular management variable compared to litters not subjected to that management variable. The management variables with the highest odds ratios have the most influence on diarrhea morbidity and mortality.

Table 5

Final models[a] for estimating adjusted odds ratios for the incidence density of diarrhea morbidity and mortality for piglets aged 4–14 days in 29,843 litters

Diarrhea morbidity

Variable	Odds Ratio[b]	95% CI (OR)
Sow health problems		
None	1.0	—
Milk problems	1.6 *	1.1 to 2.4
All other[c]	4.4 **	3.1 to 6.0
Age at castration		
> 14 d	1.0	—
1–3 d	0.78 *	0.61 to 0.99
4–14 d	0.76 **	0.63 to 0.92
Deworm sow		
No	1.0	—
Yes	1.3 *	1.1 to 1.5

Diarrhea mortality

Variable	Odds Ratio[b]	95% CI (OR)
Litter size	1.07 **	1.03 to 1.12
Sow health problems		
None	1.0	—
Milk problems	1.5	0.9 to 2.5
All other[c]	9.1 **	6.5 to 12.8
Foster in (4–14 d)		
> 14 d	1.0	—
1–3 d	1.3	0.99 to 1.7
4–14 d	0.72 **	0.55 to 0.94
Supplemental iron		
None	1.0	—
1–3 d	0.59 **	0.47 to 0.74
4–14 d	0.74	0.54 to 1.0
Vaccinate sow		
No	1.0	—
Yes	0.61 **	0.43 to 0.86
Mange/lice-treat sow		
No	1.0	—
Yes	1.6 **	1.2 to 2.1

a State in which the herd was located, and the quarter in which the herd was monitored were adjusted for in the model, but the resulting odds ratios are not shown.

b For categorical variables, the odds ratio is for each exposure category versus the reference category with OR=1.0.

c Includes producer-reported health problems classified as respiratory system, lameness, diarrhea, other known, or unknown.

* $P < .05$, as assessed using Wald's test adjusted for intraherd clustering.

** $P < .01$, as assessed using Wald's test adjusted for intraherd clustering.

Herd factors

The herd size and numbers of pigs born alive in this study is similar to that found in other observational studies.[5,22] Larger herds had a higher rate of diarrhea morbidity, but no association between herd size and diarrhea mortality was observed. Previous studies have also reported no association between diarrhea mortality and herd size,[5,7] although Friendship, et al., reported that larger herds had lower rates of preweaning mortality.[6] These previous studies included the entire preweaning period.

Herds that had a hired manager as the primary decision maker for the operation rather than an owner had lower diarrhea morbidity. This higher rate in owners may be because owners were more likely to report cases of diarrhea or were more observant and identified diarrhea more often. It has been shown that better managers adopt improved technologies and also have lower preweaning mortality rates.[3] Also, farms that have specialized farrowing personnel may benefit from having one person dedicated to the care of the preweaned pig. English, et al.,[9] stress the need for capable workers who are able to pay attention to details and thus decrease preweaning mortality to the acceptable levels of ≤10%.

Producers that managed their farrowing barns as all-in–all-out facilities had a lower rate of diarrhea morbidity (OR=0.75) than those with continuous-flow facilities. All-in–all-out provides the opportunity to clean and disinfect the premises between groups of sows. This will reduce the reservoir load of pathogenic enteric organisms such as *E. coli* and *I. suis*.[23,24] Also, this management style typically includes smaller rooms with a narrow age group of piglets in one room. Similar findings are recorded in the literature where the rate of preweaning diarrhea mortality was higher in herds with low hygiene (3.9%) than in farms with good hygiene (2.4%).[7] It is important to note that all-in–all-out management decreases morbidity in the 4- to 14-day-old pig.

Sow factors

Producers recorded health problems in the farrowing facility for 5% of the sows; 3% were milk-related problems and 2% were other causes of illness. The rate of milk-related problems in this study was lower than in previous studies, in which the rate of mastitis-metritis-agalactia (MMA) ranged from 6.9%–10.7%.[5,7] The incidence of MMA is difficult to determine because the clinical signs and the severity of the disease vary widely.[25] Also, the participating producers may not have recorded all cases. Piglets nursing agalactic sows will initially show increased activity—fighting and attempts to nurse—but then will be depressed, have diarrhea, and huddle together.[25,26] We found that litters nursing sows with milk-related problems were 1.6 times more likely to have piglets with diarrhea morbidity. Previous studies indicate that between 5% and 45% of piglets born to sows with MMA die during the first week of life.[4,7,21] Within these studies the mortality rate in piglets nursing sows with MMA was twice that of piglets nursing healthy dams.[4,7,21]

In this study, piglets nursing sows that had diarrhea, reproductive, respiratory, or musculoskeletal problems were four times more likely to scour and nine times more likely to die compared with piglets nursing healthy sows. Dams with health problems will be less able to nurse their offspring and the piglets, who depend

Table 6

Final models[a] for estimating adjusted odds ratios for the incidence density of diarrhea morbidity and mortality for piglets aged 4–14 days in 708 herds

Diarrhea morbidity

Variable	Odds Ratio[b]	95% CI (OR)
Herd size[c]	1.005 **	1.003 to 1.005
All-in–all-out		
No	1.0	—
Yes	0.75 **	0.64 to 0.88
Wash sows		
No	1.0	—
Yes	0.76 **	0.65 to 0.89
Supplemental milk		
No	1.0	—
Yes	1.9 **	1.4 to 2.6
TGE-free herd		
No	1.0	—
Yes	0.59 **	0.46 to 0.75
***E. coli* vaccination**		
No	1.0	—
Yes	0.76 **	0.62 to 0.94

Diarrhea mortality

Variable	Odds Ratio[b]	95% CI (OR)
Decision maker		
Operator	1.0	—
Partners	0.95	0.74 to 1.20
Hired manager	0.45 *	0.28 to 0.73
***E. coli* vaccination**		
No	1.0	—
Yes	0.58 **	0.50 to 0.73

a State in which the herd was located, and the quarter in which the herd was monitored were adjusted for in the model, but the resulting odds ratios are not shown.

b For categorical variables, the odds ratio is for each exposure category versus the reference category with OR=1.0.

c For every increase in 100 animals in the breeding herd, the odds of diarrhea in piglets increased 1.005 times.

* $P < .05$, as assessed using Wald's test adjusted for intraherd clustering.

** $P < .01$, as assessed using Wald's test adjusted for intraherd clustering.

on a constant supply of milk for antibodies, will be less able to fight infection. Sows that are ill or lame are less likely to eat adequate amounts of feed and may not consume sufficient quantities of water to maintain a good milk supply.[5]

Herds that provided supplemental milk to the piglets had a higher rate of diarrhea morbidity (OR=1.9) than those that did not. There are two possible explanations for this:

- the herds using milk replacer may have a problem with hypogalactia; or
- the supplemental milk may decrease the consumption of sow's milk by the piglets.

Hence, piglets that are given milk may be less likely to suckle. Sows' milk-supply antibodies are responsible for binding fimbriae and preventing fimbrial interaction with receptors on the intestinal epithelial cells.[10] Although supplemental milk provides the nutrients for piglets to grow, it does not provide the local intestinal immunity piglets require.

Litters born to dams that were vaccinated for at least one disease were less likely to suffer diarrhea mortality (OR=0.61) than litters where the sows were not vaccinated. It is difficult to interpret this nonspecific variable.

Fifty-two percent of the producers routinely vaccinated the sow herd against *E. coli*. This rate is similar to that reported in the literature.[5] Herds in which sows were vaccinated for *E. coli* had lower levels of morbidity and mortality due to diarrhea. This vaccine was also previously reported to have a sparing effect for morbidity and mortality in 1- to 3-day-old piglets.[10] Sows transfer passive immunity to the piglets through the colostrum and milk.[10,27] Although *E. coli* typically affects piglets within the first 48 hours of life, it can also cause diarrhea in the 4- to 14-day-old pig. Piglets that have diarrhea before they are 4 days old may die between 4 and 14 days of age.

Eighty-six percent of the producers believed they were not free of TGE, and 28% of producers vaccinated against the disease. Vaccinating sows against TGE or rotavirus was not associated with a reduction in the rate of diarrhea morbidity or mortality. This was also found for piglets up to 3 days of age.[12] In our study, producers who reported that they were free of TGE had less diarrhea morbidity (OR=0.59) in their piglets than producers who believed they had the disease. This agrees with Leman, et al.,[21] who found TGE was not a significant cause of diarrhea mortality; affecting only 0.7% of pigs.

Herds in which sows were washed prior to entering the farrowing crate had less diarrhea (OR=0.76) than herds in which sows were not washed. It is believed that piglets are exposed to large numbers of pathogenic bacteria that are in the feces adhered to the sows' skin. By washing the sow, the load of pathogens may be reduced.

Deworming sows in the farrowing crate was associated with higher piglet morbidity (OR=1.3) and treating sows for mange and lice in the farrowing crate was also associated with a higher piglet mortality (OR=1.6). It is recommended that sows be treated for internal and external parasites before they are moved to the farrowing crate. These variables may be surrogate measures of "poor management" and thus identify the producers who have not adopted existing knowledge of good stockmanship.[9]

Piglet factors

Larger litters had a higher rate of diarrhea mortality than did smaller litters. As the litter size increased by one pig, the odds of a piglet dying of diarrhea was 1.07. This supports previous findings that the rate of *E. coli* diarrhea increases with litter size.[7,19] Cross-fostering may be the appropriate solution to this problem. Litters that had piglets fostered out in the first 3 days of life were only two-thirds as likely to have a piglet die of diarrhea mortality than litters that did not have piglets fostered out. Unfortunately, cross fostering is a difficult management technique and is usually successful only when done early.[20] Fostering piglets after the second day of life or after the piglets have become weak and hypoglycemic may lead to an increased mortality rate.[6] Late fosters may be a producer's attempt to save piglets that are dying. In our study, litters that had a piglet fostered-in between 4 and 14 days after birth were 2.7 times more likely to have piglets die of diarrhea.

Fifteen percent of the respondents did not use supplemental iron. Litters that were given iron prior to 4 days of age had a lower rate of diarrhea mortality (OR=0.59) than litters that were not given iron or were given iron after day 4. Piglets are born with insufficient iron reserves and sows' milk does not contain adequate amounts to maintain iron at normal levels. Piglets become anemic without supplementation, which decreases their resistance to infection.[6,26,28]

Piglets castrated from 4–14 days of age were less likely to die of diarrhea (OR=0.72) than those castrated either at 0–3 days or after 14 days of age. For 6 hours after castration, piglets spend less time suckling and standing and more time lying down. If castration occurs during the first 3 days of life, these behavior changes are expected to reduce the intake of immunoglobulins, decrease the ability of the piglet to fight for the most productive nipples, and increase chilling, leading to a higher incidence of diarrhea in the 4–14 day period. Castrating of piglets after 14 days of age was associated with a higher rate of diarrhea than castrating of younger pigs. This may have been another surrogate measure of good management, as it is recommended that piglets are castrated within the first 2 weeks of life.[20]

The strength of observational studies is that the disease and management factors are measured directly on the farm so the results can be extrapolated directly to the field. Although the results of this study pertain specifically to this sample of farms, because a representative sample of farms in the United States was included, the results may apply to the United States swine industry. The weakness of this study is that the validity of producer observations is debatable: there may be bias due to the consistency of recording. Also, factors measured at the herd level cannot be causes of diarrhea measured at the piglet level. Finding a significant association between a factor and the disease of interest does not confirm a cause-and-effect relationship. However, the factors in this study that were identified in more than one model may indeed potentially represent such a relationship. These factors include: health problems in the sow, castrating pigs at 4–14 days of age, and vaccinating sows for *E.coli*. Therefore, we conclude that vaccinating sows for *E.coli* and fostering piglets off sick sows are expected to decrease preweaning losses due to diarrhea in 4- to 14-day-old pigs.

Implications

- Because diarrhea increased with sow health problems and use of supplemental milk, identify sick sows, crossfoster pigs off the sick sows by 3 days of age, and use supplemental milk only when necessary.
- Piglets of sows vaccinated against *E. coli* had lower rates of both diarrhea morbidity and mortality.
- Reduce pathogen load by flowing animals all-in–all-out and washing sows.
- Pay particular attention to piglets in larger litters.
- Use supplemental iron to prevent anemia in piglets.

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