Mixed models applied to the study of variation of grower-finisher mortality and culling rates of a large swine production system

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Abstract

Large scale production systems for swine are frequently organized in a hierarchical structure. Consequently, important production parameters, such as mortality and culling, can be analyzed at different levels. The major aims of this study were to assess variance components (VC) of mortality and culling rates attributed to sites and to barns within a site, and subsequently to investigate the impact of average entry weight, days on feed (length of the production turn), and season on the magnitude of the VC. Then, data from a large farm with 3 sites were collected during 5 y. In total, 1 720 040 pigs distributed in 1502 all-in/all-out grower-finisher groups were included. Linear mixed models were fitted for mortality and culling rates. The barn was modeled as the residual component (barn-to-barn variations) with production turn and site nested within production turn as random intercept variance components.

Barn-to-barn pig group variation was the largest VC for mortality (63.08%), when no predictors were included in the models. Predictors, such as pigs placed on quarters 2 and 3, low average entry weight, and shorter production turn length, were associated together with higher mortality. The explained proportion of variance due to these predictors was about 12.05% and the VC for barn, site, and production turn were 67.6%, 17.6%, and 14.8%, respectively. Barn-to-barn variation was also the largest VC for culling rate (46.2%), but the same predictor mentioned above explained only about 1.4% of the variation. The VC for barn, site, and production turn were 46.8%, 21.3%, and 31.8%, respectively. Since the variability among barns far exceeded the variability among sites, the barn should be used as experimental unit in studies with grower-finisher mortality, culling rate, or both, as outcome variables.

Résumé

Les systèmes de production intensive de porcs sont souvent organisés selon une structure hiérarchique. Par conséquent, des paramètres importants de production, tels que la mortalité et la réforme, peuvent être analysés à différents niveaux. Les principaux buts de cette étude étaient d'évaluer des éléments de variance (VC) des taux de mortalité et de réforme attribués aux sites et aux fermes sur les sites, et par la suite d'investiguer l'impact du poids à l'entrée moyen, le nombre de jours nourris (durée de production) et la saison sur l'ampleur du VC. Ensuite, des données provenant d'une unité importante de production en 3 sites ont été amassées pendant 5 ans. Au total, 1 720 040 porcs répartis en 1502 groupes d'animaux en engraissement de type tout plein/tout vide sont inclus dans l'étude. Des modèles linéaires mixtes ont été ajustés pour les taux de mortalité et de réforme. La ferme a été modélisée comme étant la composante résiduelle (variations de ferme à ferme) avec la durée de production et le site nichés dans la durée de production comme coordonnées à l'origine aléatoires des VC.

La variation de ferme à ferme entre les groupes de porcs était la plus importante VC pour la mortalité (63,08 %) lorsque aucun prédicateur n'était inclus dans les modèles. Des prédicateurs, tels que des porcs entrés durant le 2e et 3e trimestre de l'année, un faible poids à l'entrée et une durée de production plus courte ont été associés à une mortalité plus élevée. La proportion de variance expliquée associée à ces prédicateurs était d'environ 12,05 % et les VC pour la ferme, le site et la durée de production étaient, respectivement, 67,6 %, 17,6 % et 148 %. Les variations de ferme à ferme étaient également la plus importante VC pour le taux de réforme, mais les mêmes prédicateurs que ceux mentionnés ci-dessus ne pouvaient expliquer que seulement 1,4 % de la variation. Les VC pour la ferme, le site et la durée de production étaient, respectivement, 46,8 %, 21,3 % et 31,8 %. Étant donné que la variabilité entre les fermes dépassait largement la variabilité entre les sites, la ferme devrait être utilisée comme unité expérimentale lors d'études dans des productions de type engraissement-finition portant sur la mortalité, le taux de réforme, ou les deux.

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Introduction

In large-scale intensive production systems, pigs are usually grouped in a hierarchical structure of pens, rooms, barns, and sites. When studying such populations, it is important to define the appropriate levels where risk factor analysis and interventions should be performed. Thus, it is necessary to identify where the system expresses the highest levels of variation in health and production measures (1–3).

Culling and mortality rates are frequently used to monitor performance in grower-finisher herds (4–6). Factors that are associated with changes in mortality in nursery and grower-finisher pigs have been investigated in some detail (9–12). However, little attention has been paid to the hierarchical structure of large-scale production systems and the recommended level of analysis and intervention. Similar questions, regarding the hierarchical structure of the data, have been stated in studies on the spatial distribution of infectious bovine rhinothracheitis in dairy cattle over different ecologic regions and farms (3). The sources of variability in reproductive performance in dairy cattle have been characterized by examining how much of the variance was accounted for by the hierarchical structure of region, farm, and cows within farms (2).

Previous research in the same population as in this study, has reported the survival pattern during the grower-finisher period and the financial implications of losing older and more valuable pigs (12). The present paper explores whether the distribution of mortality and culling is clustered within a hierarchical structure of barn, site, and production turn. The objective was to quantify the variance components for mortality and culling rates considering the hierarchical structure of a grower-finisher production system, emphasizing which is the most suitable unit of analysis; barn or site.

Materials and methods

Study population and production system

The study was conducted in a large 3-site production system located in the United States. The production system consisted of 1 sow breeding unit, 5 nursery complexes (at a different location) and 14 grow-finishing sites. The sow unit consisted of 12 sow barns, each housing 2240 sows. Each nursery site consisted of 24 barns with a 1360 head capacity. Each of the grower-finisher sites consisted of 8 barns with a capacity of 1150 pigs per barn (9200 pigs per site). The term "site" refers to the grower-finisher site. Each site was managed by 1 person, the site manager. The population consisted of 1 720 040 pigs distributed in 1502 grower-finisher barn closeout groups placed between 1996 and 2000.

Pig flow, housing, and management

Piglets were weaned at approximately 18 d of age and transferred from the sow unit to the nursery complex 3 times a week. Each nursery complex was filled with pigs from multiple sow barns. At approximately 10 wk of age, nursery pigs were transferred into the grower-finisher barns, allocating 25 to 26 pigs per pen. Barrows and gilts were housed together. The grower-finisher phase was managed according to all-in/all-out procedures at the site level. After all the pigs were removed, sanitation procedures were applied followed by a 1-week stand-empty period before new pigs were placed in the site. The batch of pigs on a site from placement to pig marketing is termed the production turn (n = 16). In addition, each production was coded sequentially from 1 (the first) until the last one recorded.

The grower-finisher barns were tunnel-ventilated with fully slatted concrete floors. Feeding practices consisted of a standard diet based on corn and soybean meal delivered ad libitum in wet-dry feeders. Each grower-finisher site had 1 person exclusively in charge of the management of that population. The herd had a history of sporadic outbreaks of disease caused by *Mycoplasma hyopneumoniae, Actinobacillus pleuropneumoniae* serovar 3, and porcine reproductive and respiratory syndrome virus (PRRSV). Slaughter data showed a median prevalence of pleuritis of about 5.4% (first and third quartiles, 4.2 and 6.8%, respectively) of the pigs marketed during the study period. Two necropsy surveys performed during 1999 and 2000, including more than 1000 dead pigs, mainly found pneumonia and stomach ulcers. The breeding herd and the incoming gilts were vaccinated against PRRSV and *Escherichia coli* throughout the study, and against influenza H1N1 in the first half of the study period. Nursery pigs were vaccinated against *M. hyopneumoniae* at 6 and 8 wk of age.

Production measures and data analysis

Records included deaths, culls (pigs removed from the site before marketing), average entry weight, and the number of pigs marketed. All these data were kept at barn level with a unique identifier per pig group. Mortality rate was calculated as the number of dead pigs per 1000 wk, accounting for the weekly variation of the population at risk due to dead and culled pigs (13). Culling rate was also calculated as the number of culled pigs per 1000 wk. Number of pigs placed, average entry weight, days on feed (length of the production turn), and the quarter of the year when pigs were placed in the facility were investigated as fixed effect. Quarter of the year was used in the model as an indicator of seasonality (10,20).

The system has a structure of 14 sites with 8 barns each and at least 16 production turns were recorded by the year 2000. The unit of concern in this study was the pig group raised in one barn during a production turn, therefore site (8 barns each) and production turn were looked at as aggregation units.

Since the data on mortality and culling rate were skewed, a transformation using the natural logarithm was performed to fit the regression model (14). The back-transformed least square means were reported in Tables II and III. The mixed models fitted for mortality and culling rates with random effects grower-finisher site nested within a production turn and for production turn with the residual variance, was as follows: $Y_{ijk} = \beta' Z_{ijk} + b_i' W_{ik} + b_{j(i)}' W_{j(i)k} + \varepsilon_{ijk}$ (15,21). The response variable Y_{ijk} was the natural logarithm of the mortality or culling rate for the k barn pig group (n = 1502), j site (n = 14), and i production turn (n = 16). The first variance component, production turn (b_i), accounted for variation among turns; the second component, site ($b_{j(i)}$), accounted for the variation among sites; and the third component (ε_{ijk}) corresponded to the residual variance, which was the barn-to-barn pig group variation. The term Z and W's are the covariate vectors for the fixed and random effects, respectively. The term β is the vector of unknown fixed effects, and

Table I. Description of the study population and production parameters of grower-finisher pigs from 1996 to 2000 in a multi-site production system in the United States

Parameters	1996	1997	1998	1999	2000
Number of barn closeouts (*n*)	270	285	291	320	335
Number of pigs placed	313 205	327 891	334 823	368 612	377 508
Average entry weight (kg)	20.27	22.45	24.56	24.56	24.95
Standard deviation (s)	2.04	4.50	2.72	2.04	2.04
Average days on feed	132.34	131.33	124.31	119.26	120.08
s	3.74	8.30	3.72	2.23	2.94
Mortality rate (pigs/1000 wk)					
Median	2.25	2.97	3.38	3.22	3.67
Q1–Q3	1.82 to 2.97	2.28 to 3.86	3.38 to 4.20	3.22 to 4.24	3.67 to 4.61
Culling rate (pigs/1000 wk)					
Median	0.90	1.64	1.64	0.89	0.64
Q1–Q3	0.59 to 1.30	1.15 to 2.09	1.07 to 1.64	0.59 to 1.33	0.39 to 0.92

b*i* (bi_1…,bi_{14}) and b*j* (bj_1..,bj_{16}) are the vectors of random effect for sites and production turn, respectively. The measurement error ε_{ijk} is independent from Z, W and b and normally distributed (N[0, σ^2_{error}]). The bs' random effects are independent from each other and they are also normally distributed (N ~ [0, σ^2_i or σ^2_j]).

The proportion of the variation in the response variable accounting for one level of clustering (site) was deduced by means of the Intraclass Correlation Coefficient (ICC, ρ) (16,21). The ICC was calculated according to the following equation: $\rho = \sigma^2_{\text{hierarchical level i}} / (\sigma^2_{\text{hierarchical level i}} + \sigma^2_{\text{hierarchical level j}} + \sigma^2_{\text{error level k}})$. The term σ^2_{error} was interpreted as the variation assigned to barns and the variation left unexplained by the model and the term $\sigma^2_{\text{hierarchical level i}}$ and $_j$ as the contribution to the total variation for a given level (21). Then, the ICC for levels i and j would indicate that differences in the site or production turn account for part of the individual barn population differences observed in the combined pig barn population.

To measure the proportion of explained variance, a model with no explanatory variables (null model), with just the random effects, was compared with a model with random and fixed effects (full model). The proportion of variance explained by the model was then quantified as a change percent of full model total unexplained variance (the sum of all variance components) divided by the null model total unexplained variance (1 − var full/var null) (21). The null model estimates of the size of the total unexplained variance and the sizes of the variance partition in the population ($\sigma^2_{\text{hierarchical level i}} + \sigma^2_{\text{hierarchical level j}} + \sigma^2_k$) (21). Therefore, the changes in the size of the unexplained variance and in the ICC were interpreted as the overall influence of the predictors in the rate distribution, and at the level of hierarchy that they were operating.

The restricted maximum-likelihood (REML) method was used to model the covariance structure (random factors) and the maximum-likelihood estimator (MLE) to select the fixed effects (16,17). The Bayesian information criterion (BIC) was used to select the models' variance structures and the best predictor subset (18,19). Average entry weight, days on feed (length of the production turn), and season, as well as the second order interaction and non-linear term (average entry weight) were all evaluated in alternative models. The analyses were performed using Proc Mixed (SAS Institute, Cary, North Carolina, USA) (16). Since the study used population instead of sample data, the statistical analysis was focused on the estimation of the parameters rather than the hypothesis testing.

Results

Descriptive statistics

The study included all barn close-out groups reared in the system between 1996 and 2000. The estimates of mortality and culling rates, and average entry weight stratified by year are displayed in Table I.

Variance components for mortality rate

Fitting a model without explanatory variables (null model), the barn-to-barn pig group variations accounted for approximately 63.08% (0.099/0.16) of the total variance, followed by production turn with 23.29% (0.036/0.16) and site with 13.62% (0.021/0.16).

Low average entry weight and shorter lengths of production turns were significantly associated with higher mortality (Table II). Pigs placed during quarters 2 and 3 had higher mortality than those placed in quarters 1 and 4 (Table II). Together, average entry weight, days on feed, and quarter of the year decreased the total unexplained variance for mortality by 12.06% (1 to 0.13/0.157). For the same model, the variance components magnitude (ICC's) were, 67.6%, 14.8%, and 17.6% for barn-to-barn, production turn, and site variations, respectively (Table II).

The unexplained variance reduction in the mortality rate model was mainly due to average entry weight and days on feed. The inclusion of just average entry weight and days on feed (model unexplained variance = 0.141, BIC = 1009.2) reduced the total unexplained variance by 10.6% (1 to 0.141/0.157) versus a reduction of 12.06% when quarter of the year was also added to the model.

Variance components for culling rate

The culling rate model without explanatory variables showed that 46.2% (0.2361/0.51) of the variability rested on barn-to-barn variation, followed by production turn with 31.8% (0.1604/0.5042), and site with 21.3% (0.1077/0.5042). Lower entry weight and fewer days

Table II. Mixed models of the factors associated with grower-finisher pig mortality (1996 to 2000, 1502 pig barn groups)

Random effects	Estimate (%)	$s_{\bar{x}}$	95% CI	LMS (ln)
Production turn	0.0203 (14.8)[b]	0.0090	0.0099,0.0624	—
Site nested within turn	0.0242 (17.6)[a]	0.0040	0.0178,0.0347	—
Residual	0.1488 (67.6)[a]	0.0036	0.0861,0.1004	—
Total	0.1373 (100.0)	—	—	—
Fixed effects	β	$s_{\bar{x}}$	95% CI	
Average entry weight	−0.0246[a]	0.0028	−0.0334,−0.0122	1.43 (4.17)[e]
Days on feed	−0.0259[a]	0.0043	−0.0433,−0.0291	0.70 (2.01)[f]
Quarter 1	−0.0580[c]	0.0400	−0.1366,0.0205	1.02 (2.77)
Quarter 2	0.0958[d]	0.0431	0.0114,0.1802	1.18 (3.26)
Quarter 3	0.0932[d]	0.0389	0.0168,0.1687	1.18 (3.25)
Quarter 4	Reference[c]	—	—	1.09 (2.96)

LMS — least mean square in the log scale and the back transformed estimate; $s_{\bar{x}}$ — standard error

[a] $P < 0.05$; [b] $P < 0.01$

[cd] Values within a column with a different letter means significant difference ($P < 0.05$)

[e] LMS for a close-out group of 15 kg at entry and 120 d on feed

[f] LMS for a close-out group with 24 kg at entry and 140 d on feed

Table III. Mixed model of the factors associated with grower-finisher culling rate (1996 to 2000, 1502 pig barn groups)

Random effects	Estimate (%)	$s_{\bar{x}}$	95% CI	LMS (ln)
Production turn	0.1604 (31.8)[a]	0.0658	0.0822,0.4398	—
Site nested within turn	0.1077 (21.3)[a]	0.0152	0.0832,0.1450	—
Residual	0.2361 (46.8)[a]	0.0093	0.2189,0.2553	—
Total	0.5042 (100.0)	—	—	—
Fixed effects	β	$s_{\bar{x}}$	95% CI	
Average entry weight	−0.2298[a]	0.0105	−0.0323,−0.1365	0.43 (1.54)[d]
Average entry weight quadratic	0.0042[a]	0.0001	0.0022,0.0062	—
Days on feed	−0.0098[a]	0.0025	−0.019,−0.0002	−0.37 (0.69)[e]
Quarter 1	0.0847[b]	0.0077	−0.0663,−0.2357	−0.07 (0.92)
Quarter 2	0.1942[c]	0.0824	0.0325,0.3559	0.03 (1.03)
Quarter 3	0.2021[c]	0.0739	0.0571,0.3470	0.08 (1.09)
Quarter 4	Reference[b]	—	—	−0.16 (0.85)

LMS — least mean square in the log scale and the back transformed estimate; $s_{\bar{x}}$ — standard error

[a] $P < 0.01$

[bc] Values within a column with a different letter means significant difference ($P < 0.05$)

[d] LMS for a close-out group of 15 kg at entry and 120 d on feed

[e] LMS for a close-out group with 24 kg at entry and 140 d on feed

on feed were associated with higher culling rates (Table III). Pigs placed during quarters 2 and 3 showed increased culling rate. These predictors did not modify the total unexplained variance of the culling rate except for 1.4% (1 to 0.50/0.51). In addition, the variance components (ICC's) were 46.8%, 31.8%, and 21.3% for barn-to-barn, production turn, and site variations, respectively (Table III).

Discussion

Average entry weight, days on feed, and quarter of the year significantly reduced the variation observed in mortality attributed to production turn, explaining a large part of its effect in the model. Among these factors, the quarterly variation contributed little to such effect because the reduction on the variance component (ICC) for production turn was mainly due to the inclusion of days on feed and average entry weight in the model. However, we have no explanation for the higher mortality observed among pigs placed during quarters 2 and 3 under the production and management conditions where the study took place. In addition, part of the variance due to production turn might indicate the effect of the longer time using the same facilities (older facilities).

The length of the production turn was negatively associated with mortality, contrasting with the findings of Losinger et al (10), who found no correlation between days on feed and overall mortality.

The same authors also reported that a longer grower-finisher period increased the risk of dying due to pneumonia and they attributed that to a longer exposure time (11). In our study, the average number of days on feed decreased from 21 wk in 1998 to about 19 wk in 2000. This decrease was a management decision made simultaneously with the increasing trend in mortality and culling observed in this population over time. However, this is not thought to be causally associated with such a management decision.

The average entry weight of the pigs was consistently monitored because of its influence on weight gain and survival during the grower-finisher phases (9,20,22). Similar to previous reports, low average entry weight compromised the survival of grower-finisher groups, even after days on feed and quarter of the year were included in the analysis. In contrast with the observations made for mortality, average entry weight, days on feed, and quarter of the year did not explain much of the variation in culling rate due to complex or production turn. This was evidenced by the fact that differences in the total unexplained variance and the intraclass correlation coefficient between models were negligible. The effect of weight on subsequent mortality and culling rate seems reasonable. However, group correlations may be biased because they ignore the variation among individuals within the group (23).

The grower-finisher sites studied resembled each other in many aspects, such as housing design, ventilation system, and biosecurity measures. However, the mortality and culling rates were still reflecting some degree of clustering within each site, which means that the rates were unevenly distributed among grower-finishing sites. Then, it can be speculated that different issues, especially those related with manager style may have had implications in the differential distribution of mortality and culling rates among sites.

The stockperson, as part of the pig's environment, has important implications on the performance of the pigs (24). Specifically, in the case of mortality, the early detection of health problems, rapid intervention, and culling decisions could have modified the mortality pattern of the grower-finishers. Culling is perceived as a decision that is more prone to subjectivity of the site manager, in comparison to mortality. Indeed, the site ICC for culling (21.3%) was higher than the ICC for mortality (17.6%).

Barn-to-barn variability was the largest variance component, therefore, it can be hypothesized that factors at barn level, such as the health status of the incoming pigs (25), the pig source mixing (10,26), the barn micro-environment, and the sanitation procedures (27,28), may have had implications on the risk variation among barn groups. Specifically, the origin of the feeders could not be traced back, so that the evaluation of the sow herd as a source of variability was not feasible.

Experimental evidence has shown that rigorous early segregation weaning schemes can facilitate the mixing of different sources without experiencing many disease problems in the nursery pigs (29). Good health profile of incoming feeders was found to be associated with lower mortality in finishing pigs in Finland (25), and the higher the number of different pig sources, the higher the risk of mortality in grower-finishers in Belgium (26). Pig groups free from enzootic pneumonia and atrophic rhinitis experienced half of the finishing mortality in comparison to finishing groups made up of pigs with such diseases (25). The production system studied cannot be compared with a fattening unit in Western Europe and consequently, a lower variability on feeder pig starting conditions can be expected. However, in this type of production system, the preservation of a stable profile of health in the pig flow over time has been challenging (22). Moreover, the observed association between average entry weight and the mortality rate may have been the manifestation of the underlying effect of some of the factors mentioned above, because the health status, source mixing, and weight variation from pig-to-pig might not necessarily be independent from each other.

Hierarchical (mixed) models are very versatile tools, so the problem faced could have been looked at in different ways. Nesting site within production turn, the representation of the variation among grow-finish sites, was restricted to each particular production turn. Since the same production turn was run across all sites simultaneously, the production system conditions for all sites were similar except for the site manager and pig flow factor (sow unit of origin). Therefore, the cluster effect (ICC) due to site was well characterized. Alternatively, a correlation structure for the rates within barn over time could have been modeled. However, we believe that the most appropriate cluster structure was barn/site pig groups.

Further investigation on mortality and culling rates should include predictors at barn level, as well as at individual pig level such as entry weight, immune status, gender, and previous phases management. While mixed models are versatile tools, they require a better understanding of the micro- (pigs) and macro-level (barn) variables and their interactions (30), so that the prescription derived from the model can be better translated as management guidelines.

Although a single system study restricts the generalization of the findings to a variety of production conditions, the findings still apply to large North American swine integrations. Until a more comprehensive study is conducted, screening of source of variability can be done as a preliminary phase of a risk factor study. Since site accounted for a moderate portion of the variability, manager related factors might have been involved in the mortality and culling rate distribution within the herd. The variability in mortality attributed to production turn was mainly due to changes in average entry weight and days on feed. Unlike mortality, the culling rate was unaffected by these factors. Pig barn population characteristics might be involved in the distribution of the grower-finisher mortality and culling rates. Therefore, increased success in the explanation of variation of culling and mortality rates of grower-finishers can be achieved by determining associated risk factors at both individual pig and barn levels.

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