Predictors for wean-finish mortality events in a commercial swine production system

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Iowa State University

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Predictors for wean-finish mortality events in a commercial swine production system

by

Gregory Thomas Krahn

A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Animal Science

Program of Study Committee:
Tom Baas, Major Professor
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Clint Schwab

The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this dissertation. The Graduate College will ensure this dissertation is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University

Ames, Iowa

2018

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The objectives of this study were to evaluate water disappearance deviations, environmental stressors, common management practices, presence of pathogens and interaction effects for the start of high mortality events (SHME) in commercial wean-finish pigs. Data utilized in this study were compiled from 26 lots of pigs in Illinois and Iowa, on farms operated by The Maschhoffs, LLC (Carlyle, IL, USA) from July 2014 through January 2016. Change in mortality (CM) was calculated as the previous seven-day average mortality rate subtracted from the subsequent three-day average mortality rate, and SHME was defined as one standard deviation above the mean CM within each week post-weaning. Variables and interactions were evaluated to identify significant predictors and were included in a multivariate logistic regression model to estimate the probability for the SHME.

Water disappearance deviations were detected using three methods: linear mixed effects model, one-step ahead model and percent change water disappearance. All variables evaluated from the linear mixed effects model and one-step ahead model were not significant in increasing the probability for predicting the start of a high mortality event. Percent change water disappearance (PCWD), environmental stressors, management practices and disease status for eleven pathogens were significant predictors for the SHME in univariate logistic binomial regression analysis. Significant predictors were included in the multivariate logistic regression model to estimate the probability for the SHME.

Polymerase chain reaction assays were used to test for eleven pathogens throughout the wean-finish period. The presence of \textit{Lawsonia intracellularis} or porcine
reproductive respiratory syndrome virus increased the probability for the SHME.
Increased PCWD when rotavirus was positive, increased probability for the SHME.
Decreased PCWD when swine influenza virus (SIV) was positive, increased the probability for the SHME. Environmental temperatures below the desired barn temperature when SIV was positive, increased the probability for the SHME. Increased daily antibiotic treatments decreased the probability of SHME for the SHME.
Environmental temperatures above the thermoneutral zone in double stocked pigs increased the probability for the SHME. Early finishing pigs with increased seven-day temperature variation had increased probability for the SHME. Presence of *Mycoplasma hyopneumoniae* in early finishing pigs or presence of porcine epidemic diarrhea virus in early or late finishing pigs increased the probability for the SHME. The positive presence of both porcine circovirus type 2 and *Escherichia coli* increased the probability across all pigs ages for the SHME. Middle finishing pigs had increased probability for the SHME in fall compared to summer. Late finishing pigs had increased probability for the SHME in summer and winter compared to spring. The complex, additive and synergistic interactions between behavior, environment, management and pathogens play a critical role predicting high mortality events in wean-finish pigs. Predicting an upcoming high mortality challenge could allow caretakers an opportunity to take early action to improve treatment success, reduce impact of diseases and promote sustainable pig production. It is important to understand what indicators can be utilized to predict the onset of an upcoming high mortality event in commercial wean-finish pigs.
CHAPTER 1. GENERAL INTRODUCTION

Mortality in North American wean-finish pig herds has increased and holds considerable economic concerns, especially in older, more valuable pigs (Maes et al., 2004). Early detection of health and welfare compromises in wean-finish facilities is important to improve treatment success, reduce impact of diseases, and promote sustainable pig production (Matthews et al., 2016). Management decisions while caring for pigs are commonly based on subjective judgment by the caretaker, so methods to detect changes in behavior and health of growing pigs will improve timely intervention and treatment of diseases (Seddon, 2011). Due to larger herds and more pigs managed per person, there is less time available for observing individual pigs, so it is important to determine the risk level or health status of pigs to provide guidance for caretakers as to where to concentrate management efforts (Madsen and Kristensen, 2005).

In healthy growing pigs, water disappearance consistently increases as pigs get older and heavier in body weight, but changes in water disappearance has been observed in sick pigs (Pijpers et al., 1991; Madsen and Kristensen, 2005; Brumm, 2006; Sutherland et al., 2007; Bird, 2008; Crabtree et al., 2008; Reiner et al., 2009). Real-time automated monitoring of water disappearance provides an additional and objective observational measure that caretakers can utilize when investigating pig health to detect issues before they arise and take early action and reduce the impact from various diseases (Smith et al., 2009). Early intervention is strongly associated with improved pig welfare, increased performance, reduced mortality, and reduction in antibiotic use, which all combined provide financial benefits to the farm.
Managing the environment in swine production is important to reduce or eliminate environmental stressors that can adversely impact swine performance, health and well-being (Hahn, 1995). Low, high and cyclical temperature stressors negatively impact the performance, increase stress and challenge the homeothermic abilities and homeostasis of growing pigs (Bond et al., 1963; Morrison and Mount, 1971; Nienaber et al., 1989). Depending on the age of the growing pig, seasonal effects influence the risk for mortality in wean-finish groups (Maes et al., 2001; Maes et al., 2004; Oliveira et al., 2009). Standard management practices utilized in wean-finish production may cause stress on the pig, and the combination of social and environmental stressors has a negative linear effect on pig’s immune system, performance and mortality (McGlone et al., 1987; Morrowtesch et al., 1994; Hyun et al., 1998).

Timely detection and treatment of diseases with the use of antibiotics are an extremely important tool that are used worldwide to prevent health challenges, prevent decreased growth and reduce mortality (Bush and Biehl, 2002; Rajic et al., 2006; Jensen et al., 2007). Poor health negatively impacts performance parameters of wean-finish units, reducing feed efficiency and daily weight gain and increasing mortality (Dijkhuizen, 1989). The presence of viral or bacterial pathogens has been widely shown to be responsible for economic losses due to mortality, morbidity, decreased performance and additional medication and vaccination costs. In U.S. swine herds, there is typically a secondary infection with viral or bacterial pathogens that occur concurrently that accelerate and enhance respiratory, enteric or reproductive problems (Zimmerman et al., 1997; Opriessnig et al., 2007). Sub-clinically infected pigs show no signs of disease until a stressor results in a breakdown and clinical emergence of the disease (Taylor, 1999).
Environmental stressors have been shown to reactive or induce latent pathogens in growing pigs (Shope, 1955; Shimizu et al., 1978).

Changes in water disappearance, environmental stress, standard management practices, presence of pathogens and interactions could provide indicators of upcoming high mortality challenges in wean-finish pigs. Predicting an upcoming high mortality challenge could allow caretakers an opportunity to take early action to improve treatment success, reduce impact of diseases and promote sustainable pig production. Before that can accomplished, it is important to understand what predictors can be utilized to predict the onset of an upcoming wean-finish high mortality event under field conditions. The objectives of this study were to identify days at the start of a high mortality event and determine the effects of changes in water disappearance, environmental temperature, management practices, pathogen presence and interactions as predictors for the start of high mortality events in commercial wean-finish pigs.
CHAPTER 2. LITERATURE REVIEW

Mortality

High mortality in wean-finish complexes holds considerable economic concerns as pigs that die represent a considerable investment, especially if it occurs in older, more valuable pigs (Holden, 1991). Modern swine production is characterized by confinement housing of large groups of pigs usually on large specialized farms or production systems which this intensification creates an ideal environment for transmission of infectious agents and may negatively influence the health of the pigs (Maes et al., 2001). Due to larger herds and more animals managed per person, there is less time available for observing individual animals in weaning and finishing units (Madsen and Kristensen, 2005).

Maes et al. (2004) investigated risk factors for overall group mortality in grow-finishing pigs of 137 pig herd belonging to one company during a 2.5 year period. It was reported that type of pig herd, season and year of placement in the fattening unit, pig density in the municipality, management practices (density of the pigs in the barn, origin of the pigs), housing conditions and feeding practices were potential risk factors. The overall average mortality percentage was 4.70%. In the final multivariate regression model, season of placement in the fattening period, origin of the piglets and duration of the fattening period were significantly associated with higher mortality. Pigs that were placed in October, November and December had higher mortality than pigs placed in all other months.

Maes et al. (2001) reviewed the overall mortality patterns during the grow-finish period between January 1996 and January 2000 with 14 swine companies, including 146
closeouts. They expressed overall mortality as deaths per 1000 pig weeks and weekly mortality as the number of pigs that died during a week divided by the average inventory of pigs during that week. Because the inventory decreased throughout the grow-finish period due to death, culling, transfer and shipment to slaughter, overall mortality was not expressed as the percentage of the number of pigs initially placed in the finishing units, but as the number of pigs per 1000 pig weeks. In this way, changes in the total number of pigs were considered in the calculations. It was found that late mortality was consistently greater than early mortality and had an increased risk for mortality after week 10 of the grow-finish period in all 4 years. They reported a peak in late mortality consistently occurred each year in September, October, November for groups placed in June, July and August while groups placed during fall months had a higher early mortality, conforming a higher mortality in younger grow-finish pigs during the fall and early winter.

Economic losses based on opportunity cost due to late mortality on average, accounted for about two thirds of the total costs of overall mortality. The financial analysis of this study showed that death loss in grow-finish pigs may have a great impact on the profitability of swine operations(Maes et al., 2001).

Losinger et al. (1999) evaluated 53 grower/finisher-only swine operations that participated in the United States National Animal Health Monitoring System 1995 National Swine Study and reported that mortality among finisher pigs ranged from 0 to 12.0% over a 6-month period. Twenty-six (49.1%) had <2% mortality, and 27 (50.9%) had >2% mortality. Nine (17.0%) operations experienced >4% mortality. Fisher’s exact test revealed that operations with all-in all-out management and operations where all finisher pigs came from farrowing units belonging to the operations were significantly
likely to have <2% mortality. It was also reported that diagnosis of Salmonella in finisher pigs performed laboratory or by a veterinarian in the 12 months prior to interview was associated with both increased percent mortality and increased percent mortality per day (Losinger et al., 1999). Percent mortality per day in the grower/finisher unit was computed by dividing percent mortality by average days in the grower/finisher unit.

From the same United States National Animal Health Monitoring System 1995 National Swine Study, Losinger et al. (1998b) reported that over a six-month period, 61.7±4.1% of operations reported at least one death attributed to respiratory problems among finisher pigs. The mean mortality that attributed to respiratory problems was 0.9±0.1% of finisher pigs per operation.

Losinger et al. (1998a) evaluated the mean mortality risk based on 393 operations participating in the United States National Health Monitoring System 1995 National Swine Study over a 6-month period from operations with ≥300 market hogs in 16 states. The mean mortality rate was 2.3±0.2% in the grower/finisher phase with 13.5% of the grower/finisher operations having ≥4% mortality while 63.6% of the operations experiencing ≤2% mortality.

Larriestra et al. (2005) investigated mortality rate in 1502 all-in/all-out grower-finisher groups between 1996 and 2000 in the United States. Mortality rate was calculated as the number of dead pigs per 1000 weeks which accounted for the weekly variation of the population at risk due to dead and culled pigs. Pigs placed during quarters 2 and 3 had higher mortality than those placed during quarters 1 and 4. Larriestra et al. (2005) stated there is 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.

Oliveira et al. (2009) assessed the effects of management, environmental and temporal factors of farms on mortality from 158 all-in all-out finishing batches completed in 27 integrated systems from 1999 to 2002 in Spain. The study qualified the level of care provided by the farmer to the pigs and it was reported a bad level of care provided by the farmer, increased the risk of mortality (P=0.03). Pigs that were placed into the finishing facility between January and April and October and December had higher mortality than those placed from May to August.

Controlling the environmental temperature is critical for pig comfort, Maes et al. (2004) investigated risk factors for mortality in grow-finish pigs of 137 pig herds from one company in the north-western part of Flanders (Belgium) during a 2.5 year period and reported that the type of ventilation system in the barn (Natural without regulation flaps, natural with regulation flaps, mechanical direct air-entry) was not a significant risk factor in the associated with mortality in univariate analysis (P=0.20). On the contrary, Agostini et al. (2014) studied the effect of animal management and farm facilities on mortality rate of grower-finishing pigs in 310 batches from 244 grower-finishing farms in six Spanish pig companies. Results indicated that batches of pigs placed between January and March had higher mortality rate than those placed July and September. Pigs housed in barns that performed manual ventilation control presented higher mortality rate compared to automatic ventilation. According to Saha et al. (2010) the purpose of the ventilation system is to maintain a particular temperature while controlling levels of humidity and removing gaseous contaminants introduced by the animal and their waster
so therefore, the efficient removal of gases and moisture and proper temperature control will depend on the type of ventilation control system.

**Water Disappearance**

**Factors Influencing Water Disappearance**

Water is the most essential nutrient for life, and an inadequate supply can result in devastating consequences such as overheating, dehydration, and in extreme case, death (Kober, 1993). Amount of water consumed by pigs has been reported to be influenced by quality of the water provided, diet composition, live weight, growth rate, temperature, feed intake, social factors, equipment design and health status (Brooks et al., 1984; Quiniou et al., 2000; Schiavon and Emmans, 2000; Madsen and Kristensen, 2005). It is well understood that water is imperative for proper growth of growing pigs as water is the single largest constituent of the body and makes up 82% of a young pig’s and 55% of market hog body weight (Kober, 1993; Almond, 1995). In healthy growing pigs, water disappearance should consistently increase as pigs get older and heavier in size throughout the wean-finish period until marketing (Crabtree et al., 2008).

Total daily water intake indicates the overall metabolism and growth of the group and shows a reaction to feed. McGlone and Pond (2003) reported water intake requirements by weight of wean-finish pigs as the following: 11.3 kilograms, 1.5 liters/day; 22.7 kilograms, 2.3 liters/day; 35.0 kilograms, 3.4 Liters/day; 45.4 kilograms, 3.8 liters/day; 68.0 kilograms, 4.9 liters/day; 90.7 kilograms, 6.4 liters/day; 113.4 kilograms, 7.6 liters/day; 136.1 kilograms, 8.0 liters/day. Almond (1995) reported that 2.5-3.0 liters of water are required for every kilogram of feed consumed. Brooks et al. (1984) used large white cross Landrace growing pigs to study the relationship of water
intake with feed intake, piglet weight and daily gain, and it was found that water intake is related to all of these parameters but daily feed intake is the best single predictor of water intake. The relationship can be described by the equation: water intake (liters/day) = 0.149 + 3.053 (feed intake; kg/day) (Brooks et al., 1984). Bigelow and Houpt (1988) found that 75% of water intake was associated with feed intake. Dybkjaer et al. (2006) reported a strong positive association between the amount of time spent eating and drinking in newly weaned pigs. Growing pigs show a water turnover rate at about 120-130 mL/kg of body weight when fed normal dry pellets at the rate of 4-5% of body weight daily (Yang et al., 1981).

Seddon (2011) found a lower rate of increase in water disappearance as pigs neared slaughter weight. The narrowing gap between water intake and weight increase as pigs neared slaughter weight has been noted by other authors (Brooks et al., 1984), which is believed to be due to a reduction in body protein turnover as the pig begins to reach mature size (Whittemore and Elsley, 1976). Measuring water intake continuously at the barn or pen level is often an easier, more cost effective and more readily available method for producers to gauge how much feed is being consumed, compared to recording feed intake (Bird and Crabtree, 2000).

In terms of utilizing water consumption of pigs to detect pending health conditions, distinguishing between deviations in pattern attributable to disease and those attributable to other factors is of particular importance to reduce the number of false positives. Smith et al. (2009) interpreted data during a feed outage event in a 1000 head wean-finish barn and noticed that water intake abruptly plummeted not long after the feed auger stopped running. On the contrary, Yang et al. (1981) reported that when the
reduction of the daily feed allowance from 1.5 kg to 0.8 kg, caused the growing pigs to drink more water and increase the water turnover rate. Therefore, the pigs consumed more water when feed was restricted; a behavior attributable to hunger (Yang et al., 1981). Similar findings have been reported in the dairy industry as calving, presence of etrus, health events and hoof trimming are associated with a decrease in dry matter and water intake (Meyer et al., 2004; Lukas et al., 2008). By monitoring water disappearance, this provides another way to detect problems in the environment of a wean-finish facility.

Torrey et al. (2008) evaluated the effect of three drinker devices (standard nipple, push-lever bowl and float bowl) on piglet’s water and feed intake, water use and behavior during a two-week period following weaning. Piglets with nipple drinkers wasted more water (P<0.001; float, 295 mL pig/day; nipple, 1,114 mL pig/day; and push-lever, 186 mL pig/day) whereas piglets with float bowls consumed less water than the other piglets (P<0.001; float, 475 mL pig/day; nipple, 870 mL pig/day; push-lever, 774 mL pig/day). During the first few days after weaning, piglets are known to drink excessively, which could be attributed to the piglet’s attempt to satisfy hunger through gut fill from a change in an unfamiliar feed source (Torrey et al., 2008).

**Temperature Effect on Water Disappearance**

Although the main factors affecting water intake are feed intake, pig weight and daily gain, water requirements of pigs are also associated with ambient temperature (Mroz et al., 1995). A range of 18 to 21°C has generally been found to be the most convenient environmental temperature for optimal performance of growing-finishing pigs (Kouba and Sellier, 2011). Mroz et al. (1995) and Mount (1971) both reported that higher ambient temperature increases water intake in wean-finish pigs. In hot environments of
grow-finish pigs, increased evaporation leads to an increase in water consumption (Schiavon and Emmans, 2000). Nienaber et al. (1987) reported the inverse relationship of feed intake in growing pigs as feed intake decreased when temperature increased from 5 to 30°C and was related to temperature by a polynomial function. High ambient temperature is positively correlated with water intake in dairy cows (Meyer et al., 2004).

It has been found in several groups of pigs that a daily pattern of water uptake is revealed, which gives an insight into the group reaction to the environment, stress levels and group behavior. The typical water consumption pattern of pigs in natural light is a steady rise from dawn to dusk, and at this point the consumption falls rapidly and is followed by lower consumption overnight (Bird and Crabtree, 2000). Bigelow and Houpt (1988) reported that sixty-four percent of daily feed intake and sixty-eight percent of water intake in growing pigs is during the 12-hour light period. Grow-finish and gestating pigs consume the most amount of water in the late afternoon while lactating females consume water more consistently throughout the day (Brumm, 2006).

It was found in a group of wean-finish pigs that hot weather changes the pattern to “the double hump,” in which the group tends to increase consumption and activity earlier when it is cool, reduce activity during the hottest part of the day, and pick up activity as the temperature falls again (Bird and Crabtree, 2000). Brumm (2006) stated similar results that in times of heat stress, grow-finish pigs alter their water usage pattern with a peak between 8 to 9 a.m. and second peak around 5 to 8 p.m. When temperatures fall below the thermoneutral zone, pigs will increase feed consumption in order to raise their metabolism and generate body heat and thus, will then increase water consumption (Ingram and Legge, 1974).
**Pathogen Effect on Water Disappearance**

Changes in eating and drinking patterns are usually the first visual signs that pigs are experiencing environmental stress or health challenges (Bigelow and Houpt, 1988; Madsen and Kristensen, 2005). Different diseases stages have been found to change pig behavior as pigs spend less time drinking and eating during the onset and recovery of a variety of diseases (Reiner et al., 2009). Reiner et al. (2009) studied the behavior of 139 Meishan x Pietrain crossbred pigs, and reported that pigs infected with *Sarcocystis miescheriana* spent increased time lying inactive and spent decreased time drinking 14 and 28-days post infection. Similar results were found in twenty-five weaned pigs infected with *Escherichia coli* strains as pigs spent less time drinking 10 days after inoculation compared to nontreated controls (Krsnik et al., 1999). Sutherland et al. (2007) studied the behavior and physiology of sixty-four seven-week-old pigs infected with porcine reproductive respiratory syndrome virus (PRRSV) and found that pigs spent less time throughout the day drinking and eating compared to PRRSV negative pigs. Pijpers et al. (1991) reported that at the time of a *Actinobacillus (Haemophilus) pleuropneumoniae* challenge in crossbred growing pigs, both feed and water consumption were reduced and slowly increased to normality after the challenge. Bird (2008) detected a change in water disappearance three days prior to a swine influenza in growing pigs, while Brumm (2006) reported decreased water disappearance during a swine influenza virus challenge in growing pigs. Crabtree et al. (2008) detected a change in water disappearance pattern before disease symptoms became visually apparent to caretakers but did not state the specific disease.
Madsen and Kristensen (2005) detected increased water disappearance one day prior to an enteric disease outbreak (*Escherichia coli*) and before disease symptoms became visually apparent to caretakers in nursery pigs. Seddon (2011) stated that health scores (score of 1-4; relating to the health in each pen with a high health score indicating poor health) showed a reduction in water consumption in pens suffering from scour, but the reduction was not significant. Although no consistent pattern was found, there were significant differences in the water consumptions in relation to the severity of cough scores (relating to the severity of the coughing in each pen with a high cough score indicating poor health) in the current and following weeks (Seddon, 2011). Smith et al. (2009) evaluated two 1000 head wean-finish barns and found decreased water intake in the barn with a health problem which resulted from a change in diet specifications. Following the health problem, the group with the health problem regained an increased trend in water intake, but was consistently less than the other group in the separate barn. Brumm (2006) stated that based on producer and veterinarian observations, when daily water usage drops for three continuous days, or drops more than 30% from day to day, this may indicate that a potential health challenge is occurring in growing pigs. Similar results have been reported in the dairy industry as health events and hoof trimming is associated with a decrease in dry matter intake and water intake (Meyer et al., 2004; Lukas et al., 2008).

As previously stated, the number of days prior to a disease outbreak that water consumption changes occur will differ according to the infection and these differing patterns in water reduction could assist in the detection of different diseases.
Monitoring Water Disappearance

Real-time automated monitoring of water disappearance in groups of pigs provides an additional and objective observational measure that caretakers can utilize when investigating pig health to detect issues before they arise (Smith et al., 2009). Utilizing real-time water disappearance monitoring and using historical measurements could provide a lead indicator for upcoming health and mortality challenges which could then create an opportunity to take early action and reducing the impact from various diseases (Smith et al., 2009). While water can be recorded automatically, there is no fully automated system that can download and interpret the data into simple and meaningful messages because the factors contributing to water disappearance variation within groups of pigs remain unknown (Seddon, 2011).

Water disappearance measurement methods within a given period of time varies depending on the study. Madsen and Kristensen (2005) used a state-space model in conjunction with a CUSUM control chart to monitor water consumptions patterns in three herds and 18 batches of pigs each and found a diurnal drinking pattern were found as long as the pigs were healthy. They reported that water consumption increased approximately one day prior to an outbreak of diarrhea (Escherichia coli) and approximately one day before physical signs were seen by the caretakers (Madsen and Kristensen, 2005). Madsen and Kristensen (2005) concluded that 1-hr sums is the preferable choice in nursery pigs when modeling observed water consumption. Smith et al. (2009) recorded water intake at 15-min intervals on wean-finish pigs which provides much more reliable information to take into account the body clock effects throughout the day.
Schiavon and Emmans (2000) developed a model to predict water intake of a pig fed a known diet in a known environment with daily retentions of protein, lipid, water, and ash were estimated over time using a published pig growth model. Water intake was estimated by adding the amount required for digestion, fecal excretion, growth, evaporation, urinary excretion and by then subtracting the water arising from feed, from nutrient oxidation and synthesis of body constituents and reported a $R^2$ of 0.75 but 25% of the variability remained unexplained (Schiavon and Emmans, 2000). Brooks et al. (1984) reported an equation to understand water intake of weaned pigs three to seven weeks old and stated the relationship as water intake (liters/day) = 0.149 + 3.053 (feed intake; kg/day).

Seddon (2011) developed multiple regression models to understand mean daily water usage in growing pigs and the models included pig weight, number of pigs within the pen, daily live weight gain, room maximum temperature and feed conversion ratio. When trying to understand the factors associated with the variation in the total daily pen water usage and mean water usage per pig and per pen, multiple regression models were able to describe 31.7% and 47.0% of the variation, respectively. Monitoring water disappearance can serve as an objective measure of health and mortality for caretakers in large groups of pigs and has the potential to predict the onset of a high mortality event. Further methods need to be developed to objectively detect changes in water disappearance in large groups of pigs and factors that impact the variation and total daily water disappearance.
Environmental and Seasonal Effects on Health and Mortality

Environmental stressors can adversely impact swine performance, health and well-being, so proactive environmental management should be provided to reduce or eliminate adverse effects (Hahn, 1995). McGlone and Pond (2003) reported the preferred temperature ranges of pigs in weight ranges which are as follows: 3-15kg, 26-32°C; 15-35kg, 16-26°C; 35-70kg, 15-25°C; 70-100kg, 10-25°C and over 100kg, 10-25°C. Lower and upper extreme temperatures in each weight range are as follows: 3-15kg, 15-32°C; 15-35kg, 5-32°C; 35-70kg, -5-35°C; 70-100kg, -20-35°C and over 100kg, -20-32°C (McGlone and Pond, 2003). Kouba and Sellier (2011) stated that the optimum environmental temperature for grow-finish pigs to achieve optimal performance is between 18 to 21°C. When temperatures fall below the thermoneutral zone, pigs increase their feed consumption to raise their metabolism and generate body heat (Ingram and Legge, 1974). Nienaber et al. (1989) studied the effects of temperature with pigs housed at 20°C and 5°C, which is below the thermoneutral zone, and cyclical temperatures (temperature varied 12°C in one given day) on growing-finishing swine in a controlled environment. Growing swine (average 15.8 kg) had increased rate of feed intake and feed required per unit of gain and rate of gain decreased at 5°C compared to 20°C, while feed intake and feed conversion were not affected by cycling temperatures. Rate of gain and feed conversion of finishing swine were negatively affected both by 5°C and by cycles of ±12°C during the initial 4-week period but not during the final 3 week period (Nienaber et al., 1989). There were temperature effects on both plasma cortisol concentration and adrenal weights which symbolize the effects of cold temperature but also there was an apparent cyclic temperature effect on the adrenal weights. These results indicate that
cycles of ±12°C are potentially stressful to finishing pigs as well as causing a reduction in performance and should be avoided through environmental modification (Nienaber et al., 1989).

Bond et al. (1963) found similar results from a study that the diurnal temperature variation was constant, 11.2°C, 22.3°C and 33.4°C in a 24-hour period and reported that weight gain at the constant 21.1°C was greater than at the 22.3°C or 33.4°C diurnal temperature variation. Morrison and Mount (1971) exposed pigs to a change in environmental temperature from 33 to 20°C and after the change occurred, steady values for respiratory rate and rectal temperature were reached in one and twelve days respectively. Shimizu et al. (1978) found that a sudden decrease in ambient temperature, either before or after inoculation of transmissible gastroenteritis virus, induced severe disease in feeder pigs and caused profuse diarrhea. Similar results have been reported in the dairy industry as calves born during high temperatures in the summer and low temperatures in the winter were associated with an increased risk of death (Martin et al., 1975). Martin et al. (1975) also stated that periods of increased risk of death often were associated with large temperature fluctuations irrespective of the absolute temperature.

Grow-finish pigs housed in manually controlled ventilation barns present a higher mortality rate compared to automatic ventilation systems (Agostini et al., 2014). Differing results were reported by Maes et al. (2004) who investigated risk factors for mortality in grow-finish pigs of 137 pig herds from one company in the north-western part of Flanders (Belgium) during a 2.5 year period and reported that the type of ventilation system in the barn (natural without regulation flaps, natural with regulation flaps, mechanical direct air-entry) was not a significant risk factor in the associated with
mortality in univariate analysis. The temperature variation throughout the year in Belgium is less than in the U.S. Dallaire et al. (1996) reported that sow mortality was associated with temperatures as a 7 day period of high ambient temperatures (mean maximum daily temperature=34.0°C, mean minimum daily temperature=14.0°C) greatly increased the mortality rate across 130 swine breeding herds. Dallaire et al. (1996) stated they believed a large proportion died of cardiovascular failure associated with heat stress. Heat stress alters the immune function and negatively impacts the pig’s immune system (Morrowtesch et al., 1994).

Previous studies have reported that pigs placed in October through December (Maes et al., 2001; Maes et al., 2004; Oliveira et al., 2009), January through April (Oliveira et al., 2009) or during quarters 2 and 3 (Larriestra et al., 2005) have higher mortality compared to all other months of placement. These studies defined mortality as the percent mortality of the entire group of pigs while the present study evaluated the effects to predict the probability of the start of a high mortality event and found increased odds of early finishing pigs in spring compared to fall. Maes et al (2001) stated that late finishing mortality is higher consistently each year in September, October and November. High mortality in wean-finish complexes holds considerable economic concerns as pigs that die represent a significant investment, especially in older more valuable pigs (Holden, 1991; Maes et al., 2001). Continuously controlling the environment will reduce stress in wean-finish pigs and minimize adverse impacts on swine performance, health and well-being.
Management Practice Effects on Health and Mortality

Common management practices in wean-finish production cause stress on the pig, and the effect of stressors is additive with multiple concurrent stressors having a negative and linear effect on growth performance (Hyun et al., 1998). Double stocking during the start of wean-finish production has the potential to increase the output from a wean-finish facility, but reduces growth performance (Hyun et al., 1998; Wolter et al., 2002; DeDecker et al., 2005). Wolter et al. (2002) reported the effects of double stocking and weighing frequency on pig performance in two studies in a wean-to-finish production system. Removal rates (pigs removed due to death, poor health, or injury) in the first 10 weeks did not differ (P>0.05) but double vs single stocked pigs had lower ADG (7.7 and 7.9%, Studies 1 and 2, respectively; P<0.001) and lighter pigs at week 10 (6.8% and 7.3%, respectively; P<0.001). Weighing frequency did not affect pig growth performance or carcass characteristics and did not affect pig removal rate in the first 10 weeks of the study but the percentage of pigs removed from the study was greater (P<0.05) for pens that were weighed more frequently during the period of week 10 to the end of the study. Wolter et al. (2002) found no effect of stocking rate on morbidity and mortality. DeDecker et al. (2005) reported a linear increase in morbidity and mortality rates (8.5%, 10.2%, 12.7%; P <0.05) with three different increasing stocking rates (0.78m², 0.64m², 0.54m²).

Morrowtesch et al. (1975) reported that regrouping of pigs negatively impacts the stress, pig immunity and future mortality as aggressive behavior is common shortly after regrouping of new pen mates and socially dominant or submissive pigs had alterations in immune functions compared with socially intermediate pigs.
The interaction of social and environmental stress negatively impacts the immune system, depresses performance, and decreases feed intake (McGlone et al., 1987; Morrowtesch et al., 1994). Sub-clinically infected pigs show no signs of disease until a stressor results in a breakdown and clinical emergence of the disease (Taylor, 1999). Pigs exposed to high cyclical temperatures during social stress have decreased feed intake (Hyun et al., 1998). The interaction between social (regrouping) and thermal stress depresses gain to feed ratio among heat stressed pigs (McGlone et al., 1987).

The process of sorting and loading market pigs is stressful for the pig (Johnson et al., 2010) and split-marketing increases the risk of introduction of diseases to the farm (Rostagno et al., 2009). Rostagno et al. (2009) found split-marketing groups have a higher risk of mortality compared to close-out groups that sent all market hogs to harvest at once. Rostagno et al. (2009) stated this can be caused from the reactivation of latent infections and subsequent increased transmission, due to stress caused by the social disruption from the removal of the heaviest pigs from the pens and the mechanical transmission of diseases by the personnel and equipment entering the barns during the marketing period. These stress induced changes in immune function may cause alterations in the susceptibility of animals to diseases (Kelley, 1980).

Providing good care of pigs to improve animal well-being relies on the intuition of the observer, which may vary considerably between caretakers (Tscharke and Banhazi, 2016). Measuring and assessing the behavior of livestock is important as it can be used to indicate their welfare status (Tscharke and Banhazi, 2016). Animal welfare is difficult to monitor in practice, due to the inefficiencies involved in manually documenting and
determining, animal behavior, social interaction and health conditions of large number of animals (Tscharke and Banhazi, 2016).

Vaillancourt et al. (1994) evaluated data from 48 herds in the United States and Canada to assess retrospective perinatal mortality, which was defined as stillbirths and deaths that occur within 24 hours of birth that was recorded by producers. It was reported that the highest mortality percentage was recorded on Monday, but it was stated that most of the difference between Monday and the other days of the week could be attributed to day-0 mortality of live borns. Risk ratios were reported for day-0 mortality as Wednesday had the lowest (0.86) with Monday being the highest (1.00). Monday’s risk ratio for day-0 mortality was significantly higher than for the other 5 days of the week (P<0.05). Similar risk ratios were reported for perinatal mortality as Wednesday had the lowest (0.92) with Monday being the highest (1.00) and higher than Sunday, Tuesday, Wednesday, Thursday, Friday and Saturday. It was stated that the increase in mortality among liveborn on Monday could be explained by pigs dying on Sunday (or during the weekend) but not actually being recorded until Monday. A questionnaire was given to producers with one of the questions asking the person in charge during weekend and it was reported that: 33.3% same as during week, 8.3% different from week, 47.9% rotating schedule among personnel and 10.4% different person only during vacation (Vaillancourt et al., 1994).

In breeding herds, Rainho et al. (2010) found that frequency of abortions were higher for matings that occurred during the weekend. An increase in the frequency of abortions is associated with poor breeding by the employees. Reduced performance of employees on weekends and reduced performance during the week, following when
employees worked weekends, has been well documented in other industries (Sonnentag, 2003). Nonetheless, livestock need proper care and treatment every day, regardless of day of the week.

**Antimicrobials**

It is well documented that antibiotics are used in wean-finish pigs to treat diseases to prevent decreased health, decreased growth and economic losses (Jensen et al., 2007). Losses from mortality are less common than in the past, due to quick recognition of diseases and the prompt application of antibiotics by caretakers (Taylor, 1999). Timely detection and treatment of diseases with the use of antibiotics are an extremely important tool that are used worldwide to prevent decreased health, decreased growth and reduce mortality (Bush and Biehl, 2002; Rajic et al., 2006; Jensen et al., 2007).

Rajic et al. (2006) investigated the use of antibiotics in 90 swine farms in Alberta which represented approximately 25% of the Alberta market swine production. The majority of antibiotics were used in feed with 76% of weaner farms, 80% of grower farms and 72% of finisher farms using feed as an antibiotic route of administration. 38% of weaner farms, 18% of grower farms and 16% of finisher farms used water as an antibiotic route of administration. 65% of weaner farms, 62% of grower farms and 50% of finisher farms administered antibiotics through injection. Penicillin was found to be the most common type (37% of farms) of injectable antibiotic used in finisher farms, followed by oxytetracycline (18% of farms), trimethoprim/sulfadozine (13% of farms), tylosin (10% of farms), ceftiofur (9% of farms), and lyncomycin (3% of farms). In finishers, the use of 1, 2, 3, 4 and 5 injectable antibiotics was reported in 20%, 15.6%, 10% 8.9% and 1.1% of the farms, respectively. A similar study was done by Bush et al.
(2002) to study the use of antibiotics and feed additives in weaned market pigs by U.S. pork producers. It was reported that sites with nursery pigs, 82.7% placed antibiotics in the feed for growth promotion or disease prevention with chlortetracycline (30.1% of sites), tylosin (23.2%) and carbadox (22.9%) being the most common antibiotics. About 66% of sites administered injectable antibiotics to grower/finisher pigs, with almost 90% of the sites use injectable antibiotics to treat respiratory disease. The most common injectable antibiotics used in grower/finishers were procaine-penicillin (30.2% of sites), oxytetracycline (16.1%), ceftiofur (14.5%), tylosin (13.8%) and penicillin benzathine (15.5%).

Cromwell (2002) reviewed the effects of low (subtherapeutic) levels in feeds and found that antibiotics improve growth rate, efficiency of feed utilization, reduce mortality and morbidity and improve reproductive performance. It was reported from 67 field trials from 1960 to 1982 that the inclusion of antibiotics (chlortetracycline–sulfamethazine–penicillin or tylosin–sulfamethazine) in swine feeds was found to reduce mortality and morbidity by one-half (2.0 vs. 4.3%) in young pigs and when pigs were under high-disease conditions and environmental stress, the impact of antibiotics was even greater (3.1 vs. 15.6%). The economic return to swine producers from using antibiotics is quite significant due to the improvements in average daily gain, feed efficiency, and reduction in post-weaning mortality from weaning until market. It was estimated that the improved gain is $1.54 per pig, the benefit from improved feed to gain is $1.75 per pig and the benefit from the reduced post-weaning mortality is $0.40 per pig for a total benefit of $3.69 per pig (Cromwell, 2002). The cost of antibiotic at $0.03 per gram (cost of
chlortetracycline) is approximately $0.70 per pig, so the net return is $2.99 for each $0.70 invested in antibiotics.

Losinger et al. (1998a) evaluated the mean mortality risk based on 393 operations participating in the United States National Health Monitoring System 1995 National Swine Study over a 6-month period from operations with ≥300 market hogs in 16 states. To understand an increase percentage of operations that reported ≥4% mortality in grower/finisher, the study tested variables in univariate analysis and reported an increased tendency (P-value ≤0.25) for operations that did not regularly vaccinate grower/finisher pigs (Erysipelas, Escherichia coli scours, porcine parvovirus, leptovirus) and operations that did not give antibiotics in the feed to grower/finisher pigs (Chlortetracycline/sulfathiazole/penicillin, Tylosin/sulfamethazine, Lincomycin, Bacitracin, Virginiamycin, Zinc oxide). If variables had P-value ≤0.25, it was further modeling in a multivariable analysis. Through multivariable modeling, the odds of operations having a ≥4% mortality in grower/finisher swine that vaccinate for Escherichia coli scours was 0.41 (95% Confidence Interval: 0.20-0.82; P-value=0.02) compared to operations that did not regularly vaccinate.

Pathogen Effect on Sickness Behavior and Mortality

The presence of viral or bacterial pathogens has been widely shown to be responsible for economic losses due to mortality, morbidity, decreased performance and additional medication and vaccination costs. It has been suggested that sickness behavior including inappetence, increased sleep, lethargy and anorexia are part of an organized host defense strategy (Hart, 1988; Johnson, 2002). When an animal becomes sick, the body evolves a behavioral strategy to facilitate the role of fever in combating viral and
bacterial infections and which can be viewed as being at a life or death juncture and its behavior is an all-out effort to overcome the disease (Johnson, 2002).

**Porcine Reproductive Respiratory Syndrome Virus**

Porcine reproductive respiratory syndrome virus (PRRSV) is one of the most economically important diseases affecting pigs since its discovery in Europe in 1991 because it can cause significant losses to production in reproductive failure in breeding sows, preweaning mortality and reduced performance by growing pigs (Corzo et al., 2010). The prevalence of PPRSV is high and estimated to be positive in 60-80% of U.S. swine herds (Zimmerman et al., 1997). It has been calculated that the greatest proportion of economic loss resulting from PRRSV occurs in the grower-finish phase, which equals to 52.2% of the annual national economic loss resulting from PRRSV (Neumann et al., 2005). In 2005, Neumann et al. (2005) estimated the total annual economic impact of PRRSV on U.S. swine producers was $292.23 million in the growing-finish phase and $560 million annually when combined with breeding herds. In 2013, it was estimated the total annual economic impact due to PRRSV was $664 million annually in the U.S. national breeding and growing-pig herds (Holtkamp et al., 2013). The impact of PRRSV was estimated to add between $5.60 and $7.62 to the cost per head sold (Johnson et al., 2005). These losses typically occur from the decreased average daily gain, reduced feed efficiency, reduced pig growth, increased pneumonia and an increase in mortality and unmarketable pigs (Neumann et al., 2005; Holtkamp et al., 2013).

Holtkamp et al. (2013) evaluated 639 groups of growing pigs that were grown in Iowa, Minnesota and Oklahoma and classified into three categories as the following: PRRSV negative at weaning and marketing (GP-A), PRRSV negative at weaning but
PRRSV positive at marketing (GP-B) and PRRSV positive at weaning and marketing (GP-C). Groups classified as GP-A had significantly (P<0.05) better average daily gain and mortality than groups GP-B or GP-C, while groups classified as GP-B had significantly (P<0.05) better mortality than groups GP-C (Holtkamp et al., 2013).

Stevenson et al. (2013) reported that group nursery mortality was 3.1% prior to a PRRSV outbreak, compared with 7.4% for the 34 months following the PRRSV outbreak (Stevenson et al., 2013). Although not significant (P=0.76), Losinger et al. (1998a) reported a tendency for operations to have ≥4% mortality in grower/finisher swine, in which PRRSV was diagnosed in the operation within 12 months prior to the study interview. It has been reported that growing pigs positive with PRRSV spent less time feeding, decreased feed intake, decreased activity, increased time lying and increased body temperature (Escobar et al., 2007).

Porcine Circovirus Type-2

Porcine circovirus type 2 (PCV2)-associated disease (PCVAD) is now considered one of the most important viral pathogens in the U.S. pig population as it has been indicated that the incidence of PCV2 is on the rise in the U.S. and worldwide that is linked with a range of diseases that accelerate and enhance respiratory, enteric or reproductive problems (Opriessnig et al., 2007). PCVAD can be discernable as a systemic disease, as part of the respiratory disease complex, as an enteric disease, as porcine dermatitis and nephropathy syndrome, or as reproductive problems or can be a severe herd problem accelerated and enhanced by concurrent virus or bacterial infections (Opriessnig et al., 2007).
Swine Influenza Virus

Swine influenza virus (SIV) is a highly contagious viral infection in pigs that can have significant economic losses on an affected herd and was first recognized in the U.S. 1918 (Kothalawala et al., 2006). Positive presence of SIV can cause a respiratory disease characterized by coughing, sneezing, nasal discharge, elevated rectal temperature, lethargy, difficult breathing and depressed appetite (Kothalawala et al., 2006). Typically with SIV, morbidity rates can reach 100%, while mortality rates are generally low but secondary bacterial infections can worsen the clinical signs (Kothalawala et al., 2006). Primary economic impact is weight loss which results in an increase of the number of days needed to reach market weight in growing pigs and clinical signs exacerbate when combined with a secondary bacterial infection (VanReeth et al., 1996; Kothalawala et al., 2006). Extreme environmental conditions have previously been shown to reactivate a latent swine influenza virus (Shope, 1955)

Mycoplasma Hyopneumoniae

*Mycoplasma hyopneumoniae* (MHYO) is the primary infectious pathogen of enzootic pneumonia in pigs and is the most common pathogen affecting grower-finisher units worldwide causing increased pneumonic coughing and increased pulmonary lesions (Escobar et al., 2002; Llopart et al., 2002; Maes et al., 2008). Nearly 95-97% of intensive pig units worldwide are MHYO positive and 99% of the U.S. swine herds are infected with MHYO (Escobar et al., 2002). *Mycoplasma hyopneumoniae* affects the mucosal clearance system by disrupting the cilia on the epithelial surface and the organism modulates the immune system of the respiratory tract which predisposes animals to concurrent infections with respiratory pathogens including bacteria, parasites and viruses
Escobar et al. (2002) inoculated pigs with MHYO and those pigs had increased pneumonic coughing ($P<0.01$) and had pulmonary lesions that affected 4.5% ($P<0.01$) and 14.1% ($P<0.001$) of the total lung surface area at 14 and 28 days, respectively, after inoculation. Mortality is often associated with secondary bacterial infection and pigs often die in the later stage of the finishing phase incurring high cost penalties (Seddon, 2011). Clinical signs and lesions can lead to tentative diagnosis, but laboratory testing is necessary for conclusive diagnosis of MHYO (Thacker, 2004).

**Escherichia Coli**

*Escherichia coli* (ECOLI) is one of the most important causes of post-weaning diarrhea in pigs as it is responsible for economic losses due to mortality, morbidity, decreased growth rate, and cost of medication (Fairbrother et al., 2005). The ECOLI causing post-weaning diarrhea mostly carry the F4 (K88) or F18 adhesin and recently, there has been an increase incidence of outbreaks of severe E. coli-associated diarrhea has been observed worldwide (Fairbrother et al., 2005). Krsnik et al. (1999) found that twenty-five weaned pigs infected with *Escherichia coli* strains spent less time drinking 10 days after inoculation compared to nontreated controls. Losinger et al. (1998a) reported that the odds of operations having a $\geq$4% mortality in grower-finisher swine that vaccinated for E. coli scours, was lower compared to operations that did not regularly vaccinate for E. coli scours.

**Porcine Epidemic Diarrhea Virus**

Porcine epidemic diarrhea virus (PEDV) causes acute diarrhea, vomiting, dehydration, and high mortality in young pigs and can also cause diarrhea, agalactia and abnormal reproductive cycles in pregnant sows (Song et al., 2015). Porcine epidemic
diarrhea virus was first identified in United Kingdom in 1971 but PEDV was first found in the U.S. in May 2013 (Song et al., 2015). Between May 2013 and the end of January 2014, the outbreak had occurred in 23 U.S. states, where 2,692 confirmed cases caused severe economic losses (Song et al., 2015). During a 10-day period in April and May 2013, the Iowa State University Veterinary Diagnostic Laboratory received submissions from swine farms experiencing explosive diarrhea and vomiting affecting all ages of pigs, with 90-95% mortality in suckling pigs, which were the first known cases of PEDV in the U.S. (Stevenson et al., 2013).

The impact of PEDV infection on the U.S. pork industry has mainly been attributed to the mortality caused in suckling pigs, but Alvarez et al. (2015) found that mortality is higher in growing pigs weaned after a PEDV outbreak. Positive presence of PEDV in feeder and finishing pigs is characterized by severe watery diarrhea with low mortality (Wood, 1977). Epidemic PEDV strains tend to be more pathogenic and cause increased death in pigs, therefore causing financial losses for swine producers (Song et al., 2015).

**Lawsonia Intracellularis**

*Lawsonia intracellularis* (ILEIT) is a widely distributed disease throughout the world causing substantial economic loss and most frequently appears in pigs 6-20 weeks of age with occasional non-bloody diarrhea, decrease in weight gain and weight loss (Moller et al., 1998). Chronic cases of *Lawsonia intracellularis* cause decreased weight gain and diarrhea with high morbidity and low mortality, typically found in growing pigs (eight to 20 weeks old) (McOrist and Smits, 2007). Acute cases of *Lawsonia intracellularis* cause black-red tarry feces, anemia and sudden death in finishers, young
adults or sows and is characterized by high morbidity and high mortality in affected groups pigs (McOrist and Smits, 2007).

**Salmonella Sp.**

*Salmonella sp.* (SALMO) has the ability to colonize in a wide variety of environments and has led to SALMO becoming a widespread pathogen that causes a loss of production and typically has a synergistic relationship with other pathogens making their combined effect more potent (Seddon, 2011). Losinger et al. (Losinger et al., 1999) evaluated 53 grower/finisher-only swine operations that participated in the United States National Animal Health Monitoring System 1995 National Swine Study and reported that diagnosis of Salmonella in finisher pigs in the 12 months prior to interview, were associated with both increased percent mortality and increased percent mortality per day. Similar results were reported by Losinger et al. (1998a) that grower/finisher phase operations that diagnosed Salmonella in finisher pigs in the previous 12 months, had an increased tendency (P=0.24) to have ≥4% mortality.

Subclinical *Salmonella sp.* infections in pigs constitute an important food safety problem as carrier animals pose a potential risk for contamination of pork products (Rostagno et al., 2009). Numerous studies have broadly investigated and identified risk factors for SALMO infections in pigs which include: source of pigs, herd size, floor contamination, coinfections (with *Lawsonia intracellularis* or porcine reproductive respiratory syndrome virus), biosecurity practices, environmental temperature fluctuations and contaminated feed (Rostagno et al., 2009).
**Actinobacillus Suis**

*Actinobacillus suis* (ASUIS) is associated with sporadic cases of septicemia in very young animals and has been reported to cause arthritis, pneumonia, enteritis, meningitis, abortion, endocarditis, and erysipelas-like lesions that result in a loss of production (MacInnes and Desrosiers, 1999). Losinger et al. (1998a) reported that grower/finisher phase operations that diagnosed *Actinobacillus suis* in finisher pigs in the previous 12 months, had an increased tendency (P=0.35) to have ≥4% mortality. Losinger et al. (1999) reported similar results that grower/finisher-only operations that diagnosed ASUIS in finisher pigs in previous 12 months, had an increased tendency (P=0.29) to have >2% mortality.

**Streptococcus Suis**

*Streptococcus suis* (SSUIS) has been found as the cause of a wide range of clinical disease syndromes in swine worldwide, but is more prevalent in countries with intensive swine management practices (Staats et al., 1997). The disease syndromes caused by SSUIS in swine include arthritis, meningitis, pneumonia, septicemia, endocarditis, polyserositis, abortions and abscesses (Staats et al., 1997).

**Rotavirus**

Rotavirus is an important cause of acute gastroenteritis in young animals and is the most frequent cause of diarrhea in piglets throughout the world and rotavirus infections usually occur as enzootics affecting more than 60% of the pig population (Winiarczyk et al., 2002). The majority of natural infections with rotavirus are subclinical or are associated with mild diarrhea, however, many infections are associated with moderate to severe gastroenteritis (Winiarczyk et al., 2002).
Pathogen Interactions

Typically, in U.S. herds there is a secondary infection with viral or bacterial pathogens that occur concurrently that enhances the pathological effects, behavior and clinical effects of infected pigs (Zimmerman et al., 1997). Thacker et al. (1999) reported that *Mycoplasma hyopneumoniae* enhanced the pathological effects of porcine reproductive and respiratory syndrome virus in growing pigs as *Mycoplasma hyopneumoniae*-infected pigs with minimal to nondetectable mycoplasmal pneumonia lesions, manifested significantly increased PRRSV-induced pneumonia lesions compared to pigs infected with only PRRSV. Escobar et al. (2007) found differing results in growing pigs as there was no significant interaction between *Mycoplasma hyopneumoniae* and porcine reproductive and respiratory syndrome virus for food intake, body temperature or any behavior measurement. Secondary viral or bacterial infections typically occur with PRRSV infections such as *Salmonella choleraesuis*, *Streptococcus suis* or *Haemophilus parasuis* (Zimmerman et al., 1997).

It has also been reported that growing pigs infected with both swine influenza virus and *Mycoplasma hyopneumoniae* coughed significantly more and pneumonia was significantly more severe than in pigs infected with a single agent (Thacker et al., 2001).

Van Reeth et al. (1996) found that dual infections of PRRSV and SIV caused more severe disease and growth retardation than single PRRSV infection in growing pigs. Opriessnig et al. (2007) reported that porcine circovirus type 2 is linked with a range of diseases that accelerate and enhance respiratory, enteric or reproductive problems.
CHAPTER 3. MONITORING DEVIATIONS IN WATER DISAPPEARANCE AS PREDICTORS FOR THE START OF HIGH MORTALITY EVENTS IN COMMERCIAL WEAN-FINISH PIGS

Abstract

In normal healthy pigs, water disappearance should consistently increase as pigs get older and heavier in body weight throughout the wean-finish period. This study measured water disappearance, quantified deviations and estimated the effect on the start of a high mortality event (SHME). Data utilized in this study were compiled from 26 lots of pigs in Illinois and Iowa, on farms operated by The Maschhoffs, LLC (Carlyle, IL, USA) from July 2014 through January 2016. Change in mortality (CM) was calculated as the previous seven-day average mortality rate subtracted from the subsequent three-day average mortality rate, and SHME was defined as one standard deviation above the mean CM within each week post-weaning. Water disappearance deviations were tested as predictors of the SHME using three methods: linear mixed effects model, one-step ahead model, and percent change water disappearance. Deviations from the predicted linear mixed effects model were quantified using internally studentized residuals of -2.0, -1.5, -1.0, 1.0, 1.5 and 2.0. A multivariate linear regression model was developed for the one-step ahead model to predict the next day’s three-day average water disappearance. The one-step ahead model uses a prediction interval as a control chart with a systematically evolving baseline within each lot of pigs. Each day, the model is updated and is fitted using the previous 15-day data and prior coefficients. All variables evaluated from the linear mixed effects model and one-step ahead model were not significant in increasing the probability when predicting the start of a high mortality event. Percent change water disappearance (PCWD) was negatively associated with the probability for the SHME. In
other words, as PCWD decreased, the probability for a SHME increased. Each additional one percent increase in PCWD, reduced the odds of a SHME (OR=0.99, 95% CI: 0.98-1.00). Days with a PCWD <0%, were categorized as a negative PCWD (NegPCWD) and increased the odds of a SHME (OR=1.56, 95% CI OR: 1.20-2.01). Monitoring water disappearance can serve as an objective measure of health and mortality for caretakers in large groups of pigs and has the potential to predict the onset of a high mortality event. The objectives of this study were to: 1) identify ways to distinguish deviations in water disappearance when water disappearance is recorded daily in large groups of pigs, and 2) evaluate whether these deviations can be utilized to predict the onset of an upcoming high mortality event.

**Introduction**

Monitoring water disappearance in groups of pigs has been reported to be beneficial for the observation and management of the health status of pigs (Bird and Crabtree, 2000; Madsen and Kristensen, 2005) since management decisions while caring for pigs are commonly based on subjective judgment by the caretaker (Madsen and Kristensen, 2005). Due to larger herd sizes, increased number of herds per production system, and more animals managed per person, there is less time available for observing individual pigs in wean-finish and conventional grow-finish units (Madsen and Kristensen, 2005). In healthy growing pigs, water disappearance consistently increases as pigs get older and heavier in body weight (Crabtree et al., 2008). A reduction in drinking behavior has been found in sick pigs, which is associated with action of cytokines that are produced soon after pathogen recognition occurs within the sick pig (Reiner et al., 2009; Borghetti et al., 2011). Different diseases stages have been found to change pig behavior
(Krsnik et al., 1999), and decrease the time spent drinking during a health challenge (Reiner et al., 2009). Crabtree et al. (2008) detected a change in water disappearance pattern in pigs before disease symptoms become visually apparent to caretakers, and Madsen and Kristensen (2005) reported an increase in water disappearance one day prior to an *Escherichia coli* outbreak in nursery pigs.

When pigs become sick, the amount of feed consumed and time spent eating decreases (Dybøl et al., 2006). Few studies have evaluated pigs’ drinking pattern or behavior, while eating behavior is very well described (Bird and Crabtree, 2000; Bird et al., 2001; Madsen et al., 2005; Madsen and Kristensen, 2005). Measuring water intake continuously at the barn or pen level is often an easier, more cost effective and more readily available method for producers to gauge how much feed is being consumed, compared to recording feed intake (Bird and Crabtree, 2000; Brumm, 2006). Dybkjaer et al. (2006) reported a strong positive association between the time spent eating and drinking in newly weaned pigs. Brooks et al. (1984) stated that daily feed intake is the best single predictor of water intake in growing pigs, and Bigelow and Houpt (1988) found that 75% of water intake was associated with feed intake. Moreover, live body weight, growth rate, temperature, feed intake and health status influence water disappearance in pigs (Brooks et al., 1984; Schiavon and Emmans, 2000; Madsen and Kristensen, 2005).

While water can be recorded automatically, there is no fully automated system that can download and interpret the data into simple and meaningful messages because the factors contributing to water disappearance variation within groups of pigs remain unknown (Seddon, 2011). Water disappearance measurement methods within a given
period of time varies depending on the study. Madsen and Kristensen (2005) concluded that 1-hr sums is the preferable choice in nursery pigs when modeling observed water consumption. Smith et al. (2009) recorded water intake at 15-min intervals on wean-finish pigs which provides much more reliable information to take into account the body clock effects throughout the day. In the current study, water disappearance was only recorded daily by caretakers during daily observations.

When utilizing water disappearance to detect upcoming health and mortality challenges in wean-finish pigs, pattern deviations attributed to disease and those attributed to environmental factors is important to distinguish to reduce the number of false positive predictions. Reiner (2009), Krsnik et al., (1999) and Sutherland et al. (2007) found that pigs spent less time drinking water and eating feed during the onset and recovery from a variety of diseases. Theoretical models have been developed to predict optimum water intake for pigs under non-limiting conditions (Schiavon and Emmans, 2000). While there is an increasing number of caretakers who record daily water disappearance in groups of pigs (Seddon, 2011), there is very little published scientific work exploring the relationship between water consumption and upcoming pig health or mortality challenges in wean-finish pigs. Madsen and Kristensen (2005) demonstrated that an increase change in water disappearance was associated with the early stages of post-weaning scours, but the study was conducted using a small number of pigs (405 pigs) and water intake was recorded hourly.

Real-time automated monitoring of water disappearance in groups of pigs provides an additional and objective observational measure that caretakers can utilize when investigating pig health to detect issues before they arise (Smith et al., 2009).
Utilizing real-time water disappearance monitoring and using historical measurements could provide a lead indicator for upcoming health and mortality challenges which could then create an opportunity to take early action and reducing the impact from various diseases (Smith et al., 2009). Early intervention is strongly associated with improved pig welfare, increased performance, reduced mortality, and reduction in antibiotic use, which all combined provide financial benefits to the farm.

The objectives of this study were to: 1) identify ways to distinguish deviations in water disappearance when water disappearance is recorded daily in large groups of pigs, and 2) evaluate whether these deviations can be utilized to predict the onset of an upcoming high mortality event under field conditions. Previous research has only shown correlations between changes in water disappearance and health challenges in smaller groups of pigs, and was not conducted throughout the entire wean-finish period.

Materials and Methods

Animals And Facilities

Data utilized in this study were compiled from 26 lots of pigs at 11 different complexes which include two nursery, four conventional feeder-finish and five wean-finish complexes in Illinois and Iowa, on farms operated by The Maschhoffs, LLC (Carlyle, IL, USA) from July 2014 through January 2016. Pigs were weaned at 20-21 days of age and were of mixed sex. Pigs were sired by a PIC 359 terminal sire crossed with Yorkshire/Landrace dams. The number of pigs in each lot varied and depended on the number of rooms at each complex (2-9 rooms). All nursery and grow-finish complexes were managed all-in all-out by complex to reduce health concerns between
lots of pigs. For biosecurity reasons and to reduce age variation within each lot of pigs, all rooms at a complex were populated in a short time period, as 23 of the 26 lots were populated within 3-4 days, and the remaining 3 lots were populated within 16 days. In all nursery and wean-finish complexes, pigs were double stocked (0.28 m$^2$/pig) to normal stocking density (0.56 m$^2$/pig) to reduce the need for nursery complexes, which is standard protocol within The Maschhoffs system. Split-out is the process where half of the remaining pigs were divided and moved to another grow-finish complex, and the remaining half stayed at the original complex until they reached market weight. Split-out occurred between 5 and 12-weeks post-weaning in double stocked lots housed in wean-finish complexes. Finishing pigs within a complex were sent to harvest in multiple shipments, usually during a period of 6-8 weeks. Animal housing, feeding, handling and veterinary care were under the supervision of The Maschhoffs’ management personnel. All rooms had fully slatted floors, deep-pit manure handling, mechanically controlled ventilation, automated feeding and bowl waterers. Pigs were provided *ad libitum* access to a nine-phase corn-soybean diet from weaning to harvest in a wet-dry feeding system.

Health status of the sow farm and pigs at weaning were unknown but all pigs received standard vaccination and medication that followed The Maschhoffs standard protocol. More specifically, pigs were administered vaccinations as follows: *Mycoplasma hyopneumoniae* vaccine (Fostera® Gold PCV MH, Zoetis, Kalamazoo, MI, USA; Circumvent® PCV-M G2, Merck Animal Health, Summit, NJ, USA or Ingelvac MycoFlex®, Boehringer Ingelheim Vetmedica Inc, St. Joseph, MO, USA) at processing (3 to 5 days of age), and at 2-weeks post-weaning, porcine reproductive respiratory syndrome virus modified-live virus vaccine (Ingelvac PRRS® MLV, Boehringer
Ingelheim Vetmedica Inc, St. Joseph, MO, USA) at 2-weeks post-weaning, and porcine circovirus type 2 (PCV2) killed vaccine (Fostera Gold PCV® MH, Zoetis, Kalamazoo, MI, USA; Circumvent® PCV-M G2, Merck Animal Health, Summit, NJ, USA or Ingelvac CircoFlex®, Boehringer Ingelheim Vetmedica Inc, St. Joseph, MO, USA) vaccine at 3-weeks post-weaning.

Feed medication protocol followed the Maschhoffs standard protocols and were kept consistent between all lots of pigs. All water and injectable antimicrobial treatments and interventions performed were part of the routine care administered to animals by their caretakers.

Number of pigs dead (mortalities), total water disappearance, internal barn temperature and current pig inventory were recorded by management personnel during daily observations. Total water disappearance was recorded from a water meter as the number of gallons disappeared since the previous day’s daily observation for the entire lot of pigs. Internal maximum high and minimum low barn temperature (°C) were recorded daily from the ventilation control system within each barn and averaged across all barns at the complex.

Data Analysis

Week post-weaning (WPW) and day post-weaning (DPW) were defined as the average week and day post-weaning, respectively, for the entire lot of pigs at the complex. Daily mortality rate was defined as the number of daily mortalities divided by the number of pigs placed in the entire lot or inventory after split-out occurred and multiplied by 100. This method for calculating mortality rate was done because inventory decreased within each lot throughout the wean-finish period due to death and shipments.
that occur when marketing. Timing of euthanasia is a very subjective assessment which depends on the animal caretaker (Morrow et al., 2007). Hence, euthanized pigs were not included in the daily mortality count to remove any statistical bias that could result from the effect of changes in weekly management personnel which could unintentionally signal the start of a high mortality event.

**Quantifying high mortality events**

To detect the start of a high mortality event (SHME), a rolling average daily mortality rate was calculated throughout the wean-finish period. The previous seven-day (day -6 to 0) average daily mortality rate (P7M) was subtracted from the subsequent three-day (day 1 to 3) average daily mortality rate (S3M) to calculate the change in mortality (CM). Consequently, the first day of interest within each lot of pigs was on the 7th day, as the first 7 days were used to determine the average for detecting changes in mortality. Seven-day average daily mortality rate was used to remove the day of the week mortality rate effect. Subsequent three-day average daily mortality rate was used to detect short-term changes in mortality.

Across all lots of pigs, z-scores were computed from raw CM within each WPW, since change in mortality is not the same within each WPW throughout the wean-finish period. A z-score is the number of standard deviations from the mean and is used to more clearly identify outliers (Rothenberg, 1993). A z-score threshold of ≥ 1.0 was considered a significant positive deviation from the mean CM within each week post-weaning, and any day with a z-score ≥ 1.0 was categorized as the start of a high mortality event (SHME). Table 1 includes the upper change in mortality threshold which is equal to a z-score of 1.0 within each WPW.
Quantifying changes in water disappearance

Daily water disappearance (WD) per pig was calculated as the total volume of water disappeared (gallons was recorded and converted to liters during data analysis) since the prior day’s daily observation, divided by the current pig inventory. Since it was unknown if daily water disappearance was recorded at the same time each day during daily observations, a rolling three-day average water disappearance (3WD) was calculated which included the current day of interest (day 0) and the previous two days (days -1 and -2).

Three methods were developed to detect water disappearance deviations: (1) linear mixed effects model (2) one-step ahead model and (3) percent change water disappearance from previous days.

Quantifying deviations in water disappearance from linear mixed effects model

Predicted values for three-day average water disappearance (3WD) were estimated with a linear mixed effects model using the function lmer from the R package lme4 (Bates et al., 2015). The choice of variables in the final model was based on assessing their impact on the model fit statistics. The final model included 3WD as a dependent variable. Independent fixed effects included day post-weaning (DPW), day post-weaning squared (DPW^2), day post-weaning cubed (DPW^3), and interaction of DPW and previous 3-day (days -2, -1 and 0) average high temperature (P3HT) (°C), nested within each random effect of lot of pigs. Initial analyses included previous 3-day average low temperature as a fixed effect; however, it was not significant (P>0.05) once P3HT was included in the model.
Model residuals were calculated from each day’s predicted 3WD value using the lmer function from the R package lme4 (Bates et al., 2015) and were transformed into percent residuals (Linear model percent residual; LMPR) from the predicted value. This was done due to increased 3WD variation in the later wean-finish period. Internally studentized residuals (SR) corresponding to each LMPR value (n=2546) were produced. Studentized residuals have a mean of 0 and a standard deviation of 1 to more clearly identify outliers (Jongenelen et al., 1988). Both negative and positive large SRs were considered and categorized as a significant deviation from predicted 3WD values. Utilizing the linear model, low water events (Linear model low water event; LMLWE) and high water events (Linear model high water event; LMHWE) were defined from the SRs and described as the following binary variables: SR ≤ -1 (LMLWE1), SR ≤ -1.5 (LMLWE1.5), SR ≤ -2.0 (LMLWE2), SR ≥ 1 (LMHWE1), SR ≥ 1.5 (LMHWE1.5), and SR ≥ 2.0 (LMHWE2). A SR of 1, 1.5 and 2 were equivalent to a 11.2%, 16.8% and 22.5% deviation from the predicted 3WD, respectively.

One-step ahead model water disappearance events

A multivariate linear regression model was developed for the one-step ahead model to predict the next day’s three-day average water disappearance. The one-step ahead model uses a prediction interval as a control chart with a systematically evolving baseline within each lot of pigs. Each day, the model is updated and is fitted using the previous 15-day data and prior coefficients. Throughout the wean-finish period, the prediction interval is calculated for a given value of the covariates which includes previous three-day average high temperature (P3HT) (°C) and polynomial effects of DPW, DPW^2 and DPW^3.
The regression model was fit utilizing a Bayesian approach to classical regression, while using prior information of several coefficients as additional data points (Gelman, 2014). The prior coefficients are normally distributed. To obtain the estimated prior mean coefficients and variance, an empirical Bayesian method was used in which regression models are utilized to obtain the mean coefficients and all lots of pigs are used to generate the mean variance. The one-step ahead model predicts the next day’s three-day average water disappearance with an associated prediction interval (68.2% confidence level to represent 1 standard deviation above and below the prediction). When a day had three-day average water disappearance below or above the prediction interval, the day was categorized as a one-step ahead low water event (SALWE) or a one-step ahead high water event (SAHWE), respectively.

**Quantifying percent change water disappearance**

To understand percent change in water disappearance throughout the wean-finish period, 3WD was calculated against the prior 11-day (days -13 to -3) average water disappearance (P11WD). Percent change water disappearance (PCWD) was calculated by subtracting P11WD from 3WD, dividing by P11WD and multiplying by 100. Any day that PCWD <0%, was categorized as NegPCWD (Negative percent change water disappearance).

**Quantifying levels of percent change based on z-scores**

To categorize days with varying levels of low and high percent change water disappearance, Z-scores were computed from the PCWD within each WPW since PCWD is not equal throughout the wean-finish period. A z-score is the number of standard deviations from the mean and is used to more clearly identify outliers (Rothenberg,
1993). A range of z-score thresholds (-1.0, -1.5, -2.0, 1.0, 1.5, and 2.0) were tested and described as the following binary variables: PCWDZ-1 (Z-score ≤-1), PCWDZ-1.5 (Z-score≤-1.5), PCWDZ-2 (Z-score≤-2.0), PCWDZ1 (Z-score ≥1), PCWDZ1.5 (Z-score ≥1.5), PCWDZ2 (Z-score ≥2.0). Table 2 summarizes the mean percent change in each WPW.

**Statistical Analysis**

Mean separation and Tukey-Kramer were used for multiple comparisons using the lsmeans function from the R package lsmeans (Lenth, 2016). Logistic binomial regression analysis using the Wald test in the R package stats (Team, 2014) was used to investigate the probability and odds ratio of the start of a high mortality event occurring. Logistic regression does not require independent variables to be linearly related, nor does it require equal variance within each group, which makes it a less stringent procedure for statistical analysis (Harrell, 2015).

Variables generated as possible predictors of the start of a high mortality event were tested in univariate logistic regression analysis with SHME as the dependent variable. Results are reported as probability and odds ratios (OR) with the associated 95% Wald confidence interval (CI). Probability is the measure of the likelihood that an event will occur and is quantified as a number between 0 and 1. A probability of 0 indicates impossibility and 1 indicates certainty a SHME will occur. An odds ratio greater than 1 is indicative of an increased chance of a SHME, whereas an odds ratio less than 1 indicates a reduced chance of a SHME and a normal three-day average mortality would be expected to follow.
Results

Mortality

**Week post-weaning effect on mortality**

Least squares means for daily mortality rate by week post-weaning are reported in Table 1. Across all days, mean daily mortality rate was 0.05% per day and ranged from 0% to 0.78% per day. Daily mortality rate was greater (P<0.05) in 5-7 (0.1018%, 0.0862% and 0.0867%, respectively) weeks post-weaning when compared to 13-24 and 26-27 weeks post-weaning (Table 1).

Least squares means for change in mortality by week post-weaning are reported in Table 1. Across all individual days, mean change in mortality rate was -0.0008% per day and ranged from -0.3618% to 0.4175% per day. Change in mortality was lower (P<0.05) in 7 weeks post-weaning (-0.0158%) when compared to 2-5 and 8 weeks post-weaning. Table 1 includes the change in mortality upper threshold value which is equal to a z-score ≥1 within each week post-weaning. During data analysis, when a day had a change in mortality greater than the upper threshold, this day was categorized as the start of a high mortality event (SHME).

**Water Disappearance**

**Week post-weaning and temperature effect on water disappearance**

Least squares means for three-day average water disappearance (3WD) by week post-weaning are reported in Table 2. Across individual days, mean three-day average water disappearance was 4.89 liters/pig and ranged from 0.55 to 13.25 liters/pig. Three-day average water disappearance was greater (P<0.05) in 17-27 weeks post-weaning
when compared to weeks post-weaning 2-13 (Table 2) and continued an upward trajectory throughout the wean-finish period as week post-weaning increased.

The interaction of DPW and P3HT was significant (P<0.001), as an increase in P3HT in older pigs, increased three-day average water disappearance (Figure 1).

**Week post-weaning effect on percent change water disappearance**

Least squares means for percent change water disappearance (PCWD) by week post-weaning are reported in Table 2. Across individual days, mean PCWD was 6.1% per day and ranged from -56.0% to 103.7% per day. Percent change water disappearance was greater (P<0.05) in 3-5 weeks post-weaning when compared to 7, 10, 11 and 13-27 weeks post-weaning (Table 2) and continued a downward trajectory throughout the wean-finish period as week post-weaning increased.

**Univariate Logistic Binomial Regression Analyses**

The water variables generated as possible predictors for the start of a high mortality event were evaluated using univariate logistic binomial regression model with start of a high mortality event (SHME) as a dependent variable. Descriptions of water variables are provided in Table 3.

**Linear mixed effects model variables**

Variables generated using the linear mixed model, LMPR, LMLWE1, LMLWE1.5, LMLWE2, LMHWE1, LMHWE1.5, and LMHWE2 were not significant (P>0.05) predictors for a SHME (Table 4).

**One-step ahead model variables**

Variables generated using the one-step ahead model, SALWE and SAHWE, were not significant (P>0.05) predictors for a SHME (Table 4).
Percent change water disappearance variables

The continuous variable percent change water disappearance was a significant (P<0.05) predictor (Table 4) for a SHME. As PCWD decreased, the probability of a SHME increased (Figure 2). Each additional one percent increase in percent change water disappearance reduced the odds for a SHME (OR=0.99, 95% CI: 0.98-1.00).

Binary variable negative percent change water disappearance was a significant (P<0.001) predictor (Table 4) for a SHME in which days that had a NegPCWD had a greater odds for a SHME (OR=1.56, 95% CI: 1.21-2.01).

Categorical variables PCWDZ-1, PCWDZ-1.5, PCWDZ-2, PCWDZ1, and PCWDZ2, were not significant predictors for a SHME(P>0.05). Percent change water disappearance with a z-score ≥1.5 (PCWDZ1.5) was a significant (P<0.05) predictor but the odds for a SHME occurring was lower (OR=0.49, 95% CI: 0.23-0.91).

Discussion

This study measured three-day average water disappearance in large groups of pigs and evaluated several methods to distinguish deviations in water disappearance throughout the wean-finish period, and whether the deviations can be utilized to predict the probability of the start of a high mortality event. Monitoring of large groups of pigs was used in this study, which is standard across The Maschhoffs system and many other large production systems in the U.S. and worldwide. Since methods to detect deviations in water disappearance used in this study are significant predictors for the start of a high mortality event, this approach can be utilized throughout The Maschhoffs wean-finish facilities. Similar models may be developed for other production systems.
Maes et al. (2001) defined weekly mortality as the number of pigs that died during a week divided by the average inventory of pigs during that week. It was reported that weekly mortality was consistently greater in late finishing when compared to early finishing, and pigs had an increased risk for mortality after week 10 of the wean-finish period in a retrospective study of wean-finish mortality in 1996-1999 (Maes et al., 2001). The present study found that mortality was greater in WPW 5-7 when compared to WPW 13-24 and 26-27. Losinger et al. (1999) evaluated 53 grower/finisher-only swine operations that participated in the 1995 National Swine Study and defined percent mortality per day in the grower/finisher unit by dividing percent mortality by average days in the grower/finisher unit. They reported least squares means for percent mortality as 0.03% per day.

The results from the linear mixed effects model demonstrated a positive relationship between WPW, temperature and water disappearance in each lot of pigs. Week post-weaning was the main factor associated with water disappearance and this finding is similar to the findings of Seddon (2011), who reported 18 week old pigs (15 WPW) were consuming between 5-5.5 liters of water per day. McGlone and Pond (2003) reported water intake requirements by body weight of wean-finish pigs as the following: 11.3 kilograms, 1.5 liters/day; 22.7 kilograms, 2.3 liters/day; 35.0 kilograms, 3.4 liters/day; 45.4 kilograms, 3.8 liters/day; 68.0 kilograms, 4.9 liters/day; 90.7 kilograms, 6.4 liters/day; 113.4 kilograms, 7.6 liters/day; 136.1 kilograms, 8.0 liters/day. Almond (1995) reported that 2.5-3.0 liters of water are required for every kilogram of feed consumed. Bigelow and Houpt (1988) found that 75% of water disappearance was associated with feed disappearance in wean-finish pigs. Feed disappearance is greater in
pigs that have a greater body weight (Quiniou et al., 2000) and although not recorded in this study, feed or water disappearance could be a beneficial tool to predict an upcoming high mortality event. The relationship between WPW and water disappearance is to be expected, as increased water is required by pigs for protein deposition and protein turnover as body weight increases. Water is the most essential nutrient for life, and an inadequate supply can result in devastating consequences such as overheating, dehydration, and in extreme case, death (Kober, 1993).

Water contributes to body weight gain in pigs and recording the quantity of daily water throughout wean-finish could provide a simple low-labor measure to assess growth rate at a given stage of growth in pigs (Brooks et al., 1984). Smith et al. (2009) found that water intake plummeted not long after the feed auger stopped running in a wean-finish barn. On the contrary, Yang et al. (1981) reported that when the reduction of the daily feed allowance from 1.5 kg to 0.8 kg, caused the pigs to drink more water and increase the water turnover rate. The pigs, therefore, consumed more water when feed was restricted; a behavior attributable to hunger (Yang et al., 1981). Similar findings have been reported in the dairy industry as calving, health events and hoof trimming is associated with a decrease in dry matter and water intake (Meyer et al., 2004; Lukas et al., 2008). By monitoring water disappearance, this provides another way to detect problems in the environment of a facility.

Seddon (2011) found percent change water disappearance decreased as pigs neared slaughter weight as found in this study. The narrowing gap between water intake and weight increase as pigs neared slaughter weight has been noted by other authors
(Brooks et al., 1984), which is believed to result from a reduction in body protein turnover as the pig begins to reach mature size (Whittemore and Elsley, 1976).

In the linear mixed effects model, temperature was found to affect water disappearance which is consistent with Mroz et al. (1995) and Mount (1971) who reported higher ambient temperature increased drinking water intake in wean-finish pigs. Temperature is known to affect water consumption in wean-finish pigs, due to the positive relationship between water and metabolism (Seddon, 2011). Schiavon and Emmans (2000) stated that wean-finish pigs that experience hot environments will have increased evaporation, which leads to increased water consumption.

It has been previously reported that pigs waste less water when drinking from push-lever bowl waterers compared to nipple drinkers or float bowl waterers (Torrey et al., 2008). However, in the current study push-lever bowl waterers were used in all facilities so differences in water disappearance deviations due to different drinkers used was eliminated. During days with high temperatures, pigs could attempt to cool themselves by spraying or wasting water from nipple waterers or float bowl-waterers, that might be used in other production systems. Spraying and wasting water is less possible with push-lever bowl-waterers when compared to other water delivering mechanisms.

The optimum environmental temperature for grow-finish pigs is between 18-21°C (Kouba and Sellier, 2011). The pigs in the present study were housed in environmentally controlled facilities which included heaters and a mechanical ventilation system. However, the temperature consistently deviated from the optimum range for grow-finish pigs and from the range set as the ideal temperature (18-27°C) by the caretakers. When
temperatures fall below the thermoneutral zone, pigs increase their feed consumption to raise their metabolism and generate body heat (Ingram and Legge, 1974), and subsequently this causes increased water consumption. This demonstrates another way how water disappearance data can be utilized to detect potential problems in wean-finish or conventional finishing barns.

Reduced drinking behavior has previously been observed in sick pigs, as sickness behavior is triggered by the action of cytokines, which are produced soon after the invading pathogen is recognized by the pig (Reiner et al., 2009; Borghetti et al., 2011). In this study, water disappearance was used as a predictor for the start of a high mortality event, which was categorized as an increase in mortality in the subsequent three days. The number of days prior to a disease outbreak where a change in water consumption was observed, differs between studies as Madsen and Kristensen (2005) reported a change in water consumption one day prior to an *Escherichia coli* outbreak. Crabtree et al. (2008) observed a change in water consumption one week prior to a disease challenged, but did state the specific disease. Few studies have reported using changes in water as a predictor for a disease outbreak in pigs but no reports in scientific literature was found using water as a predictor for mortality in wean-finish pigs.

Although the linear mixed effects model and one-step ahead model included temperature in both models, none of the evaluated using those two methods were found to increase the predictability for the start of a high mortality event. The method used in this study to evaluate the percent change in water disappearance can be calculated by caretakers during daily observations and does not require a fully automated system that needs to download and interpret the data into meaningful messages. In future studies, an
automated system should be used to collect water disappearance and temperature more frequently, instead of manual collection that led us to use three-day average water disappearance.

Other methods and variables need to be developed to objectively detect various indicators in the environment and health for the pigs to increase the likelihood to correctly predict the start of a high mortality event, which is important to reduce the number of false positives. Monitoring water disappearance can serve as an objective measure that caretakers can utilize when monitoring large groups of pigs and the present study shows the potential to predict high mortality event.

References

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Table 1. Mean inventory across all lots of pigs, least squares means (±SE) for daily mortality rate (%) and change in mortality (%) and change in mortality upper threshold (%) by week-post weaning from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Week post weaning</th>
<th>Mean Inventory</th>
<th>Mean Daily Mortality Rate</th>
<th>Mean Change in Mortality</th>
<th>Change in Mortality Upper Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>12724</td>
<td>0.04±0.01%abcdef</td>
<td>0.022±0.008%bcd</td>
<td>0.103%</td>
</tr>
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<td>3</td>
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<td>0.020±0.005%d</td>
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<tr>
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<td>0.011±0.005%bcd</td>
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</tr>
<tr>
<td>5</td>
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<td>0.097%</td>
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<tr>
<td>6</td>
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</tr>
<tr>
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<tr>
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</tr>
<tr>
<td>12</td>
<td>7734</td>
<td>0.06±0.01%abcdef</td>
<td>-0.004±0.005%abc</td>
<td>0.020%</td>
</tr>
<tr>
<td>13</td>
<td>7369</td>
<td>0.05±0.01%abcdef</td>
<td>-0.007±0.004%ab</td>
<td>0.018%</td>
</tr>
<tr>
<td>14</td>
<td>7112</td>
<td>0.05±0.01%abcdef</td>
<td>-0.004±0.004%abc</td>
<td>0.020%</td>
</tr>
<tr>
<td>15</td>
<td>7031</td>
<td>0.04±0.01%ab</td>
<td>-0.002±0.004%abc</td>
<td>0.019%</td>
</tr>
<tr>
<td>16</td>
<td>7076</td>
<td>0.04±0.01%ab</td>
<td>0.001±0.004%abc</td>
<td>0.022%</td>
</tr>
<tr>
<td>17</td>
<td>6998</td>
<td>0.04±0.01%ab</td>
<td>-0.001±0.004%abc</td>
<td>0.016%</td>
</tr>
<tr>
<td>18</td>
<td>6921</td>
<td>0.04±0.01%ab</td>
<td>0.001±0.004%abc</td>
<td>0.020%</td>
</tr>
<tr>
<td>19</td>
<td>6820</td>
<td>0.05±0.01%abc</td>
<td>0.001±0.004%abc</td>
<td>0.022%</td>
</tr>
<tr>
<td>20</td>
<td>6708</td>
<td>0.05±0.01%abc</td>
<td>0.003±0.004%abc</td>
<td>0.029%</td>
</tr>
<tr>
<td>21</td>
<td>6445</td>
<td>0.04±0.01%abc</td>
<td>0.001±0.004%abc</td>
<td>0.022%</td>
</tr>
<tr>
<td>22</td>
<td>6285</td>
<td>0.05±0.01%abc</td>
<td>-0.003±0.003%abc</td>
<td>0.022%</td>
</tr>
<tr>
<td>23</td>
<td>5532</td>
<td>0.05±0.01%abc</td>
<td>-0.001±0.003%abc</td>
<td>0.024%</td>
</tr>
<tr>
<td>24</td>
<td>4565</td>
<td>0.04±0.01%abc</td>
<td>-0.004±0.004%abc</td>
<td>0.029%</td>
</tr>
<tr>
<td>25</td>
<td>3695</td>
<td>0.06±0.01%abcdef</td>
<td>-0.012±0.005%ab</td>
<td>0.029%</td>
</tr>
<tr>
<td>26</td>
<td>3049</td>
<td>0.04±0.01%abcdef</td>
<td>-0.004±0.007%abcdef</td>
<td>0.015%</td>
</tr>
<tr>
<td>27</td>
<td>2343</td>
<td>0.03±0.01%abcdef</td>
<td>-0.009±0.009%abcdef</td>
<td>0.005%</td>
</tr>
<tr>
<td>Mean</td>
<td>7911</td>
<td>0.05%</td>
<td>-0.001%</td>
<td></td>
</tr>
</tbody>
</table>

1 Change in mortality was calculated as the previous seven-day average mortality rate subtracted from the subsequent three-day average mortality rate.

2 Change in mortality upper threshold is equal to a z-score of ≥1.0 within each week post-weaning.

a-g Least squares means with different superscripts within a column are different (P<0.05).
Table 2. Least squares means (±SE) for three-day average water disappearance, percent change water disappearance by week post weaning from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Week Post-Weaning</th>
<th>Mean Three-Day Average Water Disappearance (Liters/pig/day)</th>
<th>Mean Percent Change Water Disappearance&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.07±0.32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.48±4.03%&lt;sup&gt;abcdefg&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>1.21±0.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.62±1.84%&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>1.66±0.31&lt;sup&gt;mn&lt;/sup&gt;</td>
<td>17.87±1.73%&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>2.04±0.31&lt;sup&gt;lmmn&lt;/sup&gt;</td>
<td>17.87±1.71%&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>2.42±0.30&lt;sup&gt;kln&lt;/sup&gt;</td>
<td>10.18±1.71%&lt;sup&gt;cdef&lt;/sup&gt;</td>
</tr>
<tr>
<td>7</td>
<td>2.69±0.30&lt;sup&gt;kl&lt;/sup&gt;</td>
<td>9.76±1.67%&lt;sup&gt;defg&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>3.18±0.29&lt;sup&gt;jk&lt;/sup&gt;</td>
<td>13.28±1.67%&lt;sup&gt;abcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>9</td>
<td>3.67±0.30&lt;sup&gt;i&lt;/sup&gt;</td>
<td>10.66±1.71%&lt;sup&gt;bcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>3.71±0.29&lt;sup&gt;i&lt;/sup&gt;</td>
<td>8.11±1.71%&lt;sup&gt;defgh&lt;/sup&gt;</td>
</tr>
<tr>
<td>11</td>
<td>4.06±0.29&lt;sup&gt;hi&lt;/sup&gt;</td>
<td>7.00±1.61%&lt;sup&gt;defgh&lt;/sup&gt;</td>
</tr>
<tr>
<td>12</td>
<td>4.68±0.28&lt;sup&gt;gih&lt;/sup&gt;</td>
<td>13.09±1.61%&lt;sup&gt;abcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>13</td>
<td>5.06±0.28&lt;sup&gt;ghi&lt;/sup&gt;</td>
<td>10.05±1.57%&lt;sup&gt;def&lt;/sup&gt;</td>
</tr>
<tr>
<td>14</td>
<td>5.33±0.28&lt;sup&gt;defg&lt;/sup&gt;</td>
<td>6.24±1.51%&lt;sup&gt;efgh&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>5.41±0.28&lt;sup&gt;defg&lt;/sup&gt;</td>
<td>3.39±1.50%&lt;sup&gt;ghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>16</td>
<td>5.69±0.28&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>5.48±1.50%&lt;sup&gt;efghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>17</td>
<td>5.93±0.28&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>5.13±1.48%&lt;sup&gt;efghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>18</td>
<td>6.06±0.28&lt;sup&gt;abcde&lt;/sup&gt;</td>
<td>4.32±1.47%&lt;sup&gt;efghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>19</td>
<td>6.26±0.28&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>1.92±1.47%&lt;sup&gt;hi&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>6.22±0.28&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>2.97±1.47%&lt;sup&gt;hi&lt;/sup&gt;</td>
</tr>
<tr>
<td>21</td>
<td>6.29±0.28&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>0.19±1.48%&lt;sup&gt;ij&lt;/sup&gt;</td>
</tr>
<tr>
<td>22</td>
<td>6.50±0.28&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>3.94±1.50%&lt;sup&gt;fgih&lt;/sup&gt;</td>
</tr>
<tr>
<td>23</td>
<td>6.78±0.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.55±1.51%&lt;sup&gt;efghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>24</td>
<td>6.72±0.29&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1.52±1.61%&lt;sup&gt;hij&lt;/sup&gt;</td>
</tr>
<tr>
<td>25</td>
<td>6.23±0.32&lt;sup&gt;abcde&lt;/sup&gt;</td>
<td>-5.48±1.92%&lt;sup&gt;ci&lt;/sup&gt;</td>
</tr>
<tr>
<td>26</td>
<td>6.52±0.36&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>1.68±2.72%&lt;sup&gt;efghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>27</td>
<td>6.53±0.43&lt;sup&gt;abcdef&lt;/sup&gt;</td>
<td>4.13±2.85%&lt;sup&gt;defghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean</td>
<td>4.89</td>
<td>6.10%</td>
</tr>
</tbody>
</table>

<sup>1</sup>Percent change water disappearance was calculated by subtracting prior 11-day (days -13 to -3) average water disappearance from three-day (days -2 to 0) average water disappearance, dividing by prior 11-day average water disappearance and multiplying by 100.

<sup>a-j</sup>Least squares means with different superscripts within a column are different (P<0.05).
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM</td>
<td>Change in Mortality</td>
</tr>
<tr>
<td>SHME</td>
<td>Start of a high mortality event (CM Z-score $\geq 1.0$)</td>
</tr>
<tr>
<td>3WD</td>
<td>Three-day average water disappearance (Days 0, -1 and -2). (Liters/pig/day).</td>
</tr>
<tr>
<td>LMPR</td>
<td>Linear model percent residual; categorized as a continuous variable.</td>
</tr>
<tr>
<td>LMLWE1</td>
<td>Linear model low water event studentized residual $\leq -1.0$; 3WD $\leq 11.2%$ than predicted; categorized as a binary variable.</td>
</tr>
<tr>
<td>LMLWE1.5</td>
<td>Linear model low water event studentized residual $\leq -1.5$; 3WD $\leq 16.8%$ than predicted; categorized as a binary variable.</td>
</tr>
<tr>
<td>LMLWE2</td>
<td>Linear model low water event studentized residual $\leq -2.0$; 3WD $\leq 22.5%$ than predicted; categorized as a binary variable.</td>
</tr>
<tr>
<td>LMHWE1</td>
<td>Linear model high water event studentized residual $\geq 1.0$; 3WD $\geq 11.2%$ than predicted; categorized as a binary variable.</td>
</tr>
<tr>
<td>LMHWE1.5</td>
<td>Linear model high water event studentized residual $\geq 1.5$; 3WD $\geq 16.8%$ than predicted; categorized as a binary variable.</td>
</tr>
<tr>
<td>LMHWE2</td>
<td>Linear model high water event studentized residual $\geq 2.0$; 3WD $\geq 22.5%$ than predicted; categorized as a binary variable.</td>
</tr>
<tr>
<td>SALWE</td>
<td>One-step ahead model low water event; categorized as a binary variable.</td>
</tr>
<tr>
<td>SAHWE</td>
<td>One-step ahead model high water event; categorized as a binary variable.</td>
</tr>
<tr>
<td>PCWD</td>
<td>Percent change 3-day (days -2 to 0) average water disappearance from prior 11-day (days -13 to -3) average water disappearance; categorized as a continuous variable.</td>
</tr>
<tr>
<td>NegPCWD</td>
<td>Negative percent change water disappearance; PCWD $&lt; 0%$; categorized as a binary variable.</td>
</tr>
<tr>
<td>PCWDZ-1</td>
<td>Percent change water disappearance z-score $\leq -1$; categorized as a binary variable.</td>
</tr>
<tr>
<td>PCWDZ-1.5</td>
<td>Percent change water disappearance z-score $\leq -1.5$; categorized as a binary variable.</td>
</tr>
<tr>
<td>PCWDZ-2</td>
<td>Percent change water disappearance z-score $\leq -2$; categorized as a binary variable.</td>
</tr>
<tr>
<td>PCWDZ1</td>
<td>Percent change water disappearance z-score $\geq 1$; categorized as a binary variable.</td>
</tr>
<tr>
<td>PCWDZ1.5</td>
<td>Percent change water disappearance z-score $\geq 1.5$; categorized as a binary variable.</td>
</tr>
<tr>
<td>PCWDZ2</td>
<td>Percent change water disappearance z-score $\geq 2$; categorized as a binary variable.</td>
</tr>
</tbody>
</table>
Table 4. Odds ratios\(^1\) of water disappearance variables\(^2,3\) for the start of a high mortality event from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Continuous Variables(^2)</th>
<th>Odds ratio(^3)</th>
<th>Confidence interval odds ratio (95%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMPR</td>
<td>1.43</td>
<td>0.48 - 4.22</td>
<td>0.52</td>
</tr>
<tr>
<td>PCWD</td>
<td>0.99</td>
<td>0.98 - 1.00</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Binary Variables(^3)</th>
<th>Odds ratio(^5)</th>
<th>Confidence interval odds ratio (95%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMLWE1</td>
<td>0.77</td>
<td>0.48 - 1.20</td>
<td>0.26</td>
</tr>
<tr>
<td>LMLWE1.5</td>
<td>0.76</td>
<td>0.32 - 1.56</td>
<td>0.48</td>
</tr>
<tr>
<td>LMLWE2</td>
<td>0.22</td>
<td>0.01 - 1.06</td>
<td>0.06</td>
</tr>
<tr>
<td>LMHWE1</td>
<td>0.84</td>
<td>0.50 - 1.32</td>
<td>0.46</td>
</tr>
<tr>
<td>LMHWE1.5</td>
<td>0.60</td>
<td>0.23 - 1.28</td>
<td>0.21</td>
</tr>
<tr>
<td>LMHWE2</td>
<td>0.22</td>
<td>0.01 - 1.03</td>
<td>0.06</td>
</tr>
<tr>
<td>SALWE</td>
<td>0.94</td>
<td>0.68 - 1.28</td>
<td>0.70</td>
</tr>
<tr>
<td>SAHWE</td>
<td>0.74</td>
<td>0.51 - 1.04</td>
<td>0.09</td>
</tr>
<tr>
<td>NegPCWD</td>
<td>1.56</td>
<td>1.20 - 2.01</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PCWDZ-1</td>
<td>1.15</td>
<td>0.80 - 1.61</td>
<td>0.45</td>
</tr>
<tr>
<td>PCWDZ-1.5</td>
<td>1.31</td>
<td>0.77 - 2.11</td>
<td>0.30</td>
</tr>
<tr>
<td>PCWDZ-2</td>
<td>1.27</td>
<td>0.52 - 2.66</td>
<td>0.56</td>
</tr>
<tr>
<td>PCWDZ1</td>
<td>0.90</td>
<td>0.61 - 1.31</td>
<td>0.60</td>
</tr>
<tr>
<td>PCWDZ1.5</td>
<td>0.49</td>
<td>0.23 - 0.91</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>PCWDZ2</td>
<td>0.57</td>
<td>0.20 - 1.28</td>
<td>0.18</td>
</tr>
</tbody>
</table>

\(^1\)An odds ratio (95% confidence interval odds ratio) greater than 1 is indicative of an increased chance of the start of a high mortality event, whereas an odds ratio less than 1 indicates a reduced chance.

\(^2\)Continuous Variables: LMPR: Linear model percent residual; PCWD: Percent change water disappearance. Odds ratios for continuous variables are reported as the effect of a one unit increase on the probability of the start of a high mortality event.

\(^3\)Binary Variables: LMLWE1: Linear model low water event SR \(\leq -1\); LMLWE1.5: Linear model low water event SR \(\leq -1.5\); LMLWE2: Linear model low water event SR \(\leq -2\); LMHWE1: Linear model high water event SR \(\geq 1\); LMHWE1.5: Linear model high water event SR \(\geq 1.5\); LMHWE2: Linear model high water event SR \(\geq 2\); SALWE: One-step ahead model low water event; SAHWE: One-step ahead model high water event; NegPCWD: Negative percent change water disappearance, PCWD <0; PCWDZ-1: Percent change water disappearance z-score \(\leq -1\), PCWDZ-1.5: Percent change water disappearance z-score \(\leq -1.5\), PCWDZ-2: Percent change water disappearance z-score \(\leq -2\), PCWDZ1: Percent change water disappearance z-score \(\geq 1\), PCWDZ1.5: Percent change water disappearance z-score \(\geq 1.5\), PCWDZ2: Percent change water disappearance z-score \(\geq 2\). Odds ratios for binary variables are reported as the effect of the event occurring on the probability of the start of a high mortality event.
Figure 1. Day post-weaning and temperature interaction on three-day average water disappearance from a study of crossbred wean-finish pigs raised in a commercial production system. Temperature is the previous three-day average high temperature (°C).
Figure 2. Percent change water disappearance (PCWD) effect on the probability for the start of high mortality event (SHME) from a study of crossbred wean–finish pigs raised in a commercial production system.
The objective of this study was to evaluate environmental stress and management practice effects on the start of a high mortality events (SHME) in commercial wean-finish pigs. Data utilized in this study were compiled from 26 lots of pigs raised in Illinois and Iowa, on farms operated by The Maschhoffs, LLC (Carlyle, IL, USA) from July 2014 through January 2016. Change in mortality (CM) was calculated as the previous seven-day average mortality rate subtracted from the subsequent three-day average mortality rate, and SHME was defined as one standard deviation above the mean CM within each week post-weaning. Several environmental variables were significant as seven-day average low environmental temperature in the barn (7LT) was negatively associated with the odds for the SHME. A \( \geq 6.1^\circ C \) drop in high temperature, increased the odds for the SHME. Days when average low temperature (ALT) was \( \geq 2.78^\circ C \) below the barn temperature setpoint (LTSPE) had increased the odds for the SHME. If ALT or 7LT was \( \leq 16.6^\circ C \), days were defined as ALT16 and 7LT16, respectively, and both increased the odds for the SHME. Early finishing pigs with increased seven-day temperature variation had increased odds for the SHME. Day of the week was significant as the odds for the SHME were greater on Sunday compared to Tuesday, Wednesday, Thursday, Friday and Saturday. Daily treatment rate, three-day average treatment rate, difference in treatment rate and a positive increase in treatment rate were all negatively associated with a SHME. In other words, as treatment increased, the odds for the SHME decreased. Several interactions between environmental stressors and management practices were significant.
sources of variation when evaluating the SHME. The interaction between double stocking pigs housed in barns with environmental temperatures above the thermoneutral zone, or with increased seven-day temperature variation, had increased odds for the SHME. If splitting of double stocked pig groups occurred within the previous seven days, the odds for the SHME increased as temperature increased. Removing market weight pigs in fall decreased the odds for the SHME compared to all other seasons. Odds for the SHME were greater if LTSPE or ALT16 occurred in winter. Early finishing pigs had increased odds for the SHME in spring compared to fall. Late finishing pigs had greater odds for the SHME in winter compared to spring and fall, and greater in summer compared to spring and fall.

**Introduction**

Managing the environment and providing proper care is important to maintain in wean-finish swine production. Environmental stressors can adversely impact swine performance, health and well-being. Proactive environmental management should be provided to reduce or eliminate adverse effects on wean-finish swine production (Hahn, 1995). Low and high temperature stressors impact the performance of growing pigs (Nienaber et al., 1987; Hyun et al., 1998) and increase mortality in swine breeding herds (Dallaire et al., 1996). Due to heat stress, it is estimated the United States swine industry annually loses $202 million in grow-finish production and when combined with breeding herds, $299 million as a result of reduced growth and increased mortality (St-Pierre et al., 2003).

Cyclical temperatures during the wean-finish period reduce performance, increase stress (Bond et al., 1963; Morrison and Mount, 1971; Nienaber et al., 1989) and
challenge the pig’s homeothermic abilities and homeostasis (Nienaber et al., 1989). Morrison and Mount (1971) exposed pigs to a change in environmental temperature from 33 to 20°C and after the change occurred, steady values for respiratory rate and rectal temperature were reached in the following one and twelve days, respectively. Variation in extreme temperature should be avoided through environmental modifications and a mechanically controlled ventilation system (Hahn, 1995). Mechanically controlled ventilation facilities maintain the proper temperature for the pigs, while controlling levels of humidity and removing gaseous contaminants introduced by the animal and their stored waste (Saha et al., 2010). Grow-finish pigs housed in facilities where the ventilation system is manually controlled present a greater mortality rate compared to pigs housed in facilities utilizing mechanically controlled ventilation systems (Agostini et al., 2014).

Maes et al. (2004) investigated risk factors for mortality in grow-finish pigs in Belgium and reported that type of ventilation system was not a significant risk factor for pig mortality. The difference between the Maes et al. (2004) study and the current study, is the range in temperature between the summer and winter is greater in the Midwestern U.S. than in Western Europe. Temperature effects have been reported in the dairy industry, as calves born during high temperatures in the summer, low temperatures in the winter or periods of large temperature fluctuations were associated with an increased mortality risk (Martin et al., 1975).

Seasonal effects influence the mortality risk in wean-finish pig groups. Weaned pigs placed in October through December (Maes et al., 2001; Maes et al., 2004; Oliveira et al., 2009) or January through April (Oliveira et al., 2009) have greater mortality
compared to all other placement months. This confirms greater mortality rate in younger wean-finish pigs during the fall and early winter. Larriestra et al. (2005) reported differing results as pigs placed during quarters 2 and 3 had greater mortality than those placed during quarters 1 and 4. Late finishing mortality is greater consistently each year in September, October and November (Maes et al., 2001). High mortality in wean-finish complexes holds considerable economic concerns as pigs that die represent a significant investment, especially in older more valuable pigs (Holden, 1991; Maes et al., 2001).

Providing good pig care to improve animal well-being relies on the intuition of the observer, which may vary considerably between caretakers (Tscharke and Banhazi, 2016). Mortality losses are less common at present when compared to previous years, due to quick recognition of diseases and the prompt antibiotics application by caretakers (Taylor, 1999). Timely disease detection and treatment with antibiotic use are extremely important tools that are used worldwide to prevent health challenges, decreased growth and reduce mortality (Bush and Biehl, 2002; Rajic et al., 2006; Jensen et al., 2007). Antibiotic use reduces the risk for high mortality in grow-finish operations (Losinger et al., 1998). Injectable antibiotics are used in 62% of the grow-finish farms in Canada (Rajic et al., 2006). Similarly, injectable antibiotics are used in 66% of the grow-finish farms in the United States and 90% of the U.S. farms use injectable antibiotics to treat respiratory diseases (Bush and Biehl, 2002). Sub-clinically infected pigs show no signs of disease until a stressor results in a breakdown and clinical emergence of the disease (Taylor, 1999).

Common management practices utilized in wean-finish production may cause stress on the pig, and the stressor effects are additive with multiple concurrent stressors
having a negative and linear effect on growth performance (Hyun et al., 1998). Double stocking weaned pigs during the start of wean-finish production has the potential to increase the output from a wean-finish facility, but reduces growth performance (Hyun et al., 1998; Wolter et al., 2002; DeDecker et al., 2005). Wolter et al. (2002) found no effect of stocking rate on morbidity and mortality, while DeDecker et al. (2005) reported a linear increase in morbidity and mortality with three different increasing stocking rates.

More frequent pig movement (weighing) caused additional stress and increased the risk of being removed from the pen which results from caretaker’s recognition that individual pigs have reduced health (Wolter et al., 2002). Split-out events, pig regrouping or sorting at marketing, negatively impacts stress, pig immunity and future mortality, as aggressive behavior is common shortly after new pen mates are regrouped. Morrow-Tesch et al. (1994) reported that socially dominant or submissive pigs had alterations in immune functions compared with socially intermediate pigs. The processes of sorting and loading market pigs are stressful for the pig (Johnson et al., 2010) and split-marketing increases the disease introduction risk to the farm (Rostagno et al., 2009). The social and heat stress interaction negatively impacts the pig’s immune system (Morrow-Tesch et al., 1994) and depresses performance (McGlone et al., 1987). Pigs exposed to high cyclical temperatures during social stress have decreased feed intake (Hyun et al., 1998). These stress induced changes in immune function may cause alterations in the animal’s susceptibility to diseases (Kelley, 1980). Therefore, the objective of this study was to evaluate environmental stress and management practice effects on the start of a high mortality events in commercial wean-finish pigs under field conditions.
Materials and Methods

Animals and Facilities

Data utilized in this study were compiled from 26 lots of pigs at 11 different complexes which include two nursery, four conventional feeder-finish and five wean-finish complexes in Illinois and Iowa, on farms operated by The Maschhoffs, LLC (Carlyle, IL, USA) from July 2014 through January 2016. Pigs were weaned at 20-21 days of age and were of mixed sex. Pigs were sired by a PIC 359 terminal sire crossed with Yorkshire/Landrace dams. The number of pigs in each lot varied and depended on the number of rooms at each complex (2-9 rooms). All nursery and grow-finish complexes were managed all-in all-out by complex to reduce health concerns between lots of pigs. For biosecurity reasons and to reduce age variation within each lot of pigs, all rooms at a complex were populated in a short time period, as 23 of the 26 lots were populated within 3-4 days, and the remaining 3 lots were populated within 16 days. In all nursery and wean-finish complexes, pigs were double stocked (0.28 m$^2$/pig) to normal stocking density (0.56 m$^2$/pig) to reduce the need for nursery complexes, which is standard protocol within The Maschhoffs system. Split-out is the process where half of the remaining pigs were divided and moved to another grow-finish complex, and the remaining half stayed at the original complex until they reached market weight. Split-out occurred between 5 and 12-weeks post-weaning in double stocked lots housed in wean-finish complexes. Finishing pigs within a complex were sent to harvest in multiple shipments, usually during a period of 6-8 weeks. Animal housing, feeding, handling and veterinary care were under the supervision of The Maschhoffs’ management personnel. All rooms had fully slatted floors, deep-pit manure handling, mechanically controlled
ventilation, automated feeding and bowl waterers. Pigs were provided *ad libitum* access to a nine-phase corn-soybean diet from weaning to harvest in a wet-dry feeding system.

Health status of the sow farm and pigs at weaning were unknown but all pigs received standard vaccination and medication that followed The Maschhoffs standard protocol. More specifically, pigs were administered vaccinations as follows: *Mycoplasma hyopneumoniae* vaccine (Fostera® Gold PCV MH, Zoetis, Kalamazoo, MI, USA; Circumvent® PCV-M G2, Merck Animal Health, Summit, NJ, USA or Ingelvac MycoFlex®, Boehringer Ingelheim Vetmedica Inc, St. Joseph, MO, USA) at processing (3 to 5 days of age), and at 2-weeks post-weaning, porcine reproductive respiratory syndrome virus modified-live virus vaccine (Ingelvac PRRS® MLV, Boehringer Ingelheim Vetmedica Inc, St. Joseph, MO, USA) at 2-weeks post-weaning, and porcine circovirus type 2 (PCV2) killed vaccine (Fostera Gold PCV® MH, Zoetis, Kalamazoo, MI, USA; Circumvent® PCV-M G2, Merck Animal Health, Summit, NJ, USA or Ingelvac CircoFlex®, Boehringer Ingelheim Vetmedica Inc, St. Joseph, MO, USA) vaccine at 3-weeks post-weaning.

Feed medication protocol followed the Maschhoffs standard protocols and were kept consistent between all lots of pigs. All water and injectable antimicrobial treatments and interventions performed were part of the routine care administered to animals by their caretakers.

Number of pigs dead (mortalities), internal barn temperature, number of pigs treated with injectable antibiotics and current pig inventory were recorded by management personnel during daily observations. Internal maximum high and minimum
low barn temperature (°C) were recorded daily from the ventilation control system within each barn and averaged across all barns at the complex.

**Data Analysis**

Week post-weaning (WPW) was defined as the average week post-weaning for the entire lot of pigs at the complex. Three age groups (AG) were categorized based on WPW and separated into early finishing (EF; WPW 1-7), middle finishing (MF; WPW 8-15) and late finishing (LF; WPW 16-27). Daily mortality rate was defined as the number of daily mortalities divided by the number of pigs placed in the entire lot or inventory after split-out occurred and multiplied by 100. This method for calculating mortality rate was done because inventory decreased within each lot throughout the wean-finish period due to death and shipments that occur when marketing. Timing of euthanasia is a very subjective assessment which depends on the animal caretaker (Morrow et al., 2007). Hence, euthanized pigs were not included in the daily mortality count to remove any statistical bias that could result from the effect of changes in weekly management personnel which could unintentionally signal the start of a high mortality event.

**Quantifying high mortality events**

To detect the start of a high mortality event (SHME), a rolling average daily mortality rate was calculated throughout the wean-finish period. The previous seven-day (day -6 to 0) average daily mortality rate (P7M) was subtracted from the subsequent three-day (day 1 to 3) average daily mortality rate (S3M) to calculate the change in mortality (CM). Consequently, the first day of interest within each lot of pigs was on the 7th day, as the first 7 days were used to determine the average for detecting changes in mortality. Seven-day average daily mortality rate was used to remove the day of the week
mortality rate effect. Subsequent three-day average daily mortality rate was used to detect short-term changes in mortality.

Across all lots of pigs, z-scores were computed from raw CM within each WPW, since change in mortality is not the same within each WPW throughout the wean-finish period. A z-score is the number of standard deviations from the mean and is used to more clearly identify outliers (Rothenberg, 1993). A z-score threshold of $\geq 1.0$ was considered a significant positive deviation from the mean CM within each week post-weaning, and any day with a z-score $\geq 1.0$ was categorized as the start of a high mortality event (SHME). Table 1 includes the upper change in mortality threshold which is equal to a z-score of 1.0 within each WPW.

**Environmental temperature in the barn**

Average low temperature (ALT) and average high temperature (AHT) were calculated as the average low and average high internal barn temperature ($^\circ$C), respectively, across all barns at the complex. Rolling averages were used throughout the wean-finish period to calculate the seven-day (days -6 to 0) average low temperature (7LT), seven-day (day -6 to 0) average high temperature (7HT), prior seven-day (day -7 to -1) average low temperature (P7LT) and prior seven-day (days -7 to -1) average high temperature (P7HT).

To detect temperature changes, ALT and AHT for the current day of interest (day 0) were calculated against P7LT and P7HT, respectively. Change in low temperature (CLT) was defined by subtracting ALT from P7LT. Change in high temperature (CHT) was defined by subtracting AHT from P7HT. Any day with a CHT $\geq 6.1^\circ$C was categorized as a drop in high temperature event (DHTE).
To detect large daily temperature fluctuations within each day, ALT was subtracted from AHT and defined as DIFFTEMP (Difference in daily temperature). The seven-day (days -6 to 0) coefficient of variation for DIFFTEMP (7CVDIFFTEMP) was calculated as the seven-day standard deviation of DIFFTEMP divided by the seven-day mean DIFFTEMP multiplied by 100.

The temperature setpoint is a basic temperature setting within the controller that is adjusted as animals grow and is sometimes called the desired room temperature (Harmon et al., 2012). Table 2 includes the temperature setpoints used in the present study. A low temperature setpoint event (LTSPE) was defined as a day that the average low temperature was ≥2.78°C below the barn temperature setpoint. A high temperature setpoint event (HTSPE) was defined as a day that the average high temperature was ≥7.78°C above the barn temperature setpoint.

McGlone and Pond (2003) reported lower and upper thermoneutral zone temperatures for wean-finish pigs and are included in Table 2. A low thermoneutral zone event (LTZE) was categorized when average low temperature was less than the lower thermoneutral zone temperature. A high thermoneutral zone event (HTZE) was categorized when average high temperature was greater than the upper thermoneutral zone temperature. Other low temperature events were generated when average low temperature or seven-day average low temperature was ≤16.6°C and defined as ALT16 (Average low temperature ≤16.6°C) and 7LT16 (Seven-day low temperature ≤16.6°C), respectively.
Injectable antimicrobial treatments

Daily treatment rate (DTRT) was calculated as the number of daily injectable treatments administered divided by the number of pigs placed in the entire lot or inventory after split-out occurred and multiplied by 100. This was done since inventory decreased within each lot throughout the wean-finish period due to death and shipments that occur when marketing.

Rolling averages were used throughout the wean-finish period to detect changes in daily treatment rate (DTRT). Three-day (days -2 to 0) average treatment rate (3TRT) and prior nine-day (days -11 to -3) average treatment rate (P9TRT) were calculated. Differences in daily treatment rate (DIFFTRT) was calculated by subtracting P9TRT from 3TRT. Percent change was not calculated since P9TRT was equal to zero on some days. Any day with a positive DIFFTRT (DIFFTRT >0), was categorized as PosDIFFTRT (Positive difference in daily treatment rate).

Stocking, split-out, marketing and season

Days when pigs were double stocked to standard stocking density, were categorized as DS (double stocked; 0.28 m² / pig) and once split-out occurred and pigs were stocked to single stocking density, days were categorized as SS (single stocked; 0.56 m² / pig). If split-out occurred within the past 7 days, the following 7 days were categorized as SOP7 (split-out previous 7 days). Marketing period (MARP) was defined as days between when the first pigs were sent to harvest, until the last pigs were removed from the complex. Week of the year was used to categorize season as the following: 1-11, 52 & 53 (winter), 12-25 (spring), 26-38 (summer) and 39-51 (fall).
Statistical Analysis

Mean separation and Tukey-Kramer were used for multiple comparisons using the lsmeans function from the R package lsmeans (Lenth, 2016). Logistic binomial regression analysis using the Wald test in the R package stats (Team, 2014) was used to investigate the odds ratio of the start for the high mortality event. Logistic regression does not require independent variables to be linearly related, nor does it require equal variance within each group, which makes it a less stringent procedure for statistical analysis (Harrell, 2015).

Variables generated were tested in univariate logistic binomial regression analysis with SHME as the dependent variable. Interactions were evaluated using multivariate logistic binomial regression analysis with SHME as the dependent variable. Results are reported as odds ratios (OR) with the associated 95% Wald confidence interval (CI). Probability is the measure of the likelihood that an event will occur and is quantified as a number between 0 and 1. An odds ratio greater than 1 is indicative for an increased chance for the SHME, whereas an odds ratio less than 1 indicates a reduced chance for the SHME and a normal three-day average mortality would be expected to follow.

Results

Mortality

Week post-weaning effect on mortality

Least squares means for daily mortality rate by week post-weaning are reported in Table 1. Across individual days, mean daily mortality rate was 0.05% per day and ranged from 0% to 0.78% per day. Daily mortality rate was higher (P<0.05) in WPW 5-7, (0.1018%, 0.0862% and 0.0867%, respectively) than in WPW 13-24 and 26-27 (Table 1).
Least squares means for change in mortality by week post-weaning are reported in Table 1. Across individual days, mean change in mortality rate was -0.0008% per day and ranged from -0.3618% to 0.4175% per day. Change in mortality was lower (P<0.05) in 7 weeks post-weaning (-0.0158%) than in 2-5 and 8 weeks post-weaning. Table 1 includes the change in mortality upper threshold value which is equal to a ≥1 z-score within each week post-weaning. During data analysis, when a day had a change in mortality greater than the upper threshold, this day was categorized as the start of a high mortality event (SHME).

**Day of week effect on mortality**

Least squares means for daily mortality rate by day of week are reported in Table 3. Daily mortality rate was greater (P<0.05) on Monday compared to Sunday, Thursday, Friday and Saturday. Day of week was a significant (P<0.05) predictor for the SHME in univariate logistic binomial regression analysis. The odds for the SHME were greater on Sunday compared to Tuesday (OR=1.59, 95% CI: 1.02-2.48), Wednesday (OR=1.86, 95% CI: 1.65-2.96), Thursday (OR=1.95, 95% CI: 1.22-3.12), Friday (OR=1.90, 95% CI: 1.19-3.02) and Saturday (OR=1.60, 95% CI: 1.03-2.51). Day of week odds ratios are not reported in tables.

**Environmental Temperature In The Barn**

**Environmental temperature effects on the start of a high mortality event**

Mean ALT was 19.4°C per day and ranged from 7.7 to 27.3°C. Mean AHT was 23.5°C per day and ranged from 15.7 to 35.3°C per day. Continuous variable 7LT (P<0.05) was a significant predictor for the SHME in univariate analysis (Table 4). A 1°C increase in 7LT decreased the odds for the SHME (OR=0.94, 95% CI: 0.90-0.99).
Binary variables DHTE, LTSPE, ALT16 and 7LT16 were significant predictors for the SHME in univariate analysis (Table 4). Days with DHTE had increased odds for the SHME (OR=3.00, 95% CI: 1.08-7.23). Days with LTSPE had increased odds for the SHME (OR=1.84, 95% CI: 1.12-2.91). Days with ALT16 had increased odds for the SHME (OR=1.95, 95% CI: 1.42-2.67). Days with 7LT16 had increased odds for the SHME (OR=1.74, 95% CI: 1.24-2.43). Continuous variables ALT, AHT, 7HT, CLT, CHT and 7CVDIFFTEMP and binary variables HTSPE, LTZE and HTZE were not significant (P>0.05) predictors for the SHME in univariate logistic binomial regression analysis (Table 4).

**Injectable Antimicrobial Treatments**

**Week post-weaning effect on treatment rate**

Least squares means for daily treatment rate (DTRT) by week post-weaning are reported in Table 1. Across individual days, mean DTRT was 1.60% per day and ranged from 0 to 19.80% per day. Daily treatment rate was lower (P<0.05) in 23 and 24 weeks post-weaning compared to 2-19 weeks post-weaning and greater in 2-8 weeks post-weaning compared to 13-15 and 17-27 weeks post-weaning (Table 1).

**Day of week effect on treatment rate**

Least squares means for daily treatment rate by day of week are reported in Table 3. Daily treatment rate was lower (P<0.05) on Sunday and Saturday compared to Monday, Tuesday, Wednesday, Thursday and Friday and greater (P<0.05) on Monday compared to Sunday, Friday and Saturday.
Treatment effect on the start of a high mortality event

Continuous variables DTRT, 3TRT and DIFFTRT were significant predictors for the SHME and odds ratios are reported in Table 4. Odds for the SHME decreased for each additional 1 unit increase in DTRT (OR=0.93, 95% CI: 0.86-0.99), 3TRT (OR=0.88, 95% CI: 0.80-0.95) and DIFFTRT (OR=0.83, 95% CI: 0.75-0.92).

Binary variable PosDIFFTRT was a significant (P<0.001) predictor (Table 4) for the SHME as days with a PosDIFFTRT had lower odds for the SHME (OR=0.62, 95% CI: 0.47-0.82).

Stocking, Split-out, Marketing and Season

Variables Stocking, SOP7, MARP and season were not significant (P>0.05) predictors for the SHME in univariate logistic binomial regression analysis.

Two-Way Interactions

Age group, temperature and treatment variables interactions

Two-way interactions were investigated between age group and all temperature and treatment variables. The two-way age group and 7CVDIFFTEMP interaction was significant (P<0.001) as the odds for the SHME increased linearly when 7CVDIFFTEMP increased in early finishing pigs (odds ratios are not reported in tables). The odds for the SHME did not change when 7CVDIFFTEMP increased in middle and late finishing pigs. All other two-way interactions evaluated between age group, and temperature and treatment variables were not significant (P>0.05).

Stocking rate, temperature and treatment variables interactions

Two-way interactions were investigated between stocking and all temperature and treatment variables. The two-way stocking rate and HTZE interaction was significant as
double stocked pigs with a HTZE had increased odds for the SHME (OR=2.38, 95% CI: 1.16-4.86; data not shown in tables). Two-way stocking and 7CVDIFFTEMP interaction was significant (P<0.05) as the odds for the SHME increased linearly as 7CVDIFFTEMP increased in double stocked pigs. All other two-way interactions evaluated between stocking rate and temperature and treatment variables were not significant (P>0.05).

Season, temperature and treatment variables interactions

Two-way interactions were investigated between season and CLT, CHT, 7CVDIFFTEMP, DHTE, LTSPE, HTSPE, LTZE, HTZE, ALT16, 7LT16, stocking, SOP7 and MARP. Table 5 includes significant two-way interaction odds ratio comparisons. Days in winter with a LTSPE had increased odds (OR=3.65, 95% CI: 1.94-6.86) for the SHME. If a LTSPE occurred in winter and fall, the odds for the SHME are 4.31 (95% CI: 1.18-15.77) times greater in winter than in fall.

Days in winter with an ALT16 had increased odds (OR=4.02, 95% CI: 2.32-6.97) for the SHME. Days in spring with SOP7 (split-out previous 7 days) had increased odds (OR=4.16, 95% CI: 2.07-8.37) for the SHME. Days in spring with SOP7 had increased odds (OR=13.00, 95% CI: 2.78-60.82) compared to days in fall with SOP7. Days in winter with SOP7 had decreased odds (OR=0.19, 95% CI: 0.04-0.96) compared to days in spring with SOP7. Days in summer with SOP7 had increased odds (OR=8.75, 95% CI: 1.08-70.89) compared to days in fall with SOP7. Days in fall during MARP, had lower odds (OR=0.42, 95% CI: 0.23-0.79) for the SHME. Marketing period days in winter (OR=2.88, 95% CI: 1.30-6.38), spring (OR=2.52, 95% CI: 1.21-5.27) and summer (OR=3.63, 95% CI: 1.69-7.79) had increased odds for the SHME compared to MARP days in fall.
**Age group and season interaction**

Two-way age group and season interaction was investigated and odds ratios are reported in Table 6. Early finishing pigs in spring had increased odds (OR=7.94, 95% CI: 1.02-61.14) for the SHME compared to early finishing pigs in fall. Late finishing pigs in winter had increased odds of SHME compared to LF pigs in spring (OR=2.20, 95% CI: 1.32-3.67) and LF pigs in fall (OR=1.89, 95% CI: 1.17-3.03). Late finishing pigs in summer had increased odds (OR=1.88, 95% CI: 1.19-2.96) for the SHME compared to LF pigs in fall. Late finishing pigs in spring had decreased odds (OR=0.46, 95% CI: 0.27-0.75) for the SHME compared to LF pigs in summer.

**Split-out previous seven days and environmental temperature interactions**

Two-way SOP7 and temperature variables interactions were evaluated. Two-way interactions between ALT, AHT, 7LT, 7HT and HTZE were significant (P<0.001). Days with split-out previous 7 days (SOP7), the odds for the SHME increased linearly as ALT, AHT, 7LT or 7HT independently increased. Odds for the SHME were increased (OR=6.98, 95% CI: 2.46-19.73; data not shown in tables) times higher if a HTZE occurred 7-days following a split-out. No other interactions between SOP7 and temperature variables were significant (P>0.05).

**Marketing, temperature and treatment interactions**

Two-way interactions were investigated between MARP and environmental temperature and treatment, but no two-way interactions were found significant (P>0.05).
Discussion

This study estimated the environmental stress, injectable antimicrobial treatments and management practices effects on the start of high mortality events. Maes et al. (2001) reported that weekly mortality was consistently greater in late finishing when compared to early finishing and pigs had an increased risk for mortality after week 10 of the wean-finish period. The present study found that mortality was higher in WPW 5-7 than in WPW 13-24 and 26-27.

Multiple time periods were evaluated to categorize the start of high mortality events. The previous seven-day average daily mortality rate was used to remove the day of week mortality rate effect, as described previously, when calculating change in mortality. The objective of the present study was to identify days at start of a high mortality event and estimate the odds of the event occurring, not estimate long-term subsequent mortality rate. As a result, subsequent three-day average mortality rate was used to detect short-term changes in mortality. The effect of day of the week on daily mortality rate and odds of the start of high mortality event found in the present study could be associated with the differences presented in day of the week daily treatment rate. Daily treatment rate was lower on weekends (Sunday and Saturday), so pigs that should be treated over the weekend may not be receiving proper treatment and consequentially are dying on Monday. Daily mortality rate was found to be higher on Monday than Sunday, Thursday, Friday and Saturday. Since this study used subsequent three-day average mortality rate to detect the SHME, the highest odds for the SHME is on Sunday, due to high daily mortality rate on Monday. The increase in mortality on Monday could
be explained by pigs dying on Saturday and Sunday but not actually being recorded until Monday. Vaillancourt et al. (1994) found similar results in a retrospective perinatal mortality analysis from 48 herds in the United States and Canada. It was reported that the highest mortality percentage was recorded on Monday. The risk of mortality on Monday for day-0 mortality was significantly higher than the other 6 days of the week and was lowest on Wednesday. In the current study, no changes in management were recorded but Vaillancourt et al. (1994) reported that the person in charge during the weekend was different from the week (8.3%) or personnel rotated weekend schedules (47.9%) in breeding herds. This could explain the decreased daily treatment rate found in the present study. In breeding herds, Rainho et al. (2010) found that frequency for sow abortions were greater for matings that occurred during the weekend. An increased frequency of abortions is associated with poor breeding by the employees. Reduced employee performance on weekends and reduced performance during the week, following the times when employees worked weekends, has been well documented in other industries (Sonnentag, 2003). Nonetheless, livestock need proper care and treatment every day, regardless of day of the week.

The present study evaluated environmental effects and found that low temperature (7LT, ALT16, 7LT16), low temperature events (LTSPE, HTZE) and variation in temperature (DHE, 7CVDIFFTEMP) are associated with the start for the high mortality event through univariate logistic regression analysis. When the temperature variables, age of pig, stocking or season interactions were evaluated, several were found to increase the odds for the start for the high mortality event. Similar to the present findings, it has been found that low temperature negatively impacts growing pigs performance (Nienaber et
al., 1987; Hyun et al., 1998). During manure pumping from the complexes in early spring or late fall, increased ventilation is required due to significant gaseous emissions. When additional ventilation is required and external barn temperature is low, this leads to decreased internal barn temperature and compromises the thermal environment of the pig. Manure pumping during cold months or barn heater failure, would be similar to a LTSPE as categorized in the present study, so caretakers should be aware of an increased odds for the start of a high mortality event. In the present study, no data were recorded on manure pumping or barn heater failure days. Future studies could evaluate the effects for each event on subsequent mortality.

Morrison and Mount (1971), Nienaber et al. (1989) and Bond et al. (1963) evaluated increased temperature variation effects on pig performance and the results are similar to those found in the present study as increased temperature variation negatively impacted mortality, especially early finishing pigs. All pigs in the present study were housed in automatic mechanically ventilated facilities, but previous research has shown the importance for continuously achieving the ideal thermal environment for the pigs. Grow-finish pigs housed in manually controlled ventilation barns present a higher mortality rate compared to automatic ventilation systems (Agostini et al., 2014). Differing results were reported by Maes et al. (2004) who investigated risk factors for mortality in grow-finish pigs in Belgium and reported that type of ventilation system was not a significant risk factor for mortality, but the temperature variation throughout the year in Belgium is less than in the Midwest. In the present study, it was found that increased temperature variation in the past 7 days (7CVDIFFTEMP) in early finishing pigs linearly increased the odds for the SHME. This is similar to other livestock species
as Martin et al. (1975) reported dairy calves born during high temperatures in the summer, low temperatures in the winter or periods of large temperature fluctuations were associated with an increased risk of death.

The present study found no stocking density effect on the SHME, which is similar to Wolter et al. (2002). DeDecker et al. (2005) reported differing results as morbidity and mortality linearly increased with three different increasing stocking rates. Several studies reported the interaction of social and environmental stress negatively impacts the immune system (Morrow-Tesch et al., 1994), depresses performance (McGlone et al., 1987) and decreases feed intake (Hyun et al., 1998). This is similar to the present study that found double stocked pigs with a HTZE or increased 7CVDIFFTEMP, increased the odds for the SHME.

Morrow-Tesch et al. (1994) reported that regrouping of pigs negatively impacts the stress, pig immunity and future mortality as aggressive behavior is common shortly after regrouping of new pen mates and socially dominant or submissive pigs had alterations in immune functions compared with socially intermediate pigs. In this study, SOP7 was not significant in univariate logistic regression analysis but the interaction of SOP7 with ALT, AHT, L7T, LHT and HTZE was significant. As temperature increased or if a HTZE occurred seven days following a split-out, the odds for the SHME increased. This is similar to the findings from Hyun et al. (1998) who stated the stressors effects are additive with multiple concurrent stressors having a negative and linear effect on growth performance. During a study by Wolter et al. (2002), frequent pig movement (weighing) caused additional stress and was found to increase the percentage of pigs
removed during the study. This present study found that split-out events cause additional stress for the pigs that stay at the facility due to social disruption within pen mates.

Although 7CVDIFFTEMP was found to be the only temperature variable with a significant interaction with AG, interaction effects between season and age group were found to be significant in this present study. Previous studies have reported that pigs placed in October through December (Maes et al., 2001; Maes et al., 2004; Oliveira et al., 2009), January through April (Oliveira et al., 2009) or during quarters 2 and 3 (Larriestra et al., 2005) have greater mortality compared to all other months of placement. These studies defined mortality as the percent mortality from the entire group of pigs while the present study evaluated the effects to predict the probability for the start for the high mortality event and found increased odds of early finishing pigs in spring compared to fall. The present study found that late finishing pigs have increased odds for the SHME in summer compared to fall and spring, and winter compared to spring and fall. Maes et al (2001) reported differing results as late finishing mortality is consistently greater each year in September, October and November. Dallaire et al. (1996) reported that high sow mortality was associated with a 7-day period of high ambient temperatures. Dallaire et al. (1996) stated they believed a large proportion of sows died resulting from cardiovascular failure associated with heat stress. As previously stated, no high temperature variables were found as a significant interaction with age of pigs. However, future research could show similar results of periods of high temperature in late finishing pigs.

In the present study, the marketing period was defined as the days after the first pigs were sent to harvest, and the two-way interaction with season was found significant. Rostagno et al. (2009) found similar results as split-marketing groups have greater
mortality risk compared to close-out groups that sent all market hogs to harvest at once. Rostagno et al. (2009) stated this can be caused from the reactivation of latent infections and subsequent increased transmission, due to stress caused by the social disruption from removing the heaviest pigs from the pens and the mechanical disease transmission by the personnel and equipment entering the barns during the marketing period. Pigs that are not selected in the first group sent to harvest could be affected by a subclinical disease, restricting them from attaining their full performance or be affected by the season and increase the probability of them dying. The data analyzed in this study were collected from July 2014 through January 2016. Future research is needed to include several years of seasonal data. Regardless of season, this study further emphasizes the importance of maintaining the pig’s thermal environment to reduce mortality.

It is well documented that antibiotics are used in wean-finish pigs to treat diseases to prevent decreased health, decreased growth and economic losses (Jensen et al., 2007). During the initial data analysis process in the present study, it was anticipated that increased treatments would increase the odds for the start of a high mortality event. However, the opposite was found as increased daily treatment rate, increased three-day average treatment rate, increased difference in treatment rate or a positive difference in treatment rate all decrease the odds for the start of a high mortality event. Timely detection and treatment of diseases through the use of antibiotics to reduce mortality and morbidity, is an extremely important tool in efficient pork production (Cromwell, 2002). Multiple studies have shown that using antibiotics in wean-finish pigs reduces the risk of high mortality (Losinger et al., 1998, 1999; Bush and Biehl, 2002; Rajic et al., 2006).
Sub-clinically infected pigs show no signs of disease until a stressor results in a breakdown and clinical emergence of the disease (Taylor, 1999).

Future studies should evaluate environmental temperature, additional management practices, different treatment interventions and social stressors in other production systems housed in varying facilities to predict upcoming mortality challenges. Other methods and variables need to be developed to objectively measure the behavior, well-being and health of the pigs. This study estimated the effects of several stressors on mortality in commercial wean-finish pigs and found that environmental stressors, combined with social stress increased the odds for the start of a high mortality event. Continuously controlling the environment, proper management, timely treatment of the pigs and reducing social stress will reduce mortality in wean-finish pigs.

References


Table 1. Mean inventory across all lots of pigs, least squares means (±SE) for daily mortality rate and change in mortality, change in mortality upper threshold and daily treatment rate by week post-weaning from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Week post-weaning</th>
<th>Mean Inventory</th>
<th>Mean Daily Mortality Rate</th>
<th>Mean Change in Mortality&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Change in Mortality Upper Threshold&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Mean Daily Treatment Rate</th>
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<td>12724</td>
<td>0.04±0.01%&lt;sup&gt;abcdef&lt;/sup&gt;</td>
<td>0.022±0.008%&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.103%</td>
<td>3.68±0.49%&lt;sup&gt;ij&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>12482</td>
<td>0.07±0.01%&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>0.020±0.005%&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.110%</td>
<td>2.83±0.32%&lt;sup&gt;hij&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>12189</td>
<td>0.07±0.01%&lt;sup&gt;cdef&lt;/sup&gt;</td>
<td>0.011±0.005%&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.074%</td>
<td>3.13±0.31%&lt;sup&gt;ij&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>11766</td>
<td>0.10±0.01%&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.008±0.005%&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.097%</td>
<td>2.65±0.31%&lt;sup&gt;ghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>10557</td>
<td>0.08±0.01%&lt;sup&gt;fg&lt;/sup&gt;</td>
<td>-0.004±0.005%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.064%</td>
<td>2.71±0.31%&lt;sup&gt;ghij&lt;/sup&gt;</td>
</tr>
<tr>
<td>7</td>
<td>9879</td>
<td>0.08±0.01%&lt;sup&gt;fg&lt;/sup&gt;</td>
<td>-0.016±0.004%&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.050%</td>
<td>3.03±0.30%&lt;sup&gt;ij&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>8688</td>
<td>0.07±0.01%&lt;sup&gt;defg&lt;/sup&gt;</td>
<td>0.015±0.004%&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>0.093%</td>
<td>2.74±0.30%&lt;sup&gt;hij&lt;/sup&gt;</td>
</tr>
<tr>
<td>9</td>
<td>9273</td>
<td>0.08±0.01%&lt;sup&gt;fg&lt;/sup&gt;</td>
<td>-0.010±0.005%&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.049%</td>
<td>2.18±0.30%&lt;sup&gt;ghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>9275</td>
<td>0.06±0.01%&lt;sup&gt;abcdef&lt;/sup&gt;</td>
<td>-0.009±0.005%&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.036%</td>
<td>1.78±0.30%&lt;sup&gt;defgh&lt;/sup&gt;</td>
</tr>
<tr>
<td>11</td>
<td>8858</td>
<td>0.06±0.01%&lt;sup&gt;abcdef&lt;/sup&gt;</td>
<td>-0.005±0.004%&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>0.033%</td>
<td>1.92±0.29%&lt;sup&gt;efgh&lt;/sup&gt;</td>
</tr>
<tr>
<td>12</td>
<td>7734</td>
<td>0.06±0.01%&lt;sup&gt;abcdef&lt;/sup&gt;</td>
<td>-0.004±0.004%&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>0.020%</td>
<td>2.06±0.29%&lt;sup&gt;ghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>13</td>
<td>7369</td>
<td>0.05±0.01%&lt;sup&gt;abcde&lt;/sup&gt;</td>
<td>-0.007±0.004%&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.018%</td>
<td>1.61±0.29%&lt;sup&gt;def&lt;/sup&gt;</td>
</tr>
<tr>
<td>14</td>
<td>7112</td>
<td>0.05±0.01%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>-0.004±0.004%&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>0.020%</td>
<td>1.81±0.28%&lt;sup&gt;def&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>7031</td>
<td>0.04±0.01%&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>-0.002±0.004%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.019%</td>
<td>1.68±0.28%&lt;sup&gt;def&lt;/sup&gt;</td>
</tr>
<tr>
<td>16</td>
<td>7076</td>
<td>0.04±0.01%&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.001±0.004%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.022%</td>
<td>1.88±0.28%&lt;sup&gt;efgh&lt;/sup&gt;</td>
</tr>
<tr>
<td>17</td>
<td>6998</td>
<td>0.04±0.01%&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>-0.001±0.004%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.016%</td>
<td>1.42±0.28%&lt;sup&gt;bcdef&lt;/sup&gt;</td>
</tr>
<tr>
<td>18</td>
<td>6921</td>
<td>0.04±0.01%&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.001±0.004%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.020%</td>
<td>1.49±0.28%&lt;sup&gt;bcdef&lt;/sup&gt;</td>
</tr>
<tr>
<td>19</td>
<td>6820</td>
<td>0.05±0.01%&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>0.001±0.004%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.022%</td>
<td>1.50±0.28%&lt;sup&gt;bcdef&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>6708</td>
<td>0.05±0.01%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.003±0.004%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.029%</td>
<td>1.14±0.28%&lt;sup&gt;abde&lt;/sup&gt;</td>
</tr>
<tr>
<td>21</td>
<td>6445</td>
<td>0.04±0.01%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.001±0.004%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.025%</td>
<td>1.15±0.28%&lt;sup&gt;abde&lt;/sup&gt;</td>
</tr>
<tr>
<td>22</td>
<td>6285</td>
<td>0.05±0.01%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>-0.003±0.003%&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>0.022%</td>
<td>0.87±0.28%&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>23</td>
<td>5532</td>
<td>0.05±0.01%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>-0.001±0.003%&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>0.024%</td>
<td>0.61±0.28%&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>24</td>
<td>4565</td>
<td>0.04±0.01%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>-0.004±0.004%&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>0.029%</td>
<td>0.41±0.29%&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>25</td>
<td>3695</td>
<td>0.06±0.01%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>-0.012±0.005%&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.029%</td>
<td>0.49±0.32%&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>26</td>
<td>3049</td>
<td>0.04±0.01%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>-0.004±0.007%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.015%</td>
<td>0.71±0.36%&lt;sup&gt;abcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>27</td>
<td>2343</td>
<td>0.03±0.01%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>-0.009±0.009%&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>0.005%</td>
<td>0.69±0.43%&lt;sup&gt;abcd&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup>Change in mortality was calculated as the previous seven-day average mortality rate subtracted from the subsequent three-day average mortality rate.

<sup>2</sup>Change in mortality upper threshold is equal to a z-score of ≥1.0 within each week post-weaning.

<sup>a</sup>Least squares means with different superscripts within a column are different (P<0.05).
Table 2. Internal barn temperature setpoint, lower thermoneutral zone temperature and upper thermoneutral zone temperature by day post weaning from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Day post-weaning</th>
<th>Temperature setpoint (°C)(^1)</th>
<th>Lower thermoneutral zone temperature (°C)(^2)</th>
<th>Upper thermoneutral zone temperature (°C)(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.2</td>
<td>26.0</td>
<td>32.2</td>
</tr>
<tr>
<td>6</td>
<td>27.2</td>
<td>23.1</td>
<td>30.7</td>
</tr>
<tr>
<td>10</td>
<td>26.1</td>
<td>22.3</td>
<td>29.5</td>
</tr>
<tr>
<td>14</td>
<td>25.0</td>
<td>21.4</td>
<td>28.3</td>
</tr>
<tr>
<td>22</td>
<td>22.8</td>
<td>19.8</td>
<td>26.1</td>
</tr>
<tr>
<td>28</td>
<td>22.8</td>
<td>18.6</td>
<td>25.9</td>
</tr>
<tr>
<td>35</td>
<td>21.9</td>
<td>17.2</td>
<td>25.7</td>
</tr>
<tr>
<td>42</td>
<td>20.0</td>
<td>15.2</td>
<td>25.0</td>
</tr>
<tr>
<td>100</td>
<td>18.3</td>
<td>10.0</td>
<td>25.0</td>
</tr>
<tr>
<td>180</td>
<td>18.3</td>
<td>10.0</td>
<td>25.0</td>
</tr>
</tbody>
</table>

\(^1\) Internal barn temperature (°C) setpoint used in the ventilation controller to maintain the desired room temperature.

Table 3. Least squares means (±SE) for daily mortality rate and daily treatment rate by day of week from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Day of Week</th>
<th>Mean Daily Mortality Rate</th>
<th>Mean Daily Treatment Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday</td>
<td>0.0511±0.0075%</td>
<td>1.27±0.25%</td>
</tr>
<tr>
<td>Monday</td>
<td>0.0679±0.0075%</td>
<td>2.21±0.25%</td>
</tr>
<tr>
<td>Tuesday</td>
<td>0.0578±0.0075%</td>
<td>2.08±0.25%</td>
</tr>
<tr>
<td>Wednesday</td>
<td>0.0578±0.0075%</td>
<td>1.98±0.25%</td>
</tr>
<tr>
<td>Thursday</td>
<td>0.0528±0.0075%</td>
<td>1.95±0.25%</td>
</tr>
<tr>
<td>Friday</td>
<td>0.0508±0.0075%</td>
<td>1.82±0.25%</td>
</tr>
<tr>
<td>Saturday</td>
<td>0.0476±0.0075%</td>
<td>1.13±0.25%</td>
</tr>
<tr>
<td>Mean</td>
<td>0.0500%</td>
<td>1.60%</td>
</tr>
</tbody>
</table>

*abc* Least squares means with different superscripts within a column are different (P<0.05).
Table 4. Odds ratios\(^1\) for the start of a high mortality event from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Continuous Variables(^2)</th>
<th>Odds ratio(^3)</th>
<th>Confidence interval odds ratio (95%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALT</td>
<td>0.95</td>
<td>0.91-1.00</td>
<td>0.052</td>
</tr>
<tr>
<td>AHT</td>
<td>0.98</td>
<td>0.95-1.01</td>
<td>0.268</td>
</tr>
<tr>
<td>7LT</td>
<td>0.94</td>
<td>0.90-0.99</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>7HT</td>
<td>0.98</td>
<td>0.95-1.02</td>
<td>0.290</td>
</tr>
<tr>
<td>CLT</td>
<td>0.97</td>
<td>0.88-1.07</td>
<td>0.603</td>
</tr>
<tr>
<td>CHT</td>
<td>1.02</td>
<td>0.96-1.08</td>
<td>0.556</td>
</tr>
<tr>
<td>7CVDIFFTEMP</td>
<td>1.00</td>
<td>0.99-1.01</td>
<td>0.984</td>
</tr>
<tr>
<td>DTRT</td>
<td>0.93</td>
<td>0.86-0.99</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>3TRT</td>
<td>0.88</td>
<td>0.80-0.95</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>DIFFTRT</td>
<td>0.83</td>
<td>0.75-0.92</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Binary Variables(^4)</th>
<th>Odds ratio(^5)</th>
<th>Confidence interval odds ratio (95%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHTE</td>
<td>3.00</td>
<td>1.08-7.23</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>LTSPE</td>
<td>1.84</td>
<td>1.12-2.91</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>HTSPE</td>
<td>1.04</td>
<td>0.77-1.41</td>
<td>0.786</td>
</tr>
<tr>
<td>LTZE</td>
<td>1.21</td>
<td>0.29-3.53</td>
<td>0.763</td>
</tr>
<tr>
<td>HTZE</td>
<td>1.02</td>
<td>0.78-1.34</td>
<td>0.872</td>
</tr>
<tr>
<td>ALT16</td>
<td>1.95</td>
<td>1.42-2.67</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>7LT16</td>
<td>1.74</td>
<td>1.24-2.43</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PosDIFFTRT</td>
<td>0.62</td>
<td>0.47-0.82</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

\(^1\)An odds ratio greater than 1 is indicative of an increased chance of the start of a high mortality event, whereas an odds ratio less than 1 indicates a reduced chance.

\(^2\)Continuous Variables: ALT: Average low temperature; AHT: Average high temperature; 7LT: Seven-day average low temperature; 7HT: Seven-day average high temperature; CLT: Change in low temperature; CHT: Change in high temperature; 7CVDIFFTEMP: Seven-day coefficient of variation difference in daily temperature; DTRT: Daily treatment rate; 3TRT: Three-day average treatment rate; DIFFTRT: Difference in daily treatment rate.

\(^3\)Odds ratios for continuous variables are reported as the effect of a one unit increase on the probability of the start of a high mortality event.

\(^4\)Binary Variables: DHTE: Drop in high temperature event; LTSPE: Low temperature setpoint event; HTSPE: High temperature setpoint event; LTZE: Low thermoneutral zone event; HTZE: High thermoneutral zone event; ALT16: Average low temperature ≤16.6°C; 7LT16: Seven-day low temperature ≤16.6°C; PosDIFFTRT: Positive difference in daily treatment rate.

\(^5\)Odds ratios for binary variables are reported as the effect of the event occurring on the probability of the start of a high mortality event.
Table 5. Odds ratios\(^1\) for two-way interactions of temperature variables\(^2\) and management factors\(^3\) with season\(^3\) for the start of a high mortality event in a study of commercial wean-finish pigs.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTSPE(^2)</td>
<td>Winter: 3.65 (1.94-6.86)</td>
<td>Spring: 5.10 (0.63-41.55)</td>
<td>Summer: 2.38 (0.27-20.77)</td>
<td>Fall: 4.31 (1.18-15.77)</td>
</tr>
<tr>
<td></td>
<td>Winter: 0.62 (0.08-4.80)</td>
<td>Spring: 0.47 (0.03-8.60)</td>
<td>Summer: 1.14 (0.14-9.39)</td>
<td></td>
</tr>
<tr>
<td>ALT16(^2)</td>
<td>Winter: 4.02 (2.32-6.97)</td>
<td>Spring: 2.12 (0.84-5.36)</td>
<td>Summer: 1.33 (0.15-11.72)</td>
<td>Fall: 1.81 (0.96-3.40)</td>
</tr>
<tr>
<td></td>
<td>Winter: 1.19 (0.49-2.93)</td>
<td>Spring: 0.63 (0.06-6.29)</td>
<td>Summer: 1.60 (0.18-13.89)</td>
<td></td>
</tr>
<tr>
<td>SOP7(^2)</td>
<td>Winter: 0.62 (0.14-2.67)</td>
<td>Spring: 4.16 (2.07-8.37)</td>
<td>Summer: 1.49 (0.28-7.93)</td>
<td>Fall: 2.59 (0.35-19.34)</td>
</tr>
<tr>
<td></td>
<td>Winter: 0.19 (0.04-0.96)</td>
<td>Spring: 1.49 (0.28-7.93)</td>
<td>Summer: 2.02 (0.42-9.69)</td>
<td></td>
</tr>
<tr>
<td>MARP(^2)</td>
<td>Winter: 1.48 (0.78-2.82)</td>
<td>Spring: 1.14 (0.54-2.40)</td>
<td>Summer: 0.80 (0.37-1.71)</td>
<td>Fall: 2.88 (1.30-6.38)</td>
</tr>
<tr>
<td></td>
<td>Winter: 1.47 (0.83-2.60)</td>
<td>Spring: 0.69 (0.34-1.41)</td>
<td>Summer: 1.80 (1.00-3.24)</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) An odds ratio (95% confidence interval odds ratio) greater than 1 is indicative of an increased chance of the start of a high mortality event, whereas an odds ratio less than 1 indicates a reduced chance.
2LTSPE (Average low temperature ≥2.78°C below the barn temperature setpoint), ALT16 (Average low temperature ≤16.6°C), SOP7 (Split-out previous 7 days) and MARP (Marketing period; days between when the first pigs were sent to harvest, until the last pigs at the complex were sent to harvest).

3Week of the year was used to categorize season as the following: winter; 1-11, 52 & 53, spring; week 12-25, summer; 26-38 and fall; 39-51.

4Odds ratios on diagonal indicate the odds during the season if the event occurred or did not occur (True vs. False). Odds ratios below diagonal are comparisons between the season on the horizontal axis compared to the season on the vertical axis, with the event occurring during both months (True vs. True).
Table 6. Two-way interaction odds ratios\(^1\) of age group\(^2\) and season\(^3\) for the start of a high mortality event in a study of commercial wean-finish pigs.

<table>
<thead>
<tr>
<th>Age Group(^2)</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Finishing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>0.50 (0.19-1.30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>0.67 (0.24-1.88)</td>
<td>1.35 (0.55-3.30)</td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>3.98 (0.48-33.08)</td>
<td>7.94 (1.02-62.14)</td>
<td>5.88 (0.72-47.51)</td>
</tr>
<tr>
<td>Middle Finishing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>0.53 (0.26-1.09)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>0.94 (0.46-1.92)</td>
<td>1.76 (0.91-3.37)</td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>0.52 (0.26-1.02)</td>
<td>0.97 (0.52-1.78)</td>
<td>0.55 (0.30-1.02)</td>
</tr>
<tr>
<td>Late Finishing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>2.20 (1.32-3.67)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>1.00 (0.63-1.61)</td>
<td>0.46 (0.27-0.75)</td>
<td>1.88 (1.19-2.96)</td>
</tr>
<tr>
<td>Fall</td>
<td>1.89 (1.17-3.03)</td>
<td>0.86 (0.52-1.41)</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)An odds ratio (95% confidence interval odds ratio) greater than 1 is indicative of an increased chance of the start of a high mortality event, whereas an odds ratio less than 1 indicates a reduced chance.

\(^2\)Three age groups categorized based on week post-weaning (WPW); Early Finishing (WPW 1-7), Middle Finishing (WPW 8-15) and Late Finishing (WPW 16-27).

\(^3\)Week of the year was used to categorize season as the following: winter; 1-11, 52 & 53; spring; week 12-25, summer; 26-38 and fall; 39-51.

\(^4\)Within each age group, odds ratios are between the season on the horizontal axis compared to the season on the vertical axis.
CHAPTER 5. MULTIVARIATE PREDICTION MODEL FOR THE START OF HIGH MORTALITY EVENTS IN COMMERCIAL WEAN-FINISH PIGS

Abstract

The objective of this study was to evaluate percent change in water disappearance (PCWD), environmental stressors, management practices, disease status for eleven pathogens and interaction effects on the start of a high mortality event (SHME). Data utilized in this study were compiled from 26 lots of pigs in Illinois and Iowa, on farms operated by The Maschhoffs, LLC (Carlyle, IL, USA) from July 2014 through January 2016. Change in mortality (CM) was calculated as the previous seven-day average mortality rate subtracted from the subsequent three-day average mortality rate, and SHME was defined as one standard deviation above the mean CM within each week post-weaning. Variables and interactions were evaluated to identify significant predictors for the SHME and included in a multivariate logistic regression model. Polymerase chain reaction assays were used to test for eleven pathogens throughout the wean-finish period. 

*Lawsonia intracellularis* or porcine reproductive respiratory syndrome virus increased the probability for the SHME. Increased PCWD when rotavirus was positive, increased probability for the SHME. Decreased PCWD when influenza A virus (IAV) was positive, increased the probability for the SHME. Environmental temperatures below the desired barn temperature when IAV was positive, increased the probability for the SHME. Increased daily antimicrobial treatments decreased the probability of SHME for the SHME. Environmental temperatures above the thermoneutral zone in double stocked pigs increased the probability for the SHME. Early finishing pigs with increased seven-day temperature variation had increased probability for the SHME. *Mycoplasma*
*hyopneumoniae* in early finishing pigs or porcine epidemic diarrhea virus in early or late finishing pigs increased the probability for the SHME. The presence of porcine circovirus type 2 and *Escherichia coli* increased the probability across all pigs ages for the SHME. Middle finishing pigs had increased probability for the SHME in fall compared to summer. Late finishing pigs had increased probability for the SHME in summer and winter compared to spring. The complex, additive and synergistic interactions between behavior, environment, management and pathogens play a critical role predicting high mortality events in wean-finish pigs. Continuously monitoring water disappearance, controlling the environment, proper management to reduce stress, timely treatment of pigs and frequent diagnostic tests are all essential methods to predict and ultimately, reduce upcoming high mortality events.

**Introduction**

Poor health negatively impacts performance parameters from pigs in wean-finish units, reducing feed efficiency and daily weight gain and increasing mortality (Dijkhuizen, 1989). Early detection of pig health and welfare compromises in wean-finish facilities is important to improve treatment success, reduce impact of diseases, and promote sustainable pig production (Matthews et al., 2016). Methods to detect changes in behavior and health of pigs will improve timely intervention and treatment of diseases (Seddon, 2011). Due to larger herds and more animals managed per person, there is less time available to observe individual animals, so it is important to determine the risk level or pig health status to provide guidance for caretakers as to where to concentrate management efforts (Madsen and Kristensen, 2005).
Changes in eating and drinking patterns are usually the first visual signs that pigs are experiencing environmental stress or health challenges (Bigelow and Houpt, 1988; Madsen and Kristensen, 2005). Continuously measuring water intake is an easier, more cost effective and more readily available method for producers, when compared to recording feed intake (Bird and Crabtree, 2000; Brumm, 2006). Water intake should consistently increase as pigs get older and body weight increases, but different stages of diseases change pigs behavior as pigs spend less time drinking and eating during the onset and recovery from diseases (Brooks et al., 1984; Krsnik et al., 1999; Schiavon and Emmans, 2000; Sutherland et al., 2007; Crabtree et al., 2008; Reiner et al., 2009). Real-time automated monitoring of water disappearance in groups of pigs provides an objective observational measure that caretakers can utilize when evaluating pig health to detect issues before they arise (Smith et al., 2009). Crabtree et al. (2008) and Madsen and Kristensen (2005) detected a change in water disappearance pattern before disease symptoms became visually apparent to caretakers. There are an increasing number of caretakers who record daily water intake in groups of pigs (Seddon, 2011), but there is very little published scientific literature which explains the relationship of water consumption as a predictor of upcoming pig health challenge or high mortality event.

Environmental stressors can adversely impact swine performance, health and well-being. Proactive environmental management should be provided to reduce or eliminate adverse effects on wean-finish swine production (Hahn, 1995). Environmental stressors impact the performance of growing pigs (Nienaber et al., 1987; Hyun et al., 1998), increase stress (Bond et al., 1963), challenge the pig’s homeothermic abilities and homeostasis (Bond et al., 1963; Morrison and Mount, 1971; Nienaber et al., 1989),
increase mortality (Dallaire et al., 1996) and annually cause high economic losses (St-Pierre et al., 2003). It has been well reported seasonal effects influence the risk of mortality in both early and late finishing pigs (Holden, 1991; Maes et al., 2001; Maes et al., 2004; Larriestra et al., 2005; Oliveira et al., 2009). Timely disease detection and treatment with antibiotic use are extremely important tools that are used worldwide to prevent health challenges, decreased growth and reduce mortality (Bush and Biehl, 2002; Rajic et al., 2006; Jensen et al., 2007).

In modern production systems, pigs are subjected to a number of socially stressful situations throughout their life. Mixing pigs disrupts the social group and leads to aggressive interactions between unfamiliar pigs trying to reestablish a social hierarchy, which alters the pig’s immune function (Morrow-Tesch et al., 1994; Puppe, 1998). High stocking densities during early finishing reduce growth performance (Hyun et al., 1998; Wolter et al., 2002; DeDecker et al., 2005) and has been reported to increase morbidity and mortality (DeDecker et al., 2005). The marketing period is stressful for the pig which is caused by the process of sorting and loading market pigs (Johnson et al., 2010) and the social disruption from removing the heaviest pigs from the pens (Rostagno et al., 2009). The effects of stressors are additive with multiple concurrent stressors having a negative linear impact on the pig’s immune system which causes alterations in the pig’s susceptibility to disease (Kelley, 1980; Morrow-Tesch et al., 1994). Sub-clinically infected pigs show no signs of disease until a stressor occurs which results in a breakdown and clinical emergence of the disease (Taylor, 1999).

The presence of viral or bacterial pathogens has been widely shown to be responsible for economic losses due to mortality, morbidity, decreased performance and
additional medication and vaccination costs. Porcine reproductive respiratory syndrome virus is one of the most economically important diseases affecting pigs due to increased mortality and reduced performance by growing pigs (Neumann et al., 2005; Corzo et al., 2010; Holtkamp et al., 2013). Porcine circovirus type 2 is one of the most important viral pathogens in the U.S. and worldwide, and is linked with a range of diseases that accelerate and enhance respiratory, enteric or reproductive problems in pigs (Opriessnig et al., 2007). Swine influenza virus is a highly contagious viral infection in growing pigs that causes respiratory issues and clinical signs exacerbate when combined with a secondary bacterial infection (VanReeth et al., 1996; Kothalawala et al., 2006).

*Mycoplasma hyopneumoniae* is the primary infectious pathogen causing enzootic pneumonia and is the most common pathogen affecting grow-finish units worldwide, resulting in increased pneumonic coughing and increased pulmonary lesions (Escobar et al., 2002; Llopart et al., 2002; Thacker, 2004; Maes et al., 2008). *Escherichia coli* is a major cause for post-weaning diarrhea in pigs and is responsible for high economic losses (Losinger et al., 1998; Fairbrother et al., 2005). Porcine epidemic diarrhea virus (PEDV) was first found in the U.S. in May 2013 and causes diarrhea, vomiting, dehydration and high mortality in young pigs (Stevenson et al., 2013; Song et al., 2015). Rotavirus and *Lawsonia intracellularis* are widely distributed diseases that are frequently found in young pigs and cause substantial economic loss (Moller et al., 1998; Winiarczyk et al., 2002). *Actinobacillus suis* is associated with sporadic cases of septicemia in very young animals and causes a variety of conditions that result in production losses (MacInnes and Desrosiers, 1999). *Streptococcus suis* has been found as the cause of a wide range of clinical disease syndromes in swine worldwide (Staats et al., 1997). *Salmonella sp.*
presence results in a loss of production and typically has a synergistic relationship with other pathogens making their combined effect more potent (Seddon, 2011).

Typically, in U.S. swine herds there is a secondary infection with viral or bacterial pathogens that occur concurrently (Zimmerman et al., 1997). The presence of two pathogens has been shown to enhance pathological effects, behavior and clinical effects from infected pigs (VanReeth et al., 1996; Thacker et al., 1999; Thacker et al., 2001). Extreme environmental conditions have previously been shown to reactivate a latent swine influenza virus (Shope, 1955) while a sudden decrease in ambient temperature can induce an enteric disease in young pigs (Shimizu et al., 1978). Diagnostic tests are an essential component when monitoring pig health to identify and quantify disease challenged pigs (Seddon, 2011).

The objectives of this study were to determine the effects of changes in water disappearance, environmental stress, management practices, presence of pathogens and interactions on the start of high mortality events in wean-finish pigs.

**Materials and Methods**

**Animals and Facilities**

Data utilized in this study were compiled from 26 lots of pigs at 11 different complexes which include two nursery, four conventional feeder-finish and five wean-finish complexes in Illinois and Iowa, on farms operated by The Maschhoffs, LLC (Carlyle, IL, USA) from July 2014 through January 2016. Pigs were weaned at 20-21 days of age and were of mixed sex. Pigs were sired by a PIC 359 terminal sire crossed with Yorkshire/Landrace dams. The number of pigs in each lot varied and depended on the number of rooms at each complex (2-9 rooms). All nursery and grow-finish
complexes were managed all-in all-out by complex to reduce health concerns between lots of pigs. For biosecurity reasons and to reduce age variation within each lot of pigs, all rooms at a complex were populated in a short time period, as 23 of the 26 lots were populated within 3-4 days, and the remaining 3 lots were populated within 16 days. In all nursery and wean-finish complexes, pigs were double stocked (0.28 m² / pig) to normal stocking density (0.56 m² / pig) to reduce the need for nursery complexes, which is standard protocol within The Maschhoffs system. Split-out is the process where half of the remaining pigs were divided and moved to another grow-finish complex, and the remaining half stayed at the original complex until they reached market weight. Split-out occurred between 5 and 12-weeks post-weaning in double stocked lots housed in wean-finish complexes. Finishing pigs within a complex were sent to harvest in multiple shipments, usually during a period of 6-8 weeks. Animal housing, feeding, handling and veterinary care were under the supervision of The Maschhoffs’ management personnel. All rooms had fully slatted floors, deep-pit manure handling, mechanically controlled ventilation, automated feeding and bowl waterers. Pigs were provided ad libitum access to a nine-phase corn-soybean diet from weaning to harvest in a wet-dry feeding system.

Health status of the sow farm and pigs at weaning were unknown but all pigs received standard vaccination and medication that followed The Maschhoffs standard protocol. More specifically, pigs were administered vaccinations as follows: *Mycoplasma hyopneumoniae* vaccine (Fostera® Gold PCV MH, Zoetis, Kalamazoo, MI, USA; Circumvent® PCV-M G2, Merck Animal Health, Summit, NJ, USA or Ingelvac MycoFlex®, Boehringer Ingelheim Vetmedica Inc, St. Joseph, MO, USA) at processing (3 to 5 days of age), and at 2-weeks post-weaning, porcine reproductive respiratory
syndrome virus modified-live virus vaccine (Ingelvac PRRS® MLV, Boehringer Ingelheim Vetmedica Inc, St. Joseph, MO, USA) at 2-weeks post-weaning, and porcine circovirus type 2 (PCV2) killed vaccine (Fostera Gold PCV® MH, Zoetis, Kalamazoo, MI, USA; Circumvent® PCV-M G2, Merck Animal Health, Summit, NJ, USA or Ingelvac CircoFlex®, Boehringer Ingelheim Vetmedica Inc, St. Joseph, MO, USA) vaccine at 3-weeks post-weaning.

Feed medication protocol followed the Maschhoffs standard protocols and were kept consistent between all lots of pigs. All water and injectable antimicrobial treatments and interventions performed were part of the routine care administered to animals by their caretakers.

Number of pigs dead (mortalities), total water disappearance, internal barn temperature, number of pigs treated with injectable antibiotics and current pig inventory were recorded by management personnel during daily observations. Total water disappearance was recorded from a water meter as the number of gallons disappeared since the previous day’s daily observation for the entire lot of pigs. Internal maximum high and minimum low barn temperature (°C) were recorded daily from the ventilation control system within each barn and averaged across all barns in the complex.

Diagnostic Testing

Tissue samples were collected from clinically infected necropsied pigs (n=421) from all lots during the wean-finish period. On the day of collection, tissue samples were sent to the University of Minnesota Veterinary Diagnostic Laboratory to be tested for pathogens of interest using Polymerase chain reaction (PCR) assays. Pathogens tested for included: *Actinobacillus suis* (ASUIS), *Escherichia coli* (ECOLI), Influenza A virus
(IAV), *Lawsonia intracellularis* (ILEIT), *Mycoplasma hyopneumoniae* (MHYO), porcine circovirus type 2 (PCV2), porcine epidemic diarrhea virus (PEDV), porcine reproductive respiratory syndrome virus (PRRSV), rotavirus (ROTA), *Salmonella sp.* (SALMO) and *Streptococcus suis* (SSUIS).

**Data Analysis**

Week post-weaning (WPW) and day post-weaning (DPW) were defined as the average week and day post-weaning, respectively, for the entire lot of pigs at the complex. Three age groups (AG) were categorized based on WPW and separated into early finishing (EF; WPW 1-7), middle finishing (MF; WPW 8-15) and late finishing (LF; WPW 16-27). Daily mortality rate was defined as the number of daily mortalities divided by the number of pigs placed in the entire lot or inventory after split-out occurred and multiplied by 100. This method for calculating mortality rate was done because inventory decreased within each lot throughout the wean-finish period due to death and shipments that occur when marketing. Timing of euthanasia is a very subjective assessment which depends on the animal caretaker (Morrow et al., 2007). Hence, euthanized pigs were not included in the daily mortality count to remove any statistical bias that could result from the effect of changes in weekly management personnel which could unintentionally signal the start of a high mortality event.

**Quantifying high mortality events**

To detect the start of a high mortality event (SHME), a rolling average daily mortality rate was calculated throughout the wean-finish period. The previous seven-day (day -6 to 0) average daily mortality rate (P7M) was subtracted from the subsequent three-day (day 1 to 3) average daily mortality rate (S3M) to calculate the change in
mortality (CM). Consequently, the first day of interest within each lot of pigs was on the 7th day, as the first 7 days were used to determine the average for detecting changes in mortality. Seven-day average daily mortality rate was used to remove the day of the week mortality rate effect. Subsequent three-day average daily mortality rate was used to detect short-term changes in mortality.

Across all lots of pigs, z-scores were computed from raw CM within each WPW, since change in mortality is not the same within each WPW throughout the wean-finish period. A z-score is the number of standard deviations from the mean and is used to more clearly identify outliers (Rothenberg, 1993). A z-score threshold of $\geq 1.0$ was considered a significant positive deviation from the mean CM within each week post-weaning, and any day with a z-score $\geq 1.0$ was categorized as the start of a high mortality event (SHME). Table 1 includes the upper change in mortality threshold which is equal to a z-score of 1.0 within each WPW.

**Quantifying percent change water disappearance**

Daily water disappearance (WD) per pig was calculated as the total volume of water disappeared (gallons was recorded and converted to liters during data analysis) since the prior day’s daily observation, divided by the current pig inventory. Since it was unknown if daily water disappearance was recorded at the same time each day during daily observations, a rolling three-day average water disappearance (3WD) was calculated which included the current day of interest (day 0) and the previous two days (days -1 and -2).

To understand percent change in water disappearance throughout the wean-finish period, 3WD was calculated against the prior 11-day (days -13 to -3) average water
disappearance (P11WD). Percent change water disappearance (PCWD) was calculated by subtracting P11WD from 3WD, dividing by P11WD and multiplying by 100. Any day that PCWD <0%, was categorized as NegPCWD (Negative percent change water disappearance).

**Environmental temperature in the barn**

Average low temperature (ALT) and average high temperature (AHT) were calculated as the average low and average high internal barn temperature (°C), respectively, across all barns at the complex. Rolling averages were used throughout the wean-finish period to calculate the seven-day (day -6 to 0) average low temperature (7LT), seven-day (day -6 to 0) average high temperature (7HT), prior seven-day (day -7 to -1) average low temperature (P7LT) and prior seven-day (day -7 to -1) average high temperature (P7HT).

To detect temperature changes, ALT and AHT of the current day of interest (day 0) were calculated against P7LT and P7HT, respectively. Change in low temperature (CLT) was defined by subtracting ALT from P7LT. Change in high temperature (CHT) was defined by subtracting AHT from P7HT. Any day with a CHT ≥6.1°C was categorized as a drop in high temperature event (DHTE).

To detect large daily temperature fluctuations within each day, ALT was subtracted from AHT and defined as DIFFTEMP (Difference in daily temperature). The seven-day (day -6 to 0) coefficient of variation for DIFFTEMP (7CVDIFFTEMP) was calculated as the seven-day standard deviation of DIFFTEMP divided by the seven-day mean DIFFTEMP multiplied by 100.
The temperature setpoint is a basic temperature setting within the controller that is adjusted as animals grow and is sometimes called the desired room temperature (Harmon et al., 2012). Table 2 includes the temperature setpoints. A low temperature setpoint event (LTSPE) was defined as a day that the ALT was ≥2.78°C below the barn temperature setpoint. A high temperature setpoint event (HTSPE) was defined as a day that the AHT was ≥7.78°C above the barn temperature setpoint. Difference in ALT from the SP (DIFFALTSP) and difference in 7LT from the temperature setpoint (DIFF7LTSP) were calculated by subtracting ALT and 7LT from the SP, respectively.

McGlone and Pond (2003) reported lower and upper thermoneutral zone temperatures for wean-finish pigs and are included in Table 2. A low thermoneutral zone event (LTZE) was categorized when ALT was less than the lower thermoneutral zone temperature. A high thermoneutral zone event (HTZE) was categorized when AHT was greater than the upper thermoneutral zone temperature. Other low temperature events were generated when ALT or 7LT was ≤16.6°C and defined as ALT16 (Average low temperature ≤16.6°C) and 7LT16 (Seven-day low temperature ≤16.6°C), respectively.

**Injectable antimicrobial treatments**

Daily treatment rate (DTRT) was calculated as the number of daily injectable treatments administered divided by the number of pigs placed in the entire lot or inventory after split-out occurred and multiplied by 100. This was done since inventory decreased within each lot throughout the wean-finish period due to death and shipments that occur when marketing.

To understand changes in daily treatment rate (DTRT) throughout the wean-finish period, average treatment rate was calculated using a rolling three-day average treatment
rate (3TRT) which included DTRT from the current day of interest (day 0) and the previous two days (days -1 and -2). Prior nine-day (days -11 to -3) average DTRT (P9TRT) was calculated. Difference in daily treatment rate (DIFFTRT) was calculated by subtracting P9TRT from 3TRT. Percent change was not calculated since P9TRT was equal to zero on some days. Days with DIFFTRT >0 were categorized as PosDIFFTRT (Positive difference in daily treatment rate).

Stocking, split-out, marketing and season

Days when pigs were double stocked to standard stocking density were categorized as DS (double stocked; 0.28 m² / pig), and once split-out occurred and pigs were stocked to single stocking density, days were categorized as SS (single stocked; 0.56 m² / pig). If split-out occurred within the past 7 days, the following 7 days were categorized as SOP7 (split-out previous 7 days). Marketing period (MARP) was defined as days between when the first pigs were sent to harvest until the last pigs at the complex were sent to harvest. Week of the year was used to categorize season as the following: 1-11, 52 & 53 (winter), 12-25 (spring), 26-38 (summer) and 39-51 (fall).

Diagnostic testing

The lot of pigs at the complex was considered positive for the pathogen if diagnostic samples were PCR positive. The full calendar week and the following two calendar weeks were considered positive if a pathogen was found positive through diagnostic testing. This was done since diagnostic samples were not collected each week throughout the wean-finish period.
Statistical Analysis

Mean separation and Tukey-Kramer were used for multiple comparisons using the lsmeans function from the R package lsmeans (Lenth, 2016). Logistic binomial regression analysis using the Wald test in the R package stats (Team, 2014) was used to investigate the probability and odds ratio of the start for the high mortality event. Logistic regression does not require independent variables to be linearly related, nor does it require equal variance within each group, which makes it a less stringent procedure for statistical analysis (Harrell, 2015).

Variables generated were tested in univariate logistic binomial regression analysis with SHME days as the dependent variable. Variables that had P<0.05 were selected to be included in the final multivariate logistic binomial regression analysis. All two-way interactions were evaluated using multivariate logistic binomial regression analysis and selected for use in final multivariate analysis if P<0.05. Variables were selected by comparing P-values in the univariate analysis as well as considering its biological relevance with respect to the dependent variable. Multicollinearity of independent variables was assessed using the vif function from the R package car (Fox et al., 2012). Multicollinearity was considered to exist in variables if the variance inflation factor was found to be greater than 10. The final multivariate model was developed using the step function in from the R package stats (Team, 2014). All variables and interactions with a P<0.05 were retained in the final multivariate model.

Results are reported as probability or odds ratios (OR) with the associated 95% confidence interval (CI). Probability is the measure of the likelihood that an event will occur and is quantified as a number between 0 and 1. Probability of 0 indicates
impossibility and 1 indicates certainty a SHME will occur. An odds ratio greater than 1 is indicative of an increased chance for the SHME, whereas an odds ratio less than 1 indicates a reduced chance for the SHME and a normal three-day average mortality would be expected to follow.

To evaluate the additive effects of multiple concurrent pathogens and stressors on the probability for the SHME, a new data set was generated containing the combinations of variables that were of interest. The final multivariate model was used to estimate the probability for the SHME using the predict function from the R package stats (Team, 2014). Within each age group, only variables that significantly increased the probability for the SHME were evaluated. During predictions, continuous variable means were used and all binary variables were considered false and pathogens were considered negative, unless the variable effect was investigated. To display and visualize the varying estimated probabilities for the SHME between multiple concurrent pathogens and stressors, table cells with an increased estimated probability were tinted with a darker colored cell.

Results

Mortality

Least squares means for daily mortality rate by week post-weaning are reported in Table 1. Across individual days, mean daily mortality rate was 0.05% per day and ranged from 0% to 0.78% per day. Daily mortality rate was greater (P<0.05) in WPW 5-7, (0.1018%, 0.0862% and 0.0867%, respectively) when compared to WPW 13-24 and 26-27 (Table 1).

Least squares means for change in mortality by week post-weaning are reported in Table 1. Across individual days, mean change in mortality rate was -0.0008% per day
and ranged from -0.3618% to 0.4175% per day. Mean change in mortality was lower (P<0.05) in 7 weeks post-weaning (-0.0158%) than in 2-5 and 8 weeks post-weaning. Table 1 includes the change in mortality upper threshold value which is equal to a z-score ≥1 within each week post-weaning. During data analysis, when the change in mortality within a given day was greater than the upper threshold, this day was categorized as the start of a high mortality event (SHME).

**Univariate Analyses**

**Water**

The continuous variable percent change water disappearance and binary variable negative percent change water disappearance were significant predictors for the SHME in univariate analysis (odds not reported in tables). A one percent increase in PCWD reduced the odds of the SHME (OR=0.99, 95% CI: 0.98-1.00). Days with a NegPCWD had greater odds for the SHME (OR=1.63, 95% CI: 1.25-2.12).

**Environmental temperature in the barn**

Across individual days, mean ALT was 19.4°C per day and ranged from 7.7 to 27.3°C per day. Across individual days, mean AHT was 23.4°C per day and ranged from 15.7 to 35.3°C per day. Continuous variable 7LT was a significant predictor for the SHME in univariate analysis. A 1°C increase in 7LT, decreased the odds for the SHME (OR=0.94, 95% CI: 0.90-0.99; odds not reported in tables).

Binary variables DHTE, LTSPE, ALT16 and 7LT16 were significant (P<0.05) predictors for the SHME in univariate logistic regression analysis (odds not reported in tables). Odds for the SHME increased for days that had a DHTE (OR=3.06, 95% CI: 1.10-7.39), LTSPE (OR=1.84, 95% CI: 1.11-2.95), ALT16 (OR=1.97, 95% CI: 1.43-
2.69) or 7LT16 (OR=1.80, 95% CI: 1.27-2.50). All other temperature variables were not significant (P>0.05) predictors for the SHME in univariate logistic regression analysis.

**Injectable antimicrobial treatments**

Continuous variables daily treatment rate, three-day average treatment rate and difference in daily treatment rate and the binary variable positive difference in daily treatment rate were significant predictors for the start of a high mortality event (odds not reported in tables). Odds for the SHME decreased for each additional one unit increase in DTRT (OR=0.93, 95% CI: 0.87-1.00), 3TRT (OR=0.88, 95% CI: 0.80-0.96) and DIFFTRT (OR=0.83, 95% CI: 0.75-0.92). Days with a PosDIFFTRT had lower odds for the SHME (OR=0.62, 95% CI: 0.47-0.82).

**Stocking, split-out, marketing and season**

Variables stocking, SOP7, MARP and season were not significant (P>0.05) predictors for the start of a high mortality event in univariate logistic regression analysis.

**Day of week**

Day of week (DOW) was a significant (P<0.05) predictor for the SHME in univariate logistic binomial regression analysis (odds not reported in tables). The odds for the SHME are greater on Sunday compared to Tuesday (OR=1.59, 95% CI: 1.02-2.48), Wednesday (OR=1.86, 95% CI: 1.65-2.96), Thursday (OR=1.95, 95% CI: 1.22-3.12), Friday (OR=1.90, 95% CI: 1.19-3.02) and Saturday (OR=1.60, 95% CI: 1.03-2.51).

**Pathogens**

Odds ratios for the SHME and frequency of positive samples for each pathogen by age group are reported in Table 3. Pathogens ILEIT, PEDV, PRRSV, SALMO and
SSUIS were significant predictors for the SHME when evaluated using univariate logistic regression analysis. Odds for the SHME were greater in days positive with ILEIT (OR=2.44, 95% CI: 1.55-3.73), PEDV (OR=2.03, 95% CI: 1.36-2.96), PRRSV (OR=1.39, 95% CI: 1.07-1.80) or SALMO (OR=1.46, 95% CI: 1.01-2.07). Streptococcus suis was significant (P<0.05) in decreasing the odds (OR=0.00, 95% CI: 0.00-115.36) for the SHME, but SSUIS was not detected on any SHME days. All other pathogen variables were not significant (P>0.05) predictors for the SHME in univariate logistic regression analysis.

**Interactions**

Interactions between pathogens were investigated. Odds for the SHME were greater in days positive with PCV2 and ECOLI (OR=4.39, 95% CI: 1.74-11.28), IAV and MHYO (OR=4.88, 95% CI: 2.46-9.96), or MHYO and ECOLI (OR=2.64, 95% CI: 1.03-7.37) (odds ratios not reported in tables).

Interactions between age group, water disappearance, environmental temperature, treatment, stocking, split-out previous 7 days, marketing, season, day of week and pathogens were evaluated and significant (P<0.05) interactions were included in the final multivariate model.

**Final Multivariate Model**

The final multivariate logistic binomial regression model included main effects: PCWD, DIFF7LTSP, HTZE, 7CVDIFFTEMP, PosDIFFTRT, season, stocking, AG, ECOLI, ILEIT, MHYO, PCV2, PRRSV, PEDV, ROTAV, IAV; and interactions: stocking*HTZE, AG*PEDV, AG*MHYO, AG*season, AG*7CVDIFFTEMP, IAV *DIFF7LTSP, IAV *PCWD, ROTAV*PCWD and PCV2*ECOLI.
Final multivariate logistic regression odds ratios are reported in Table 4. Days with a PosDIFFTRT had decreased odds for the SHME (OR=0.55, 95% CI: 0.41-0.75). Days positive with ILEIT (OR=2.22, 95% CI: 1.25-3.92) or PRRSV (OR=1.52, 95% CI: 1.09-2.11) had increased odds for the SHME. Odds for the SHME increased (OR = 1.10, 95% CI: 1.02-1.17) and probability for the SHME (Figure 1a) increased as PCWD increased when pigs tested positive for ROTAV. It is important to note that no diagnostic samples were ROTAV positive in MF or LF pigs (Table 3). Odds for the SHME decreased (OR = 0.92, 95% CI: 0.90-0.95) and probability for the SHME decreased (Figure 1b) as PCWD increased when IAV was positive. Odds for the SHME decreased (OR = 0.68, 95% CI: 0.52-0.88) and probability for the SHME decreased (Figure 1c) as DIFF7LTSP increased when IAV was positive. A HTZE in double stocked pigs increased (OR=2.81, 95% CI: 1.11-7.14) the odds for the SHME compared to double stocked pigs without a HTZE. A HTZE in single stocked pigs had no effect on the odds for the SHME (P>0.05). Odds for the SHME were greater (OR=11.39, 95% CI: 4.46-29.07) when ECOLI and PCV2 were positive compared to days when pigs tested negative for both pathogens. Odds for the SHME increased (OR = 1.07, 95% CI: 1.03-1.10) and probability for the SHME increased (Figure 1d) as 7CVDIFFTEMP increased in EF pigs. An increase in 7CVDIFFTEMP had no effect on middle or late finishing pigs (P>0.05). Positive PEDV presence in early finishing (OR=22.76, 95% CI: 5.15-76.16) or late finishing (OR=2.49, 95% CI: 1.29-4.78) pigs increased the odds for the SHME.

Early finishing pigs with MHYO had increased odds (OR=6.94, 95% CI: 1.48-32.49) for the SHME. Middle finishing pigs in fall had increased odds (OR=2.75, 95% CI: 1.24-6.10) for the SHME compared to middle finishing pigs in summer. Late
finishing pigs in winter (OR=3.33, 95% CI: 1.44-5.52) and summer (OR=2.82, 95% CI: 1.44-5.52) had increased odds for the SHME compared to late finishing pigs in spring.

Estimated Probabilities

**Early finishing pigs**

The additive effects for ILEIT, PRRSV, MHYO, PEDV, PCV2, ECOLI, DS and HTZE on the probability for the SHME in early finishing pigs are reported in Table 5. Additional pathogens or stressors increased the probability for the SHME. The positive presence of PEDV, PCV2, ECOLI and MHYO in early finishing, resulted in the greatest predicted probability of 0.97 (prediction standard error = 0.05), which is almost a certainty a SHME will occur.

**Middle finishing pigs**

The additive effects for ILEIT, PRRSV, PCV2, ECOLI and fall on the probability for the SHME in middle finishing pigs are reported in Table 6. Additional pathogens and the fall seasonal effect increased the probability for the SHME. The positive presence of ILEIT, PCV2 and ECOLI in fall resulted in the greatest predicted probability in middle finishing pigs (probability = 0.75, prediction standard error: 0.14).

**Late finishing pigs**

The additive effects of ILEIT, PRRSV, PEDV, PCV2, ECOLI and winter on the probability for the SHME in late finishing pigs are reported in Table 7. Additional pathogens and the winter seasonal effect increased the probability for the SHME. The positive presence of PEDV, PCV2 and ECOLI in winter resulted in the greatest predicted probability for the SHME in late finishing pigs (probability = 0.77, prediction standard error: 0.13).
Discussion

This study evaluated the effects of changes in water disappearance, environmental stress, management practices, presence of pathogens and interactions effects on the probability for the start of high mortality events in wean-finish pigs. Multiple time periods were evaluated to categorize the start of high mortality events. The previous seven-day average daily mortality rate was used to remove the day of week mortality rate effect, as described previously, when calculating change in mortality. The objective of the present study was to identify days at start of a high mortality event and estimate the probability of the event occurring, not estimate long-term subsequent mortality rate. As a result, subsequent three-day average mortality rate was used to detect short-term changes in mortality.

A reduction in drinking behavior has been observed in sick pigs, which is associated with action of cytokines that are produced soon after pathogen recognition occurs within the sick pig (Reiner et al., 2009; Borghetti et al., 2011). It has been reported that sickness behavior includes inappetence, increased sleep, lethargy and anorexia are part of an organized host defense strategy (Hart, 1988). When a pig becomes sick, the pig’s body evolves which is a behavioral strategy to facilitate the role of fever in combating viral and bacterial infections. This can be viewed as being at a life or death juncture and its behavior is an all-out effort to overcome the disease (Johnson, 2002). In this study, a decrease in percent change in water disappearance, combined with the positive IAV presence, increased the probability for the SHME which could be directly correlated to a loss of appetite and sickness behavior.
Sutherland et al. (2007) reported PRRSV infected pigs spent less time drinking water and Crabtree et al. (2008) detected a change in water disappearance pattern before disease symptoms became visually apparent to caretakers but not did not state the specific disease. Pijpers et al. (1991) reported that at the time of a Actinobacillus (Haemophilus) pleuropneumoniae challenge, both feed and water consumption were reduced and slowly increased to normality after the challenge. Bird (2008) detected a change in water disappearance three days prior to a swine influenza virus outbreak while Brumm (2006) found decreased water disappearance during a swine influenza challenge in growing pigs. This is similar to the present study that found a decrease in PCWD during an IAV challenge increased the probability for the SHME. Madsen and Kristensen (2005) reported an increase in water intake one day prior to an enteric disease outbreak in nursery pigs (Escherichia coli), which is similar to the current study that found increased PCWD during the positive presence of rotavirus increased probability for the SHME.

*Escherichia coli* and rotavirus are enteric diseases that cause diarrhea and high mortality in young pigs, and death is generally due to dehydration (Winiarczyk et al., 2002; Fairbrother et al., 2005). The increase in PCWD may be due to pigs consuming additional water in an attempt to remain hydrated during an enteric disease challenge. The method used in this study to evaluate deviations in water disappearance can be calculated by caretakers during daily observations and does not require a fully automated system that needs to download and interpret the data into meaningful messages. Monitoring water disappearance can serve as an objective measure to monitor health status in large groups of pigs that caretakers can easily implement.
In the present study, several temperature variables were significant in increasing the probability for the SHME in univariate analysis and several interactions were significant with management practices. In the multivariate model, the following temperature interactions were significant (P<0.05): AG*7CVDIFFTEMP, Stocking*HTZE and IAV*DIFF7LTSP. In the present study, the probability for the SHME increased as 7CVDIFFTEMP increased in early finishing pigs. This is similar to previous research that found cyclical temperatures during the wean-finish period reduce performance, increase stress and challenge the pig’s homeothermic abilities and homeostasis (Bond et al., 1963; Morrison and Mount, 1971; Nienaber et al., 1989). This is similar to other livestock species, as Martin et al. (1975) reported dairy calves born during high temperatures in the summer, during low temperatures in the winter or during large temperature fluctuations were associated with an increased risk of death.

The present study found that a high thermoneutral zone event in double stocked pigs increased the odds for the SHME. Several studies reported similar results that the combination of social and environmental stress negatively impacts the immune system (Morrow-Tesch et al., 1994), depresses performance (McGlone et al., 1987), and decreases feed intake (Hyun et al., 1998). Low and high temperature environmental stressors negatively impacts the performance of growing pigs (Nienaber et al., 1987; Hyun et al., 1998), increase smortality in swine breeding herds (Dallaire et al., 1996) and annually causes high economic loses for swine producers in the United States (St-Pierre et al., 2003).

The multivariate model included the interaction between IAV and DIFF7LTSP and as stated earlier, the positive presence of swine influenza virus and decreased
DIFF7LTSP, increased the probability for the SHME. The same results were found by Shope (1955) who reported low environmental conditions reactivated a latent swine influenza virus. Shimizu et al. (1978) found that a sudden decrease in ambient temperature, either before or after inoculation of transmissible gastroenteritis virus, induced severe disease in feeder pigs and caused profuse diarrhea. Sub-clinically infected pigs show no signs of disease until a stressor results in a breakdown and clinical emergence of the disease (Taylor, 1999). This emphasizes the importance of maintaining the pig’s thermal environment when attempting to reduce the pathogen impact and decrease the risk of mortality.

It is well documented that antibiotics are used to treat disease outbreaks in wean-finish pigs to prevent decreased health, decreased growth and economic losses (Jensen et al., 2007). During the initial data analysis process of the present study, it was anticipated that an increase in treatments would increase the probability for the start of a high mortality event. All treatment variables were significant during univariate analysis and a positive difference in daily treatment rate decreased the odds for the SHME in the multivariate model. This agrees with multiple studies that have reported antibiotic use is common worldwide in wean-finish pigs to reduce the risk of high mortality (Losinger et al., 1998, 1999; Bush and Biehl, 2002; Rajic et al., 2006). Timely disease detection and treatment through antibiotic use to reduce mortality and morbidity is an extremely important tool in efficient pork production (Cromwell, 2002).

The interaction of season and age group was significant in the multivariate model. Seasonal effects were not observed in early finishing pigs. Previous studies defined mortality as the percent mortality of the entire group of pigs, and reported that pigs
placed in October through December (Maes et al., 2001; Maes et al., 2004; Oliveira et al., 2009) or January through April (Oliveira et al., 2009) had greater mortality, indicating early finishing mortality is greater in fall and winter. In the present study, middle finishing pigs had increased odds for the SHME in fall compared to summer. In addition, late finishing pigs had increased odds for the SHME in winter and summer compared to spring. Maes et al. (2001) found differing results as late finishing mortality is greater consistently each year in September, October and November. High mortality in wean-finish complexes holds substantial economic concerns as pigs that die represent a considerable investment, especially if it occurs in older, more valuable pigs (Holden, 1991).

Porcine reproductive respiratory syndrome virus is one of the most economically important diseases affecting pigs because of its significant losses to production in reproductive failure in breeding sows, increased mortality and reduced performance by growing pigs and is currently endemic in the major swine producing regions of the world (Neumann et al., 2005; Corzo et al., 2010). In 2005, Neumann et al. (2005) estimated the total annual economic impact of PRRSV on U.S. swine producers was $560 million in breeding and grow-finish populations, while in 2013, Holtkamp et al. (2013) estimated its impact at $664 million annually. The impact of PRRSV was estimated to add between $5.60 and $7.62 to the cost per head sold (Johnson et al., 2005). In the present study, positive PRRSV presence was significant in the multivariate model and increased the odds for the SHME. Holtkamp et al. (2013) and Stevenson et al. (2013) found similar results that the presence of PRRSV in wean-finish pigs increased mortality. No PRRSV interactions were observed in the present study but previous studies have reported
interaction between PRRSV and other pathogens (VanReeth et al., 1996; Thacker et al., 1999).

In the current study, the positive ILEIT presence increased the odds for the SHME, regardless of age of pigs. Similar results have been reported that chronic cases of ILEIT cause decreased weight gain and diarrhea with high morbidity and mortality typically found in growing pigs (eight to 20 weeks old) (McOrist and Smits, 2007). Acute cases of *Lawsonia intracellularis* cause black-red feces and anemia, and are characterized by high morbidity and high mortality in affected groups of growing pigs (McOrist and Smits, 2007).

Porcine epidemic diarrhea virus (PEDV) was first found in the U.S. in May 2013 and causes diarrhea, vomiting, dehydration, and high mortality in young pigs (Stevenson et al., 2013; Song et al., 2015). Similar results were found in the present study as the odds for the SHME were 22.76 times greater in early finishing pigs with PEDV. The PEDV infection impact on the U.S. pork industry has been largely attributed to the mortality caused in suckling pigs, but Alvarez et al. (2015) found that mortality is greater in growing pigs weaned after a PEDV outbreak. This enteric disease in feeder and finishing pigs is characterized by severe watery diarrhea with low mortality (Wood, 1977). Contrary to previous findings, late finishing pigs with PEDV had increased odds for the SHME in the current study.

*Mycoplasma hyopneumoniae* is the primary infectious pathogen for enzootic pneumonia in pigs, is the most common pathogen affecting grow-finish units worldwide and is found in 99% of the U.S. swine herds (Escobar et al., 2002; Llopart et al., 2002; Maes et al., 2008). *Mycoplasma hyopneumoniae* modulates the immune system of the
respiratory tract which predisposes animals to concurrent infections with respiratory pathogens including bacteria, parasites and viruses, which have been found to increase pneumonic coughing and increase rate of pulmonary lesions (Escobar et al., 2002). In the current study, interactions of IAV*MHYO, MHYO*ECOLI and MHYO*AG were significant during testing of individual interactions (results were not reported). The interaction between *Mycoplasma hyopneumoniae* and age group was significant in the multivariate model, which is similar to Thacker et al. (2001) who reported pigs infected with both swine influenza virus and *Mycoplasma hyopneumoniae* coughed significantly more than pigs infected with a single pathogen. Although not significant in the current study, the interaction between *Mycoplasma hyopneumoniae* and porcine reproductive respiratory syndrome virus has previously been reported to be significant, as pigs infected with both pathogens had increased pneumonic lesions (Thacker et al., 1999). In the present study, the interaction between *porcine circovirus type 2* and *Escherichia coli* was significant as pigs infected with both pathogens had increased odds for the SHME. Opriessnig et al. (2007) stated that *porcine circovirus type 2* is linked with a range of diseases that accelerate and enhance respiratory, enteric or reproductive problems. Typically, in U.S. herds there is a secondary infection with viral or bacterial pathogens that occur concurrently (Zimmerman et al., 1997).

The complex, additive and synergistic interactions among behavior, environment, management factors and pathogen status play a critical role in high mortality events in wean-finish pigs. Continuously monitoring water disappearance, controlling the environment, proper management to reduce stress, timely treatment of pigs and frequent diagnostic tests are all essential to identify and ultimately prevent upcoming high
mortality events. Automation is a new tool within animal agriculture that has the potential to detect behavioral changes as a result of health and welfare compromises. Around the world, technologies to objectively identify changes in drinking, eating, activity, social behavior, coughing and several other health related measures are being investigated to provide caretaker guidance to determine where management efforts should be concentrated.

References


and feed conversion in boars at a Danish test station. Livestock Science 112(1-2):34-42. doi: 10.1016/j.livsci.2007.01.153


Table 1. Mean inventory across all lots of pigs, least squares means (±SE) for daily mortality rate and change in mortality and change in mortality upper threshold by week post-weaning from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Week post weaning</th>
<th>Mean Inventory</th>
<th>Mean Daily Mortality Rate</th>
<th>Mean Change in Mortality</th>
<th>Change in Mortality Upper Threshold&lt;sup&gt;2&lt;/sup&gt;</th>
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<tr>
<td>2</td>
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</table>

<sup>1</sup>Change in mortality was calculated as the previous seven-day average mortality rate subtracted from the subsequent three-day average mortality rate.

<sup>2</sup>Change in mortality upper threshold is equal to a z-score of ≥1.0 within each week post-weaning.

<sup>a-g</sup>Least squares means with different superscripts within a column are different (P<0.05).
Table 2. Internal barn temperature setpoint, lower thermoneutral zone temperature and upper thermoneutral zone temperature by day post weaning from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Day post-weaning</th>
<th>Temperature setpoint (°C)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Lower thermoneutral zone temperature (°C)&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Upper thermoneutral zone temperature (°C)&lt;sup&gt;2&lt;/sup&gt;</th>
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<tbody>
<tr>
<td>1</td>
<td>27.2</td>
<td>26.0</td>
<td>32.2</td>
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<td>27.2</td>
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<tr>
<td>180</td>
<td>18.3</td>
<td>10.0</td>
<td>25.0</td>
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</table>

<sup>1</sup>Internal barn temperature (°C) setpoint used in the ventilation controller to maintain the desired room temperature.

Table 3. Odds ratios\(^1\) for the start of a high mortality event and frequency of positive samples for eleven pathogens\(^2\) by age group\(^3\) from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Pathogen(^2)</th>
<th>Odds ratios (95% confidence interval odds ratio)(^1)</th>
<th>Early Finishing(^2)</th>
<th>Middle Finishing(^2)</th>
<th>Late Finishing(^2)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Positive samples</td>
<td>Positive samples</td>
<td>Positive samples</td>
<td>Positive samples</td>
<td></td>
</tr>
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<td>ASUIS</td>
<td>1.45 (0.89-2.28)</td>
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<td>13</td>
<td>10</td>
<td>24</td>
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<td>ECOLI</td>
<td>1.20 (0.75-1.84)</td>
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<td>11</td>
<td>1</td>
<td>26</td>
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<td>IAV</td>
<td>1.30 (0.93-1.79)</td>
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<td>13</td>
<td>18</td>
<td>47</td>
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<td>ILEIT</td>
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<td>0</td>
<td>8</td>
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<td>15</td>
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<tr>
<td>MHYO</td>
<td>1.29 (0.99-1.69)</td>
<td>7</td>
<td>35</td>
<td>73</td>
<td>115</td>
</tr>
<tr>
<td>PCV2</td>
<td>1.07 (0.79-1.42)</td>
<td>5</td>
<td>32</td>
<td>43</td>
<td>80</td>
</tr>
<tr>
<td>PEDV</td>
<td>2.03 (1.36-2.97)***</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>PRRSV</td>
<td>1.39 (1.07-1.80)*</td>
<td>23</td>
<td>65</td>
<td>61</td>
<td>149</td>
</tr>
<tr>
<td>ROTAV</td>
<td>0.46 (0.16-1.02)</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>SALMO</td>
<td>1.46 (1.01-2.07)*</td>
<td>8</td>
<td>13</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>SSUIS</td>
<td>0.00 (0.00-115.36)*</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>73</td>
<td>184</td>
<td>164</td>
<td>421</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Univariate logistic regression odds ratio for the start of a high mortality event. Odds ratio greater than 1 is indicative of an increased chance of the start of a high mortality event, whereas an odds ratio less than 1 indicates a reduced chance. Odds ratios are reported as the effect of the positive presence of the pathogen on the start of a high mortality event.

\(^2\)Pathogens: ASUIS (Actinobacillus suis), ECOLI (Escherichia coli), IAV (Influenza A virus), ILEIT (Lawsonia intracellularis), MHYO (Mycoplasma hyopneumoniae), PCV2 (Porcine circovirus type 2), PEDV (Porcine epidemic diarrhea virus), PRRSV (Porcine reproductive respiratory virus), ROTAV (Rotavirus), SALMO (Salmonella sp.), and SSUIS (Streptococcus suis).

\(^3\)Three age groups categorized based on week post-weaning (WPW); Early Finishing (WPW 1-7), Middle Finishing (WPW 8-15) and Late Finishing (WPW 16-27).

* P<0.05.

*** P<0.001.
Table 4. Multivariate logistic regression analysis odds ratios\(^1\) for the start of a high mortality event from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Variables:</th>
<th>False</th>
<th>True</th>
</tr>
</thead>
<tbody>
<tr>
<td>PosDIFFTRT(^2)</td>
<td>Reference</td>
<td>0.55 (0.41-0.75)</td>
</tr>
<tr>
<td>ILEIT(^2)</td>
<td>Reference</td>
<td>2.22 (1.25-3.92)</td>
</tr>
<tr>
<td>PRRSV(^2)</td>
<td>Reference</td>
<td>1.52 (1.09-2.11)</td>
</tr>
<tr>
<td>ROTAV(^2)</td>
<td>Negative</td>
<td>Positive</td>
</tr>
<tr>
<td>PCWD(^3)</td>
<td>1.00 (0.99-1.01)</td>
<td>1.10 (1.02-1.17)</td>
</tr>
<tr>
<td>IAV(^2)</td>
<td>Negative</td>
<td>Positive</td>
</tr>
<tr>
<td>PCWD(^3)</td>
<td>1.00 (0.99-1.01)</td>
<td>0.92 (0.90-0.95)</td>
</tr>
<tr>
<td>DIFF7LTSP(^3)</td>
<td>1.05 (0.93-1.17)</td>
<td>0.68 (0.52-0.88)</td>
</tr>
<tr>
<td>Stocking(^2)</td>
<td>False</td>
<td>True</td>
</tr>
<tr>
<td>HTZE(^2)</td>
<td>Reference</td>
<td>0.83 (0.51-1.33)</td>
</tr>
<tr>
<td>ECOLI(^2)</td>
<td>Negative</td>
<td>Positive</td>
</tr>
<tr>
<td>PCV2(^2)</td>
<td>Reference</td>
<td>0.54 (0.23-1.25)</td>
</tr>
<tr>
<td>Positive</td>
<td>0.74 (0.51-1.07)</td>
<td>11.39 (4.46-29.07)</td>
</tr>
<tr>
<td>PEDV(^2)</td>
<td>Negative</td>
<td>Reference</td>
</tr>
<tr>
<td>Positive</td>
<td>22.76 (5.15-76.16)</td>
<td>0.94 (0.41-2.26)</td>
</tr>
<tr>
<td>MHYO(^2)</td>
<td>Negative</td>
<td>Reference</td>
</tr>
<tr>
<td>Positive</td>
<td>6.94 (1.48-32.49)</td>
<td>1.13 (0.57-2.25)</td>
</tr>
<tr>
<td>Season(^5)</td>
<td>Winter</td>
<td>2.28 (0.17-30.93)</td>
</tr>
<tr>
<td>Spring</td>
<td>2.19 (0.19-25.35)</td>
<td>1.26 (0.55-2.91)</td>
</tr>
<tr>
<td>Summer</td>
<td>2.34 (0.21-26.26)</td>
<td>Reference</td>
</tr>
<tr>
<td>Fall</td>
<td>Reference</td>
<td>2.75 (1.24-6.10)</td>
</tr>
</tbody>
</table>

\(^1\) An odds ratio (95% confidence interval odds ratio) greater than 1 is indicative of an increased chance of the start of a high mortality event, whereas an odds ratio less than 1 indicates a reduced chance.

\(^2\) Binary Variables: PosDIFFTRT (Positive difference in daily treatment rate), ILEIT (*Lawsonia intracellularis*), PRRSV (Porcine reproductive respiratory syndrome virus), ROTAV (Rotavirus), IAV (Influenza A virus), HTZE (High thermoneutral zone event), ECOLI (*Escherichia coli*), PCV2 (Porcine circovirus type 2), stocking (Double and single stocked lots), PEDV (Porcine epidemic diarrhea virus), MHYO (*Mycoplasma hyopneumoniae*). Odds ratios for binary variables are reported as the odds compared to the reference level (Reference) within each variable or interaction.
Continuous variables: PCWD (Percent change water disappearance), DIFF7LTSP (Difference in seven-day average low temperature from setpoint), and 7CVDIFFTEMP (seven-day coefficient of variation difference in daily temperature). Odds ratios for continuous variables are reported as the effect of a one unit increase on the probability of the start of a high mortality event.

Three age groups categorized based on week post-weaning (WPW): Early Finishing (EF: WPW 1-7), Middle Finishing (MF: WPW 8-15) and Late Finishing (LF: WPW 16-27).

Week of the year was used to categorize season as the following: winter: 1-11, 52 & 53, spring: 12-25, summer: 26-38 and fall: 39-51.
Table 5. Multivariate logistic regression model predictions for the probability\(^1\) of the start of a high mortality event (SHME) in early finishing pigs from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Variables: (^2)</th>
<th>ILEIT</th>
<th>SE</th>
<th>PRRSV</th>
<th>SE</th>
<th>MHYO</th>
<th>SE</th>
<th>PEDV</th>
<th>SE</th>
<th>PCV2+ECOLI</th>
<th>SE</th>
<th>DS+HTZE</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILEIT</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.22</td>
<td>0.25</td>
<td>0.39</td>
<td>0.33</td>
<td>0.26</td>
<td>0.25</td>
<td>0.08</td>
<td>0.09</td>
</tr>
<tr>
<td>PRRSV</td>
<td>0.04</td>
<td>0.05</td>
<td>0.02</td>
<td>0.02</td>
<td>0.16</td>
<td>0.19</td>
<td>0.31</td>
<td>0.30</td>
<td>0.20</td>
<td>0.20</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>MHYO</td>
<td>0.22</td>
<td>0.25</td>
<td>0.16</td>
<td>0.19</td>
<td>0.11</td>
<td>0.14</td>
<td>0.73</td>
<td>0.32</td>
<td>0.60</td>
<td>0.36</td>
<td>0.28</td>
<td>0.30</td>
</tr>
<tr>
<td>PEDV</td>
<td>0.39</td>
<td>0.33</td>
<td>0.31</td>
<td>0.30</td>
<td>0.73</td>
<td>0.32</td>
<td>0.23</td>
<td>0.24</td>
<td>0.78</td>
<td>0.25</td>
<td>0.48</td>
<td>0.35</td>
</tr>
<tr>
<td>PCV2+ECOLI</td>
<td>0.26</td>
<td>0.25</td>
<td>0.20</td>
<td>0.20</td>
<td>0.60</td>
<td>0.36</td>
<td>0.78</td>
<td>0.25</td>
<td>0.14</td>
<td>0.15</td>
<td>0.33</td>
<td>0.28</td>
</tr>
<tr>
<td>ILEIT+PRRSV</td>
<td>0.04</td>
<td>0.05</td>
<td>0.04</td>
<td>0.05</td>
<td>0.29</td>
<td>0.30</td>
<td>0.49</td>
<td>0.35</td>
<td>0.29</td>
<td>0.12</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>ILEIT+MHYO</td>
<td>0.22</td>
<td>0.25</td>
<td>0.29</td>
<td>0.30</td>
<td>0.22</td>
<td>0.25</td>
<td>0.86</td>
<td>0.20</td>
<td>0.77</td>
<td>0.27</td>
<td>0.46</td>
<td>0.37</td>
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<tr>
<td>ILEIT+PEDV</td>
<td>0.39</td>
<td>0.33</td>
<td>0.49</td>
<td>0.35</td>
<td>0.86</td>
<td>0.20</td>
<td>0.39</td>
<td>0.33</td>
<td>0.88</td>
<td>0.16</td>
<td>0.66</td>
<td>0.32</td>
</tr>
<tr>
<td>ILEIT+PCV2+ECOLI</td>
<td>0.26</td>
<td>0.25</td>
<td>0.35</td>
<td>0.29</td>
<td>0.77</td>
<td>0.27</td>
<td>0.88</td>
<td>0.16</td>
<td>0.26</td>
<td>0.25</td>
<td>0.52</td>
<td>0.33</td>
</tr>
<tr>
<td>PRRSV+MHYO</td>
<td>0.29</td>
<td>0.30</td>
<td>0.16</td>
<td>0.19</td>
<td>0.16</td>
<td>0.19</td>
<td>0.80</td>
<td>0.26</td>
<td>0.69</td>
<td>0.32</td>
<td>0.37</td>
<td>0.35</td>
</tr>
<tr>
<td>PRRSV+PEDV</td>
<td>0.49</td>
<td>0.35</td>
<td>0.31</td>
<td>0.30</td>
<td>0.88</td>
<td>0.16</td>
<td>0.31</td>
<td>0.30</td>
<td>0.84</td>
<td>0.20</td>
<td>0.58</td>
<td>0.34</td>
</tr>
<tr>
<td>PRRSV+PCV2+ECOLI</td>
<td>0.35</td>
<td>0.29</td>
<td>0.20</td>
<td>0.20</td>
<td>0.69</td>
<td>0.32</td>
<td>0.84</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.43</td>
<td>0.31</td>
</tr>
<tr>
<td>MHYO+PEDV</td>
<td>0.86</td>
<td>0.20</td>
<td>0.88</td>
<td>0.16</td>
<td>0.73</td>
<td>0.32</td>
<td>0.73</td>
<td>0.32</td>
<td>0.97</td>
<td>0.05</td>
<td>0.89</td>
<td>0.16</td>
</tr>
<tr>
<td>MHYO+PCV2+ECOLI</td>
<td>0.77</td>
<td>0.27</td>
<td>0.69</td>
<td>0.32</td>
<td>0.60</td>
<td>0.36</td>
<td>0.97</td>
<td>0.05</td>
<td>0.60</td>
<td>0.36</td>
<td>0.82</td>
<td>0.23</td>
</tr>
<tr>
<td>PEDV+PCV2+ECOLI</td>
<td>0.88</td>
<td>0.16</td>
<td>0.84</td>
<td>0.20</td>
<td>0.97</td>
<td>0.05</td>
<td>0.78</td>
<td>0.25</td>
<td>0.78</td>
<td>0.25</td>
<td>0.91</td>
<td>0.12</td>
</tr>
</tbody>
</table>

\(^1\)Prediction for the probability (SE: prediction standard error) of the SHME in early finishing pigs (1-7 weeks post-weaning) was estimated using the multivariate logistic regression model. Continuous variable means and binary variables were considered false or negative during predictions unless the effect of the variable was investigated. Fall (Week 39-51 of the year) was used as the season categorical variable during all predictions within table.

Probability is the measure of the likelihood that the event will occur and is quantified as a number between 0 and 1. A Probability of 0 indicates impossibility and 1 indicates certainty a SHME will occur. An increased probability is identified with a darker colored cell.

\(^2\)Variables: ILEIT (\textit{Lawsonia intracellularis}), PRRSV (Porcine reproductive respiratory syndrome virus), MHYO (\textit{Mycoplasma hyopneumoniae}), PEDV (Porcine epidemic diarrhea virus), PCV2 (Porcine circovirus type 2), ECOLI (\textit{Escherichia coli}), DS (Double stocking), HTZE (High thermoneutral zone event).
Table 6. Multivariate logistic regression model predictions for the probability\(^1\) of the start of a high mortality event (SHME) in middle finishing pigs from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Variables:(^2)</th>
<th>ILEIT</th>
<th>SE</th>
<th>PRRSV</th>
<th>SE</th>
<th>PCV2+ECOLI</th>
<th>SE</th>
<th>Fall</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILEIT</td>
<td>0.09</td>
<td>0.05</td>
<td>0.13</td>
<td>0.06</td>
<td>0.53</td>
<td>0.18</td>
<td>0.20</td>
<td>0.08</td>
</tr>
<tr>
<td>PRRSV</td>
<td>0.13</td>
<td>0.06</td>
<td>0.06</td>
<td>0.03</td>
<td>0.44</td>
<td>0.16</td>
<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
<td>PCV2+ECOLI</td>
<td>0.53</td>
<td>0.18</td>
<td>0.44</td>
<td>0.16</td>
<td>0.35</td>
<td>0.14</td>
<td>0.58</td>
<td>0.16</td>
</tr>
<tr>
<td>Fall</td>
<td>0.20</td>
<td>0.08</td>
<td>0.15</td>
<td>0.05</td>
<td>0.58</td>
<td>0.16</td>
<td>0.11</td>
<td>0.04</td>
</tr>
<tr>
<td>ILEIT+PRRSV</td>
<td>0.13</td>
<td>0.06</td>
<td>0.13</td>
<td>0.06</td>
<td>0.63</td>
<td>0.17</td>
<td>0.27</td>
<td>0.10</td>
</tr>
<tr>
<td>ILEIT+PCV2+ECOLI</td>
<td>0.53</td>
<td>0.18</td>
<td>0.63</td>
<td>0.17</td>
<td>0.53</td>
<td>0.18</td>
<td>0.75</td>
<td>0.14</td>
</tr>
<tr>
<td>PRRSV+PCV2+ECOLI</td>
<td>0.63</td>
<td>0.17</td>
<td>0.44</td>
<td>0.16</td>
<td>0.44</td>
<td>0.16</td>
<td>0.67</td>
<td>0.15</td>
</tr>
</tbody>
</table>

\(^1\)Prediction for the probability (SE: prediction standard error) of the SHME in middle finishing pigs (8-15 weeks post-weaning) was estimated using the multivariate logistic regression model. Continuous variable means and binary variables were considered False or Negative during predictions unless the effect of the variable was investigated. Summer (week 26-38 of the year) was used as the season categorical variable during predictions except when the effect of fall (week 39-51 of the year) was investigated. Probability is the measure of the likelihood that the event will occur and is quantified as a number between 0 and 1. A Probability of 0 indicates impossibility and 1 indicates certainty a SHME will occur. An increased probability is identified with a darker colored cell.

\(^2\)Variables: ILEIT (*Lawsonia intracellularis*), PRRSV (Porcine reproductive respiratory syndrome virus), PCV2 (Porcine circovirus type 2), ECOLI (*Escherichia coli*), fall (week 39-51 of the year).
Table 7. Multivariate logistic regression model predictions for the probability\(^1\) of the start of a high mortality event (SHME) in late finishing pigs from a study of crossbred wean-finish pigs raised in a commercial production system.

<table>
<thead>
<tr>
<th>Variables: (^2)</th>
<th>ILEIT</th>
<th>SE</th>
<th>PRRSV</th>
<th>SE</th>
<th>PEDV</th>
<th>SE</th>
<th>PCV2+ECOLI</th>
<th>SE</th>
<th>Winter</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILEIT</td>
<td>0.08</td>
<td>0.04</td>
<td>0.11</td>
<td>0.05</td>
<td>0.17</td>
<td>0.08</td>
<td>0.49</td>
<td>0.18</td>
<td>0.21</td>
<td>0.09</td>
</tr>
<tr>
<td>PRRSV</td>
<td>0.11</td>
<td>0.05</td>
<td>0.53</td>
<td>0.02</td>
<td>0.12</td>
<td>0.57</td>
<td>0.40</td>
<td>0.15</td>
<td>0.16</td>
<td>0.06</td>
</tr>
<tr>
<td>PEDV</td>
<td>0.17</td>
<td>0.08</td>
<td>0.12</td>
<td>0.57</td>
<td>0.08</td>
<td>0.04</td>
<td>0.52</td>
<td>0.17</td>
<td>0.23</td>
<td>0.10</td>
</tr>
<tr>
<td>PCV2+ECOLI</td>
<td>0.49</td>
<td>0.18</td>
<td>0.40</td>
<td>0.15</td>
<td>0.52</td>
<td>0.17</td>
<td>0.31</td>
<td>0.14</td>
<td>0.60</td>
<td>0.15</td>
</tr>
<tr>
<td>Winter</td>
<td>0.21</td>
<td>0.09</td>
<td>0.16</td>
<td>0.06</td>
<td>0.23</td>
<td>0.10</td>
<td>0.60</td>
<td>0.15</td>
<td>0.11</td>
<td>0.04</td>
</tr>
<tr>
<td>ILEIT+PRRSV</td>
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<td>0.05</td>
<td>0.11</td>
<td>0.05</td>
<td>0.23</td>
<td>0.10</td>
<td>0.59</td>
<td>0.17</td>
<td>0.29</td>
<td>0.11</td>
</tr>
<tr>
<td>ILEIT+PEDV</td>
<td>0.17</td>
<td>0.08</td>
<td>0.23</td>
<td>0.10</td>
<td>0.17</td>
<td>0.08</td>
<td>0.70</td>
<td>0.16</td>
<td>0.40</td>
<td>0.16</td>
</tr>
<tr>
<td>ILEIT+PCV2*ECOLI</td>
<td>0.49</td>
<td>0.18</td>
<td>0.59</td>
<td>0.17</td>
<td>0.70</td>
<td>0.16</td>
<td>0.49</td>
<td>0.18</td>
<td>0.75</td>
<td>0.13</td>
</tr>
<tr>
<td>PRRSV+PEDV</td>
<td>0.23</td>
<td>0.10</td>
<td>0.12</td>
<td>0.57</td>
<td>0.12</td>
<td>0.57</td>
<td>0.62</td>
<td>0.16</td>
<td>0.31</td>
<td>0.12</td>
</tr>
<tr>
<td>PRRSV+PCV2+ECOLI</td>
<td>0.59</td>
<td>0.17</td>
<td>0.40</td>
<td>0.15</td>
<td>0.62</td>
<td>0.16</td>
<td>0.40</td>
<td>0.15</td>
<td>0.69</td>
<td>0.14</td>
</tr>
<tr>
<td>PEDV+PCV2+ECOLI</td>
<td>0.70</td>
<td>0.16</td>
<td>0.62</td>
<td>0.16</td>
<td>0.52</td>
<td>0.17</td>
<td>0.52</td>
<td>0.17</td>
<td>0.77</td>
<td>0.13</td>
</tr>
</tbody>
</table>

\(^1\)Prediction for the probability (SE: prediction standard error) of the SHME in late finishing pigs (16-27 weeks post-weaning) was estimated using the multivariate logistic regression model. Continuous variable means and binary variables were considered False or Negative during predictions, unless the effect of the variable was investigated. Spring (week 12-25 of the year) was used as the season categorical variable during predictions except when the effect of winter (week 1-11, 52 & 53 of the year) was investigated. Probability is the measure of the likelihood that the event will occur and is quantified as a number between 0 and 1. A Probability of 0 indicates impossibility and 1 indicates certainty a SHME will occur. An increased probability is identified with a darker colored cell.

\(^2\)Variables: ILEIT (\textit{Lawsonia intracellularis}), PRRSV (Porcine reproductive respiratory syndrome virus), PEDV (Porcine epidemic diarrhea virus), PCV2 (Porcine circovirus type 2), ECOLI (\textit{Escherichia coli}), winter (week 1-11, 52 & 53 of the year).
Figure 1. Variable interaction effects on the probability (± SE) for the start of a high mortality event (SHME) from a study of crossbred wean–finish pigs raised in a commercial production system.

Variables: ROTAV (Rotavirus), PCWD (Percent change water disappearance), SIV (Swine influenza virus), DIFF7LTSP (Difference in seven–day average low temperature from setpoint), 7CVDIFFTEMP (seven–day coefficient of variation difference in daily temperature), P (Positive presence of pathogen), N (Negative presence of pathogen), AG (age group) categorized based on week post–weaning (WPW); early finishing (EF; WPW 1–7), middle finishing (MF; WPW 8–15) and late finishing (LF; WPW 16–27).

Probability is the measure of the likelihood that an event will occur and is quantified as a number between 0 and 1. Probability of 0 indicates impossibility and 1 indicates certainty a SHME will occur.
CHAPTER 6. GENERAL SUMMARY

Mortality in North American wean-finish pig herds has increased and holds considerable economic concerns, especially in older, more valuable pigs. Larger herd sizes, increased number of herds per production system and more animals managed per person has led to less available time to observe individual pigs in wean-finish production. Diseases have been found to change pig behavior and time spent eating and drinking during the onset and recovery of a health challenge. Management decisions while caring for pigs are commonly based on subjective judgment by the caretaker, so methods to need to be developed to detect changes in behavior and health status of growing pigs. Early detection of a health challenge can improve treatment success, reduce impact of diseases, reduce mortality and ultimately promote sustainable pig production. The objectives of this study were to identify days at the start of a high mortality event and determine the effects of changes in water disappearance, environmental stress, management practices, pathogen presence and interactions as predictors for the start of high mortality events (SHME) in commercial wean-finish pigs.

In healthy growing pigs, water disappearance consistently increases as pigs get older and heavier in body weight. Due to the differences in water disappearance within each lot of pigs throughout the wean-finish phase, detecting changes in water disappearance needed to be assessed within each lot of pigs. Three methods were developed to detect low and high water disappearance deviations which included: linear mixed effects model, one-step ahead model and percent change water disappearance. Percent change water disappearance was significant in predicting the SHME.
Low, high and increased variation in environmental temperature impacted the odds for the SHME, depending on the age of pig and stocking density at the complex. Environmental stressors, combined with social stress significantly increased the odds for the start of a high mortality event. Seasonal effects influence the SHME and differed based on the age of the pig. Antimicrobial use decreased the odds for the SHME and solidifies that antimicrobials are an extremely important tool in efficient pork production. Day of the week effects were observed in daily treatment rate and daily mortality rate which validates the subjective assessment of pig health by caretakers.

In the present study, viral or bacterial pathogens were found to increase the odds for the SHME and like many U.S. swine herds, a secondary infection enhanced the negative effects. The odds for the SHME were 11.39 times greater when *porcine circovirus type 2* and *Escherichia coli* were positive. Influenza A virus combined with low percent change water disappearance or low temperatures, increased the odds for the SHME. This emphasizes the importance of maintaining the pig’s thermal environment when attempting to reduce the pathogen impact and decrease the risk of mortality. High percent change water disappearance when rotavirus was positive, increased the odds for the SHME which may be due to pigs consuming additional water in an attempt to remain hydrated during an enteric disease challenge. In the present study, the odds for the SHME were 22.76 times greater in early finishing pigs with porcine epidemic diarrhea virus and 6.94 times greater in early finishing pigs with *Mycoplasma hyopneumoniae*.

This study showed the complex, additive and synergistic interactions among behavior, environment, management factors and pathogen status play a critical role in high mortality events in wean-finish pigs. Continuously monitoring water disappearance,
controlling the environment, proper management to reduce stress, timely treatment of pigs and frequent diagnostic tests are all essential to identify and ultimately prevent upcoming high mortality events. Automation is a new tool within animal agriculture that has the potential to detect behavioral changes as a result of health and welfare compromises. Around the world, technologies to objectively identify changes in drinking, eating, activity, social behavior, coughing and several other health related measures are being investigated to provide caretaker guidance to determine where management efforts should be concentrated.
CHAPTER 7. REFERENCES


