

Project Title and NPB project identification number: Impact of Finishing Facility Environment on Feed Efficiency, #PR-005316

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Industry Summary:

Mortality, feed efficiency, and growth rates vary between groups of wean-to-finish pigs. It is broadly understood that indoor environment and management factors impact pig performance, but there is a lack of empirical, farm-based data to quantify the impact of each factor under commercial production conditions. To address this need, sensor technologies not commonly found in commercial finishing barns were deployed to monitor barn environmental conditions. Researchers monitored 16 pig barns in North Carolina with similar construction and in the same sow flow for three turns of pigs, except for one site which was monitored for two turns. Sensors measured temperature, humidity, carbon dioxide every 10 min in the barns. Ammonia levels were recorded every 10 min in six of the barns. In weeks 1 and 17 of the production cycle, water flow rate, feed pan coverage, airspeeds, particulate matter concentrations, and pig health observations were also collected. In week 17 for turns two and three oral fluid samples were collected to measure viral load. One water quality sample was tested per site. Daily mortalities and health treatments were obtained from farm records. Results showed that week after placement, season at placement, proportion of barn fill capacity, humidity, carbon dioxide, and temperature difference from setpoint significantly affected pig mortality rates. A model was developed to predict weekly mortality based on these factors. Overall, the study highlights which environmental conditions and management practices could be improved to help improve pig performance during the finishing phase.

Key Findings:

- Environmental sensors not commonly found in commercial finish barns were able to withstand the environment to retain precise measurements for two to three turns of pigs
- Weekly mortality rates were influenced by number of weeks after placement, season, proportion of barn fill capacity, season at placement, and indoor air temperature and quality
- Predictive model of weekly mortality had an $R^2 = 0.2372$ and an RMSE of 0.38%
- Management metrics and health observations varied between sites, highlighting the importance of the basics of pig and barn husbandry

Keywords: indoor environment, sensors, survivability, ventilation, wean-finish

Scientific Abstract:

The finishing phase of pig production represents an area of opportunity in the swine industry. Feed accounts for the majority of costs at this stage of production. Impacts of indoor environment quality and management strategies have been highlighted individually in scientific literature. This study aimed to evaluate these factors on a large-scale field experiment under commercial conditions. Sixteen wean-finish barns in North Carolina of similar age and construction were monitored. All sites were within the same sow farm flow with 14 barns having a pig capacity of 880 and 2 barns with 1440 head capacity. Each barn was mechanically tunnel ventilated and had radiant tube heaters, standard dry feeders, and a shallow pit that was either pull-plug (12 barns) or flush type (4 barns). Barns were monitored for three turns of pigs, with the exception of site E being monitored for two turns. The same service technician and veterinarian serviced all sites. Sensors to measure temperature, relative humidity, and carbon dioxide were placed at the front and back of each barn to measure these parameters every 10 min. Ammonia was also recorded every 10 min in one barn per site and waste management system type, for six barns total. At week one and week 17 during the finishing period additional measurements of feed pan coverage, water flow rates, particulate matter, airspeeds, and pig health observations were collected. In week 17 for turns two and three oral fluids were collected via cotton ropes and tested for Influenza A, PEDV, PRRSV, and *M. hyopneumoniae*. One water quality sample was tested per site. Daily mortalities and pig treatments including vaccinations, NSAIDs, and antibiotics were recorded. A longitudinal generalized linear mixed model (GLMM) was developed to relate weekly mortality rates to measured conditions. Statistically significant factors were week after placement ($p < 0.0001$), proportion of barn fill capacity ($p = 0.0019$), season ($p < 0.05$), average relative humidity at the front of the barn ($p < 0.0001$), variation in relative humidity at the front of the barn ($p < 0.0001$), temperature difference from setpoint at the back of the barn ($p < 0.0001$), average ($p = 0.0049$) and variation ($p = 0.0011$) in CO_2 at the front of the barn, variation in CO_2 at the back of the barn ($p < 0.0001$), and a tendency for variation in temperature at the front of the barn ($p = 0.052$). Pigs placed during the Summer (June, July, August) had lower mortality compared to Winter ($p < 0.001$), Spring ($p < 0.001$), and tended to have lower mortality compared to Fall ($p = 0.0574$). Spring placement groups had greater mortality compared to Fall ($p < 0.0001$) and Winter ($p = 0.0110$), but no differences were detected between pigs placed in Winter and Fall. The model had an $R^2 = 0.2372$ and an RMSE of 0.38%. Ten percent of measured nipple water flow rates were below 1 L min^{-1} . Respirable dust ($< 2.5 \mu\text{m}$) measurements were below the recommended OSHA 8 hour time weighted average limit for humans ($5000 \mu\text{g m}^{-3}$) in 3.7% of measurements recorded, with no measurements for total dust ($< 10 \mu\text{m}$) above the recommended limit ($15000 \mu\text{g m}^{-3}$). Results provide insight into quantitative relationships between environmental and management factors and finishing pig performance, highlighting opportunities for improved efficiencies.

Introduction:

Pig feed is expensive. As feed costs account for approximately 60% of total expenses for finishing pigs, reducing feed costs provides an opportunity to improve financial viability of swine production systems (Pomar et al., 2009). One method to reduce feed costs is to optimize the production environment to improve feed efficiency. Excluding genetic factors, finisher pig growth has been correlated with environmental conditions such as air temperature, ammonia (NH_3) and carbon dioxide (CO_2) concentrations, dust, feeder space, pig health, and stocking density (Drummond et al., 1980; Gaines et al., 2012; Lee et al., 2005; Patience et al., 2015). It is widely accepted in the scientific community that these parameters influence productivity, but the specifics of how great their individual and combined influences may be is not well understood. Feed conversion ratio can vary as much as 30 points within a single sow flow (personal communication, North Carolina production system), demonstrating that

there are opportunities to optimize facility environments. A detailed understanding of the specific environmental differences between high and low performing facilities is needed to understand how environmental conditions influence the differences in feed efficiency. This large-scale commercial research project targeted enhanced understanding of these environmental factors and their influence on feed efficiency.

If the specific impacts of varying environmental conditions are understood, then the financial implications of different management strategies can be estimated. There are trade-off costs associated with environmental conditions and pig productivity and growth. Once these precise relationships are understood, a financial analysis can provide information on how changes in feed conversion may influence the overall facility profitability to enhance decision making for management strategy selection.

A better understanding of how environmental parameters influence production will enable producers to prioritize specific aspects of facility management and grading strategies. This will inform best practices for in-barn data collection by prioritizing sensor types to be purchased and acceptable ranges of readings for more intelligent control systems. Greater, more uniform feed efficiency can reduce input resources, streamline feed and pig movements, as well as reduce pig waste volume and nutrients. This study aims to inform producers on where to focus their efforts and strategies to reduce variation in feed efficiency by reducing sources of variation or impact of the variation between facilities, with a focus on reducing feed costs.

Objectives:

1. Deploy sensor technologies not commonly found in commercial finishing barns to monitor barn environmental conditions.
2. Relate finishing barn environment to growth, feed intake, and caloric efficiency.
3. Identify where production systems should focus their efforts to reduce finishing feed cost.

Materials & Methods:

Sites and Barns

A single sow flow with historical variation in finishing mortality from a commercially integrated system was selected for study. Grow-finish sites were all located in eastern North Carolina, USA and barns were of comparable age and construction. All sites were serviced by the same service technician and veterinarian. Five of the seven sites in the flow were selected to capture year-round placement dates of pigs. On each site a subset of barns was selected for observation with no prior researcher knowledge of individual barn or site performance. In total, there were 16 barns observed with each barn housing three turns of pigs, with the exception of Site F with two turns of pigs (Table 1). Each site utilized dry 5-hole feeders and mechanical tunnel ventilation systems with emergency drop sidewall curtains. Radiant tube heaters provided supplemental heat as needed. All barns were shallow pit and manure management systems were either pull-plug (manually emptied every 7 d) or flush systems (automatically emptied approximately twice per d).

Table 1. Five wean-finish sites from a single sow flow were selected for observation. A subset of barns on each site were monitored for a total of 16 barns.

Site	Number of Barns Total	Number of Barns Observed	Capacity (hd)	Manure System	Turns Observed
A	12	2	880	Pull-plug	3
		4	880	Flush	3
B	4	2	1440	Pull-plug	3
C	10	4	880	Pull-plug	3
D	8	2	880	Pull-plug	3
E	4	2	880	Pull-plug	2

Pigs and Husbandry

Pigs were placed in the grow-finish facilities at weaning, approximately 21 d of age. Approximately 1600 pigs were placed each week, resulting in some barns being totally filled in one week while other weeks had only partial fills (i.e., new pigs were placed in the same barn twice, 7 d apart). Pigs were first marketed in approximately week 18, with all pigs removed in week 23 or 24 to allow for cleaning and disinfecting before the next turn of pigs.

All pigs were from a single PRRS positive sow farm located in eastern NC. Pigs were provided comfort mats and mat feeding for the first week after placement. Pigs were vaccinated after placement and an additional vaccination given part-way through the finishing period. Health diagnostics and treatments were administered on an as-needed basis under the guidance of a single veterinarian.

Sensors

Dry-bulb temperature (T), relative humidity (RH), and carbon dioxide (CO₂) sensors were installed in the front and back of each barn in the first week of pig placement. Sensors were mounted near the ceiling above the first and last pen in the barn to ensure consistent measurement locations. In the first turn Temco sensors were used exclusively (CO₂-W-TH, Tempco Controls, Ltd., Spokane, WA 99223); however, the CO₂ in the back of the barn exceeded the sensor's range. Beginning in the second turn sensors with greater CO₂ measurement range (DOL139, dol-sensors, Aarhus, Denmark) were used in the back of the barns. A DOL 52 ammonia sensor was mounted 1.2 m above the floor of the last pen in six of the barns, with one sensor per site and manure system type. All sensors collected data every 10 min for each turn of pigs from approximately week 1 (placement) to week 23 (one week prior to final closeout). Sensors were removed before the barns were emptied, cleaned and disinfected, and reinstalled for the subsequent turn of pigs. Analog dataloggers (MX1105, Onset Computer Corporation, Bourne, MA) recorded all voltage outputs for post-processing. All sensors were checked for agreeance and calibration in a laboratory setting prior to each deployment. Ammonia sensor cartridges were replaced after two turns of pigs.

Intermittent Observations

In weeks 1 and 17 additional measurements were recorded during site visits to capture quantitative and qualitative information related to pig health, facility operation, and husbandry.

Feed Pan Coverage

Feed pan coverage was collected in all pens twice per turn at weeks 1 and 17. The estimation of feed pan coverage was based on the extent to which the bottom of the feed pan was covered with feed. Feed pan coverage percentages varied between 0 and 100, representing the percentage of the pan's bottom surface area covered. Dry type stainless steel feeders were used at all sites.

Water Quality Analysis

A singular water quality sample was analyzed at each of the five sites. Researchers gathered a pooled sample of 0.355 L from two barns at each site from at least four water nipples. Samples were taken under typical operating conditions when no water-soluble medication was being administered. Samples were promptly placed in a cooler to maintain integrity and transported to the North Carolina Department of Agriculture State Agronomy Laboratory for analysis. Standard quality assessments and analysis for heavy metal content were performed.

Water Flow Rate

Each pen had a single suspended water source with two nipples. To measure the flow rate a water bottle of known volume was filled by one researcher while a second researcher timed the event with a stopwatch. Both nipples were measured to the nearest second and water flow rates were averaged per pen. Approximately 20% of the pens' water flow rates were measured (Fig 1).

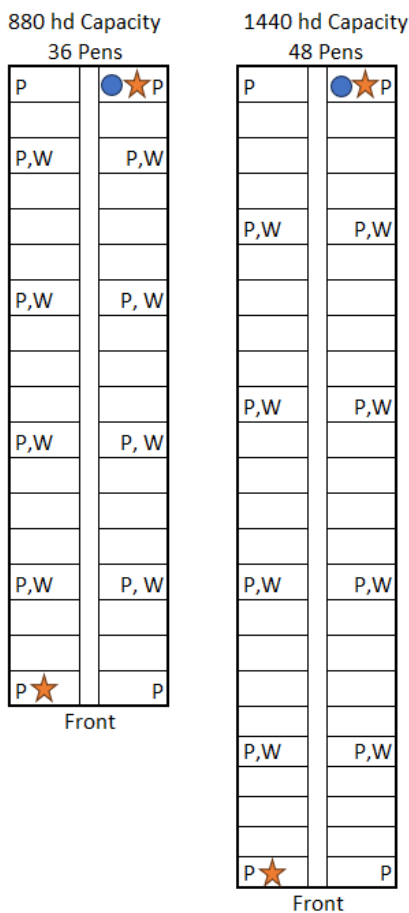


Figure 1. Layouts of the 880 and 1440 hd capacity barns. Letters indicate pens where particulate matter (P) and water flow rates (W) were measured. Orange stars indicate CO₂, relative humidity, and temperature sensor placement while the blue circles indicate ammonia sensor locations.

Airspeeds

A handheld anemometer (Kestral 3000, Nielsen-Kellerman Co., Boothwyn, PA) was used to measure airspeed at the ceiling inlets or endwall curtains, depending on ventilation stage. At the ceiling inlets airspeed was measured on each side of the quad ceiling inlet for the specified pen. Curtain airspeed and opening height were measured on both the left and right sides at the front of the barns, with three measurements obtained for each side.

Particulate Matter

An accredited particulate matter counter (CEM DT-9880, CEM Corporation, Matthews, NC) was used to measure dust particle sizes ranging from 0.3 μm to 10 μm . Measurements were taken at pig height (approximately 0.4 m in week 1, 1 m in week 17) with the researcher positioned in the middle of the pen facing towards the sidewall curtains during sampling. A fresh air sample was taken in between barns.

Oral Fluids

Oral fluids were collected for viral analysis at week 17 of the study for turns two and three. Cotton ropes were utilized for virus testing, with each rope securely tied to the divider panel between two pens. Ropes were placed one-fourth, halfway, and three-fourths of the way down the barn. Pigs had access to the ropes for approximately 30 min. Then, saliva was milked from the ropes into a single plastic disposable bag, mixed, and a subsample of 45 mL was poured in a 50 mL centrifuge tube. Saliva samples were promptly stored in a cooler and sent to the Veterinary Diagnostic Laboratory in Ames, IA to be tested for Influenza A, PEDV, PRRSV, and M. hyopneumoniae.

Production Information

Information on vaccinations, medical interventions, and daily mortalities were obtained from farm records.

Health Observations

Qualitative health assessments involved a range of parameters including the incidence and severity of coughing, sneezing, aberrant respiratory patterns, level of alertness, fecal consistency, occurrences of tail and flank injuries, presence of scratches, hernias, and severe wounds. Number and severity (none, mild, moderate, severe, extreme) were recorded for each category.

Data Analysis

Indoor Environment Modeling

Occasional hardware failure resulted in missing environmental data measurements. If one of the sensors within the barn remained operational, linear regressions were used to backfill missing data using the working sensor data, site, and barn information with high reliability ($R^2 > 0.73$ for all metrics). Data were cleaned and any zero readings from sensor power outages were removed. The primary focus of indoor environmental monitoring was on mortality prediction, as mortalities are a main indicator of feed efficiency and performance (Agostini et al., 2014; Gebhardt et al., 2020). To account for the lag effects of indoor environment on mortality the data were summarized on a weekly basis. Ambient weather data were obtained from the North Carolina Climate Office's online database to contextualize environmental conditions during the study period. Due to occasional weather station downtime, three nearby weather stations were used to create a complete dataset.

Temperature was evaluated as difference from desired setpoint, T_{diff} (PIC UK Ltd., 2019). The weekly mean and standard error values were calculated for T_{diff} , RH, CO_2 , and NH_3 . Weekly minimum and maximum values were excluded due to their strong correlation with average values. A longitudinal generalized linear mixed model (GLMM) was used for analysis to account for the time series and proportion relatedness of the weekly mortality data. Survivability was transformed using a logit link function and all inputs were scaled. The full model

included mean and standard error for T_{diff} , RH, CO_2 , weeks after placement, season, proportion of fill capacity, site, and barn, with weekly proportion of mortality (weekly losses divided by total head) as the response.

Observational Data

Manually recorded data were only collected twice per turn, making them unsuitable for inclusion in the mortality model with the continuous environmental data. Instead, the observational data were investigated separately to further explore site and barn differences discovered in the mortality/indoor environment model. Each metric was compared within and across site, barn, turn, and week of observation.

Results:

1. Deploy sensor technologies not commonly found in commercial finishing barns to monitor barn environmental conditions.

In this study several types of sensors were tested in commercial swine barns. While this was a relatively short study of only three turns of pigs spanning approximately 18 months, overall, the sensors held up better than expected in the challenging environment. The majority of the hardware failures were due to corroded batteries in the data loggers or user error when launching the loggers. For real-time, long-term barn monitoring an alternative data logger system is recommended. While this was a simple system for quick deployment in this research project, utilizing a hard-wired system would be more robust long term. Internet and cellular connectivity remain a challenge on many farms, especially the ones in this study, so real-time data access was not possible.

Over the course of this study one set of sensors were pressure washed, rendering them a loss. Otherwise, all sensors were removed before cleaning and hand-cleaned in the lab and checked for agreement prior to re-deployment. The lower-grade Tempco sensors required replacement after approximately two turns of pigs, likely due to their external sensor probes. The DOL sensors had a lower failure rate at re-deployment. The ammonia sensor cartridges were determined reliable for research-level precision for two turns of pigs before being replaced.

The placement of the sensors near the ceiling likely contributed to the longevity of the sensors in this study. Placing sensors closer to pig height would have resulted in more pig-representative condition measurements; however, with 16 barns we opted to place the sensors in a more conservative location as we were not able to visit each barn frequently to adjust position or ensure operation. Sensor placement likely influenced measurement outcomes due to stratification within the barn, but the correlation of measurements and consistency of placement ensured reliable comparisons between barns and sites.

2. Relate finishing barn environment to growth, feed intake, and caloric efficiency.

Mortality is a major indicator of performance and a significant driver of costs and feed efficiency, and therefore was the focus of our productivity analysis. The final model to predict weekly mortality was:

$$\text{Losses/Head} \sim \text{Week} + \text{Site} + \text{Site:Barn} + \text{PropCapacity} + \text{Season} + \text{RH_F_Avg} + \\ \text{RH_F_SE} + \text{Tdiff_B_Avg} + \text{Tdiff_F_SE} + \text{CO2_F_Avg} + \text{CO2_F_SE} + \text{CO2_B_SE}$$

Where

Week = Weeks after placement

Site = Site of production

Barn = Within site, the specific barn

PropCapacity = Proportion of fill capacity, weekly basis

Season = Season at placement. Summer: June, July, Aug. Fall: Sept, Oct, Nov. Winter: Dec, Jan, Feb.

Spring: March, April, May.

RH_F_Avg = Relative humidity at the front of the barn, average
 RH_F_SE = Relative humidity at the front of the barn, standard error
 Tdiff_B_Avg = Temperature difference from set point at the back of the barn, average
 Tdiff_F_SE = Temperature difference from set point at the front of the barn, standard error
 CO2_F_Avg = CO₂ at the front of the barn, average
 CO2_F_SE = CO₂ at the front of the barn, standard error
 CO2_B_SE = CO₂ at the back of the barn, standard error

Table 2. Model effects, intercepts, and p-values. Site and barn intercept values are shown in Table 3.

Factor	Intercept	P-value
Week	-0.2076	4.06E-02
PropCapacity	-1.422	0.00194
Season ¹		
Spring	0.61	3.43E-08
Summer	-0.43	0.01185
Winter	0.51	0.72896
RH_F_Avg	1.173	7.46E-10
RH_F_SE	1.031	6.53E-09
Tdiff_B_Avg	-2.1040000	< 2.2e-16
T_F_SE	-0.3319000	0.052139
CO2_F_Avg	0.0001688	0.004853
CO2_F_SE	-0.7452	0.001054
CO2_B_SE	0.7208	1.69E-05

¹ As compared to baseline Fall season

Site and barn effects are described by the mortality rate intercept values, associated with each individual barn when all other factors are equal to zero (Table 3). Results span from 0.006% to 0.014%, with the barn intercept values being of 10 times greater magnitude than site intercept values. Differences between sites is likely attributed to management and husbandry differences, and potentially related to pig placement quality metrics not well described by only the number of no value/reject pigs at placement. Differences between barns within sites suggest individual facility differences not captured by only indoor environment conditions. Feed deliveries and water line delivery are individual barn qualities that were not measured in this study but could have contributed to these differences. As barns were filled on consecutive weeks it was expected that site and barn pairs would have similar starting pig quality; however, this was not necessarily the case, suggesting there are additional differences between individual barns not well captured with these data.

Table 3. Mortality rate intercept values for each site and barn combination.

Site	Barn	Mortality Rate Intercept, %
C	2	0.006
C	1	0.007
A	4	0.007
D	1	0.008
C	4	0.008
B	2	0.009
E	2	0.009
A	5	0.009
A	6	0.009
A	3	0.009
A	2	0.010
D	2	0.010
C	3	0.011
E	1	0.013
B	1	0.013
A	1	0.014

As week increases the weekly mortality decreases in the model. This was expected as the greatest mortality rates occur three to seven weeks after placement. Weaning and transport stress make pigs more susceptible to illness and the most common health challenges during this period have a 7 to 14 d incubation period. It may take several days or weeks for a pig to succumb to the delayed effects of these stressors or cumulative challenges, explaining the peak in weekly mortality rates around this time (Fig 2).

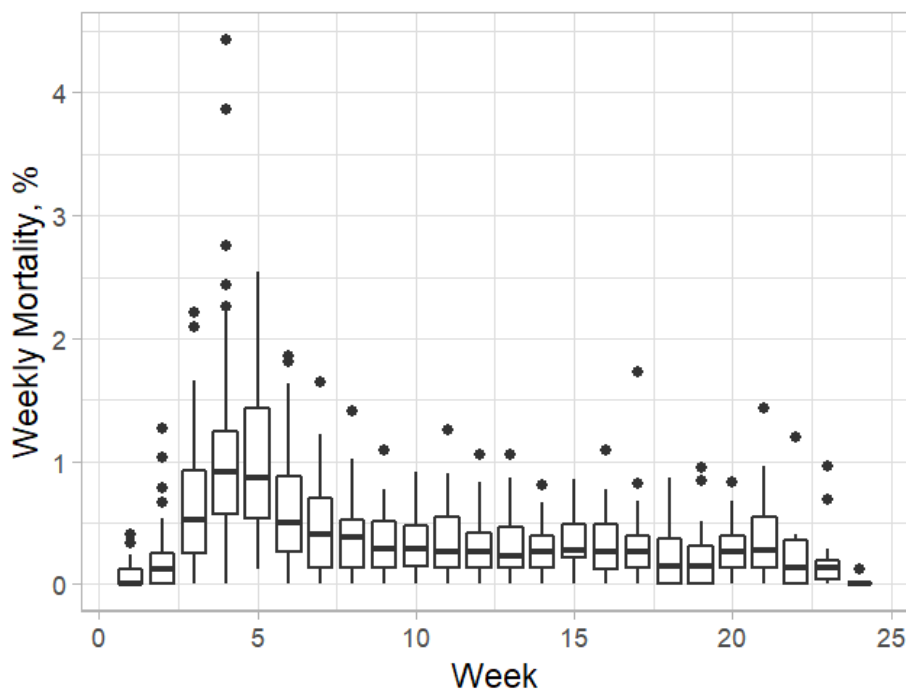


Figure 2. Weekly mortality percentages by week after pig placement.

The proportion of fill capacity was calculated each week based on the number of pigs in the barn compared to the number of design pig spaces in the barn. The model's intercept was negative, meaning that as proportion of fill capacity increases weekly mortality decreases. Fill capacity can be an indicator of stocking density, especially in later weeks as the pigs approach full size. However, in this dataset all barns were at or below design stocking density by week 6. Fill capacity may be more indicative of pig quality at placement, as lower health weaned groups would likely have fewer weaned piglets and result in lower fill capacity. Low-health pigs at weaning would as a result also have higher mortality rates during the finishing period.

Pigs placed during the Summer season (June, July, August) had lower mortality as compared to pigs placed in Winter ($p < 0.001$), Spring ($p < 0.001$), and tended to have lower mortality compared to Fall ($p = 0.0574$). Spring placement groups had greater mortality compared to Fall ($p < 0.0001$) and Winter ($p = 0.0110$), but no differences were detected between pigs placed in Winter and Fall. In eastern North Carolina disease pressures tend to be greatest in Fall and Winter, agreeing with these results. Further, pigs placed in warmer summer months likely had warmer barn environments at placement as little to no supplemental heat was needed to maintain desired setpoint, reducing thermal stress at weaning and resulting in better pig outcomes.

At the front of the barn, the significant environmental factors were relative humidity average ($p < 0.0001$) and standard error, CO₂ average and standard error ($p < 0.0001$), and a tendency for temperature standard error ($p = 0.0521$). The front sensor was placed in the first pen of the barn, so these terms are likely related to the impact of tunnel mode on air quality. When the tunnel curtain is used for ventilation the influx of fresh air has lower humidity and CO₂ and increases the variance in CO₂ and temperature, which the model suggests reduces mortality. However, the intercept reports an increase in relative humidity standard error at the front of the barn increases mortality, which is counter to this interpretation. This deviation could be explained using wet bulb temperature to combine the temperature and relative humidity impacts; however, we opted to analyze dry bulb temperature and humidity separately to allow for direct interpretation of results.

At the back of the barn the temperature average difference from setpoint ($p < 0.0001$) and CO₂ standard error ($p < 0.0001$) significantly influenced weekly mortality. The temperature difference was calculated as actual minus desired setpoint, meaning that average weekly temperatures below setpoint increase mortality. It is important to note that the facilities in this study utilized radiant tube heaters, which by design heat surfaces rather than the air directly.

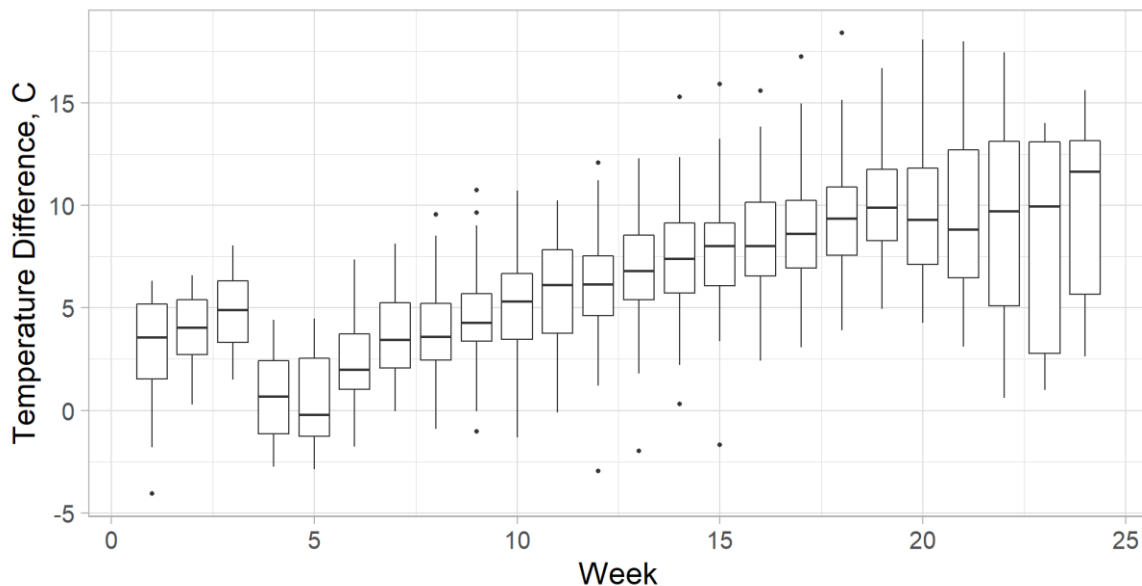


Figure 3. Weekly average actual temperature at the back of the barns minus set point temperature.

Utilizing the developed model, predictions were made for weekly mortality for each set of barn data. Predicted mortality as compared to actual mortality for each turn can be seen in Figure 4. The model was least accurate in weeks 4 and 5 (Fig 5), demonstrating that there are additional factors beyond indoor environment that influence peak mortality rates. Overall, the predicted model had an R^2 of 0.2372 and an RMSE of 0.38%. The data collected and modeled in this project demonstrate the potential to predict wean-finish mortality, but additional factors are needed to account for group-to-group variation not well captured with these observed variables.

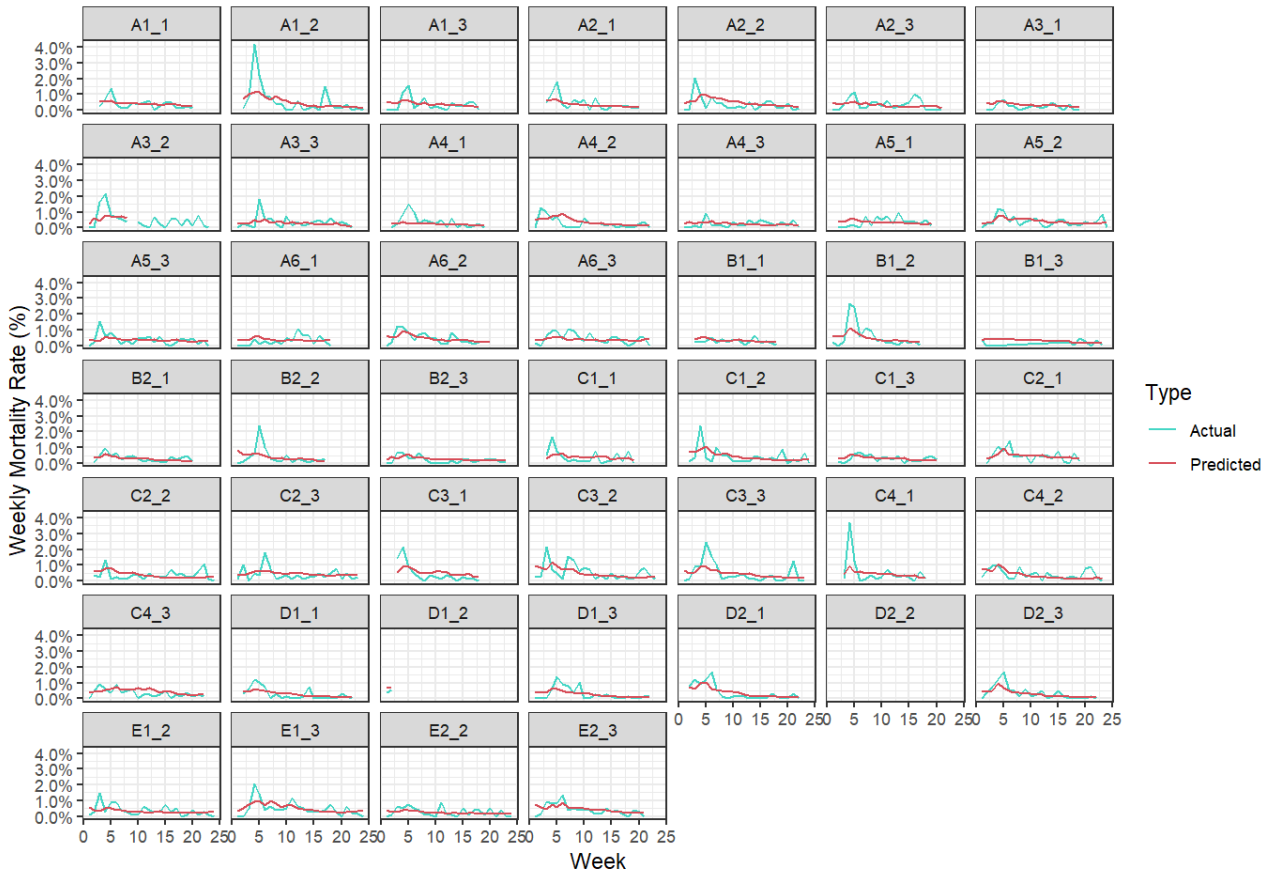


Figure 4. Predicted (red) and actual (blue) weekly mortality rates for each barn and turn. Each group is labeled as SiteBarn_Turn.

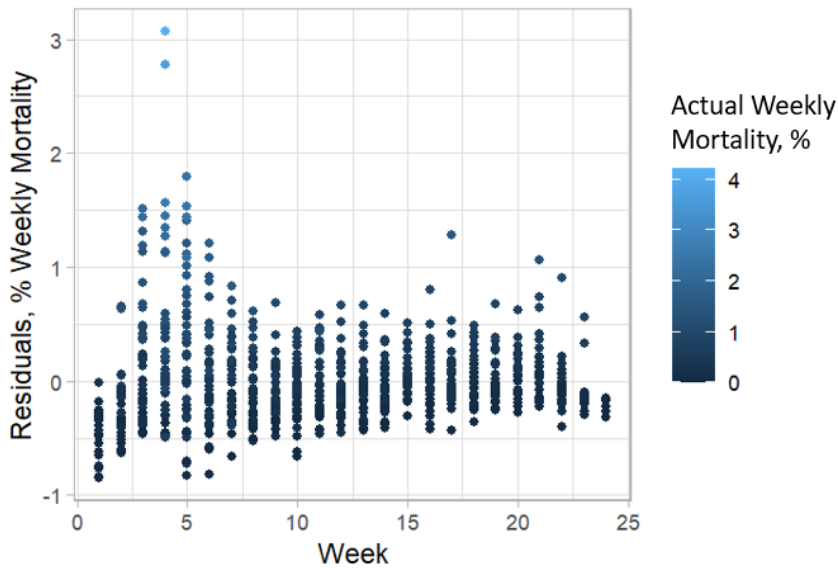


Figure 5. Residual (actual minus predicted) plot for predicted weekly mortality.

Ammonia sensors were placed in one barn per site and weekly ammonia levels were modeled (Fig 6). There was no impact of waste management system type on ammonia levels ($p = 0.9992$). Three weeks (1%) resulted in average ammonia values greater than the recommended 20 ppm. The overall average ammonia concentration was 8 ppm.

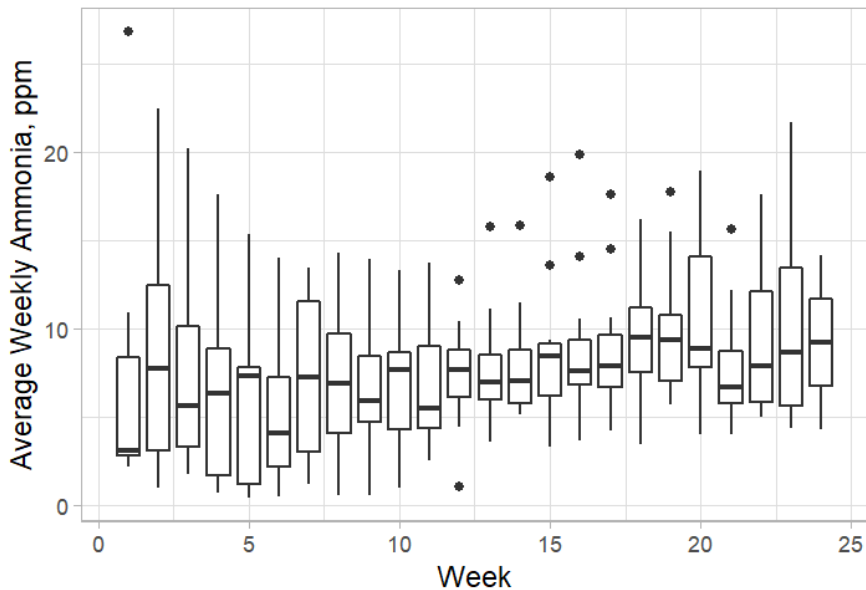


Figure 6. Average weekly ammonia concentrations.

3. Identify where production systems should focus their efforts to reduce finishing feed cost.

Feed Pan Coverage

Feed is a major cost in finishing pig production, suggesting the importance of consistent provision of feed and managing feed pan coverage. On 15% of the farm visits at least one pen had high (> 80%) feed pan coverage and/or spillage. This occurred at all sites observed at least once, with site B having the greatest incidence. However, in the majority of these cases it was noted that the pelleted feed was crumbly and had many fines, suggesting the overflow was not solely due to feeder management. Regardless of reason, high feed pan coverage presents an opportunity to improve efficiency.

Water Quality

Water quantity and quality are important factors for determining pig performance. In the water quality tests performed in this study, no heavy metals (Arsenic, Cadmium, Chromium, Nickel, Lead, Selenium) were detected at any site (Table 4). All sites were similar in water quality metrics and within the recommended ranges with the exception of site B. The pH at site B was lower, 4.22, compared to the average 7.71 of the other four sites. Site B had greater iron and sulfur concentrations than other sites, likely contributing to the lower pH. Water samples were pulled directly from the in-barn water nipples when no water-soluble medications were being administered, so it is unknown if the low pH is due to well water quality or the water lines/distribution system. All sites, including site B, utilize water soluble medications as needed, including citric acid, so knowledge of the pH at each site is necessary for determining proper dilution rates.

Table 4. Water quality results from one pooled sample per site, collected at pig water nipples.

Site	Hardness	Nitrate	Sulfur	Iron	Sodium	pH	
	(ppm CaCO ₃)	(ppm NO ₃ -N)	(ppm)	(ppm)	(ppm)		
	Recommended	< 120 ^{1,2}	< 100 ppm ⁴	< 1,000 ^{1,2}	< 10.0 ^{1,4}	6.5 – 8.5 ^{1,2,3}	
A		106	0.00	1.65	0.07	4.82	7.67
B		46.8	1.29	22.6	5.06	10.4	4.22
C		106	0.14	1.09	0.01	11.8	7.70
D		118	0.00	0.46	0.00	5.82	7.72
E		139	0.21	1.21	0.01	16.0	7.75

¹ Romoser et al., 2022

² Menegat et al., 2019

³ University of Wisconsin College of Veterinary Medicine, 2008

⁴ Alltech, 2017

Water Flow Rates

Water flow rates were measured during week 1 and week 17. None of the sites implemented water pressure adjustment protocols during the production cycles. Of the 1,492 water nipple flow rates measured, 4 nipples (0.3%) had no water flow. In each case, the nipple had water flow at the next measurement timepoint. At the first week measurement 27 nipples (4%) had flow rates below the recommended nursery placement flow rate of 0.5 L/min. At the week 17 measurements 74 nipples (10%) were below the recommended finishing pig flow rate of 1 L/min. Low flow nipples represent an opportunity to improve growth, especially during warm summer months when water usage is expected to be greater. At least one leaking nipple were reported on 11% of site visits. Visual observations suggest extra attention to cleaning of water nipples during washing and disinfection between turns could be an opportunity to improve piglet outcomes at placement.

Airspeeds

Airspeeds were measured at either the ceiling inlets during lower ventilation stages or the endwall curtain during tunnel ventilation stages. As anticipated, measured speeds varied with fan stage, ambient conditions, and indoor setpoint. Site B barns had greater design capacity of 1440 head versus 880 head at the other sites, with a total barn length of approximately 204 ft compared to the 150 ft length of the smaller barns.



Figure 7. Airspeeds in feet per minute as measured at the curtain (left) and ceiling inlets (right).

Dust Concentrations

Dust concentrations can present challenges to both pig and caretaker health. Generally, dust concentrations were greater in week 17 than week 1 (Fig 8). Respirable dust ($< 2.5 \mu\text{m}$) measurements were below the OSHA 8 hour time weighted average limit for humans ($5000 \mu\text{g}/\text{m}^3$) in 3.7% of measurements recorded, with no measurements for total dust ($< 10 \mu\text{m}$) above the recommended limit ($15000 \mu\text{g}/\text{m}^3$). It is important to note that researchers entered the pen with the pigs to collect dust measurements, resulting in increased pig activity and introducing bias into measurement results.

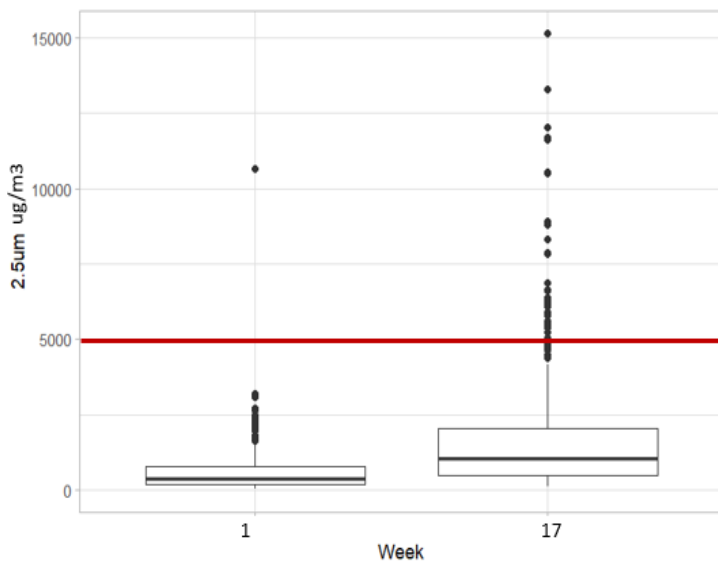


Figure 8. Respirable dust concentrations as measured in weeks 1 and 17. The OSHA 8 hr TWA limit of 5000 $\mu\text{g m}^{-3}$ is represented by the red horizontal line.

Oral Fluids

Oral fluid tests were conducted in week 17 in turns 2 and 3, with one pooled sample per barn. The sow farm was a PRRS positive herd, so it was expected to see positive PRRSv results. PRRSV1 was detected 19 times, PRRSV2 9 times, PED 11 times, M. hypo 3 times, and Influenza A 3 times. Of the 30 barns tested, 13 tests had more than one virus detected and 3 tests were negative for all viruses. The oral fluid results did not correlate well with the clinical observations made during weeks 1 or 17; however, the cotton rope sampling method deployed in this study creates bias towards healthier animals, as clinically ill pigs likely would not voluntarily engage with the rope for sample collection.

Health and Treatments Administered

Other health observations included the frequency and severity of hernias, tailbiting, and injury. These were observed at low incidence (0.13%, 0.27%, and 0.28% of pigs observed, respectively). Presence of hernias, tailbiting, or injuries within barn were not significantly correlated with mortality ($p > 0.10$).

The number of treatments given per group were summarized and calculated based on treatments per head per day (Fig 9). Groups with less than 120 days of treatment data were excluded. All treatment types were lumped together and included vaccinations, citric acid, NSAIDS, and antibiotics. Number of treatments per head per day ranged from 0.03 to 0.14, with an average of 0.07. There was no correlation between treatments per head per day and mortality ($R^2 = 0.0025$). The wide range for number of treatments represents major differences in cost of production. Site E tended to use fewer treatments compared to the other sites, yet had similar cumulative mortality outcomes. Site E did have the fewest pigs per site of the studied locations; however, the caretakers at this site also managed pigs at another location not included in this study. Earlier identification of health challenges or better biosecurity likely influenced the lower treatment values at site E.

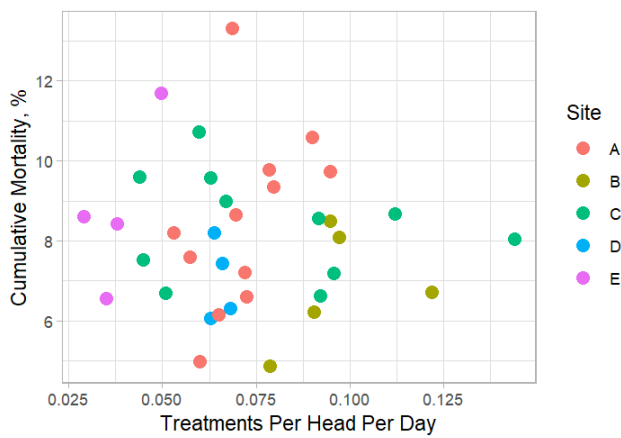


Figure 9. Cumulative mortality per group vs treatments per head per day. Treatment types included vaccinations, citric acid, NSAIDS, and antibiotics.

Discussion:

Indoor environmental conditions and management practices influence pig growth and subsequently production efficiency and profitability. While existing scientific literature have explored various factors individually, this large-scale field study aimed to quantify the impacts of these factors in conjunction in on-farm production scenarios. To investigate this question, the first step was to deploy sensors not typically found in commercial finishing barns. While temperature is usually monitored to automate ventilation management, additional temperature sensors, relative humidity, carbon dioxide (CO₂), and ammonia sensors were deployed in the pig space in this study. Ammonia sensor lifespan was determined as two turns of pigs, while the combination temperature, relative humidity, and CO₂ sensors remained reliable after two or three turns. There were some sensor failures and inconsistencies due to drift over time, as not all CO₂ sensors passed calibration agreement for a third deployment. One barn experienced multiple unresponsive sensors and dataloggers, suggesting localized dirty power and the need for an uninterrupted power supply. Removal of the sensors prior to cleaning and disinfection between turns of pigs was critical to sensor longevity. This study demonstrates the feasibility of mid- to long-term monitoring of swine barn environmental conditions with electrochemical sensors.

A model was developed to relate mortality, a key driver of feed efficiency, to indoor environmental conditions. Statistically significant factors were week after placement ($p < 0.0001$), proportion of barn fill capacity ($p = 0.0019$), season ($p < 0.05$), average relative humidity at the front of the barn ($p < 0.0001$), variation in relative humidity at the front of the barn ($p < 0.0001$), temperature difference from setpoint at the back of the barn ($p < 0.0001$), average ($p = 0.0049$) and variation ($p = 0.0011$) in CO₂ at the front of the barn, variation in CO₂ at the back of the barn ($p < 0.0001$), and a tendency for variation in temperature at the front of the barn ($p = 0.052$). The number of rejected pigs at placement was not significant, suggesting that a more comprehensive metric such as group prewean mortality, total number of pigs weaned, or average bodyweight at placement may be needed to better describe pig quality at placement (Magalhães et al., 2022). Overall, the predicted weekly mortality model had an R² of 0.2372 and an RMSE of 0.38%. The data collected and modeled in this project demonstrate the potential to predict wean-finish mortality, but additional factors are needed to account for group-to-group variation not well captured with these observed variables.

Quantitative and qualitative observations were collected on various environmental and management factors with an emphasis on metrics related to feed efficiency. Feed pan coverage and individual feeder management were limited by pellet quality. Ten percent of water nipple flow rates were below the recommended 1 L/min for finishing pigs. Regular inspection of nipples is needed to validate water flow rates for optimum pig performance, especially in late finishing and during heat stress events. All sites were located in a similar geographic area and

water quality results were similar for four of the five sites. The fourth site had comparatively greater iron concentrations and a lower pH of 4.22. Water pH can influence the administration rates and efficacy of water-soluble health treatments. As changes in well water quality are typically gradual in nature, periodic testing can confirm conditions and provide timely information on needed interventions. Particulate matter concentrations were below the recommended limits in 96.3% of measurements for respirable dust and 100% of measurements for total dust concentrations. Concentrations of particulate matter of all sizes were greater in late finishing than early finishing. Health observations and viral loads as determined by oral fluid tests were not well correlated. Viral pathology within large populations can be complex, especially within an endemically impacted herd such as this PRRS positive pig flow. Overall frequency and severity of hernias, tailbiting, and injuries collected in weeks one and 17 were low and not correlated with mortality rates ($p > 0.1$). Number of medical treatments per pig per day was variable and not correlated with overall group mortality ($R^2 = 0.0025$). This area is worthy of further investigation, as treatments represent a major cost to production systems.

Results from this study provide benefit to producers by further enhancing understanding of environmental and management impacts on finishing pigs. Indoor environmental conditions are key contributors to finishing pig mortality, specifically the temperature deviation from setpoint and air quality as described by relative humidity and carbon dioxide. Study results demonstrate the impacts of management of feed, water, air, and health interventions on mortality, and thus production efficiency and financial profitability.

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