Heat lamps and heat mats in the farrowing house: Effect on piglet production, piglet and sow behavior and energy usage

Karli Lane
Iowa State University

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Heat lamps and heat mats in the farrowing house: Effect on piglet production, piglet and sow behavior and energy usage

by

Karli Jessica Lane

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

MASTER OF SCIENCE

Major: Animal Science

Program of Study Committee:
Kenneth J. Stalder, Co-major Professor
Anna K. Johnson, Co-major Professor
Jay D. Harmon
Locke A. Karriker

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 thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University
Ames, Iowa
2019

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAPTER 1. GENERAL INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Thesis Organization</td>
<td>2</td>
</tr>
<tr>
<td>Expected Outcomes and Practical Implications</td>
<td>3</td>
</tr>
<tr>
<td>CHAPTER 2. LITERATURE REVIEW</td>
<td>5</td>
</tr>
<tr>
<td>Pre-weaning Mortality within the U.S. Swine Industry</td>
<td>5</td>
</tr>
<tr>
<td>Neonatal Piglet Overview</td>
<td>6</td>
</tr>
<tr>
<td>Thermoregulation</td>
<td>6</td>
</tr>
<tr>
<td>Factors Affecting Pre-weaning Mortality</td>
<td>8</td>
</tr>
<tr>
<td>Overview of the Sow during Lactation</td>
<td>10</td>
</tr>
<tr>
<td>Factors Affecting Pre-weaning Mortality</td>
<td>13</td>
</tr>
<tr>
<td>Farrowing House Environment Overview</td>
<td>18</td>
</tr>
<tr>
<td>Heat Sources</td>
<td>19</td>
</tr>
<tr>
<td>Energy Usage</td>
<td>23</td>
</tr>
<tr>
<td>Factors Affecting Pre-weaning Mortality</td>
<td>23</td>
</tr>
<tr>
<td>CHAPTER 3. COMPARISON OF HEAT LAMPS AND HEAT MATS IN THE FARROWING HOUSE: EFFECT ON PIGLET PRODUCTION, ENERGY USAGE AND PIGLET AND SOW BEHAVIOR THROUGH DIGITAL OBSERVATION</td>
<td>42</td>
</tr>
<tr>
<td>Introduction</td>
<td>44</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>45</td>
</tr>
<tr>
<td>Animals, Location and Housing</td>
<td>45</td>
</tr>
<tr>
<td>Treatments</td>
<td>46</td>
</tr>
<tr>
<td>Production Measures</td>
<td>47</td>
</tr>
<tr>
<td>Behavioral Evaluation</td>
<td>47</td>
</tr>
<tr>
<td>Electrical Usage</td>
<td>48</td>
</tr>
<tr>
<td>Statistical Analysis</td>
<td>48</td>
</tr>
<tr>
<td>CHAPTER 4. COMPARISON OF HEAT LAMPS AND HEAT MATS IN THE FARROWING HOUSE: EFFECT ON PIGLET PRODUCTION, ENERGY USAGE AND PIGLET AND SOW BEHAVIOR THROUGH LIVE OBSERVATION</td>
<td>60</td>
</tr>
<tr>
<td>Introduction</td>
<td>61</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>63</td>
</tr>
<tr>
<td>Treatments</td>
<td>64</td>
</tr>
<tr>
<td>Production Measures</td>
<td>65</td>
</tr>
<tr>
<td>Behavioral Evaluation</td>
<td>65</td>
</tr>
<tr>
<td>CHAPTER 5. CONCLUSION</td>
<td>81</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>85</td>
</tr>
</tbody>
</table>
ABSTRACT
There is opportunity to capitalize on piglet and sow behavior in the farrowing to aide in the decrease of pre-weaning mortality. However, there is limited knowledge in the scientific literature concerning how supplemental heat sources affect piglet and sow behavior and performance during parturition and lactation. Additionally, the farrowing house represents a significant portion of energy usage in farrow-to-wean swine production. However, energy use studies have not expanded on the costs associated with providing different supplemental heat sources including implementation. The overall thesis goal was to create a comparison of heat lamps and heat mats as supplemental heat sources in the farrowing house to assist in the decision-making process. Therefore, three objectives were identified for the present study: 1) To evaluate piglet production measures including pre-weaning mortality, litter weaning weight and average daily gain, 2) To evaluate piglet behavior in respect to heat source usage and physical contact with the dam, as well as the sow’s behavior in relation to heat source placement and 3) To evaluate the energy usage of each supplemental heat source and create a cost analysis.

Observed results from these studies demonstrated that piglet production including litter weaning weight, litter average daily gain and pre-weaning mortality were not affected by supplemental heat source treatment type. In chapters 3 and 4, the study utilized crossbred pigs to evaluate piglet behavior in respect to heat source usage and physical contact with the sow and sow lying behavior. Sow and piglet behavior showed no difference based on supplemental heat source type therefore it suggests that factors other than supplemental heat source may be motivators for piglet behavior in the farrowing stall. In research chapters 3 and 4, a cost analysis was conducted using energy usage and initial implementation costs of two supplemental heat source types. Based on
these studies, substantial energy and cost savings can be achieved when heat mats are utilized as the supplemental heat source for the piglets from parturition through lactation and until weaning occurs. In conclusion, neither supplemental heat source has a distinct advantage from a productivity standpoint in the farrowing house, however heat mats offer an opportunity for energy and cost savings even though initial costs are substantially greater when compared to heat lamps.
CHAPTER 1. GENERAL INTRODUCTION

Pre-weaning mortality presents a major United States (U.S.) pork production inefficiency resulting in lost profit opportunities for producers and at a 20% pre-weaning mortality, has been estimated to cost $650- to $800 million annually (USDA, 2019). At birth, piglets are poorly equipped to deal with the environment outside of the sow. Piglets are susceptible to cold stress due to a lack of insulation, a large surface area to body weight ratio, lack of suitable energy reserves from brown fat and poor body thermostability at birth (English and Morrison, 1984). When the environmental temperature falls below 34°C the newborn piglet is subjected to cold stress and mobilizes glycogen reserves in the liver and skeletal muscles and nutrients supplied through the sows’ colostrum to increase its heat production (Johnson, 2001). Under cold stress, the piglet reduces its locomotion and soon becomes weak through starvation leading to decreased ability to avoid the restless movements of the sow (Aumaitre and Le Dividich, 1984; Arey, 1992). Once the piglet has exhausted its thermoregulatory mechanisms, it is up to the caretaker to provide warm, dry bedding and/or additional heat (Marchant-Forde, 2009). In conventional systems, caretakers can provide piglets with supplemental heat sources (lamps and mats) to try and keep the piglets warm and away from their mother to reduce pre-weaning mortality. Previous work by Stinn and Xin (2014) compared heat mats to heat lamps effects on piglet mortality, weaning weight (litter weight and piglet gain), and electric power use. The authors concluded that there was no difference in weight gain or mortality between the two heating systems, but there was a difference in energy usage, with heat mats using 36% less power compared to heat lamps. There is limited scientific knowledge in the literature that provides a perspective
on sow and piglet behavior in the farrowing house relative to heat lamp and heat mat supplementation. Given the production inefficiencies resulting from pre-weaning mortality and limited literature regarding sow and piglet behavior in the farrowing house in relation to a heat mat or heat lamp, this is a critical research area that could positively impact economics and pig welfare. The overall thesis goal was to create a comparison of heat lamps and heat mats as supplemental heat sources in the farrowing house to assist in the decision-making process. Therefore, three objectives were identified for the overall thesis goal: 1) To evaluate piglet production measures including pre-weaning mortality, litter weaning weight and average daily gain, 2) To evaluate piglet behavior in respect to heat source usage and physical contact with the dam, as well as the sow’s behavior in relation to heat source placement and 3) To evaluate the energy usage of each supplemental heat source and create a cost analysis.

**Thesis Organization**

This thesis is organized into five chapters. The first chapter is a general introduction to providing supplemental heat sources in the farrowing house. The second chapter is a literature review covering four major research areas including an overview of pre-weaning mortality in the United States followed by an overview of the sow during lactation, the neonatal piglet and the farrowing house environment. The third chapter is titled “Comparison of heat lamps and heat mats in the farrowing house: Effect on piglet production, energy usage and piglet and sow behavior through video observation.” The fourth chapter is titled “Comparison of heat lamps and heat mats in the farrowing house:
Effect on piglet production, energy usage and piglet and sow behavior through live observation.” The fifth chapter is a general summary of both research studies.

**Expected Outcomes and Practical Implications**

One research poster based on the research results from this study has been presented at the American Society of Animal Science Midwest Meeting (Lane et al., 2019). Two Animal Industry Reports have been published based on this research work. One Iowa State University MS thesis will be the final outcome. Two peer-reviewed manuscripts will be submitted to the Journal of Swine Health and Production and Applied Animal Science. The results from this research are expected to aid the U.S. swine industry in minimizing the impact of pre-weaning mortality through the effective use of supplemental heat sources during lactation.

**Literature Cited**


CHAPTER 2. LITERATURE REVIEW

This literature review covers four major areas of research. The first area addresses pre-weaning mortality within the U.S. swine industry. The second addresses the neonatal piglet. The third area covers the sow during lactation. The last area reviews the farrowing environment and costs associated with supplemental heat.

Pre-weaning Mortality within the U.S. Swine Industry

For the purpose of this thesis, pre-weaning mortality will include liveborn piglets that die before weaning. This is to clarify that this number does not include stillborn or mummy piglets in the pre-weaning mortality discussion and calculation. Pre-weaning mortality presents a major pork production inefficiency and results in lost profit opportunities for producers (Dial et al., 1992; Crooks et al., 1992; Stalder, 2013). Pre-weaning mortality within the U.S. has remained relatively stable between 2015 to 2017 at approximately 17.5% (Stalder, 2018). For 2017, the average sow farm had an average number born alive of 12.6 of which only 10.3 were weaned (Stalder, 2018). In comparison, in 2000 the average number born alive was 10.0 pigs with 8.8 being weaned (NAHMS, 2000). According to the 2017 Pork Industry Productivity Analysis report (2018) farms in the top 25% are achieving 11.1 pigs weaned per sow and 13.2% (±4.5%) pre-weaning mortality rates, meanwhile farms in the bottom 25% are weaning 9.4 pigs per sow and 21.4% (±9.0%) pre-weaning mortality. At a 20% pre-weaning mortality level the estimated cost to the industry would be $650 to $800 million annually (USDA, 2019). Given these inefficiencies, pre-weaning mortality is an area of potential significant improvement from both an economic and welfare standpoint.
The majority of pre-weaning mortality occurs in the perinatal period, often representing over 50% of the mortality occurring before weaning (Bille N, 1974). On farm data typically classifies pre-weaning mortality to discrete causes from an ease perspective; however, piglet deaths are typically from an interaction of several possible causes (Shankar et al., 2009). The complex phenomenon of pre-weaning mortality has been well researched, with 30% of the losses attributable to a single factor and 70% to multiple factors (Le Dividich et al., 1996). Crushing or laid on is the number one producer-identified cause of death, accounting for over 50% of pre-weaning deaths. Laid on and starvation combined account for over two-thirds of pre-weaning mortalities (NAHMS, 2000). The factors affecting pre-weaning mortality can be put into three general categories: piglet, sow and environment. These will now further be discussed.

**Neonatal Piglet Overview**

Neonatal piglet mortality remains high in U.S. swine production, despite improved litter size and technological advances (KilBride et al., 2010; Kirkden et al., 2013). The majority of these mortalities occur during the first week, with the first 72 h being the most critical (Shankar et al., 2009).

**Thermoregulation**

Thermoregulation is a process allowing the pig’s body to maintain its core temperature and keep the body in a state of homeostasis. Poor thermoregulation can be defined as the piglet’s inability to maintain its core body temperature at 34°C; its lower critical temperature (Swine Care Handbook, 2018). At birth, piglets are poorly equipped
to deal with the environment outside of the sow making them susceptible to cold stress. Because farrowing rooms are designed to maintain environmental temperatures at or near the sow’s thermal neutral zone, piglets experience a rapid heat loss (15 to 20°C) through conduction, convection, radiation and evaporation (Curtis, 1970; Berthon et al., 1994). Minimal hair coat insulation, a large surface area to body weight ratio, minimal brown adipose for energy reserves and poor body thermostability at birth all result in the piglet being physiologically limited in its ability to maintain its own thermal regulation (English and Morrison, 1984). Body mass index (BMI) is correlated with glycogen storage, body muscle and survival rate (Amdi et al., 2013). Low birth weight pigs have low BMI and subsequently have reduced energy reserves resulting in higher incidences of hypothermia and pre-weaning mortality (Muns et al., 2016).

When the environmental temperature falls below the piglet’s lower critical temperature, the piglet becomes subjected to cold stress. During cold stress, the piglet will mobilize its glycogen reserves from the liver and skeletal muscles and utilize nutrients supplied through the sows’ milk to increase heat production (Johnson, 2001). Heat loss per unit of body weight is inversely related, therefore smaller pigs are at greater risk for cold stress (Muns et al., 2016). Additionally, litters can huddle to increase thermal insulation and reduce heat loss due to convection (Mount, 1963; Bel Isle, 1978). Once the piglet has exhausted these thermoregulatory options, the caretaker must provide additional heat or warm bedding to assist the piglet in maintaining its thermoregulation.
Factors Affecting Pre-weaning Mortality

Factors contributing to greater neonatal piglet death loss include: low birth weight, poor thermoregulation (discussed above), gender and behavior (Bowman, et al., 1996). Many pre-weaning mortality causes are interlinked as hypothermia resulting from cold stress can lead to starvation, crushing, and/or disease (Edwards and Baxter, 2015).

Birth weight

Birth weight is considered an important factor that effects pre-weaning mortality. Piglets weighing <1 kg at birth are 40% more likely to succumb to pre-weaning mortality (Roehe and Kalm, 2000; Edwards and Baxter, 2015). Chris et al. (2012) reported that piglets having a birth weight of > 1.8 kg have survival rates greater than 90%. Body weight influences a piglet’s thermoregulatory ability through surface area to body mass ratio, an enhanced suckling ability and greater colostrum consumption (Amdi et al., 2013; Ferrari et al., 2014). Body weight is not independent of the degree of physiological development. Better developed piglets (i.e. fully developed internal organs and correct suckling behaviors) have an enhanced ability to ingest greater volumes of colostrum and better colostrum digestion (Edwards and Baxter, 2015). Small pigs can be classified into two categories: small for gestational age (SGA) and intrauterine growth restriction (IUGR). Piglets classified as SGA have been defined as “.piglets weighing less than the tenth percentile of the litter at birth that demonstrate normal proportions” (Edwards and Baxter, 2015). Piglets classified as IUGR are defined as “.piglets that are disproportionate or do not indicate normal allometry” (Edwards and Baxter, 2015). These differentiations are critical as studies have suggested that SGA piglets have a
greater chance of survival when compared to IUGR piglets because they are more physiologically mature and vigorous (Baxter et al., 2008).

**Gender**

Previous studies suggest that female piglets are more likely to survive from birth to weaning than male counterparts (7% pre-weaning female mortality compared to 12% for males) (Baxter et al., 2012; Panzardi et al., 2012; Hales et al., 2013). Baxter et al. (2012) speculated that males invest more energy into body size and composition while females invest in thermoregulation and immunocompetence. Although males have a greater weight at birth ($1516 \pm 24.8 \text{ g}$) when compared to females ($1468 \pm 23.6 \text{ g}$) they typically show decreased thermoregulation having lower rectal temperatures at 24 h post farrowing (Baxter et al., 2012). Baxter and colleagues (2012) reported a rectal temperature difference between male and female piglets of approximately $0.25^\circ \text{C}$ at birth and 24-h post farrowing. Gender bias may be masked slightly by competition because larger piglets are typically more dominant.

**Behavior**

Piglets that survive demonstrate greater vitality at birth, quickly finding the udder and functional teats to suckle colostrum (Baxter et al., 2008). Piglets will fight to establish and maintain preferred teat fidelity and those piglets unable to establish teat fidelity are likely to grow slower resulting in starvation or lower energy reserves (De Passillé et al., 1988). Piglets will fight with littermates while trying to establish a teat and may experience wounds (Drake et al., 2008). Once a teat preference is established by
individuals, piglets must perform optimal udder massaging and suckling behaviors or their dams milk yield may be hindered resulting in increased pre-weaning mortality. De Passillé and Rushen (1989) demonstrated that heavier piglets, that are farrowed earlier in the birth order, were at a distinct advantage over smaller, less vigorous piglets within the same litter regarding teat disputes and teat fidelity which resulted in increased suckling by the heavier piglets. To minimize piglet competition, teat number and within-litter weight variation must be taken into consideration. Behaviors that predispose piglets to crushing are often driven by physiological challenges including hypoxia, starvation and/or hypothermia (Edwards and Baxter, 2015). Studies have reported piglets nursing and lying near the sow accounts for 60 to 75% of the time for a day-old piglet regardless of supplemental heat source placement (Titterington and Fraser, 1975; Lewis and Hurnik, 1985). The innate need to suckle and establish teat fidelity results in the piglets’ spending increased time in high risk areas (under the sitting or standing sow) regardless of the risk of being crushed (Edwards and Baxter, 2015). As piglets become lethargic due to their extreme energy expenditure from these challenges, the piglet’s ability to escape the sow’s movements becomes limited (Weary et al., 1996). Piglet’s with low vigor lying away from the udder to avoid crushing is just as detrimental to their survival because the crushing risk is decreased; however, the piglet death risks mentioned above increase resulting in the complex, multi-faceted concept of pre-weaning mortality.

**Overview of the Sow during Lactation**

Proper sow care before, during and after parturition is critical to get piglets to weaning. Pre-partum is before parturition, peri-partum is defined as the period
immediately prior to parturition, parturition and the time following parturition up to three
days and the post-partum period is any time following the peri-partum period until
weaning (Animal Reproduction Science, 1992). The first 72-h after labor has ceased is
the most critical for pre-weaning piglet morality (Edwards and Baxter, 2015; Lay et al.,
2002; Marchant et al., 2000; Svendsen, 1992 English and Morrison, 1984). For the
purpose of this thesis, attention will be focused primarily on the peri-partum and post-
partum periods.

**Thermoregulation**

Optimal temperatures for the lactating sow ranges between 15 to 26°C (Swine
Care Handbook, 2018). Within this temperature range it is not necessary for the sow to
utilize heat-conserving or heat-dissipating mechanisms to maintain body heat. Adjusting
the farrowing house temperature to maintain the sow’s comfort level and providing a
micro-environment suitable to meet the piglet’s thermal needs will help reduce
incidences of sow heat stress. Maintaining the environment to meet the sow’s
thermoregulatory needs is vital. It not only influences her comfort and welfare but also
affects her feed consumption, growth and efficiency and her overall health (Swine Care
reports that for every 1°C increase above 16°C feed intake declines by 0.17 kg. Gilts and
young sows are continuing to grow as well as support a litter, therefore as they mobilize
body reserves to support milk production when nutrient intake is decreased their growth
and subsequent reproduction may be reduced (Kings and Williams, 1984; Mullan and
Williams, 1989). However, milk production will be hindered during heat stress with
studies reporting anywhere from 1 to 3.5 kg/day differences and corresponding decreased
piglet growth expressed as litter weight of 0.2 to 0.7 kg/day differences (Schoenherr et al., 1989; Vidal et al., 1991).

Identifying signs of heat stress including increased respiration, increased body temperatures, reduced feed intake, and increased water consumption and taking corrective management actions can ultimately affect the sow and subsequently pre-weaning morbidity and mortality. To assess respiration, count the number of times the rib cage moves in and out in one minute; 15 to 25 breaths with rates in the range of 40-60 breaths per minute indicating risk of heat stress and >60 meaning the animal is under heat stress (Rozeboom et al., 2000). During lactation, normal sow rectal temperatures will range from 38.6°C to 40.0°C, anything above these measures would indicate heat stress (Martin, 2012). After parturition, the sow’s energy balance is typically negative; however, the NRC recommends a range of 4.3 kg to 5.7 kg per day, anything below this could result in large weight loss during lactation and subsequent reproductive or health problems (Aherne, 2005). Increasing temperature from 12.2°C to 15.6°C to 30°C to 35°C will result in 50% greater water consumption, with lactating sows under normal conditions requiring 30 to 40 liters per day and 45 to 60 liters per day during heat stress (Rozeboom et al., 2000). In a study heat stress was shown to decrease sow feed intake by over 13% and while piglet survival in the heat stressed group was lower (5.6% as compared to 15.0%) piglet weaning weight was significantly decreased likely due to decreased milk production in the sow from decreased feed intake (McGlone et al., 1988). Management strategies to combat the effects of heat stress can include providing evaporative cooling through drippers or increasing the interval, increasing feeding
frequency and feed earlier or later when the temperatures are cooler, switch to wet feeding, or increase air movement in the room (Rozeboom, et al., 2000).

**Factors Affecting Pre-weaning Mortality**

The sow is an ungulate that is polytocous and builds a nest prior to farrowing. However, the sow remains in lateral recumbency during farrowing and as a result the sow licking of fetal membranes is rare (McGlone and Johnson, 2011). Newborn piglets are highly dependent on their mother for food, protection from disease, cold and predators (Arey and Brooke, 2006). Yet the sow can be a major contributor to pre-weaning mortality (Edwards and Baxter, 2015). The way sows contribute to pre-weaning mortality include colostrum quality and quantity, parity, stress, conformation and behavior, and nutrition.

**Colostrum**

Colostrum is the first milk produced by mammals which is continuously produced until 12 to 24 h post farrowing (Quesnel, et al., 2012). At this time point, milk secretion becomes cyclic and piglet nursing bouts begin (Auldist et al., 2000). There is a finite time following birth in which the piglet’s gut is permeable to the macromolecules, including immunoglobins. Early colostrum consumption is crucial to neonatal piglet subsequent survival and growth. It is not only critical for the piglet’s thermogenic responses to the environment, but also for absorbing immunoglobulins produced by its mother to acquire passive immunity to many infectious organisms (Rooke and Bland, 2002). The colostrum provides the piglet with a source of highly metabolizable energy and its high fat content
allows for the piglet to increase its metabolic rate to thermoregulate its body temperature (Le Dividich et al., 1994).

Studies have shown second and third parity sows typically produce greater quantities (4278 ± 288 g) of colostrum when compared to sows at other parities (primiparous: 3435 ± 184 g; parity 4+: 3616 ± 288 g; Devillers et al., 2007). Parities four to six produce colostrum in greater quantities than the primiparous sows (Ferrari et al., 2014). It is suggested that reduced colostrum and milk production may account for 6 to 17% pre-weaning mortality (Alonso-Spilsbury et al., 2007).

**Parity**

Parity effects on pre-weaning mortality can be contradictory as previous study results are varied. Some research has reported no relationship between parity and pre-weaning mortality (Knol et al., 2002; Carney-Hinkle et al., 2013). Other studies have reported an approximately 1.5% lower pre-weaning mortality rate in parity two to parity four sows when compared to primiparous sow (Nuntapaitoon and Tummaruk, 2015). Yet other studies have reported a negative correlation between parity and pre-weaning mortality; suggesting primiparous sows have higher pre-weaning mortality due to lower colostrum yield and quality, smaller piglets at birth or poorer reproductive performance as a result of inexperience (Koketsu et al., 2006; Li et al., 2012; Nuntapaitoon and Tummaruk, 2015; Muns et al., 2016).

No relationship or a lower pre-weaning mortality from primiparous sows could be the result from increased litter size and parity (Roehé and Kalm, 2000) since the number of low birth weight piglets increased with increasing parity. The difference in colostrum
quantity as previously described, may explain the negative correlation between parity and pre-weaning mortality. Decreased colostrum consumption by piglets from primiparous sows may contribute to differences in immunity and daily gain when compared to piglets from older sows (Ferrari et al., 2014).

**Functional biological changes**

The peri-partum period is a sensitive period of piglet production and stress for the female (Muns et al., 2016). Stress is defined as “*physical, mental or emotional factors that cause bodily or mental tension that can be internal or external.*” (Shiel, 2018). The stress that sows experience can start before farrowing resulting from changes in the environment due to relocation into the farrowing environment or physiologic changes resulting from the parturition process (Muns et al., 2014; Yun et al., 2015). Indicators of stress can behavioral (increased postural changes, decreased lateral recumbency, trembling etc.) or physiological (increased heart and respiratory rate, increased cortisol levels, decreased feed intake, etc.; Mainau et al., 2018). The stress that sows experience during parturition can increase farrowing duration, resulting in increased stillborns, and decreased colostrum production which negatively impact piglet survival (Oliviero et al., 2008). In addition, stress impacts her behavior resulting in restlessness and potential aggressiveness (Kalantaridou et al., 2004). Stress can also be caused by housing type, temperature and human interaction (Baxter et al., 2011; Silva et al., 2006; Hemsworth et al., 1995). The sow’s behavior can result in increased crushing, decreased piglet suckling or potentially piglet savaging (Baxter et al., 2011). Sows experiencing increased stress as a result of hypothyroidism have higher incidences of mortality and reduced daily gain
demonstrated by lower levels of thyroxine (TT4) critical for growth and thermoregulation than control piglets (P<0.05) (Berthon et al., 1993).

**Nutrition**

The sow’s nutrition during gestation impacts piglet pre-weaning mortality. Piglet birth weight is positively correlated to the sow’s energy intake during gestation (Campos et al., 2012). Sow diets during gestation that are limited in proteins or lacking essential amino acids, such as the arginine family, will hinder fetal development and result in low birth weight piglets which contributes directly to high pre-weaning mortality (Kim et al., 2009; Wu et al., 2011). L-carnitine, L-arginine and L-glutamine have all been reported to impact fetal growth and development likely through an increased intrauterine glucose supply, GLUT1 and IGF-I (Raghavan and Dikshit, 2004; Doberenz et al., 2006; Gao et al., 2012; Wu et al., 2013). Late gestational nutrition plans have been reported to impact mammary function and colostrum yield and composition (Theil et al., 2014). Overfeeding during late gestation has been reported to negatively impact mammogenesis through excessive fat deposition, however feed restriction during this time frame will likely have a minimal impact on colostrum production due to the sow’s ability to utilize its body reserves (Dourmad et al., 1999). As a result of overfeeding, sows with excess condition develop insulin resistance that disrupts glucose transport to mammary tissue to facilitate milk production (Shennan and Peaker, 2000; Père and Etienne, 2007).

The sow’s nutritional plan is important to support the high energy expenditure during lactation to support piglet growth for large litter. Supplementing dietary fat during lactation has been reported to increase the sow’s milk production, support piglets gut
health and increase piglet growth and survival (Laws et al., 2009; Jackson, 2004). Laws and colleagues (2008) reported that supplementation of oils during the first half of gestation increased immunoglobulin concentrations in the milk 1.5 to 2 fold (mg/mL) more IgA or IgM present to support piglet immune function. Additionally, Tilton and colleagues (1999) reported that feeding 10% tallow during lactation increased piglet weaning weight by 270 g/pig.

**Conformation and behavior**

Sow lameness can be defined as being unable to use one or more limbs in a normal manner, which can vary in severity from reduced ability to bear weight to complete immobility (Pluym, 2013). Lameness can have a variety of causes resulting in physical injury (limb and claw lesions, muscle or tendon damage, and bone fractures) that can be influenced by environmental factors such as flooring type, group size and stocking density, housing type and nutrition (Quinn, 2015). Other conditions resulting in lameness include osteochondrosis, arthritis, neurological deficits, and infectious diseases (Campler et al., 2016).

Sow lameness that results from feet and leg injury can lead to extensive postural adjustments or abnormal lying-down behavior that contributes to increased pre-weaning mortality due to crushing (Fitzgerald, 2009). It has been reported that the incidence of piglet crushing increases when a sow changes posture (Lao, 2016) These findings are supported by Johnson and colleagues (2007) which reported the greatest incidence of pre-weaning mortality when sows shift from lying sternal to lying lateral as opposed to postural changes from standing to a lying posture. Lameness can also result in decreased
feed consumption as a result of increased in lateral lying which impacts milk production and subsequently piglet health and growth (Valros et al., 2009). Studies have reported that using rubber mats can decrease lesions and lameness (Calderón Díaz and Boyle, 2014; Elmore et al., 2010). Caretakers can monitor the environment to ensure proper functioning facilities to help eliminate environmental causes of lameness, provide mats to alleviate flooring induced lameness that can otherwise not be avoided and provide timely and proper treatment of identified lameness to improve welfare of the sow and her piglets.

Crushing due to sow lameness and posture are not the only maternal behaviors that cause piglet mortalities (Edwards and Baxter, 2015). Sow temperament and maternal ability can directly impact pre-weaning mortality. Studies have reported that there is high variation within populations regarding piglet crushing as some sow’s demonstrate a pre-lying behavior directed towards piglets (Anderson et al., 2005). Some sows are more likely to exhibit savaging with higher incidences in farrowing stalls as opposed to alternative housing and in primiparous sows (Chen et al., 2007; Lawrence et al., 1994). During instances of savaging, sow behavior tends to be more restless, resulting in increased incidence of crushing if the piglet avoids direct aggression from the sow (Ahlstrom et al., 2002).

**Farrowing House Environment Overview**

The farrowing environment is unique in that it involves the sow and her piglets. The sow and piglets have distinctly different requirements including their thermal, social and physical environments. Meeting these requirements within the same facility presents
a unique challenge to pork producers, veterinarians and animal scientists (Johnson and Marchant-Forde, 2009). Previous research to mitigate pre-weaning mortality has focused heavily on the farrowing environment with control over the macro- and micro environments and the introduction of the farrowing stall in the 1960s (Roberston et al., 1966). Therefore, a farrowing environment ideal for a sow is far from what is optimal for her litter.

**Heat Sources**

Heat source supplementation in the farrowing house is a common practice. Due to differing thermal needs for the sow and piglets a typical production management practice is to maintain room temperatures within the sow’s thermal neutral zone while providing localized creep heat sources to meet the environmental temperature requirements for the piglet. Work from Harmon and colleagues (1996) reported piglets should be provided an environment that is maintained at 32-35°C temperature range at birth. After farrowing the temperature can be decreased to approximately 31-32°C by the time the piglets reach three weeks of age.

There are a variety of heat sources available to achieve the desired environmental temperature including heat lamps, heat mats, and straw. Producers have to determine what works best for their specific farrowing system, for example, straw is commonly used in pasture or open pen type situations (Pedersen et al., 2016; Berger et al., 1997). Heat lamps and mats are more commonly utilized in conventional confinement farrowing settings (Swine Care Handbook, 2018). For the purposes of this thesis, the focus will be
on meetings the piglet’s thermal needs by using heat mats or heat lamps from farrowing through weaning.

Heat source placement can be at the rear or either side of the sow within the farrowing stall. A study by Zhang (2000) provided piglets with the choice of either a heat mat or a heat lamp, both provided on the same side of the sow, with four different set ups to not confound location or side. It reported that positioning the heat source at the rear of the sow is preferred as piglets consistently choose the rear heat source regardless of heat source type. Stinn and Xin (2014) evaluated the effects of different heating systems (heat mats versus heat lamps) on piglet mortality, rate of gain, and electric power use. The authors concluded that there was no difference in rate of gain or mortality amongst the two systems, but there was a difference in energy usage, with mats using 36% less power compared to heat lamps.

**Heat lamp**

The popularity of the heat lamp centers around the low initial investment cost ($11.71 to $21.95 per lamp). The lamp provides radiant heating. It is critical to properly adjust the lamp and monitor temperature at floor level. If the temperature is too hot, the piglets will tend to lie in closer proximity to the sow and this can increase the likelihood of injury or crushing (Harmon et al., 2012). Heat lamps have several drawbacks including relatively high energy usage and a limited thermal comfort zone (Zhang, 2000). Heating large areas is more difficult to accomplish without disrupting the sow’s environment and creating an overlap of heating zones for the piglet and the sow that could potentially lead
to additional crushing deaths. Additionally, heat lamps are a potential fire hazard and present risk to pigs and caretakers from burns or breakage.

Multiple options exist when heat lamps are the method of choice to meet the piglet’s thermal needs including differences in wattage and bulb type. Xin and colleagues (1997) compared three infrared bulb that differed in wattage including 250W, 175W and 125W that resulted in higher levels of heat source usage during the day with usage of 28%, 31%, and 39%, respectively. During the night the 250W had a usage of 13%, 175W piglet usage of 24% and 125W had a 24% usage. Piglets also decreased heat lamp usage with age across treatments including 30% to 11% for 250W, 34% to 22% for 175W and 33% to 30% for 125W (Xin et al., 1997). Piglets with 175W demonstrated normal lying patterns. Normal lying patterns are defined by Yuhzi Li from the University of Minnesota as the majority of piglets lying laterally with 40-50% of the litter touching each other. Litters with 125W bulbs exhibited more huddling, or a higher percentage of piglets touching or piling and litters with 250W bulbs exhibited a spread-out lying pattern avoiding the heat source. Piglet lying behaviors demonstrated too hot of surface under the heat lamp when supplied with a 250W bulb, an acceptable amount of additional heat was provided with a 175W bulb and not enough supplemental heat was provided by a 125W bulb. Ultimately, smaller wattage bulbs save energy and reduce costs per weaned pig.

required to provide supplemental heat for piglets during lactation. Typically, a 175W bulbs saves approximately 360 kWh per stall in a year as compared to 250W bulbs (Harmon et al., 2012). Using variable output lamp can yield energy savings of 21% when compared to constant output heat bulbs (Zhou et al., 1998). These energy savings cannot be achieved through the use of a rheostat, which functions by “chopping” the output
voltage and giving off the unused power as heat while the input voltage remains the same (Harmon et al., 2012). Therefore, a controller such as a triac or any device which varies the electrical frequency must be used to capture these savings (Harmon et al., 2012).

**Heat mat**

The heat mat is promoted as an energy-efficient alternative to heat lamps (Zhang, 2000). Heat is provided beneath the piglets through conductive heating. The heat mat additionally acts as a draft barrier for any non-solid flooring commonly found in farrowing stalls. Mats can be heated through water or electricity. Heat mats are generally controlled in a similar manner to heat lamps with reduced heat output as piglets age. Additional energy savings can be captured when using the appropriate controllers are used to reduce heat output, such as a triac or any device that varies electrical frequency. A drawback to heat mats is the potential for uneven surface temperature distribution, hot spots could deter piglets from utilizing the heat source while a more evenly distributed temperature is conducive to providing supplemental heat to the litter. Uneven heat distribution may present a problem and can be dependent on the manufacturing of the mat (Xin, 1999). Initial cost is greater for mats ranging from $95.01 to $235.87.

There are various options when using heat mats to provide supplemental heat for piglets including differences in wattage (60W-100W) and size (approximately 0.30 m x 0.9-1.5 m). “Double mats” (Heat mats with a recess for pen dividers to supply supplemental heat to two stalls with one energy input) are the most commonly used, although single mats are available. Mats also vary in sizes. Typical wattages for heat mats
are between 60-100 W per stall which can lead to potential efficiency and lower costs per pig weaned.

**Energy Usage**

Raising swine indoors for pork production is considered a relatively high energy use system. In these modern production systems, there are opportunities to improve throughput and efficiency which is central to production systems. These efficiencies create the opportunity to reduce fossil fuel consumption. Electric usage (kWh) and associated costs remain fairly constant per pig across all production systems, with heat lamps using 50% of the total electricity (Lammers et al., 2012; Buchanan et al., 2017). Annually, a 3,000-sow farm is projected to use approximately 685,000 kWh from electrical use including ventilation, supplemental heat, lighting, feed and water delivery and power washing. Additionally, this unit would use an estimated additional 1 million kWh from propane or natural gas usage for space and water heating (Jacobson, 2014). In a study during 2015 to 2016 it was reported that heat lamp usage accounts for nearly 50% of the electrical usage from a typical sow facility (Buchanan et al., 2017). Based on Jacobson (2014), heat lamp usage can account for approximately 36% of electrical usage or approximately 15% of total energy usage from a 3,000 head sow farm (Figure 2.1).

**Factors Affecting Pre-weaning Mortality**

Environmental factors that can affect pre-weaning mortality include season and temperature, housing and management (Muns et al., 2016).
**Season and temperature**

The impact that season and temperature have on pre-weaning mortality is unclear. Koketsu and colleagues (2006) reported that pre-weaning mortality during summer (July to September) was greater at 11.6% when compared to spring (April to June) at 9.4%. However, other studies have reported that the risk for higher pre-weaning mortality during the cold season. It is speculated this is due to the low environmental temperatures and cold stress that results in poor piglet temperature thermoregulation (Dial et al., 1992; Maderbacher et al., 1993). Conversely, high summer seasonal temperatures can cause sow heat stress when it exceeds her thermal neutral temperature (15 to 26°C; Swine Care Handbook, 2018). Heat stress on the sow results in decreased feed intake resulting in lower colostrum and milk production and subsequently poorer piglet growth (Farmer et al., 2010; Malmkvist et al., 2012). Understanding the thermoregulatory needs of both the sow and piglets is crucial to maintain an optimum farrowing environment for both sows and piglets.

**Housing**

Herd size and housing type can play a role in piglet pre-weaning mortality. Studies have reported that pre-weaning mortality is typically lower in larger herds (>200 sows) when compared to smaller herds (<200 sows). Herd size impact may be associated with management quality and farrowing supervision allocated to larger herds (Hoshino et al., 2009).

Individual housing (total confinement) during farrowing and lactation is preferred in the U.S. pork industry (Table 2.1; NAHMS, 2000). Farrowing stalls were designed to
minimize piglet deaths due to crushing (Vosough Ahmadi et al., 2011). The standard farrowing stall in the U.S. is typically 1.5 m X 2.2 m with creep area of 0.5 m\(^2\) arranged on the sides with some combination of either partially slatted or fully slatted flooring from substrates that include woven wire, metal, plastic coated metal or plastic (Johnson and Marchant-Forde, 2009). Stalls restrict the sow to a confined area and provide creep areas for piglets as a safe retreat. It has been demonstrated that housing sows in stalls during farrowing and lactation increases signs of stress in sows including increased heart rate and negative or abnormal behaviors (Baxter et al., 2011). Sow housing options are further described and compared to farrowing stall size in Table 2.2.

Group housed systems include multi-suckling systems or get-away systems (Nieuwamerongen et al., 2014). Group housing provides environmental complexity and full freedom of movement for the sows, however there is increased incidence of piglet crushing and hence piglet mortality, disruption to suckling and possibly early lactation termination (Van Nieuwamerongen et al., 2014). Another group-housed study reported that sows should be housed in individual accommodations during this production phase (Wechsler et al., 2007).

**Management**

It should be acknowledged that animal management (caretaker skills) employed from gilt development forward can impact piglet survival (Baxter and Edwards, 2015). However, for the purpose of this thesis only direct management implemented in the farrowing house will be discussed. Management risks include poor animal handling, failure to assist weak piglets to ensure colostrum uptake, lack of intervention when litter
size exceeds teat count, failure to assist in maintaining thermoregulation, poor hygiene and disease management, etc. (Baxter and Edwards, 2015).

Poor animal handling can lead to increased fear and nervousness among sows due to handler presence that results in increased piglet mortality due to crushing or savaging (Lensink et al., 2009). Studies by Hemsworth and colleagues (1995) reported that when fear levels are high, caretaker presence becomes a risk factor for piglet mortality. Since high levels of fear are attributable to recent handling by caretakers, it is suggested to make movements slow so as not to startle the sow with quick and sudden movements, continue human contact after mating during gestation and avoid harsh movements to get the sow in a stall or up to eat (Hemsworth, 1999).

Caretakers can improve piglet survivability by placing piglets by the teat and assisting suckling (Edwards and Baxter, 2015). Muns and colleagues (2014), orally supplemented colostrum to piglets weighing under 1.35 kg within several hours of birth which positively impacted piglet IgG levels 4-d post farrowing. These measures become increasingly important in today’s modern sows farrow larger and larger litters that frequently exceed the sow’s teat count and have a greater proportion of piglets that become low viability individuals at or shortly after farrowing. Other caretaker skills and management practices ensuring colostrum uptake and to minimizing detrimental effects of large litter size which exceeding functional teat space include split suckling, cross-fostering, nurse sows or artificial rearing. Split suckling can be an effective strategy to reduce the impact of large litters; however, it requires careful time management and increases labor requirements (Baxter and Edwards, 2015). Therefore, if cross-fostering (fostering piglets from one sow to another in the same farrowing group) is an option and
done correctly it can enhance piglet survival and reduce the need for further intervention (Harper, 2001; Cecchinato et al., 2008). Correct cross-fostering includes keeping fostering to a minimum, fostering as early as possible (12-h to 24-h post farrowing) and ensuring colostrum consumption by the piglet from its dam (Calderón Díaz et al., 2018). Nurse sows are commonly used in countries such as Denmark and the Netherlands where highly prolific sows are prevalent (Baxter and Edwards, 2015). Utilizing nurse sows is generally implemented in two different management types: one-step and two-step; both require diligent caretaker stockmanship and have potential risks to the sow and piglets welfare and health (Baxter et al., 2013). Farrowing management efforts targeting sows with large litters during the critical 72-h period post-farrowing. Interventions include drying piglets at birth or moving them to the supplemental heat source have been reported to improve piglet survival from 21% mortality with no intervention to 6% mortality with intervention (Christison et al., 1997). Studies by Anderson and colleagues (2009) and Vasdal and colleagues (2011) reported that drying piglets and placing them at the sow’s udder is the management practice that reduced pre-weaning mortality that most in a loose-housed farrowing environment. All management practices can benefit from the proper management of an all-in-all-out flow (Owsley, 2013). This decreases the risk of disease spread between farrowing groups which minimizes pre-weaning mortality that result from infectious diseases which ultimately allows caretakers to focus on their management skills in other areas rather than treating sick animals. This improves animal welfare and welfare and ultimately improves the operations efficiency and producer profitability.
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Figure 2.1. Percentage of direct electrical usage from a 3,000 U.S. sow farm (Jacobson, 2014).
Table 2.1. Percentage of farrowing facilities by type and percentage of pigs raised in the respective types (NAHMS, 2000).

<table>
<thead>
<tr>
<th>Farrowing facility type</th>
<th>Site (%)</th>
<th>Pig (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total confinement (mechanical ventilation)</td>
<td>64.8</td>
<td>83.4</td>
</tr>
<tr>
<td>Open building with no outside access</td>
<td>12.2</td>
<td>12.4</td>
</tr>
<tr>
<td>Open building with outside access</td>
<td>17.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Lot with hut or no building</td>
<td>3.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Pasture with hut or no building</td>
<td>2.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Table 2.2 Farrowing facility brief descriptions, area allocation and pre-weaning mortality percentages (McGlone, 2002).

<table>
<thead>
<tr>
<th>Farrowing Facility</th>
<th>Description</th>
<th>Total space (m)</th>
<th>Pre-weaning mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farrowing stall¹,²</td>
<td>A fixed metal structure within a pen with piglet creep area provided</td>
<td>1.5 X 2.2</td>
<td>20.0</td>
</tr>
<tr>
<td>Turn-Around³</td>
<td>A triangular shaped pen with fixed walls that flare outward</td>
<td>1.5 X 2.6</td>
<td>9.4</td>
</tr>
<tr>
<td>Sloped pen⁴</td>
<td>A pen with a sloped floor similar to a hillside</td>
<td>2.1 X 2.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Family pen⁵</td>
<td>A pen that provides an area where the sow can be with her piglets and an area where the sow can get away from her piglets</td>
<td>2.1 X 3.3</td>
<td>26.9</td>
</tr>
<tr>
<td>Werribee pen⁶</td>
<td>A sow and piglet area (nest) and dunging area are provided (non-nest area)</td>
<td>2.33 X 3.5</td>
<td>15.8</td>
</tr>
<tr>
<td>Ellipsoid stall⁷</td>
<td>A farrowing stall with concave side walls, allowing the sow to turn around</td>
<td>1.7 X 2.0</td>
<td>22.3</td>
</tr>
<tr>
<td>Outdoor english-arc style hut⁸</td>
<td>A half cylinder arc typically with a wood base and a single entrance</td>
<td>2.8 X 1.7</td>
<td>11.8</td>
</tr>
</tbody>
</table>

¹ Johnson and Marchant-Forde, 2009
² McGlone, 2002
³ McGlone and Blecha, 1987
⁴ McGlone and Morrow-Tesch, 1990
⁵ Arey and Sancha, 1996
⁶ Cronin et al., 2000
⁷ Lou and Hurnik, 1994
⁸ Johnson et al., 2001
CHAPTER 3. COMPARISON OF HEAT LAMPS AND HEAT MATS IN THE FARROWING HOUSE: EFFECT ON PIGLET PRODUCTION, ENERGY USAGE AND PIGLET AND SOW BEHAVIOR THROUGH DIGITAL OBSERVATION

K. J. Lane¹, A. K. Johnson¹, J. D. Harmon², L. A. Karriker³, and K. J. Stalder¹*

¹Department of Animal Science,
²Department of Agricultural and Biosystems Engineering
³Veterinary Diagnostics and Production Animal Medicine and Swine Medical Education Center
Iowa State University, Ames, Iowa, 50011, USA

*Corresponding Author: Dr. Kenneth J. Stalder, 806 Stange Rd. 109C Kildee Hall, Department of Animal Science, Iowa State University, Ames, IA, 50011; Tel: 515-294-4683; Email: stalder@iastate.edu

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Abstract

Objective

Pre-weaning mortality remains an industry concern. The study objectives were to 1) evaluate piglet performance and pre-weaning mortality when supplied with two heat source treatments at a constant temperature, 2) evaluate sow lying behavior and piglet location behavior in regard to heat source and proximity to the sow and 3) evaluate the energy usage of two different heat sources at a constant temperature.
Materials and Methods

Twenty-two multiparous crossbred sows housed in farrowing stalls were part of a completely randomized study and assigned to heat source treatment; Baby Pig Heat Mat – Single 48 (MAT; n=12) or Poly Heat Lamp Fixture LAMP; n=10). Piglets were weighed on D1 and weaning and any mortalities were recorded to evaluate piglet production measures. For seven days over the course of lactation (D1, D2, D3, D4, D5, W-7, and W-1) sows and their litters were recorded for 24-h. Still images were selected at 20-minute time increments and evaluated using a behavioral ethogram.

Results and Discussion

No piglet production differences were observed in, litter weaning weight (P = .97) and pre-weaning mortality (P = .90). There were piglet behavior differences within day by supplemental heat source treatment, however additional research is needed to further evaluate piglet behavior (P<.0001). Sows spent the majority of the time during observations lying laterally, further work is warranted to evaluate if heat source placement affects this behavior. Energy usage in kWh was different among treatments (P<.0001). Heat lamps (63.67±0.79) utilized 3.8 times more electricity (kWh) than heats mats.

Implications and Applications

Significant energy and cost savings can be captured through the use of heat mats in the farrowing house as supplemental heat for the neonatal piglet from parturition to the end of lactation without negatively affecting pre-weaning mortality or piglet growth.
Introduction

Within the farrowing environment, the sow and her piglets are at two very different life stages and have different social, physical environmental and thermal requirements. For example, ambient temperature requirements for lactating sows ranges from 15 to 26°C, but individual newborn piglets prefer a higher temperature of 34°C (Curtis, 1995; Johnson and Marchant-Forde, 2009; Swine Care Handbook, 2018). To reconcile these thermal differences, supplemental heat or warm bedding can be provided. This enhanced thermal microenvironment can minimize piglet pre-weaning mortality associated with cold stress. Implementing a 125-watt heat lamps for supplemental heat can account for over 36% of total electrical usage on a 3,000 head sow operation (Jacobson, 2014). However, a 20% pre-weaning mortality level is estimated to cost the United States (U.S.) pork industry between $650 to $800 million annually, therefore economical compromises need to be considered (USDA, 2019).

Previous work by Stinn and Xin (2014) compared a heat mat to a heat lamp on piglet pre-weaning mortality, rate of gain, and electric power use. The authors concluded that there was no difference in rate of gain or mortality, but mats used 36% less power compared to heat lamps. Further, MacDonald and colleagues (2000) reported that heat mats resulted in a 50% cost savings without detrimentally affecting piglet weaning weight or average daily weight gain. Hrupka and colleagues (1998) reported that heat lamp location within a farrowing stall did not affect pre-weaning mortality, but fewer piglets were within 8 cm of the sow and more were located in the heat source area (Hrupka et al., 1998). Therefore, the objectives of this work were to 1) evaluate piglet performance and pre-weaning mortality when supplied with two heat source treatments at
a constant temperature, 2) evaluate sow lying behavior and piglet location behavior in regard to heat source and proximity to the sow and 3) evaluate the energy usage of two different heat sources at a constant temperature.

**Materials and Methods**

The research protocol was approved by the Iowa State University Institutional Animal Care and Use Committee (8-17-8583-S). Sows were provided a minimum of a 72-h acclimation period to the farrowing stall with heat source treatment prior to farrowing.

**Animals, Location and Housing**

A total of 22 farrowing stalls, containing a sow and her litter, were used in this study. Stalls had interlocking plastic flooring and a creep area on both sides of sow. The total stall area measured 2.0 m x 1.7 m. The center sow area measured 2.0 m x 0.6 m with two creep areas measuring 2.0 m x 0.55 m on either side. Solid flooring was provided, 1.2 m x 0.4 m, on one side of the piglet creep area where the heat source was provided. The stalls were distributed across two farrowing rooms (7 stalls per room) in a negative pressure, mechanically ventilated barn where the temperature was set at 21.1 ºC. Six stalls were included in the study, with the first crate being excluded for off-test animals. Data was collected from September to December at the Iowa State University Allen E. Christian Swine Teaching Farm in Ames, IA. Multiparous crossbred sows (P1= 5, P2= 3, P3= 5, P4=1, P5 = 3 and P7+=4) and their litters were enrolled. Sows were provided ad libitum access to water via one 1.9 cm nipple and were hand fed once daily prior to
farrowing. Post-farrowing, sows were hand fed to appetite three times daily in 0.90 kg increments. Feeding to appetite to ensure constant access to fresh feed started with a 2.72 kg feeding when feed was fully consumed and at the next scheduled feeding an additional increment was added until more than 0.90 kg of feed remained in the feeder. Once the sow had reached full appetite this amount of feed was fed to her for the remainder of lactation. All diets were prepared by a commercial feed mill (Key Cooperative, Gilbert, IA) composed of primarily corn, soybean meal and dried distillers grains and nutrients formulated according to NRC (2012) guidelines to meet or exceed gestating/lactating sow nutrient requirements. The diet contained 19.6% crude protein, 32 Mcal ME/kg and 1.17% total lysine.

**Treatments**

Two treatments were compared, treatment one; Baby Pig Heat Mat – Single 48 (MAT; 85 W, 34.29 cm x 121.92 cm, polyethylene; Kane Manufacturing, Pleasant Hill, IA; n=12, Figure 3.1) and treatment two; Poly Heat Lamp Fixture (LAMP; 125 W, 25.4 cm x 30.48 cm, polypropylene; HogSlat, Newton Grove, NC; n=10, Figure 3.2) with a 125 W Infrared Heat Bulb (QC Supply, Ames, IA). Both heat source treatment setpoint (defined as desired temperature at which the thermostat is set) was 32.2 ℃. The LAMP was controlled via a single step mechanical thermostat for a maximum temperature. LAMP height was set to match the temperature of MAT, which was controlled via Thermostat Programmable 1 Zone (Kane Manufacturing, Pleasant Hill, IA). The temperature settings for both treatments was confirmed using a handheld infrared temperature gun (Tool House Digital Infrared Thermometer: model 770343S, Alltrade
Tools, LLC, Long Beach, CA; ± 2°C). Sows and their piglets were assigned to one of the heat source treatments, blocked by parity, throughout lactation and pigs were weaned at an average of 21-d of age.

**Production Measures**

Number born alive and number weaned was recorded for each litter. Pre-weaning mortality was defined as a piglet death post-farrowing and prior to weaning, calculated as a percentage ([pigs weaned / pigs born alive] * 100). Piglets were weighed individually at processing (assignment of an individual ear notch, tail docking, 1cc IM iron supplement injection and 0.25cc IM antibiotic injection) and at weaning using a digital scale (Mettler PM30-K, Mettler Toledo. Columbus, OH; ±0.5 g). All piglet mortalities were recorded and included day, sex, weight.

**Behavioral Evaluation**

Video recordings of sows and their litters while in their stalls occurred continually over a 24-h period from D1 through D5, a week before weaning (W-7) and a day before weaning (W-1). Video was recorded using One 12 V color Close Circuit Television (CCTV) camera (Model WV-CP484, Matsushita Co Ltd., Japan) positioned centrally over the stall (2.54 m). Behavioral measures were captured digitally utilizing a Noldus portable lab (Noldus Information Technology, Wageningen, The Netherlands). Cameras were fed into a multiplexer, allowing images to be recorded using a PC with HandiAvi (v4.3, Anderson’s, AZcendant Software, Tempe, AZ, USA) at 30 fps. A computer screen was used to view the output to ensure picture clarity and camera positioning prior to each
behavioral recording session. Videos were converted to a still frame image every 20-mins using a JPG converter (Free video to JPG converter, Digital Wave Ltd., London, United Kingdom). A total of 11 (10 female and 1 male) observers were used. One trainer with 16 years of swine and behavioral experience was responsible for observer training prior to image analysis. An ethogram was create/adapted that included five mutually exclusive sow postures, two piglet locations and piglet contacting or not contacting the sow were recorded (Table 3.1). To test for inter-observer reliability, 14 images were viewed. One image per day per treatment were utilized in the training. All observers independently reviewed these images using the previously described ethogram. All observers reached a 90% or greater agreement with the trainer. Due to the nature of the images, observers were unable to be blinded to the treatment, therefore observers were assigned to images involving a heat source that they had no previous experience.

**Electrical Usage**

Kill-A-Watt EZ Meter P4460 (P3 International Corporation, New York, NY; Accuracy: 0.02%) were connected to the allotted heat source for the entire lactation duration to measure kilowatt hour (kWh) energy usage by each experimental unit. Electric meter readings were recorded twice weekly by farm staff. Final kWh usage readings were recorded at weaning.

**Statistical Analysis**

All data was evaluated using mixed model methodology (Proc Mixed, SAS version 9.4, SAS Institute Inc., Cary, NC). Sources of model variation were considered
significant at \( P < 0.05 \). When fixed effect model variation was significant, LS means for each level within the fixed effect source were separated using the pdiff option within the Proc Mixed procedure (SAS version 9.4, SAS Institute Inc., Cary, NC). Fixed effects in the model included group, parity, and treatment. Production data was analyzed using a generalized mixed model (Proc GLM, SAS version 9.3, SAS Institute Inc., Cary, NC). A random effect for the interaction between farrowing room and stall was included in the model. Behavioral data was analyzed using a generalized mixed model with an i-link distribution (Proc Glimmix, SAS version 9.3, SAS Institute Inc., Cary, NC). Fixed effects in the model included day, treatment and time. A random effect for room and stall within room were included in analysis models.

**Results and Discussion**

When comparing supplemental heat source treatments (i.e. heat lamps and heat mats) there were no litter weaning weight (\( P = .97 \)) or pre-weaning mortality (\( P = .90 \)) differences observed.

Behavioral differences were observed with supplemental heat source type. The number of piglets utilizing heat source differed by supplemental heat source treatment within day with more piglets using the LAMP on D5, W-7 and W-1 compared to piglets in the MAT treatment (\( P < .0001 \); Figure 3.3). The number of piglets in physical contact with the dam was different among treatments within day of lactation (\( P < .0001 \); Figure 3.4). A greater number of piglets within the LAMP heat source treatment were in contact with their dam over D3 through D5 compared to piglets within the MAT treatment. On W-1, piglet contact with the dam was greater for MAT (Figure 3.4). Due to
environmental and recording limitations in the current study, a category for ‘location
unknown’ and ‘touch unknown’ were recorded, these categories accounted for 1.5±2.3
pigs per litter per day. Due to the large variation in unknown and limitations in this study
as a result of recording equipment and environmental factors, additional research work
will be required to ascertain piglet heat source usage and contact with the sow utilizing a
different observation method such as live observation or different camera location. Sow
lying patterns observed in the present study demonstrated that sows spent nearly 80% of
their time in a lateral lying position. A total of 7,751 sow observations over D1-D5, W-7
and W-1 were evaluated throughout the duration of the project, during which 2,744
incidences of lateral lie left (35.4%) and 3,256 incidences of lateral lie right (42.0%) were
recorded. With sows spending the majority of time lying laterally (77.4%), further
research work is required to evaluate if heat source position effects sow lying patterns
across days within lactation and during the entire lactation phase of production.

Energy usage (kWh) was different between the two supplemental heat sources
evaluated in the present study (P<.0001). LAMP (63.6±0.79 kWh) utilized 3.8 times
more electricity (kWh) when compared to MAT(16.4±0.73 kWh). The 47.3 kWh
difference between the two supplemental heat systems utilized in this study can be
translated into an energy cost savings by multiplying by the kWh difference by the cost
per kWh. According to the Bureau of Labor Statistics (2019), the average cost per kWh
in the Midwest is $0.12. Therefore, an energy cost savings of $5.67 per litter can be
achieved when heat mats with a programmable control are used to provide supplemental
heat during lactation when compared to heat lamps operated in a manner to mimic the
mats temperature regiment (energy difference in kWh x kWh cost). The 2017 Pork
Industry Analysis reports litters/sow/year of 2.28, implementation of mats in this manner may result in a savings of $12.92 sow/year. Heats mats have a higher initial cost of implementation at $86.00 which includes the heat mat and portion of the controller capable of running 20 mat units. In contrast, heat lamps have a lower initial cost at $14.43 which includes one light bulb however, a minimum one additional light bulb would be required per year based off expected usage according to the manufacturer with the potential for larger numbers being required based on breakage rates on specific farms. Given this information, heat mats present a payback period of one year when implemented using a controller. This results on a 17.6% return on investment (ROI) is anticipated in year 1 and 100% ROI in following years that do not require supplemental heat source replacement (Table 3.2). Additionally, disease risk from mat use may be a cause for concern and would warrant further work, but proper cleaning and disinfecting should mitigate risk.

Applications

Implementing heat mats along with a programmable controller as the supplemental heat source for piglets in the farrowing house may result in a significant return on investment, despite higher initial investment of $86.00 for MAT compared to LAMP at $14.43. These savings are a result of decreased energy usage when compared to the more traditional heat lamp managed to follow the temperature regiment of the MAT controller. However, additional research work is needed to evaluate piglet and/or sow behavioral differences resulting from using different supplemental heat sources in the farrowing phase.
Acknowledgements

This project was funded in part by Kane Manufacturing. Support from the Department of Animal Science, College of Agriculture and Life Sciences at Iowa State University, and USDA. A special thanks to the farm staff at the Allen E. Christian Iowa State University Swine Teaching farm for their assistance in completing this project.

Literature Cited


Swine Care Handbook. 2018. National Pork Board, Des Moines, IA. 
https://www.pork.org/certifications/pork-quality-assurance-plus/
Figure 3.1. Image of farrowing stall with treatment Baby Pig Heat Mat used in study comparing heat mats and heat lamp to provide supplemental heat for piglets during lactation.

1 Baby Pig Heat Mat – Single 48 (34.29 cm x 121.92 cm) (Kane Manufacturing, Pleasant Hill, IA)
Figure 3.2. Image of farrowing stall with treatment Poly Heat Lamp Fixture used in a study comparing heat mats and heat lamps to provide supplemental heat for piglets during lactation.

1 Poly Heat Lamp Fixture with 125W heat bulb (Hogslat, Newton Grove, NC)
Figure 3.3. Piglet heat source usage within day of lactation by treatment (P<.0001).  

1. Differing superscripts within day of lactation represent differences by treatment.  
2. Error bars represent standard error.  
3. Number of piglets represents the piglets using the heat source within day of lactation, other piglets are in other stall location or location unknown.  
4. Energy usage was obtained using a Kill-A-Watt EZ Meter P4460 (P3 International Corporation, New York, NY; Accuracy: 0.02%).
Figure 3.4. Piglet physical contact with the dam within day of lactation by treatment (P<.0001).  

1 Differing superscripts within day of lactation represent differences by treatment (P<.05)  
2 Error bars represent standard error  
3 Number of piglets represents the piglets in physical contact with the dam within day of lactation, other piglets are not in contact with the sow or contact could not be determined
Table 3.1. Behavioral measures recorded when evaluating sows and their litters using a 20-minute scan sample through digital images for D1 through D5 of the trial, a week before (W-7) and a day before weaning (W-1).1

<table>
<thead>
<tr>
<th>Measure2</th>
<th>Defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piglet Location3</td>
<td></td>
</tr>
<tr>
<td>Mat</td>
<td>75% or more of the piglet is touching the heat mat</td>
</tr>
<tr>
<td>Lamp</td>
<td>75% or more of the piglet is under the heat lamp</td>
</tr>
<tr>
<td>Other</td>
<td>Anywhere in the stall not associated with the heat source</td>
</tr>
<tr>
<td>Piglet Contact4</td>
<td></td>
</tr>
<tr>
<td>Touch</td>
<td>Any part of the piglet is touching the sow</td>
</tr>
<tr>
<td>Not</td>
<td>No part of the piglet is touching the sow</td>
</tr>
<tr>
<td>Sow Posture5</td>
<td></td>
</tr>
<tr>
<td>Lateral lie left</td>
<td>Lying on pig’s left side</td>
</tr>
<tr>
<td>Lateral lie right</td>
<td>Lying on pig’s right side</td>
</tr>
<tr>
<td>Sternal lie</td>
<td>Lying on pig’s sternum</td>
</tr>
<tr>
<td>Standing</td>
<td>All four feet on flooring</td>
</tr>
<tr>
<td>Sitting</td>
<td>Hindquarter on floor, front feet on flooring</td>
</tr>
</tbody>
</table>

---

1 Behavioral measures were obtained through digital observation
2 This was used in a study comparing heat lamp and heat mats as supplemental heat sources for piglets during lactation.
3 Piglet location within the stall
4 Piglet physical contact with the sow
5 Sow lying posture within the stall
Table 3.2. Initial cost comparison of heat mats run on a controller systems at a set temperature compared to heat lamps set at a specific height to maintain the same temperature for an example 20-room farrowing house with 4 rows per room and 10 stalls per row, totaling 40 stalls per room and 800 total farrowing stalls.

<table>
<thead>
<tr>
<th>Item</th>
<th>Heat Mat&lt;sup&gt;4&lt;/sup&gt;</th>
<th>Heat Lamp&lt;sup&gt;5&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farrowing House&lt;sup&gt;3&lt;/sup&gt;</td>
<td>$68,800.00</td>
<td>$11,544.00</td>
</tr>
<tr>
<td>Farrowing Room&lt;sup&gt;4&lt;/sup&gt;</td>
<td>$3,440.00</td>
<td>$577.20</td>
</tr>
<tr>
<td>Farrowing Stall&lt;sup&gt;5&lt;/sup&gt;</td>
<td>$86.00</td>
<td>$14.43</td>
</tr>
<tr>
<td>Replacement&lt;sup&gt;6&lt;/sup&gt;</td>
<td>$0.00&lt;sup&gt;7&lt;/sup&gt;</td>
<td>$1.58&lt;sup&gt;8&lt;/sup&gt;</td>
</tr>
<tr>
<td>Energy Usage per Year (kWh)&lt;sup&gt;9&lt;/sup&gt;</td>
<td>247</td>
<td>954</td>
</tr>
<tr>
<td>Energy Cost per Year&lt;sup&gt;10&lt;/sup&gt;</td>
<td>$29.52</td>
<td>$114.48</td>
</tr>
<tr>
<td>Total Cost Year 1</td>
<td>$115.52</td>
<td>$130.69</td>
</tr>
<tr>
<td>Payback Period</td>
<td>12 months</td>
<td></td>
</tr>
<tr>
<td>ROI – Replacement</td>
<td>17.6%</td>
<td></td>
</tr>
<tr>
<td>ROI – Non- Replacement</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> Heat Mat set up includes controller mats and relays required to achieve energy savings; Baby Pig Heat Mat – Single 48 (Kane Manufacturing, Pleasant Hill, IA)
<sup>2</sup> Heat Lamp includes one 125W bulb per lamp for initial cost; Poly Heat Lamp Fixture (Hogslat, Newton Grove, NC)
<sup>3</sup> Cost to entire 20 room, 800 stall farrowing house
<sup>4</sup> Cost to outfit on 40 stall room
<sup>5</sup> Cost per single farrowing stall
<sup>6</sup> Replacement of units or bulbs annually
<sup>7</sup> Heat mat replacement rate is every 7-10 years
<sup>8</sup> Bulbs have a 5,000-hour life or 208 days, therefore at least one replacement will be required per year
<sup>9</sup> Assuming 15 turns per year (2 days pre-farrowing, 21-day lactation, and 1 day for cleaning)
<sup>10</sup> Assuming $0.12 per kWh
CHAPTER 4. COMPARISON OF HEAT LAMPS AND HEAT MATS IN THE FARROWING HOUSE: EFFECT ON PIGLET PRODUCTION, ENERGY USAGE AND PIGLET AND SOW BEHAVIOR THROUGH LIVE OBSERVATION

Karli J. Lane, BS; Anna K. Johnson, PhD; Carson E.J. Stilwill, BS; Locke A. Karriker, DVM; Jay D. Harmon, PhD; Kenneth J. Stalder, PhD

KJL, AKJ, CEJS, KJS: Department of Animal Science, College of Agriculture and Life Sciences, Iowa State University, Ames, Iowa.

LAK: Veterinary Diagnostics and Production Animal Medicine and Swine Medical Education Center, College of Veterinary Medicine, Iowa State University, Ames, Iowa.

JDH: Department of Agricultural and Biosystems Engineering, College of Engineering and College of Agricultural and Life Sciences, Iowa State University, Ames, Iowa.

Corresponding author: Dr. Kenneth J. Stalder, 806 Stange Rd. 109C Kildee Hall, Department of Animal Science, Iowa State University, Ames, IA, 50011; Tel: 515-294-4683; Email: stalder@iastate.edu

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Abstract

Objective: To determine the effects of heat lamps versus heat mats on piglet performance measures, sow lying behavior, piglet behavior and energy usage.

Materials and methods: 17 multiparous crossbred sows housed in farrowing stalls were randomly assigned to a heat source treatment; Baby Pig Heat Mat – Single 48 (MAT; n=8) or Poly Heat Lamp Fixture LAMP; n=9). Piglets were weighed on D1 and weaning and any mortalities were recorded to evaluate piglet production measures. For seven days over the course of lactation (D1, D2, D3, D4, D5, DW, and DD) sows and their litters were observed for two hours twice daily to evaluate behavior. Electric meters were attached to individual heat source treatments to monitor energy usage.

Results: Piglet production parameters were unaffected by treatment type; litter weaning weight ($P = .85$), litter average daily gain ($P = 0.79$) and pre-weaning mortality ($P = .58$).
Piglet behavior had variation in the number of piglets using a heat source within day across treatments ($P < .0001$). The number of piglets in contact with the sow decreased during early lactation for both treatment types and increased during late lactation with more MAT pigs tending to be in contact with the sow ($P < .0001$).

**Implications:** Utilizing heat mats as supplemental heat in the farrowing house may result in decreased energy usage and increased savings without hindering piglet production parameters.

**Keywords:** swine, farrowing, pre-weaning mortality, heat sources, energy usage

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**Introduction**

Pre-weaning mortality continues to be a cause for concern in the United States (U.S.) swine industry. Current pre-weaning mortality estimates from U.S. commercial swine operations have been relatively stable at 17.5% between 2015 to 2017. At a 20% pre-weaning mortality level, it has been estimated to cost the U.S. pork industry $650 to $800 million annually. The majority of these losses occur during the perinatal period (during farrowing and the first three days after birth) and can account for up to 50% of total pre-weaning mortality. Pre-weaning mortality has been described as multi-factorial and the factors include low birth weight, lack of sufficient energy stores, poor body temperature regulation, and/or strong competition between littermates for colostrum and milk.

Within the farrowing environment, the sow and her piglets are at two very different life stages and have different requirements regarding their thermal, social and physical (the production system) environments. For example, ambient temperature
requirements for the lactating sow range from 15 to 26°C, but individual newborn piglets prefer a higher temperature of 34°C. At birth, piglets are poorly equipped to deal with the environment they experience outside of the sow. They are especially susceptible to cold stress because they lack a coat of hair, have a large surface area to body weight ratio, lack suitable energy reserves and have poor body thermostability at birth. When the environmental temperature falls below 34°C the newborn piglet is subjected to cold stress and will begin to mobilize its glycogen reserves from the liver and skeletal muscles. Nutrients supplied through the sows’ colostrum increase heat production. Under cold stress, the piglet undergoes reduced locomotive vigor resulting from weakness through starvation leading to decreased capabilities to avoid movements exhibited by the sow. During lactation, littermates utilize huddling to increase their thermal insulation and conduction. In conventional indoor confinement systems, caretakers can provide piglets with supplemental heat sources (lamps and mats) in order to keep the piglets warm and away from their mother to reduce pre-weaning mortality.

Previous work by Stinn and Xin compared a heat mat to a heat lamp on piglet mortality, rate of gain, and electric power use. The authors concluded that there was no difference in rate of gain or mortality, but mats used 36% less power compared to heat lamps. In agreement to this study, MacDonald and colleagues found that heat mats can have a 50% cost savings without detrimentally affecting piglet weaning weight or average daily weight gain. Finally, Hrupka and colleagues reported that heat lamp location within a farrowing stall did not affect pre-weaning mortality, but did conclude that fewer piglets were within 8 cm of the sow and more were located in the area of the heat source. Therefore, the objectives of this work were to 1) evaluate piglet
performance and pre-weaning mortality when supplied two different heat source
treatments, 2) evaluate sow lying behavior and piglet location behavior in regard to heat
source and proximity to the sow and 3) evaluate the energy efficiency of two different
heat sources.

**Materials and Methods**

The research protocol was approved by the Iowa State University Institutional
Animal Care and Use Committee (IACUC-18-256). Sows were allotted a minimum of a
72-h acclimation period prior to farrowing.

**Animals, Location and Housing**

A total of 17 farrowing stalls, across two groups, that had interlocking plastic
flooring and a creep area on both sides of sow were used in this study. The total stall area
measured 2.0 x 1.7 M. The center sow area measured 2.0 m x 0.6 m with two creep areas
measuring 2.0 m x 0.55 m on either side. Solid flooring was provided, 1.2 m x 0.4 m, on
one side of the piglet creep area where the heat source was provided. The stalls were
distributed across two farrowing houses (7 stalls per room) in a negative pressure,
mechanically ventilated barn set at 21.1 °C. Sows were all part of the Iowa State
University Allen E. Christian Swine Teaching Farm in Ames, IA. Each stall contained a
sow and her litter with no cross fostering, and the stall was the experimental unit.
Multiparous crossbred sows (P1= 5, P2= 3, P3= 4, P4=1, and P7+=4) were randomly
assigned to treatment prior to entering farrowing. Sows were provided ad libitum access
to water via one nipple and were hand fed once daily prior to farrowing. Post-farrowing,
sows were hand fed to appetite three times daily in 0.90 kg increments. All diets were
prepared by a commercial feed mill (Key Cooperative, Gilbert, IA) composed of primarily corn, soybean meal, dried distillers grains and nutrients formulated according to NRC (2012) guidelines to meet or exceed gestating/lactating sow nutrient requirements. The diet contained 19.6% crude protein, 32 Mcal ME/kg and 1.17% total lysine. This study was conducted during November and December 2018.

Treatments

Two treatments were compared, treatment one; Baby Pig Heat Mat – Single 48 (MAT; 85 W, 34.29 cm x 121.92 cm, polyethylene; Kane Manufacturing, Pleasant Hill, IA; n=8, Figure 4.1) and treatment two; Poly Heat Lamp Fixture (LAMP; 125 W, 25.4 cm x 30.48 cm, polypropylene; HogSlat, Newton Grove, NC; n=9, Figure 4.2) with a 125 W Infrared Heat Bulb (QC Supply, Ames, IA).

Both heat sources were set at 32.2 °C. The LAMP was controlled via a single step mechanical thermostat for a maximum temperature and height was adjusted to match the temperature regimen of MAT, which was controlled via Thermostat Programmable 1 Zone (Kane Manufacturing, Pleasant Hill, IA) both confirmed with infrared temperature gun (Tool House Digital Infrared Thermometer: model 770343S, Alltrade Tools, LLC, Long Beach, CA; ± 2°C). Sows and their piglets were assigned to one of the heat source treatments, blocked by parity, throughout lactation and pigs were weaned at an average of 21 days of age.
Production Measures

Piglets were counted and weighed at processing and weaning. Number born alive was recorded for each litter. Pre-weaning mortality was defined as a loss incurred post-farrowing and prior to wean, calculated as a percentage by the number of pigs weaned divided by number of pigs born alive times 100. Piglets were weighed individually using a digital scale (Mettler PM30-K, Mettler Toledo. Columbus, OH; ±0.5 g) on D1 and at weaning. All piglet deaths were recorded and included day, sex, and weight.

Behavioral Evaluation

Sows and their litters were observed by a single trained observer at two-time segments over a 24-h time period for D1 through D5, DW (week before weaning) and DD (day before weaning) using a live methodology. Each time segment consisted of two consecutive hours (09:00 to 11:00 or 21:00 to 23:00) and observations were collected every 15 minutes. Observer training took place prior to the first farrowing until the observer had a >95% agreement. An ethogram was created/adapted that included five mutually exclusive sow postures, two piglet locations and piglet contacting the sow or not contacting the sow were recorded (Table 4.1).

Electrical Usage

Kill-A-Watt EZ Meter P4460 (P3 International Corporation, New York, NY; Accuracy: 0.02%) were connected to the allotted heat source for the entire lactation duration to measure kilowatt hour (kWh) energy usage by each experimental unit.
Electric meter readings were monitored and recorded twice weekly by farm staff. Final kWh usage readings were recorded at weaning.

**Statistical Analysis**

All data was evaluated using mixed model methodology (Proc Mixed, SAS version 9.4, SAS Institute Inc., Cary, NC). Sources of model variation were considered significant at $P < 0.05$. When fixed effect model variation was significant, LS means for each level within the fixed effect source were separated using the pdiff option within the Proc Mixed procedure (SAS version 9.4, SAS Institute Inc., Cary, NC). Fixed effects in the model included group, parity, location of heat source and treatment. Production data was analyzed using a generalized mixed model (Proc Glimmix, SAS version 9.3, SAS Institute Inc., Cary, NC). A random effect for the interaction between room and stall was included in the model. Behavioral data was analyzed using a generalized mixed model with i-link distribution (Proc Glimmix, SAS version 9.3, SAS Institute Inc., Cary, NC). Fixed effects in the model included day, treatment and time. Random effect was room and stall.

**Results**

**Production**

No litter weaning weight ($P = 0.85$) or litter average daily gain ($P = 0.79$) differences were observed when comparing piglets provided heat lamps and piglets provided heat mats in the study (Table 4.2). No treatment differences were observed in
pre-weaning mortality \((P = .58)\). Sixty percent of mortalities occurred within the first 24h post-farrowing.

**Behavior**

Number of piglets using either a heat lamp or heat mat differed within a treatment day, with lamp being used by more piglets on D1, D3, D4, DW and DD (Figure 4.3; \(P < .0001\)). The number of piglets using the heat lamp treatment across days of lactation decreased after D4 (Figure 4.4; \(P < .0001\)). Similarly, the number of piglets utilizing the heat mat treatment over days of lactation decreased at DW until the end of lactation (Figure 4.5; \(P < .0001\)).

The number of piglets in physical contact with their dam by treatment within lactation day differed, with MAT piglets had greater physical contact with their dam on D3 and D4 (Figure 4.6; \(P < .0001\)). The number of piglets with physical contact with their dam, within treatment, across days of lactation resulted in greater variation within LAMP treatment (Figure 4.7; \(P < .0001\)). The number of piglets with physical contact with their dam, within treatment, over days of lactation demonstrated that the piglet’s physical contact with their dam remained relatively constant when provided supplemental heat using the MAT treatment (Figure 4.8; \(P < .0001\)).

Sow lying behavior was not affected by heat source type or location (Chi Square, \((X^2) (2, N = 17) = 2.14, p = .14\). As a result of sows spending most of the time lying laterally, analysis was focused on these traits. Sow lying preference demonstrated that 7 sows prefer to lateral lie right and 8 sows preferred lateral lie left, 5 favored lying with their udder towards the heat source and 10 favored lying with their udder away from the
heat source. There were 2 sows that had no preference for lying position and therefore udder direction to the heat source.

Energy

The energy consumption for the heat mat treatment (19.4±2.99) was less than the energy usage for heat lamp treatment (68.5±1.97) with a difference of 49.1 kwh per litter ($P < .001$). Initial heat lamp and heat mat costs vary, with heat lamps requiring less initial investment, but has a greater cost associated with energy use (Table 4.3). Using an average cost of $0.12/kWh in the Midwest (Bureau of Labor Statistics, 2019), the average 49.05 kwh energy savings can be translated into an average cost savings of $5.89 per litter (49.1 kwh * 0.12 = 5.89).

Discussion

Challenges continue to exist in the farrowing house for the caretaker to supply a suitable environment for the sow and her piglets immediately after parturition and through the lactation period. Consistent results across studies indicate that pre-weaning mortality will remain relatively constant regardless of supplemental heat source (i.e. heat lamps or heat mats) are used. The current study supports the production parameter findings from previous studies, with no supplemental heat source effects on weaning weight, daily gain or pre-weaning mortality, further indicating that heat source type should be a management decision regarding what works best within a particular system. In agreement with previous studies, the majority of pre-weaning mortality occurred within the first 24-h post farrowing.
During the first 24-h, when mortality rates were the highest, behavior findings showed a greater number of piglets spending time in contact with their dam across treatments. Other studies have reported that the day-old piglets spend 60 to 75% of their time nursing or lying near their dam regardless of supplemental heat source position. In the current study, heat source type did not have an effect on this behavior. Several biological factors could provide explanation to this piglet behavior difference. The sow provides the nutrition for the piglet, which is critical for the piglet to produce heat so that it can maintain its thermodynamics. Additionally, milk letdown initially is constant, therefore piglet nursing bouts and teat fidelity have not been established until later in lactation. Other contributing factors could include an odor or sound that may provide comfort to piglets, but further behavior work would be required to ascertain this behavioral mechanism. Regardless of motivation, the area around the sow remains dangerous to piglet’s with crushing being an imminent threat, as the number one reason for piglet mortality continues to be crushing or laid on by the sow. After the initial 24-h post-farrowing, supplemental heat source usage by piglet’s increased across treatments, likely as a result of better thermodynamics and nursing bouts being initiated. Sow posture was unaffected by supplemental heat source location, decreasing heat stress concern from the supplemental heat provided for piglets. Additional research work is needed that examines other supplemental heat source options and piglet preference or motivation for each heat source.

However, consideration should be placed on the energy savings when utilizing heat mats. Under the circumstances in the current study, controlling heat mats with a controller as compared to varying heat lamp height, energy savings can be achieved. Heat
mats can result in a savings of $18.30 per farrowing stall or total of $5,856 return on investment (ROI) in year 1, a 21.2% ROI [\((\text{initial cost of heat lamp} + \text{heat mat energy costs}) - (\text{initial cost of lamp} + \text{bulb replacement} + \text{heat lamps energy costs}) = \text{initial year savings}\)]. In subsequent years, that do not require heat source replacement, a savings of $89.87 per stall or $28,758.40 total ROI, or 104.5%, can be acquired (energy cost of mat – energy cost of lamp = total savings with mat). Given the energy savings of the heat mat, a payback period of 11.7 months can be achieved. As stewards of the land and the environment, according to the PQA Good Production Practices, additional value can be found in minimizing the carbon footprint of swine production.\(^{20}\)

**Implications**

- Choice of heat supplementation remains the decision of farm management
- Significant savings can be achieved by using heat mats with a controller

**Acknowledgements**

This project was funded in part by Kane Manufacturing. Support from the Department of Animal Science, College of Agriculture and Life Sciences at Iowa State University, and USDA. A special thanks to the farm staff at the Allen E. Christian Iowa State University Swine Teaching farm for their assistance in completing this project.

**Conflict of Interest**

None Reported
Disclaimer

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Literature Cited


Figure 4.1. Image of farrowing stall with treatment Baby Pig Heat Mat used in a study comparing heat mats and heat lamps to provide supplemental heat for piglets during lactation.

1 Baby Pig Heat Mat – Single 48 (34.29 cm x 121.92 cm) (Kane Manufacturing, Pleasant Hill, IA)
Figure 4.2. Image of farrowing stall with treatment Poly Heat Lamp Fixture used in a study comparing heat mats and heat lamps to provide supplemental heat for piglets during lactation.

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1 Poly Heat Lamp Fixture with 125W heat bulb (Hogslat, Newton Grove, NC)
Figure 4.3. Piglet heat source usage within lactation day ($P<.0001$). $^{1,2,3}$

$^1$ $^a$ and $^b$ within a lactation day means treatments are significantly different ($P<.05$)

$^2$ Number of piglets represents the piglets using the heat source within day of lactation, other piglets are in another stall location

$^3$ Error bars represent standard error
Figure 4.4. Piglet heat lamp usage by lactation day within treatment ($P<.0001$). $^{1,2,3}$

1 Differing letters indicate a significant difference between lactation day within treatment ($P<.05$)
2 Number of piglets represents those using the heat source treatment only.
3 Error bars represent standard error
Figure 4.5. Piglet heat mat usage by lactation day within treatment ($P<.0001$). ¹,²,³

¹ Differing letters indicate a significant difference between lactation day within treatment ($P<.05$)
² Number of piglets represents those using the heat source treatment only.
³ Error bars represent standard error
Figure 4.6. Physical piglet contact with the dam across treatments by lactation day ($P<.0001$).\textsuperscript{1,2,3}

\textsuperscript{1} and \textsuperscript{2} within a lactation day means treatments are significantly different ($P<.05$)
\textsuperscript{2} Number of piglets represents the piglets in physical contact with the dam within lactation day, other piglets are in another stall location
\textsuperscript{3} Error bars represent standard error
Figure 4.7. Piglet physical contact with the dam within heat lamp treatment by lactation day ($P<.0001$).$^{1,2,3}$

$^1$ Differing letters indicate a significant difference between lactation day within treatment ($P<.05$)
$^2$ Number of piglets represents those in physical contact with the dam
$^3$ Error bars represent standard error
Figure 4.8. Piglet physical contact with dam within heat mat treatment by lactation day ($P<.0001$).\footnote{Differing letters indicate a significant difference between lactation day within treatment ($P<.05$)}\footnote{Number of piglets represents those in physical contact with the dam} \footnote{Error bars represent standard error}

$1$ Differing letters indicate a significant difference between lactation day within treatment ($P<.05$)
$2$ Number of piglets represents those in physical contact with the dam
$3$ Error bars represent standard error
Table 4.1. Behavioral measures recorded when evaluating sows and their litters using a 15-minute scan sample with live observation between 9 and 11 am and pm for D1 through D5 of the trial, a week before (DW) and a day before weaning (DD).

<table>
<thead>
<tr>
<th>Measure(^2)</th>
<th>Defined</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Piglet Location(^3)</strong></td>
<td></td>
</tr>
<tr>
<td><em>Mat</em></td>
<td>75% or more of the piglet is touching the heat mat</td>
</tr>
<tr>
<td><em>Lamp</em></td>
<td>75% or more of the piglet is under the heat lamp</td>
</tr>
<tr>
<td><em>Other</em></td>
<td>Anywhere in the stall not associated with the heat source</td>
</tr>
<tr>
<td><strong>Piglet Contact(^4)</strong></td>
<td></td>
</tr>
<tr>
<td><em>Touch</em></td>
<td>Any part of the piglet is touching the sow</td>
</tr>
<tr>
<td><em>Not</em></td>
<td>No part of the piglet is touching the sow</td>
</tr>
<tr>
<td><strong>Sow Posture(^5)</strong></td>
<td></td>
</tr>
<tr>
<td><em>Lateral lie left</em></td>
<td>Lying on pig’s left side</td>
</tr>
<tr>
<td><em>Lateral lie right</em></td>
<td>Lying on pig’s right side</td>
</tr>
<tr>
<td><em>Sternal lie</em></td>
<td>Lying on pig’s sternum</td>
</tr>
<tr>
<td><em>Standing</em></td>
<td>All four feet on flooring</td>
</tr>
<tr>
<td><em>Sitting</em></td>
<td>Hindquarter on floor, front feet on flooring</td>
</tr>
</tbody>
</table>

\(^1\) This was used in a study comparing heat lamp and heat mats as supplemental heat sources for piglets during lactation.

\(^2\) Measures were observed through live observation by a single observer

\(^3\) Piglet location in the farrowing stall

\(^4\) Physical contact between the piglet and dam

\(^5\) Sow lying posture within the farrowing stall
Table 4.2. Production traits by treatment Least Square Means (±SE) from a study comparing heat lamps and heat mats as supplemental heat sources for piglets during lactation.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Litter Wean Weight&lt;sup&gt;1&lt;/sup&gt; (kg)</th>
<th>Litter Average Daily Gain&lt;sup&gt;2&lt;/sup&gt; (kg/day)</th>
<th>Mortality&lt;sup&gt;3&lt;/sup&gt; (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp</td>
<td>44.5±8.50</td>
<td>1.5±0.29</td>
<td>15.3±2.52</td>
</tr>
<tr>
<td>Mat</td>
<td>47.0±8.86</td>
<td>1.6±0.30</td>
<td>12.3±3.32&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> Piglets were weighed individually then summed together for litter weaning weight  
<sup>2</sup> [(litter wean weight – litter birth weight) / days of lactation]  
<sup>3</sup> [(total mortalities / total number born alive) * 100] calculated by treatment  
<sup>4</sup> No differences in production traits observed (P ≥ 0.58)
Table 4.3. Initial cost comparison of heat mats managed with a controller on a decreasing temperature regiment compared to heat lamps raised to decrease temperature for an example farm with an 8-room farrowing house that contains 4 rows per room and 10 stalls per row, with a total of 40 stalls per room and 320 total farrowing stalls in the farrowing house.\(^1\)

<table>
<thead>
<tr>
<th></th>
<th>Heat Mat(^2)</th>
<th>Heat Lamp(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farrowing House</td>
<td>$27,520.00(^5)</td>
<td>$4,617.60(^6)</td>
</tr>
<tr>
<td>Farrowing Room</td>
<td>$3,440.00</td>
<td>$577.20</td>
</tr>
<tr>
<td>Farrowing Stall</td>
<td>$86.00</td>
<td>$14.43</td>
</tr>
<tr>
<td>Replacement(^9)</td>
<td>$0.00(^10)</td>
<td>$1.58(^11)</td>
</tr>
<tr>
<td>Energy Usage per Turn (kWh)</td>
<td>19.4</td>
<td>68.5</td>
</tr>
<tr>
<td>Energy Usage per Year (kWh)(^12)</td>
<td>291.3</td>
<td>1,027.05</td>
</tr>
<tr>
<td>Energy Cost per Year(^13)</td>
<td>$34.96</td>
<td>$123.25</td>
</tr>
<tr>
<td>Total Cost Year 1</td>
<td>$120.96</td>
<td>$139.26</td>
</tr>
<tr>
<td>Payback Period</td>
<td>11.7 months</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Disclaimer: numbers used may vary; check with your supplier and energy company to evaluate your individual situation.
\(^2\) Heat Mat set up includes controller mats and relays required to achieve energy savings; Baby Pig Heat Mat – Single 48 (Kane Manufacturing, Pleasant Hill, IA)
\(^3\) Heat Lamp includes one 125W bulb per lamp for initial cost; \(^3\) Poly Heat Lamp Fixture (Hogslat, Newton Grove, NC)
\(^4\) Cost to outfit one 20-room, 800-farrowing stall house
\(^5\) Cost provided by Kane Manufacturing
\(^6\) Costs available at Hogslat.com
\(^7\) Cost to outfit one 40-stall room
\(^8\) Cost per individual farrowing stall
\(^9\) Replacement is assumed on an annual basis on this line
\(^10\) Heat mat replacement rate is every 7-10 years
\(^11\) Bulbs have a 5,000-hour life or 208 days, therefore at least one replacement will be required per year
\(^12\) Assuming 15 turns per year (2 days pre-farrowing, 21-day lactation, and 1 day for cleaning)
\(^13\) Assuming $0.12 per kWh
CHAPTER 5. CONCLUSION

Pre-weaning mortality continues to impact the productivity of the United States (U.S.) swine industry. Recent pre-weaning mortality percentages range from 13.2% on the best farms and 21.4% in the bottom 25% of farms, which indicates there is potential for significant improvement (Stalder, 2018). It is a common practice to provide supplemental heat to piglets during parturition and lactation to meet their thermoregulatory needs and mitigate a major factor contributing to pre-weaning mortality (chilling) while maintaining a comfortable sow environment. Supplemental heating practices that include the addition of heat mats and/or heat lamps use energy. The overall thesis goal was to create a comparison of heat lamps and heat mats as supplemental heat sources in the farrowing house to assist in the decision-making process. To address this overall goal, two research chapters (3 and 4) focused on the following objectives:

1) To evaluate piglet production measures including pre-weaning mortality, litter weaning weight and average daily gain.

2) To evaluate piglet behavior in respect to heat source usage and physical contact with the dam, as well as the sow’s behavior in relation to heat source placement.

3) To evaluate the energy usage of each supplemental heat source and create a cost analysis.

The objective of Chapter 3 was as follows: To evaluate piglet production measures including pre-weaning mortality, litter weaning weight and average daily gain, evaluate piglet behavior in respect to heat source usage and physical contact with the dam, as well
as the sow’s behavior in relation to heat source placement and evaluate the energy usage of each supplemental heat source and create a cost analysis when supplemental heat sources are applied at a constant temperature as supplemental heat during lactation using a digital methodology. The hypothesis of this study was there would be no differences in production measures and behavior between heat source type with heat mats being more energy efficient.

In support of the hypothesis, production measures were not impacted by supplemental heat source treatment. The heat mat treatment used over a third less energy when compared to heat lamps. Contrary to the hypothesis, behavior did vary across heat source treatments. However, environmental and equipment limitations resulted in greater numbers of unknown piglet location and physical contact with their dam when evaluating behavior aspects within the current study. Therefore, further investigation on piglet behavior should be conducted which utilize different observation methods to capture all piglet and sow behaviors when evaluating supplemental heat sources during lactation.

The objective of Chapter 4 was to evaluate piglet production measures including pre-weaning mortality, litter weaning weight and average daily gain, evaluate piglet behavior in respect to heat source usage and physical contact with the dam, as well as the sow’s behavior in relation to heat source placement and evaluate the energy usage of each supplemental heat source and create a cost analysis at a decreasing supplemental heat temperature regiment over lactation. The hypothesis of this study was that there would be no difference in piglet production, sow and piglet behavior or energy use between heat mats and heat lamps when utilized to provide supplemental heat during lactation.
In support of the hypothesis, production measures were not affected by supplemental heat source treatment in the present study. Contrary to the hypothesis, energy usage was different, resulting in substantial energy and cost savings when heat mats are implemented as the supplemental heat source during lactation when compared to heat lamps. Behavior measures varied between treatments with piglets within the heat mat treatment spending more time in physical contact with their dam and a greater number of piglets utilizing the heat source when the supplemental heat source was a heat lamp.

Further research is warranted to determine motivations of piglet behavior in the farrowing house to attempt to minimize pre-weaning mortality. Knowledge on piglet motivation as it relates to olfactory, auditory and touch that could be included into the heat source may affect pre-weaning mortality and warrants attention. Additional research comparing other alternative supplemental heat sources, such as brooders or bedding, during lactation would help producers to better quantify potential energy usage and cost savings.

The overall goal for the present study was the provide U.S. swine producers with a comparison between heat lamps and heat mats in the farrowing house through three objectives: 1) To evaluate piglet production measures including pre-weaning mortality, litter weaning weight and average daily gain, 2) To evaluate piglet behavior in respect to heat source usage and physical contact with the dam, as well as the sow’s behavior in relation to heat source placement and 3) To evaluate the energy usage of each supplemental heat source and create a cost analysis. The results of this research support supplemental heat source decisions being a management decision as there are no detrimental effects on production performance when either are used to provide supplemental heat from parturition
through lactation. However, significant energy and cost savings can be achieved when heat mats are utilized as the supplemental heat source during the same time period.

**Literature Cited**

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