EFFECTS OF HEAT STRESS ON THERMOREGULATION, REPRODUCTION AND

PERFORMANCE OF DIFFERENT PARITY SOWS

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EFFECTS OF HEAT STRESS ON THERMOREGULATION, REPRODUCTION AND PERFORMANCE OF DIFFERENT PARITY SOWS

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ABSTRACT

Heat stress caused by high ambient temperatures causes seasonal infertility in sows, leading to decreased production and a loss in reproductive efficiency. The objective of these studies was to specifically determine the effect of heat stress on the thermoregulatory behavior, growth and production characteristics as well as endocrine responses of sows during lactation. Factors such as parity, energy balance and farrowing facility design were closely examined to determine their role in controlling body temperature and respiration rate of sows during heat stress and lactation. Primiparous and multiparous Landrace or Landrace x Large White sows of different parities were studied from late gestation through weaning. The study was performed at the University of Missouri Swine Research Complex (Columbia, MO) in order to provide similar results as would be found in a real-world commercial swine farm setting. Rectal temperature (RT), respiration rate (RR), shoulder skin temperature, ear skin temperature, metabolite concentrations, energy balance (EB), sow body weights and piglet body weights were measured throughout the studies.

CHAPTER 1

INTRODUCTION

Heat stress adversely impacts pig performance. In particular, growth, reproduction, feed conversion, health and welfare of animals can be severely affected. Heat stress not only negatively impacts the health and performance of pigs, but it is also costly to swine producers. According to St-Pierre et al. (2003), heat stress and its consequences result in \$299 million annual losses for U.S. swine producers.

When exposed to heat stress, pigs must either decrease heat production or increase the rate of heat loss to maintain core body temperature (Nichols et al., 1982). Compared with other species of farm animals, pigs are especially sensitive to heat stress because they have limited physiological mechanisms for evaporative cooling. Pigs use thermoregulatory mechanisms such as changing posture, vasodilation and increasing respiration rate to increase the transfer of excess heat to the environment. However, as ambient temperature rises above pigs' thermoneutral zone and approaches their body temperature, they are unable to lose as much heat to the environment. Under these extreme conditions, energy balance is negatively affected because feed consumption is reduced. Thus, significant losses in reproduction and performance can occur.

Heat stress during lactation can be particularly damaging to the swine herd because it has deleterious effects on the reproduction of sows and the growth rate of their litters. More specifically, heat stress can detrimentally alter weaning-to-estrus intervals, occurrence of anestrus, follicular growth, and piglet performance. High ambient summer

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temperatures during lactation can decrease subsequent farrowing rates and depress litter size for sows and gilts. During heat stress conditions, sows decrease feed intake to minimize heat production during lactation (Messias de Bragança et al., 1998; Noblet et al., 1993). This can lower milk production, leading to smaller piglet size at weaning and a decrease in subsequent growth rate (Almond and Bilkei, 2005; Renaudeau and Noblet, 2001).

The detrimental effect of heat stress on sow and piglet performance has been a major obstacle in the swine industry for many decades. Most commercial swine farms house pigs in confinement facilities that provide protection from seasonal weather patterns to allow year-round production cycles. Although these facilities provide shelter from extreme temperatures, not all types of facilities are adequate in preventing heat stress in pigs of all ages and phases of production (Harmon et al., 2001). Pregnant and lactating sows, in particular, are particularly sensitive to the effects of heat stress, as will be described in the literature below. The significant production losses in pregnant and lactating sows associated with heat stress justify the development of novel research methods to determine the most cost-effective way of minimizing the problem. The objectives of this research were to determine the thermal, metabolic, and endocrine responses of sows to heat stress during lactation. The purpose of this research was to determine what housing management methods would be most beneficial in order to minimize the effect of heat stress on sow and piglet performance. Information gathered from these experiments will be used to make recommendations for producers to modify the environment of lactating sows during periods of heat stress.

CHAPTER 2

LITERATURE REVIEW

Introduction

Heat stress during summer months is a common problem for commercial sow farms globally. It causes a sow to reduce feed intake, leading to negative energy balance and weight loss, which ultimately leads to herd production losses. The purpose of this chapter is to review the relevant literature on thermoregulation, reproduction, milk production, endocrinology and energy balance to determine how they interact to affect gilts and sows during periods of heat stress.

Design and management of sow production facilities

In the United States, most commercial swine production facilities are designed so that all pigs of a similar age are housed together in a specified room until they are moved together to the next room designed for their stage of production (Harmon et al., 2001). This movement not only minimizes the potential for disease, but also allows for more effective temperature regulation. The optimal ambient temperature for a sow changes depending on the pregnancy and metabolic status of the sow. Producers may choose, therefore, to modify the ventilation environment within a farrowing, breeding or gestation facility accordingly. In a farrow-to-finish enterprise, sows are moved from gestation to farrowing to breeding facilities, and repeat this process in a continuous cycle. Breeding and gestation rooms are usually within the same building; however, there is a separate facility used for farrowing that contains multiple farrowing rooms. Replacement gilts and/or newly weaned sows housed in the breeding barn are checked for estrus expression and are inseminated when in estrus. Sows weaned at the same time are inseminated at about the same time (4 to 7 days after weaning; Harmon et al., 2001), and therefore, are expected to farrow within a few days of one another. Sows are housed in gestation stalls during breeding and for the majority of pregnancy. About one week before their anticipated farrowing date, sows are moved from the gestation barn into farrowing crates within specified farrowing rooms. Farrowing crates are generally between 2.1 to 2.4 m long and 0.6 m wide (Skorupski, 2001), with a creep area on one or both sides of the sow that allows piglets to escape when the sow is standing up or lying down. Sows remain in their respective farrowing crates until the day of weaning around d 21 of lactation (Harmon et al., 2001). At this time, sows are moved back to the breeding barn, and piglets are either moved to a nursery on the same farm or to a separate wean-to-finish production facility.

Thermoregulation in swine

Thermoregulation can be defined as the ability of an animal to keep its core body temperature (average of 38.5°C for a pig; Gourdine and Renaudeau, 2006) within certain boundaries. Adult pigs are homeotherms that maintain a relatively constant internal body temperature using thermoregulation to balance the heat gained by metabolism with the heat gained or lost from the environment. When pigs experience heat stress, they respond by invoking physiological and behavioral mechanisms to increase heat loss or minimize heat gain from the environment. Behavioral thermoregulation is when the animal changes its posture, orientation and/or microclimate to regulate its body temperature. Physiological thermoregulation is when the animal alters metabolic heat load to control

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its body temperature. Physiological thermoregulation will be the main focus of this literature review. The ambient temperature below which the animal increases heat production using shivering and/or non-shivering thermogenesis in order to maintain thermal balance is called the lower critical temperature (LCT; Mercer, 2001). Conversely, the ambient temperature above which the animal increases the rate of evaporative heat loss in order to maintain thermal balance is called the upper critical temperature (UCT; Mercer, 2001). The range of ambient temperatures between the upper and lower critical temperature in which the animal changes sensible heat loss, but does not have to alter its rate of metabolic heat production or evaporative heat loss to offset maintenance and production requirements is called the thermoneutral zone (Mercer, 2001; Ames, 1980). According to Black et al. (1993), the thermoneutral zone for pregnant and lactating sows is usually maintained between 12 and 20°C. Verstegen and Henken (1987), however, reported that the preferred temperature range for lactating sows is between 15 to 22°C (Table 1).

When ambient temperature nears LCT, pigs will reduce blood flow to the skin, alter posture to minimize heat loss, increase feed intake and may start to shiver. In contrast, as ambient temperature approaches UCT, pigs may sprawl to increase conduction to the cooler floor, increase the rate of blood flow to the skin, and raise their respiratory rate in order to improve convective and evaporative heat loss (Renaudeau and Noblet, 2001). Enhanced air movement allows pigs to perform the maximal rate of evaporative heat loss (through skin surface and respiratory tract). Although core body temperature may remain constant during this period, skin temperature may change in response to the environment. According to The National Pork Board (2011), the average respiration rate for a lactating sow is between 15 and 22 breaths per minute (BPM; Table 1). Pigs will usually increase their respiration rate with increasing ambient temperature. Breathing rates above 40 BPM indicate that a pig may be experiencing heat stress. The ability of pig to maintain its body temperature may be overwhelmed if the ambient temperature increases substantially above the animal's UCT. When the pig's compensatory mechanisms to dissipate excess heat are overwhelmed, myocardial and circulatory insufficiency, and eventually death may occur (Renaudeau and Noblet, 2001). Pigs have a relatively low ability to dissipate body heat, even when employing evaporative cooling methods. They rely, therefore, more than most other farm species, on reducing metabolic heat production to maintain a constant body temperature in hot conditions. The most common thermoregulatory mechanism that pigs participate in during heat stress is reducing voluntary feed intake (VFI; Quiniou and Noblet, 1999). Although this method may minimize heat load during heat stress conditions, it has a negative impact on growth performance.

According to Hahn (1995), the risk of negative effects of heat stress on livestock production can be predicted by combined animal performance and environmental factors. When performance level (such as growth rate, milk production per day, fetal growth, etc.) and environmental influences (such as ambient temperature) together create a low level of vulnerability, there is little risk. As performance levels rise or environmental conditions worsen, however, the animals are at greater risk of being adversely affected by the environment. Combining an adverse environment with high performance raises the level of vulnerability even more. Pregnant and lactating sows, therefore, are at the greatest risk for being negatively affected by heat stress because they have high performance levels (growth of the pregnancy and lactation).

Each pig's magnitude of heat production and heat exchange with the environment is dependent upon multiple factors, including production state of the pig, growth vs. maintenance requirements, pregnancy, lactation, diet composition, stocking density, floor or crate type, facility insulation, ambient temperature, humidity, rate of air movement, radiant heat, as well as conduction and convection methods (Myer and Bucklin, 2001). In general, as the pig gets older and larger, its thermoneutral zone decreases. Therefore, the effects of heat stress are more of a concern with older finishing swine (greater than 50 kg) and with sows and boars than with younger pigs. Sows, boars and finishing pigs begin to feel the negative effects of heat stress above 20°C (Gourdine and Renaudeau, 2006; Table 1).

Relative humidity levels alone do not have a negative effect on swine performance, but the combined effect of humidity and ambient temperatures approaching UCT can negatively affect an animal performance. Vapor pressure gradient is a very important factor to consider in relation to heat stress because it drives evaporative processes (Mercer, 2001). Pigs use both wet skin evaporation as well as respiratory evaporation to dissipate excess heat. Less moisture can evaporate into humid air than dry air. The greater the humidity level is in the air, the less effective the process of evaporative cooling. Consequently, when relative humidity is 50% or greater, the pig will feel the effects of heat stress at a lower temperature than when the air is drier. At air temperatures above 30°C, an 18% increase in relative humidity is equivalent to a 1°C rise in ambient temperature (Myer and Bucklin, 2001). Using wet-skin cooling methods (such as water misters or drippers) during periods of combined heat stress and humidity, therefore, may not be as effective as when heat stress is not present. Flowers and Day (2002), however, concluded that drippers or misters in conjunction with proper ventilation will effectively cool sows during high ambient temperatures and high humidity.

The effect of heat stress on gilts and sows

Heat stress conditions increase respiration rate, as well as body and skin temperatures in pigs. Specific physiological responses to these environmental changes differ depending on the pig's production phase and reproductive status (non-pregnant, pregnant or lactating). In particular, pregnant sows seem to be more sensitive to the effect of heat stress compared with non-pregnant sows. Heitman et al. (1951) determined that, when housed at the same temperature of 37°C, the respiration rate of a gestating sow was 186 BPM while a non-pregnant sow had a respiration rate of 64 BPM. In a similar study, Omtvedt et al. (1971) found that gestating gilts increased rectal temperature and respiration rate to a greater extent than non-pregnant gilts at 32 to 38°C. This study indicated that pregnant sows have more heat to dissipate through skin vasodilation or respiration rate compared to non-pregnant sows. According to Black et al. (1993), sows increase heat loss during pregnancy and, therefore, exhibit vasodilation in order to redirect blood flow from other tissues and organs to the skin for heat dissipation. This redirection of blood flow causes an increase in skin temperature.

Before farrowing, sows have a slightly lower body temperature and may also have a greater metabolic rate than after farrowing (King et al., 1972). Rectal temperature increases at the time of farrowing in sows (on average, from $38.34 \pm 0.57^{\circ}$ C to $39.25 \pm$ 0.72°C; King et al., 1972). Greater rectal temperature at the time of farrowing and throughout lactation occurs perhaps because of an increase in metabolic demand. This greater metabolic demand during lactation causes sows to be more sensitive to heat stress.

In a study by Spencer et al. (2003), thermoregulatory ability of multiparous and primiparous sows housed either in thermoneutral (21°C) or hot environments (32°C) was measured during lactation. Sows housed in the hot environment had greater rectal temperatures and respiration rates than sows in the thermoneutral environment, indicating that sows adapt to this rise in body temperature during lactation by increasing respiratory evaporative cooling in warmer temperatures. The sows housed in warmer ambient temperatures, however, showed a long-term adaptation to heat stress, as evidenced by a decline in respiration rate. Prunier et al. (1997) also found that rectal temperatures at parturition and during lactation were greater for sows exposed to 30°C compared with 20°C. This is in contrast to results found by Quiniou and Noblet (1999) and Reneadaeu and Noblet (2001), in which sows adapted during the first 3 days in high ambient temperatures (29°C) by decreasing respiration rate, but showed no additional adaptations throughout lactation.

At the time of weaning, nursing piglets are removed from the sow. Weaning causes a reduction in metabolic heat production due to decrease in milk production and feed intake on the sow's part. As a result, both respiration rate and rectal temperatures decrease at the time of weaning (Renaudeau and Noblet, 2001).

Parity differences during heat stress

According to Flowers and Day (2002), heat stress can limit the expression of behavioral estrus, lower ovulation rate, increase embryonic mortality and extend the rebreeding interval for all parity sows. Recent research has shown that first parity sows, in particular, seem to be more sensitive to the effects of heat stress as reflected in their body temperatures and respiration rates. Kelley and Curtis (1978) measured respiratory rate and rectal temperature of first and second parity sows from day 109 of gestation to 5 days after farrowing in either thermoneutral (20.5°C) or hot (29.8°C) ambient temperatures. An ambient temperature of 29.8°C was sufficient to cause heat stress in farrowing and lactating sows of either parity, as indicated by an increase in rectal temperature and respiration rate. Rectal temperature and respiratory rate increased in thermoneutral sows, but not in heat-stressed sows within the four hour period before farrowing. The stress of parturition caused the sows housed in the thermoneutral environment to have similar rectal temperatures to the sows housed in the heat stress environment.

In the same study by Kelley and Curtis (1978), rectal temperatures and respiration rates for gilts and sows within each treatment were similar at each point of measurement throughout the trial. For pigs in all treatments, rectal temperature was lower after farrowing than during farrowing, possibly due to the heat production during parturition. There was a reduction in respiration rate of sows in the heat stressed environment after farrowing. This may reflect a partial acclimation to the sows to the heat stress, although the respiration rate of pigs in the thermoneutral environment also decreased (Kelley and Curtis, 1978).

General aspects of reproduction from lactation through weaning in sows

After farrowing, the sow's reproductive system needs time to recover from pregnancy. The organs and glands that play a major role in this recovery process are the

ovary, pituitary, hypothalamus and uterus. The sow's ovarian follicles grow in response to luteinizing hormone (LH) and follicle stimulating hormone (FSH). Both LH and FSH are secreted from the pituitary in response to gonadotropin releasing hormone (GnRH) that is released from the hypothalamus. The follicles will eventually ovulate after weaning and release their eggs, which are fertilized after breeding. According to Flowers (2002), LH and FSH are necessary to maintain the growth of small follicles on the ovaries after parturition and throughout most of lactation. During lactation, there is a continuous cycle of growth and atresia of ovarian follicles, but maximum follicular diameter (4 to 6 mm) is less than that observed after weaning. The pituitary is capable of secreting low levels of LH and FSH within a few days after farrowing. As lactation progresses, however, increased amounts of FSH and LH are needed for further follicular development. The pituitary usually does not have the ability to secrete sufficient levels of LH and FSH to support the last phases of follicular growth until 10 to 12 days after farrowing (Kemp and Soede, 2004). During lactation, suckling by the piglets causes the inhibition of LH and FSH release. When LH concentrations are low, follicular development, and therefore, estrus and ovulation do not occur (Flowers, 2002).

During lactation, recovery of the uterus also occurs; uterine involution generally requires 14 to16 days (Kemp and Soede, 2004). During gestation, the uterus increases in size to accommodate the developing piglets; therefore, it must undergo involution to return to its previous condition before a new pregnancy can begin. Also, the uterine endometrium must be repaired at this time to adequately support developing embryos and fetuses. Lactation provides a quiescent period for the sow in which the pituitary,

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hypothalamus and uterus can recover before the next reproductive cycle begins (Flowers, 2002).

At weaning, the average follicular population is < 5 mm in diameter (Lucy et al., 2001). The piglet's suckling inhibition is removed at weaning, thereby causing the pituitary to release high levels of LH. Studies by Cox (1997) indicated that this increase in LH at the time of weaning causes follicular growth and recruitment, which results in increased concentrations of circulating estradiol. Estradiol is the main trigger for the pre-ovulatory surge of LH that causes ovulation. At the time of estrus, there are about 15 small (< 3 mm) and medium (3.0 to 6.9 mm) follicles as well as 15 large (> 7 mm) follicles on the ovary. After weaning, there is a recruited pool of about 50 follicles, 1 to 6 mm in size, on the surface of the ovary in sows (Knox, 2005). Follicular growth after weaning, which requires the highest levels of LH, leads to ovulation.

Weaning is a management event that signals the sow's reproductive system to resume normal activity. Reproductively healthy sows generally show estrus around five to six days after weaning and can be inseminated at this time (Kemp and Soede, 2004). If the reproductive organs are not fully recovered from the previous gestation, however, the sows may experience anestrus (the complete absence of estrous activity). This situation occurs when there is not enough LH and FSH secreted to support adequate follicular growth (Flowers, 2002). Sows are, therefore, unable to develop large enough ovarian follicles to produce sufficient estradiol, the hormone responsible for estrous behavior and for initiating the LH surge. Weaning to estrus intervals (WEI) are non-productive periods between weaning and the first day a sow exhibits standing estrus. This interval can be influenced by lactation length, parity, litter size, season, nutrition, boar exposure after

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weaning, genetics, diseases and management (Dial et al., 1992). Circulating LH concentrations, which stimulate follicular growth, appear to be an important factor in determining WEI in sows. Several studies have shown that LH concentrations during lactation and pulse frequencies at weaning are inversely related to WEI (Shaw and Foxcroft, 1985; Tokach et al., 1992). In particular, in healthy sows after weaning, high frequency/low amplitude pulses of LH induce recruitment of populations of large follicles. Some of these follicles will grow and eventually ovulate from one to five days after the sow exhibits standing heat, while the other follicles will undergo atresia. If the GnRH pulse generator fails to induce this LH pulse from the pituitary after weaning, however, sows will show a prolonged WEI (Shaw and Foxcroft, 1985).

Factors that affect reproduction in sows

Heat stress

The European wild pig (Sus scrofa) has strong seasonal reproductive patterns (Almond and Bilkei, 2005). Based on results from heat stress studies with domestic pigs, it seems that domestic pigs have also retained sensitivity to season. Extreme heat during the summer months increases the occurrence of infertility in swine herds, leading to decreased subsequent reproductive performance of pregnant and lactating sows. In a study by Almond and Bilkei (2005), sows had longer weaning to service intervals during periods when the daily ambient temperature exceeded 35°C compared with an ambient temperature of less than 30°C. In this study, a greater percentage of younger sows showed this seasonal delay in return to estrus than older sows. Exposing sows of any parity or age to heat stress, however, can have negative effects on reproduction in sows. According to Prunier et al. (1997), only 39% of multiparous and primiparous sows

exposed to heat stress (27°C) returned to estrus within 10 days after weaning compared with 77% of the sows in a thermoneutral (18°C) environment.

Heat stress also decreases conception and farrowing rates for all parity sows. Koketsu and Dial (1997) found that sows farrowing in the summer not only had the longest weaning-to-conception interval, but also produced the lightest litter at weaning. Similarly, Almond and Bilkei (2005) found that sows exposed to ambient temperatures greater than 35°C had lower farrowing rates and total litter sizes than when ambient temperature did not exceed 30°C. The low farrowing rates and litter sizes may be attributed to early embryonic losses that decreased the number of piglets born alive. Tummaruk et al. (2004) found that the number of piglets born and number born alive decreased as ambient temperature and humidity increased during the first five weeks of gestation.

Teague et al. (1968) showed that heat stress not only decreased ovulation rate, but also increased embryonic mortality when sows were exposed to these temperatures up to three weeks after mating. According to Wildt et al. (1975), sows that were heat-stressed during the pre-implantation and early implantation period (day 2 through 13 of gestation) had greater embryonic mortality than sows in a thermoneutral environment (63% compared with 35%, respectively). The heat-stressed sows also showed a greater number of degenerating fetuses compared with the sows in thermoneutral environment (70% compared with 44%), suggesting that exposing embryos to heat stress at an early age may have a negative effect on subsequent fetal development. In another trial by Tompkins et al. (1967), sows exposed to heat stress (35°C) from day 1 through 5 of gestation had a lesser percentage of viable embryos per 100 corpora lutea as compared with sows housed

in a thermoneutral environment (24°C) at this time (74 vs. 78% of viable embryos, respectively). Sows exposed to heat stress on days 20 through 25 of gestation also had a lesser percent of viable embryos compared with those housed in a thermoneutral environment (78 vs. 92% of viable embryos, respectively). The embryo seems to be less vulnerable to the effects of heat stress after implantation has occurred. Heat stress during conception or implantation, however, increases the risk of fetal loss later in pregnancy.

Heat stress during mid to late pregnancy results in an increase in the number of stillborns. Renaudeau et al. (2003) recorded that there was an increase in the number stillborns for sows that were gestating during the hot season compared with those gestating during cooler seasons. Omtvedt et al. (1971) found that there was a correlation between stillborn occurrence and the timing of heat stress. In particular, sows that were heat stressed during late pregnancy (102 to 110 days post-breeding) had a greater incidence of stillborns than sows exposed to heat stress during mid-pregnancy (53 to 61 days post-breeding; 0.7 ± 0.62 compared with 5.2 ± 0.62 stillborns, respectively). These results suggest that heat stress has a greater effect on the incidence of stillborns during late gestation.

Parity

Differences in the time that gilts reach puberty, as well as pregnancy failure in some gilts and sows can result in variations in the age of sows within a specific parity category. According to Belstra and See (2004), reproductive performance generally increases over the first three to four parities and begins to decline as sows reach their seventh or eighth parity. Physiological differences in the reproductive systems of primiparous sows could be responsible for their decreased reproductive performance compared with multiparous sows. Another factor may be that reproductive failure of some infertile gilts or first parity sows removes them from the breeding pool, and therefore, increases reproductive performance of the group in the subsequent parity. This natural culling process may be a reason that reproductive performance gradually increases over the first three to four parities.

Gilts typically exhibit a 10 to 15% lower farrowing rate (farrow successfully after mating) as compared with multiparous sows because younger sows generally have reduced conception rates and embryo survival (Belstra and See, 2004). Both farrowing rate and litter size show a similar pattern in terms of reproductive performance in pigs: lowest in first parity, remains relatively constant from the second through fifth or sixth parity and begins to decrease significantly around parity seven or eight. Belstra and See (2004) argue that an increase in uterine capacity or fetal survival may be responsible for the increase in litter size up to fifth parity sows. Parity one sows also have the longest weaning-to-first-service interval, weaning-to-conception interval and the lightest litter weight at weaning compared with mid-parity sows (parities two to five). Bracken et al. (2003) also reported longer WEI for first parity sows, especially for those with low body condition.

Factors such as nutrition, genetics, environment and other physiological and management aspects influence the reproductive performance of first parity sows. The first parity sow is more likely to experience reproductive problems and be culled from the breeding herd than higher parity sows because first parity sows are more sensitive to the effects of poor management practices or less-than optimal production environments (Flowers and Day, 2002). During lactation, the metabolism of the sow adjusts to produce

milk. In particular, more than 75% of the energy metabolites in the blood stream are used by the mammary gland for milk synthesis (Belstra and See, 2004). Nutrients necessary to meet the metabolic demands of lactation are obtained from the consumption of feed or from the mobilization of body tissues (Flowers and Day, 2002). When there is a limited supply of nutrients from the feed, body stores of fat and protein are used to meet metabolic requirements. These physiological processes compete with milk synthesis for nutrients. Consequently, most sows lose weight during lactation. In addition to milk production, first parity sows have excess energy requirements for growth and reproductive processes. Primiparous sows, therefore, can be detrimentally affected by lower feed intake due to heat stress because they need excess nutrients for growth (Flowers and Day, 2002). These first parity sows may exhibit more extreme weight loss than older sows, leading to delayed estrous activity and lower ovulation rates.

Feed intake and nutrition

Animals prioritize nutrients first to support maintenance needs, secondly to either growth or milk production, and lastly to reproduction. Reproduction is sacrificed in pigs that are either underfed or have inadequate nutrition so that maintenance and growth requirements are supported. If a pig is severely underfed or deprived of nutrients, milk production and growth will also suffer to provide energy solely for maintenance.

Effect of nutrition on reproduction

After farrowing, there is a 7 to 10 day period of insensitivity in which the sow's hypothalamus and pituitary gland are unresponsive to physiological stimuli required to initiate reproductive activity. The nursing piglets' suckling stimulus blocks the release of

GnRH from the hypothalamus, thus preventing the occurrence of estrus and ovulation until after weaning (Flowers and Day, 2002). The metabolic state of the sow during lactation, at the time of weaning and post-weaning can also prevent the sow from resuming reproductive activity. Estrus and ovulation may not occur if the sow is in poor body condition or if the sow's metabolism has not had sufficient time to recover from lactation. Dourmad et al. (2000) suggests that in order to improve long-term sow reproductive performance, producers should minimize metabolic stress, as well as losses in body weight and fat during gestation and lactation.

Sow body weight and fat stores may influence feed intake by changing the longterm regulation of metabolism. According to Mullan and Williams (1989), the amount of fat reserves at farrowing greatly influences successive reproductive performances because it determines the extent that fat can be mobilized during lactation. For instance, a high level of body fat at farrowing (due to high pregnancy feeding levels) reduces voluntary feed intake (VFI) during lactation and, therefore decreases weight gain. This reduction in VFI may be due to obesity (Revell et al., 1998), resulting in increased tissue mobilization during lactation. A very low gestation feeding level also negatively affects body composition by decreasing back-fat thickness and body weight at weaning; this lack of body condition at weaning may create a longer WEI.

Underfeeding sows during lactation can lead to post-weaning anestrus, decreased farrowing rates and reduced litter size. As mentioned previously, increased feed intake during lactation reduces a sow's WEI. Sows should be fed ad-libitum during their first lactation. According to Flowers and Day (2002), however, overfeeding primiparous sows during lactation is rarely problematic

Mullan and Williams (1989) found that sows with greater feed intake during lactation exhibited less tissue mobilization and were in a less severe catabolic state. In comparison, sows that were limit-fed during lactation had excessive tissue depletion (9 to 12% loss in body protein) and milk yield was reduced. This decline in body protein may even result in a change in milk composition in limit-fed sows. Flowers and Day (2002) reported that increasing feed intake after weaning helped primiparous sows replace body stores of fat and protein that were lost during lactation. They also found that ad-libitum feeding from weaning to breeding reduced the WEI and increased ovulation rate in first parity sows.

Relationship between nutrition, endocrinology and reproduction in gilts and sows

Nutrition has a large effect on ovarian and follicular development, as well as circulating hormone concentrations. According to Cooper et al. (1973), underfeeding gilts causes an increase in pituitary LH. Similarly, LH and FSH secretion after exogenous GnRH administration is greater in gilts with lower feed intake as compared with gilts with greater feed intake (Armstrong and Britt, 1987). These observations suggest that feed restriction inhibits LH release to a greater extent that LH synthesis, possibly resulting in an increase in the pituitary stores of gonadotropins in underfed females. This mechanism could explain the effect of nutrition on reproduction in the female pigs: inhibition of the GnRH pulse generator system by undernutrition.

Numerous researchers have determined the influence of feed restriction on ovulation rate. Data obtained in sows showed that feed restriction during the luteal phase inhibited corpora lutea development after the subsequent ovulation. Therefore, this nutritional deficit inhibits subsequent recruitment of preovulatory follicles as well as pulse frequency and circulating concentrations of LH in lactating sows (Koketsu et al., 1996). In a study by King and Williams (1984), however, lack of nutrients during lactation did not have a clear effect on ovulation rate. They reported prolonged WEI but similar ovulation rate in primiparous sows on protein restricted diets during lactation as compared with controls that were not protein restricted. King and Williams (1984) and Tokach et al. (1992) also found that levels of lysine/protein intake and energy intake in lactating primiparous sows are highly correlated. In particular, LH secretion and the number of sows with a short WEI increased with improved dietary lysine/protein intake.

Feeding level during lactation also influenced the percentage of healthy follicles at weaning. Feed restricted sows had a greater percentage of follicles that were $\leq 1 \text{ mm}$ in size than follicles of 1 to 3 mm in size (Quesnel et al., 1998). This decrease in the number of follicles developing to larger stages may be due to insufficient gonadotropin levels. In particular, the decrease in LH pulsatility due to nutritional deficiency limits the number of follicles developing to medium and large sizes. Follicles that will ovulate after weaning are more likely to be in medium size classes (Foxcroft et al., 1987); therefore, a decrease in the number of medium follicles at weaning in feed restricted sows may result in lower subsequent ovulation rates (Zak et al., 1997). A compromised state of follicular development during lactation due to undernutrition can also increase WEI. According to Lucy et al. (2001), sows with larger follicles have greater estrogenic activity before weaning and shorter WEI. During lactation, gonadotropin secretion is inhibited by piglet suckling. In well-fed sows, this inhibition due to suckling ends at the time of weaning, which allows for recruitment of a new wave of follicles. Feed restricted sows tend to have

greater inhibition of gonadotropin secretion during late lactation; the resumption of follicular development after weaning is variable in these sows (Lucy et al., 2001).

Hormones such as growth hormone (GH), insulin and insulin-like growth factor I (IGF-I) are under metabolic influence and are involved in the nutritional modulation of the reproductive system during and after lactation. These hormones affect the response of cells to gonadotropins (LH and FSH) through autocrine or paracrine actions. Undernutrition leads to a rise in circulating GH concentrations, a decrease in the liver's response to GH (through decreased GH binding), a reduction in circulating insulin and IGF-I levels and irregularities in the number of IGF binding proteins (Quesnel et al., 1998). Altered concentrations of insulin and IGF-I can also affect ovarian activity by reducing the ovary's responsiveness to gonadotropins. According to Echternkamp et al. (1994), an increase in GH secretion has a beneficial effect on the number of mediumsized follicles as well as the plasma and follicular concentrations of IGF-I in sows. Insulin has been found to reduce atresia in small and medium follicles, thereby improving ovulation rate in pre-pubertal gilts (Matamoros et al., 1990). Interestingly, low insulin concentrations in poorly fed sows have been shown to decrease the growth of small and medium follicles. Quesnel et al. (1998) found a similar relationship between follicular size and levels of IGF-I in follicular fluid. Decreased peripheral and follicular concentrations of IGF-I during lactation reduced the number of growing follicles as well as ovulation rate in sows. According to Zak et al. (1997), reduced IGF-I concentrations can also increase WEI and limit embryonic survival. In contrast, Charlton et al. (1993) and Carroll et al. (1998) did not report these results with peripheral and follicular IGF-I concentrations in feed restricted lactating sows. Ovarian IGF-I is synthesized locally
(Charlton et al., 1993); therefore, the decrease in follicular IGF-I is probably not a result of diminished peripheral concentrations. Quesnel et al. (1998) hypothesized that there is an uncoupling between GH and IGF-I secretion at both the ovarian and systemic levels in feed restricted sows. Since insulin causes greater IGF-I concentration in follicular fluid (Matamoros et al., 1991), low secretion of insulin caused by undernutrition may also play a role in reducing follicular IGF-I concentrations. Growth hormone, insulin and IGF-I, therefore, play important roles in mediating the effects of nutrition on the reproductive activity in gilts and sows.

Metabolic events such as lactation are also tied to reproductive events through an endocrine link that involves GH, IGF-I and insulin. In contrast to beef and dairy cows, these hormones of the somatotropic axis in sows remain coupled during lactation; both GH and IGF-I are elevated at this time (Lucy, 2008). Growth hormone not only causes a release in IGF-I during lactation, but also antagonizes insulin action (Etherton and Bauman, 1998) through a nutrient partitioning effect that stimulates the development of lean tissue and milk production. If sows are well-fed during lactation, they will have elevated IGF-I concentrations in their bloodstream; however, if sows have inadequate nutrition during lactation, the hormones of the somatotropic axis may become uncoupled and IGF-I concentrations may be reduced. This uncoupling usually occurs during the second to third week of lactation when litter milk consumption and sow milk production are the highest (Noblet and Etienne, 1989). During this uncoupling process, the sow becomes catabolic because she is not consuming enough feed to compensate for the high levels of milk production. Regardless of feeding levels during lactation, sows will usually recover from this negative energy balance and show improving IGF-I levels within three days after weaning (Lucy, 2008).

Energy balance in sows

Metabolizable energy (ME) is defined as the total energy of the feed consumed (gross energy; GE) minus the energy within the feces, urine, and gaseous products of digestion and metabolism (digestible energy; DE). More specifically, ME is the energy that can be used by the pig for growth, lactation, body maintenance, activity and heat production (Figure 1). Generally, ME is 94 to 97% of DE in traditional swine diets (Farrell, 1979; Agricultural Research Council, 1981). Gross energy of a feed ingredient is dependent on the quantities of carbohydrate, fat, and protein within the feed. Water and minerals do not provide energy to the animal; carbohydrates provide 3.7 kcal/g of glucose and 4.2 kcal/g of starch, protein provides 5.6 kcal/g and fat provides 9.4 kcal/g (Agricultural Research Council, 1981).

The ME requirement for maintenance (ME_M) is for physiological functions, such as physical activity and heat production or loss. These requirements are usually expressed on a body weight basis, as body weight $(BW)^{0.75}$. Net energy (NE) is the energy the animal uses to meet maintenance and production requirements. Net energy can also be defined as the difference between ME and heat increment (HI; Agricultural Research Council, 1981). Heat increment is the amount of heat given off from digestive and metabolic processes (Figure 1). In order to accurately determine NE energy balance and heat increment must be taken into consideration. Measurement of total heat production must include the energy required for maintenance as well as the energy expended in response to environmental fluctuations, such as temperature. According to Noblet et al. (1994), NE is the best indication of the total existing energy remaining for maintenance and production in an animal. For pigs fed standard diets and kept at thermoneutral temperatures, the ratio of NE to ME ranges from 0.66 to 0.75 (Noblet et al., 1994).

Energy requirements for sows are also different depending on the phase of production and ambient temperature. The National Research Council (1981) suggested that DE intake is reduced by 1.7% for each 1°C that ambient temperature exceeds the animal's UCT. According to Noblet and Etienne (1986), the maintenance requirement for lactating sows may be 5 to 10% greater than that of gestating sows due to the heat load associated with milk production. More specifically, average daily maintenance requirements in thermoneutral environments for gestating and lactating sows of all parities are 105 and 110 kcal ME/kg BW^{0.75}, respectively (Noblet et al., 1990; National Research Council, 1981). Similarly, Beyer et al. (1994) found that primiparous sows used 103 kcal of ME/kg of BW^{0.75} per day for maintenance requirements, but also reported an increase in ME as parity increased, up to 113 kcal of ME/kg of BW^{0.75} for parity four sows. Sows that do not consume enough ME to meet maintenance and lactation requirements have decreased performance during lactation.

Pregnant sows offered feed *ad libitum* will consume more energy during gestation than required for maintenance and fetal growth, resulting in an increase in deposition of body fat and protein. Limiting energy intake during gestation to minimize excess weight gain and back-fat deposition, therefore, is desirable. Energy intake generally increases; however, weight loss also increases during lactation (Baker et al., 1969; O'Grady, 1980). Negative energy balance occurs because the energy intake is not sufficient to meet the combined demands for maintenance and milk production; therefore, tissue will be mobilized to provide the necessary nutrients for milk production (Dourmad et al., 2000). The energy requirement for milk production can be estimated from the number of piglets in the litter and by their individual growth rates (Noblet and Etienne, 1989).

Sow energy balance is generally negative after parturition, regardless of ambient temperature and parity. Heat stress will aggravate the negative energy balance in lactating sows by causing a further decrease in feed intake. Though sows of any parity can exhibit negative energy balance, lesser parity sows are more prone to this phenomenon (Eissen et al., 2000). This is because parity one and two sows usually consume less feed and have greater body weight loss during lactation than older sows. Decreased feed intake and increased energy demand for body growth and lactation result in a catabolic state in primiparous sows that inhibits reproductive function and litter performance.

Maintenance requirements of pregnant and lactating sows

Energy recommendations for lactation must be designed with these factors in mind: pregnancy status, previous lactation performance, and goals for maternal tissue growth and body composition changes over successive parities (Dourmad et al., 2000). The optimal feeding method for sows is to maximize nutrient intake during lactation so that body reserves can be replenished and requirements for growth can be met to adequately prepare for pregnancy. This approach minimizes fluctuations in body reserves and reproductive problems during gestation and lactation as well as promotes healthy development of offspring.

Lactating sows have high nutritional requirements in order to support milk production. Nutritional requirements for lactating sows depend on length of lactation, sow weight change during this phase and daily litter growth rate (National Research Council, 1981). Nutrients received from the diet will be partitioned by the sow into three components: maintenance, milk production (litter growth), and maternal weight gain (Figure 2). Adequate lysine and metabolizable energy (ME) intake are crucial in assisting sows to achieve increased daily litter weight gain, short WEI, and large subsequent litter sizes. Meeting these two nutrient requirements can also prevent excessive fat deposition and protein mobilization during lactation.

Total energy requirements in lactating sows (ME) are equal to the combination of requirements for maintenance as well as milk production, $ME = 110 \text{ BW}^{.75} + \text{Energy in}$ milk/0.72 (Noblet et al., 1990). In this equation, body weight corresponds to sow body weight after farrowing (kg) and 0.72 is the efficiency of utilization of ME for milk production. The amount of milk produced by each sow can be estimated using litter weight gain. The total energy requirements in lactating sows can be calculated using this equation: $ME = 110 \text{ BW}^{.75} + 6.83 \text{ LG} - 125 \text{ n}$, when LG represents the gain of the litter throughout lactation (g per day) and n is equal to the number of piglets in a litter. After solving this equation, the results show that requirements directly related to milk production represent about 75% of total requirements in the average sow (Noblet et al., 1990). These calculations indicate that some sows may require up to 18 Mcal ME per day, which is greater than the average voluntary feed intake (VFI) for most sows. According to National Research Council (1981), the minimum recommended daily ME intake, however, is only 17,135 kcal per day for lactating sows. When the discrepancy between ME intake and ME requirements is excessive, extreme lactation body weight loss can occur and must be compensated for in subsequent pregnancies.

According to Touchette et al. (1998), sows that have larger litter sizes and increased milk production also have greater amino acid requirements during lactation. More specifically, each kilogram of litter weight gain requires approximately 25 g of lysine to be consumed by the sow (Close and Cole, 2000). Sows whose piglets consume more milk should be fed more (and be given more lysine in their diet) during lactation to prevent excess mobilization of body reserves for milk production. A significant mobilization of sow body reserves is undesirable because it has a negative effect on subsequent growth and reproductive performance.

Parity is an important aspect to consider when formulating lactation diets because first parity sows have different levels of feed intake and lysine requirements than older sows. First parity sows typically have 20% less overall VFI than the average of the herd. Also, first parity sows require approximately 1.20% greater lysine concentrations within their lactation diet as compared with older sows to maintain the same level milk production, and therefore, similar litter weaning weights (Richert et al., 1997). Noblet et al. (1990) stated that ME_M , when expressed per kg of body weight, is similar for primiparous and multiparous sows during lactation. However, Beyer et al. (1994) showed increased maintenance requirements with parity number, while Everts (1994) obtained slightly reduced maintenance requirements in older as compared with younger sows. According to Etienne et al. (1998), when *ad libitum* daily feed intake was considered with respect to metabolic live weight, maintenance requirements for multiparous sows were greater than for primiparous sows (88.7 vs. 77.9 g/kg, respectively). This indicates that when sows met their maintenance requirements, the excess energy available for maternal tissue growth and milk production was greater for primiparous than for multiparous sows.

Primiparous sows should theoretically be able to meet their maintenance requirements more rapidly than multiparous sows. Inadequate feed intake (due to heat stress) during lactation, however, could cause first parity sows to have poorer body condition at weaning and subsequently lower reproductive performance.

Many researchers disagree with the notion that multiparous sows have greater ME requirements than primiparous sows. Pluske et al. (1998) hypothesized that lower parity sows have greater energy and protein requirements for body growth than older sows because they are still growing. In particular, they found that primiparous sows direct more energy towards body growth rather than milk production, whereas multiparous sows show an increase in milk yield. This supports the theory that parity may also affect the partitioning of energy and/or protein between maternal tissue and milk production during lactation. Cole (1990) also supported the notion that primiparous sows have greater maintenance requirements during lactation; he argued that they need a greater dietary energy intake to avoid maternal losses in body weight and condition during lactation than older sows.

Sow milk production and metabolism

Effect of ambient temperature on milk production and blood flow to the mammary gland

Ambient temperature can affect the milk output of the lactating sow. In a hot environment, sow feed intake and milk production decrease to prevent a rise in body temperature (Quiniou and Noblet, 1999; Renaudeau and Noblet, 2001). According to O'Grady et al. (1985), milk output decreases as air temperature increases above the sow's thermoneutral zone. Exposing lactating sows to heat stress reduces their VFI, as well as nutrient availability for milk synthesis, causing a decline in milk yield and a decrease in litter growth. Milk yield during the third week of lactation was reduced by 10 to 15% in sows kept at 32°C compared with sows in a 20°C environment (Barb et al., 1991). This decrease in milk production may also be caused by a change in endocrine function that reduces the nutrient supply to the mammary gland during heat stress. Thyroid hormones and cortisol are catabolic hormones that regulate nutrient partitioning toward milk production. During heat stress, there is a decrease in the circulating concentrations of these hormones which limits body reserve mobilization, thereby leading to decreased milk production (Messias de Bragança et al., 1998). Prunier et al. (1997) found that daily litter growth was decreased by 18% for the sows and litters kept at 30°C compared with those kept at 20°C, supporting the notion that increased ambient temperature causes a reduction in milk yield.

Milk synthesis is not only dependent on the nutritional status of the sow, but also on mammary blood flow and its changes in response to heat stress (Dourmad et al., 2000). The rate of heat loss is dependent on the rate of blood flow to the periphery; therefore, the mammary gland may be involved in the dissipation of body heat during heat stress. Heat-stressed sows require a greater amount of blood flow to the mammary gland to produce 1 kilogram of milk compared with sows housed in thermoneutral conditions (Renaudeau et al., 2002). This suggests that the inefficiency of the sow mammary gland in heat stressed conditions could be related to an increase in the proportion of blood within skin capillaries in order to dissipate body heat. Black et al. (1993) also suggested that during heat stress, there is increased blood flow to the skin at the expense of the mammary glands, which may reduce the availability of nutrients for milk synthesis.

Piglet nursing behavior and growth rate can also have an effect on milk production. There are two factors that result in greater milk yield by sows: the size of the sow (heavier pigs are able to produce and secrete more milk) and more frequent nursing by any size piglet. In particular, when there is more regular and complete removal of milk from the mammary gland by piglets, an autocrine response to increase milk secretion occurs. Renaudeau and Noblet (2001) found that piglets from heat-stressed sows nursed more often than those not heat-stressed. In agreement with the previous studies, Quiniou and Noblet (1999) established that piglets nursed 40 times per 24 h during lactation when sows were exposed to an ambient temperature of 29°C compared with 26 times per 24 h while housed at a temperature of 18°C. These results show that piglets may be expending more energy to obtain the milk during heat stress, but still may not meet their necessary energy requirements, ultimately leading to decreased growth performance.

Effect of sow nutrition and feed intake on milk production

Milk yield responds to maternal energy intake during lactation. Greater feed (protein and energy) consumption allows for greater milk production. On average for lactating sows, 75% of total energy intake and 90% of total amino acid intake are used for milk production (Dourmad et al., 2000). This means that sows must consume more feed during lactation than at any other phase of production. In general, sow feed intake is low immediately after farrowing and increases as lactation proceeds, reaching a maximum in the second or third week (Koketsu et al., 1996). Most sows do not consume enough feed energy for adequate milk production during lactation; therefore, they must

obtain energy through catabolism of body reserves. Revell and Williams (1993) suggested that sows lose body reserves during the first two to three weeks of lactation in order to support milk production. After that point, sows start to recover body weight and composition; however, the remaining time in lactation is usually too short to compensate completely for the losses that occurred earlier in lactation. Mullan and Williams (1989) also concluded that feed intake during early lactation is generally too low to meet sow energy requirements; therefore, high producing sows mobilize body reserves to provide nutrients for milk production in order to maintain adequate piglet growth.

As mentioned previously, ambient temperature has a large effect on feed intake during lactation. The upper limit of the zone of thermal comfort (UCT) is around 22°C for a lactating sow. When the environmental temperature rises above the sow's UCT, the sow can only decrease or maintain body temperature within a normal range using thermoregulatory mechanisms or through decreased feed intake (Williams, 1998). Messias de Bragança et al. (1998) found a decrease in VFI of 40 and 43% in lactating sows when the temperature was raised from 18 to 28°C and 20 to 30°C, respectively. This reduction in VFI due to heat stress not only decreased milk production, but also had negative effects on sow growth rate, reproductive ability and subsequent fetal growth.

According to Mullan et al. (1993), there is a strong correlation between litter growth rate and maternal feed intake; as feed intake by the sow increases, litter growth rate also rises. This can be attributed to increased milk production caused by greater feeding levels. Milk consumption per pig increases with a smaller litter size due to increased gland size and decreased competition with litter mates for a teat (Fraser, 1990). In comparison, as litter sizes increases and during late lactation, milk yield tends to approach a maximum point because milk intake of individual pigs decreases. Fraser (1990) also suggested that piglet body weight can have a significant impact on the amount of milk consumed. For example, a larger pig may massage the teat more forcefully before milk ejection which would allow for a greater blood flow to the teat and cause a larger amount of milk to be secreted from the teat during milk letdown. Thus, litter growth rate and individual piglet weight are factors that can indirectly contribute to milk production.

Effect of parity on milk yield

According to Eissen et al. (2000), sow body weight increases with parity; therefore, older sows usually have greater maintenance requirements during lactation. However, lower parity sows are still not fully grown and have larger energy and protein requirements for growth than older sows. Cole (1990) suggested that primiparous sows need a greater dietary energy intake than second parity sows to avoid excessive body weight loss and body condition during lactation. Parity may affect the partitioning of energy and/or protein, therefore, between maternal tissue and milk during lactation. This is supported by Pluske et al. (1998) who found that primiparous sows partitioned extra energy into body growth rather than milk production, whereas multiparous sows showed an increase in milk yield throughout lactation.

Parity not only affects the partitioning of nutrients towards milk production, but it may also play a role in the amount of milk produced during lactation. According to Vanschoubroek and Van Spaendonck (1973), second parity sows produced about 26% more milk than primiparous sows during lactation. Etienne et al. (1998) found that milk production increases from the first to second parity, is similar from the second to fourth parity and slowly decreases in later parity sows. Differences in milk production between parities may be a reflection of differences in litter size. In a study by Mahan (1998), feed intake (weekly and total) increased by 0.81 kg from parity one to parity five sows. Similarly, feed intake and litter size also increased with increasing parity in a study by Neil et al. (1996). There was also an effect of parity by VFI on protein content within the diet; greater dietary protein content increased VFI of primiparous sows, but not VFI of multiparous sows during lactation. These results indicate that primiparous sows may have greater maternal protein requirements or lower protein body reserves during lactation as compared with older sows (Mahan, 1998). Differences in milk yield between parities can also be attributed to differences in feed intake. Koketsu et al. (1996) found a lower feed intake for primiparous sows than for older sows. Likewise, Williams (1998) reported that gilts consume 15% less feed than older sows during lactation and that daily feed intake of sows increased by 0.73 kg from parity one to parity seven sows.

Effective management of lactating sows during heat stress

Environmental modifications

Producers have attempted to alleviate the detrimental effects of heat stress on gilts and sows by implementing ventilation techniques and changing diet composition. According to Lammers et al. (2007), the most effective ways to reduce heat stress on gilts and sows are to have adequate facility ventilation and provide a sufficient number of feeders and waterers for the animals. Temperature-controlled drippers, along with appropriate ventilation, may provide effective supplemental cooling for sows during gestation and lactation. Two of the most common types of ventilation methods currently used in swine gestation/breeding and farrowing facilities are: forced-air ventilation and evaporatively-cooled ventilation.

In forced-air facilities, outside air is pulled into the barn through inlets at the top and side of the room by fans located on the opposite wall to create negative pressure. Fans pull air across the pigs at a rapid rate to allow for cooling. In evaporative cooling systems, water drips between ridged pads mounted on the side or end of the building. Fans pull the air through the pads, cooling the air by evaporation as it travels through the room and across the pigs. This type of indirect cooling also increases the air moisture level within the room and will eventually limit the amount of cooling that is possible by evaporation (Harmon et al., 2001). According to Mercer (2001), relative humidity (RH) is a measurement of the fraction of water vapor in a volume of air at a given air temperature; air temperature will decrease until the RH reaches about 85% (Zulovich, 2002). The amount of moisture in the outside air will have a direct effect on how much the air temperature will be reduced while entering the farrowing room. For example, when the outside air is very humid (RH > 70%), the reduction in air temperature will be marginal (< 3 to 6°C). However, when the outside air is dry (RH < 55%), evaporative cooling can reduce incoming air temperature by at least 8°C. As the ambient air temperature increases during the day, the RH will decrease (usually to levels between 55 and 70%), even though the actual moisture level in the air remains constant. Therefore, evaporative cooling should still provide cooling benefits to sows, even in very humid areas. However, the actual temperature reduction provided by indirect cooling will depend on the specific environmental and housing conditions of the sow herd (Zulovich, 2002).

Additional cooling in the form of drippers, sprinklers and fans can also be used to decrease the effect of heat stress and increase heat loss of sows housed in farrowing rooms and gestation/breeding barns (Harmon et al., 2001). Drippers and sprinklers that allow for direct skin contact increase the effectiveness of evaporative cooling. In fact, direct evaporative cooling by drippers and sprinklers and can effectively cool swine herds in environments with RH reaching 100% (Zulovich, 2002). When provided with direct evaporative cooling methods, sows showed improved body condition and increased piglet performance during lactation. In particular, sows provided with water drippers had greater feed consumption, a reduction in body weight loss and weaned heavier piglets when compared with sows without a water drip during heat stress (McGlone et al., 1988). Mechanized ventilation systems, such as fans, are also installed in swine facilities to provide adequate air movement and to remove any dust, moisture and gases that would otherwise build-up in confined facilities.

According to Curtis (1983), pigs on commercial farms spend about 79% of the day (19 h) resting; this number will likely increase during heat stress conditions when pigs will lay down and sprawl to dissipate body heat. This indicates that most of the time, a large part of a pig's body is in contact with the floor. The thermal conditions of the floor are very important, therefore, to consider when managing a group of pigs. The amount of conductive heat loss that occurs in swine herds is chiefly related to the type of flooring material used. In order to contribute to cooling, floors should be made of materials that conduct heat away from the sow. When ambient temperature is above the UCT, pigs will change their position to increase their effective surface area for conductive and convective heat exchange (Steinbach, 1987). On insulated solid floors,

pigs are less able to dissipate their excess heat through conduction and convection, which is especially detrimental at high ambient temperatures. This is because the surface temperature of a slatted floor is generally about 3 to 5°C cooler than an insulated solid floor (Randall et al., 1983). Aarnink et al. (1996) showed that at increasing ambient temperatures, more pigs will lay on a slatted floor than on a solid floor. These data indicate that a slatted floor seems to be a more comfortable option for pigs and more effective option for thermoregulation during heat stress conditions.

Diet adjustments

Many researchers have tried to alleviate the effects of lactation and/or heat stress on sow and piglet performance by changing the diet composition of lactating sows. Noblet and Etienne (1986) manipulated the composition of energy in the diet of lactating sows. They found that sows fed a high (14.2 Mcal of ME per day) energy diet reached maximum milk production by day 21 while sows fed a low (10.4 Mcal of ME per day) energy diet reached a lower maximum milk production by day 17 of lactation. Renaudeau and Noblet (2001) performed a study to determine whether changes in dietary protein or fiber levels could minimize the effect of heat stress on milk production and piglet performance. In their study, dietary protein changes did not lessen the unfavorable effects of heat stress on sow performance; however, dietary fiber changes did have a positive effect on performance. An increase in dietary fiber (and concurrent decrease in energy intake) allowed a greater tissue mobilization for milk production, resulting in increased litter weight gain. These results not only indicate that moderate feed energy restriction during lactation does not depress litter growth, but also shows that sows maintain milk production at the expense of protein and fat body reserves. King and Williams (1984) hypothesized that energy restriction would only affect milk production and litter growth in severely nutrient depleted sows.

Gonçalves dos Santos et al. (2006) found that during lactation, many sows show reductions in both body weight and back-fat thickness because they are not meeting the nutritional requirements for maintenance and milk production. The severity of weight and back-fat thickness losses have been attributed to length of lactation period, litter size and weight gain of litter, sow body composition at farrowing, parity, and environmental conditions (Close and Cole, 2000). Spencer et al. (2003) suggested that reducing lactation length could minimize the negative effects of heat stress on sow growth rate and subsequent reproductive performance, especially in first-parity sows.

Other studies have examined the effects of feed ingredients on alleviating heat stress on the performance of lactating and gestating sows. To avoid excessive weight loss during lactation, the ideal feeding strategy for sows is to maximize feed intake during lactation and modify pregnancy feeding level to promote steady growth so sows reach their mature size at third to fourth parity. According to Close and Cole (2000) and Gonçalves dos Santos et al. (2006), increasing energy content in sow diets can minimize fluctuations in weight and back-fat thickness. Although high energy diets may be beneficial in alleviating adverse effects of heat stress on lactating sows, it may not be as advantageous in gestating sows.

Many studies have also compared the effect of energy and protein levels in sow lactation diets on milk yield and subsequent litter performance. In most trials, decreasing energy and protein levels in the diet depressed milk production and reduced litter weight gain for multiparous sows. In primiparous sows, however, piglet growth and survival were usually not affected by energy restriction, as long as protein concentrations in the diet were constant throughout lactation (O'Grady et al., 1985; Noblet and Etienne, 1986; Touchette et al., 1998). Although energy restriction does not have adverse effects on litter growth rate, it can be detrimental to piglet body composition and survival within the first days of life. Noblet and Etienne (1986) measured the effect of energy restriction of primiparous sows on their litter performance during a 21-day lactation period. The total amount of milk produced during lactation was similar between the energy restricted and control group. However, fat, energy, and nitrogen contents of the milk were significantly greater in sows fed a low energy diet, presumably because the sows were compensating for this lack of energy by catabolizing more of their own body reserves. Consequently, piglets suckling these sows had greater fat and energy contents in their carcasses at weaning. Inevitably, these growing pigs may have more undesirable carcass traits in the future due to the lack of protein concentration in their mother's milk. The piglets of energy restricted sows also had decreased survival rates within the first few days of life, indicating that energy restricted sows are not providing adequate nutrients to their young for the first few days of life.

The decrease in VFI during periods of heat stress can be attenuated through addition of fat or by reduction of protein concentration within lactating sow diets (Renaudeau and Noblet, 2001). Noblet and Etienne (1989) found that low feed intake in conjunction with high milk production results in about 50% of total weight loss from muscle. This loss of muscle mass is associated with a decline in reproductive function in lactating sows. In order to minimize the amount of muscle depletion that occurs during lactation, Noblet and Etienne (1989) recommend increasing protein intake (in the form of lysine) in sow diets. In a study by Yang et al. (2000), maximal litter growth rate occurred at about 44, 55, and 56 g/day of lysine intake in parities one, two and three, respectively, when these sows consumed net energy of 10.9, 13.6, and 13.7 Mcal daily. Increased protein intake, however, also causes greater heat production in sows, which can have negative effects on feed intake, and therefore, growth and performance. Silva et al. (2009) found that limiting protein concentrations in sows diets reduced heat load and decreased feed consumption (by 215 g per meal) more during the summer than in cooler seasons. Sows fed diets with standard quantities of crude protein or those supplemented with amino acids were more likely to exhibit a greater heat increment and lower feed intake during heat stress. Therefore, it may be more beneficial to limit protein content within the lactating sow diet, thereby expending some muscle mass, in order to reduce heat load during lactation.

Conclusions

The objective of this review was to discuss how heat stress affects reproduction, thermoregulation and metabolism as well as the growth and performance of gestating and lactating sows. During heat stress, sows reduce feed intake, which not only leads to negative energy balance but also decreases milk production in lactating sows. Lack of nutrients from low feeding levels during lactation negatively affects piglet growth rate and subsequent sow performance. Heat stress can also negatively impact reproduction, reflected in decreased follicular growth, extended weaning-to-estrus intervals, increased incidence of embryonic losses and reduced farrowing rates. Further research to determine the mechanisms of sow thermoregulation during pregnancy and lactation may help to

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determine more effective management practices for sows and their piglets in heat stress conditions.

Production	LCT $(^{\circ}C)^{1}$	UCT ($^{\circ}$ C) ²	Preferred Range,	Respiration
Phase			(°C)	Rate
				(BPM)
Lactating sow	10 for sow	25 for sow	15 to 22 for sow	15 to 22 for
and litter	25 for piglets		29 to 32 for	SOWS
			piglets	(increases
				24 h before
				farrowing
				and should
				return to
				normal by
				24 h after
				farrowing)
Prenursery,	15	35	26 to 32	50 to 60
4.5 to 13.6 kg				
Gestating	18	32	20 to 26	13 to 18
sow/gilt				

Table 1. Thermal limits and average respiration rate for swine of varying ages in different production phases.

The National Pork Board (2011), Verstegen and Henken (1987) ¹LCT = lower critical temperature ²UCT = upper critical temperature



Figure 1. Flow chart diagramming how dietary energy is converted into net energy that is used to meet production and maintenance requirements of the sow. Adapted from NRC (1981).



Figure 2. Flow chart of the energy metabolism of lactating sows and their litters. Adapted from Bergsma et al. (2008).

CHAPTER 3

EFFECT OF HEAT STRESS ON SOW THERMOREGULATION AND PERFORMANCE FROM LATE GESTATION THROUGH WEANING

SUMMARY

Heat stress decreases reproductive efficiency and performance of lactating sows. The objective was to examine the body temperatures, respiration rate and performance of sows exposed to heat stress during lactation in a real-world farrowing facility and compare the results to a previous study performed within the Brody Environmental Chambers at the University of Missouri (Williams, 2009). Primiparous (P1) and multiparous (P \geq 2) Landrace or Landrace x Large White sows were studied while housed in forced air ventilated breeding/gestation and farrowing facilities. Body temperatures, respiration rate and aspects of reproductive performance were measured. Daily average rectal temperature (RT) increased after farrowing and decreased after weaning. This is in agreement with Williams (2009), who found that RT increased by approximately 1°C at farrowing. Rectal temperature for P1 sows during lactation was greater than that of $P \ge 2$ sows (P < 0.019; 39.0°C \pm 0.1 and 38.7°C \pm 0.1, respectively). There was an effect of day of lactation (DOL) and day relative to weaning (DRW) on ear, shoulder, rump and tail temperatures as well as respiration rate (RR; P < 0.01). Unlike RT, these measures did not follow an obvious pattern with DOL. They did, however, appear to decrease after weaning. In contrast to results by Williams (2009), shoulder skin temperatures did not

decrease to gestational levels after weaning. All measurements had greater magnitude in the afternoon than in the morning due to an increase in ambient temperature throughout the day (effect of time, P < 0.001) There was an effect of parity by time on shoulder (P < 0.02), ear (P < 0.04), rump (P < 0.01) and tail (P < 0.03) temperatures for the DOL analysis because P1 sows had a greater increase in these measurements between the morning and afternoon as compared with P \geq 2. There was no effect of parity by time on RT (P > 0.11) and only a trend for parity by time to have an effect on RR (P < 0.05).

These results show that sows have an increase in RT during lactation that seems to be independent of ambient temperature and that P1 sows appear to have greater RT than $P \ge 2$ sows at this time. The P1 sows did not increase their RR to a greater extent than $P \ge 2$ sows, even though they had greater RT throughout lactation. The P1 sows may also be using skin vasodilation to a greater degree than $P \ge 2$ sows in the afternoon. These data demonstrate differences in thermoregulatory behavior for P1 and $P \ge 2$ lactating sows during heat stress and that sows may present different thermoregulatory mechanisms in a real-world farrowing facility compared to environmentally controlled chambers.

INTRODUCTION

Seasonal infertility, caused by heat stress, is a phenomenon that causes significant production losses in the swine industry. In particular, heat stress can increase the incidence of anestrus in sows, decrease farrowing rates and depress litter size. The objectives of this research were to specifically determine the body temperatures and respiration rate of lactating sows in a real-world environment and to compare the results to a previous study performed within the Brody Environmental Chambers of the Animal Science Research Center (ASRC) at the University of Missouri (Williams, 2009). Information from this research can be used to provide recommendations to producers in regards to managing the sows in their facilities during periods of seasonal infertility. More specifically, producers may opt to modify the farrowing environment to prevent the negative effects of heat stress on health, reproduction and performance on sows.

MATERIALS AND METHODS

Animals and Facilities

All animal procedures were reviewed and approved by the University of Missouri Animal Care and Use Committee. Primiparous (P1) and multiparous (P \ge 2) pregnant/lactating Landrace or Landrace x Large White sows of Genes Diffusion, Inc. (n = 16) that were artificially inseminated with Landrace x Large White or Large White pooled semen were studied. First parity (n = 7), second parity (n = 8), and fourth parity (n = 1) sows were used to compare the thermoregulatory mechanisms of primiparous and multiparous sows in a heat stress environment. The trial occurred between June and July 2008 (51 days) within the breeding/gestation barn and forced air farrowing room of the University of Missouri Swine Research Complex (Columbia, Missouri). Both facilities are forced air ventilated with fans along one of the long sides of each building; there were three 36 inch fans along the side of the forced air room and three 36 inch exhaust fans along the breeding/gestation barn. These fans pulled outside air into the room and across the sows via inlets located in the ceiling. In the breeding/gestation barn, sows were housed in individual gestation stalls (2.1 m x 0.6 m) with concrete slatted floors. In the farrowing room, sows were housed in individual metal farrowing crates (2.1 m x 1.5 m, including creep area) with plastisol-covered (Tenderfoot[®]; Tandem Products, Inc., Minneapolis, MN, USA), iron slatted floors. The farrowing room contained 24 farrowing crates total, although only 16 farrowing crates were used during this trial.

Experimental design

Sows were initially housed within the breeding/gestation barn for the first 18 days of the trial (they had been housed in gestation since they were inseminated). Sows were moved into the farrowing room a few days before their expected farrowing dates and remained there until the day of weaning (26 days), when they were moved back to the breeding/gestation barn for subsequent re-breeding. All sows farrowed between July 2 and July 10, 2008 and their piglets were weaned on July 24, 2008. Sows were moved back into the breeding/gestation barn on the day of weaning for the last seven days of the trial. Water drippers were turned on during days in which the ambient temperature reached above 32°C within the farrowing room. These drippers allowed for cool water to fall onto the sows' shoulder or head for skin evaporation. Sows and piglets had *ad-libitum* access to water by nipple valve waterers. All sows were fed 1.8 kg of a standard corn-soybean meal-based diet (Table 2) once daily between 0800 and 0900 h. After parturition, feed offered to lactating sows was increased by 0.9 kg per day in increments depending on feed consumption. Sows that consumed the morning meal in its entirety were offered additional feed in the afternoon. Sows that failed to consume the previous meal in its entirety were offered less feed.

Body Temperature and Body Weight Measurements

Body temperature measurements began on day 0 of the trial when the sows were housed in gestation and continued for 7 days after the sows were moved back into the breeding/gestation facility on day 51. Sow body temperature and respiration rate data was collected twice daily: once at 0900 h (AM) and once at 1500 h (PM) on alternating days. These data included RT collected by a Cole Parmer thermometer model 8110-20 with a calibrated thermistor probe (Cole Parmer; Vernon Hills, IL) and shoulder, ear, rump, and tail temperatures collected using a calibrated Raytek Raynger (Raytek Corp.; Santa Cruz, CA) infrared thermometer. Respiration rate for each sow was measured using a timer and by counting the number of breaths per minute (BPM) using flank movement. Body weights of sows were taken using a calibrated Rockshaft Scale Cart (Mosdal Scale Systems Inc.; Broadview, MT) at the start of the trial on day 0, when sows entered the farrowing barn on day 18 and when sows were moved back into breeding/gestation on day 44. Total piglet litter weights were measured on the day of processing (\leq 3 days after birth) and at weaning (day 44) using a calibrated Mosdal Smart Cart (Mosdal Scale Systems Inc.; Broadview, MT). Once the sows farrowed, the number of piglets born alive, mummies, stillborns and deaths were documented.

Statistical Analyses

Data were analyzed as repeated measures with Proc Mixed of SAS (SAS Institute Inc., Cary, NC) using the day of lactation (DOL) timeline of -20 to 20 days relative to farrowing on day 0. Odd numbered days were assigned the nearest even number (i.e. d 19 was assigned d 18) to ensure that each sow had similar DOL. Sows of parity two or greater were combined into one greater or equal to parity two group ($P \ge 2$). The statistical model included the effects of parity, DOL, time (time of day), parity by time, parity by DOL, DOL by time and parity by DOL by time interactions. Data were also analyzed by days relative to weaning (DRW), using the timeline of -6 to 6 days relative to weaning on day 0, with a statistical model including the effects of parity, DRW, time (time of day), parity by time, parity by DRW, and parity by DRW by time. Ambient temperatures within the farrowing room were analyzed using Proc Summary to find the average AM and PM temperature throughout DOL and DRW. For the sow body weights and piglet measurements, data were analyzed using Proc GLM with a mathematical model including parity. A type I error rate of P < 0.05 was considered significant. Data are expressed as least squares means \pm SEM.

RESULTS

When analyzed as DOL and DRW, farrowing room ambient temperatures in the AM were lower than temperatures in the PM (Figure 3A and B). Based on DOL, morning

temperatures ranged from 22.6 to 27.4°C, while afternoon temperatures ranged between and 25.9 to 33.6°C. For DRW analysis, morning temperatures ranged between 22 and 28°C, while afternoon temperatures ranged from 29 to 35°C. The AM and PM ambient temperatures were similar for each parity on any given DOL (Figure 3A and B).

There was an effect of DOL and DRW on RT (P < 0.001) because RT increased after farrowing and decreased after weaning. There was an effect of parity on RT when analyzed by DOL and DRW (Fig 4A and B; P < 0.02). Rectal temperatures of P1 sows were greater than those for P \geq 2 sows (39.0 \pm 0.1°C and 38.7 \pm 0.1°C, respectively). This difference in rectal temperature between P1 and P \geq 2 sows was greatest after farrowing (Fig. 4A).

There was no effect of parity on ear, shoulder, rump or tail temperatures or respiration rate. However, there was an effect of DOL and DRW on ear, shoulder, rump and tail temperatures as well as RR (P < 0.01; Tables 3 and 4). There was no obvious pattern of change relative to DOL. All measures decreased 2 days after weaning. Time also had an effect on all measures (P < 0.01) except ear temperature for DOL (P < 0.06). There was an effect of DRW by time on all measures except respiration rate (P < 0.06). There was an effect of DRW by time for all measurements (P < 0.01).

There was no effect of parity by DOL on ear (P > 0.53; Figure 6A), shoulder (P > 0.97; Fig 7A), rump (P > 0.91; Figure 8A) or tail (P > 0.57; Figure 9A) temperatures. There was, however, an effect of parity by DOL on RR (P < 0.03; Figure 5A), but this result was not seen in the DRW analysis (P > 0.09; Figure 5B). There was no effect of parity by DRW on ear (P > 0.24; Figure 6B), shoulder (P > 0.15; Figure 7B), or rump (P > 0.68; Figure 8B) temperatures; however there was an effect of parity by DRW on tail temperatures (P < 0.03; Figure 9B). Although there was an effect of parity by time on shoulder (P < 0.02: Tables 3 and 5), ear (P < 0.04; Tables 3 and 5), rump (P < 0.01; Tables 3 and 5) and tail (P < 0.03; Tables 3 and 5) temperatures for the DOL analysis, there was no effect on RT (P > 0.11; Tables 3 and 5). Shoulder temperatures for P1 sows were lower in the morning, but showed a greater increase throughout the day as compared with those of P \ge 2 sows (Table 5). This pattern was similar for rump, tail and ear temperatures (Table 5). There was a trend for an effect of parity by time on RR as analyzed by DOL (P < 0.05; Table 3).

There was an effect of parity on sow body weight at gestation (P < 0.001), farrowing (P < 0.001) and weaning (P < 0.002; Table 6). Parity also had a significant effect on the difference in sow weight between the start of the trial and when the sows were moved into farrowing (G-F; P < 0.005; Table 6). However, parity did not have an effect on the difference in sow weight from when sows were moved into farrowing to weaning (F-W; P > 0.09; Table 6). Also, parity did not have an effect on sow weight loss between weaning and gestation (W-G; P > 0.37; Table 6). There were no differences for parity on any piglet measurements (litter weights at processing or weaning, number of piglets born alive and number piglets weaned; Table 6).

DISCUSSION

The body temperatures, respiration rate and reproductive performance of sows to heat stress conditions in a real-world commercial swine setting were studied. Real-world conditions within the facilities at the South Farm were more variable and typically more extreme with regards to ambient temperatures than studies conducted previously in the Brody Environmental Chambers. Ambient temperatures within the farrowing room increased after farrowing because of an increase in outside ambient temperature (outside ambient temperatures not shown; Figure 3A and B). The variability in ambient temperature during the field trial led to spikes in rectal temperature and respiration rate that were not observed in the controlled environment of the Brody chambers (Williams, 2009).

First parity sows had greater RT than older (P \geq 2) sows, indicating that primiparous sows may be affected to a greater degree by heat stress during lactation. This reduced ability to maintain homeothermia by first parity sows indicates that they may have a decrease in ME efficiency for milk production, a decrease in heat loss efficiency or both factors during lactation (Gourdine et al., 2007). Regardless of ambient temperature, RT for all sows was lowest before farrowing and increased during lactation. This finding agrees with results by Messias de Bragança et al. (1998) and Prunier et al. (1997), who found that sow RT increased by 1°C at the time of farrowing and remained at this level until weaning in both primiparous and multiparous sows. This large and uniform increase in body temperature may be also caused by an increase in metabolic rate in lactating sows. According to Noblet and Etienne (1987) this pattern occurs because there is a direct relationship between heat production and energy supply in lactating sows; the elevated body temperatures during lactation are related to the increase of metabolic heat production due to greater feed intake and milk synthesis. The decrease in RT after weaning may reflect a decline in heat production related to the interruption of

suckling by the piglets, and therefore, milk production (Noblet and Etienne, 1987). Interestingly, sow RT decreased after weaning, but did not decline to a level that was equivalent to that found during late gestation. This change in thermoregulatory set point may be a mechanism that allows sows to better acclimate to an increased heat load during lactation. These finding also agree with Williams (2009), who found that RT for heat stressed sows increased by approximately 1°C at the time of farrowing and decreased at weaning, but not to gestational levels.

Although the average sow RT increased during lactation, the RR for primiparous and multiparous sows did not increase at this time to compensate for the rise in RT. Even though the average daily RT was greater for primiparous compared to multiparous sows, RR for both parities was similar (Figure 4A and B). This is in contrast to results from Renadeau et al. (2001) who found that multiparous sows had an increase in RR from 30 to 105 BPM when ambient temperature increased from 20 to 29°C and Prunier et al. (2007) who found similar results in primiparous sows. The current results indicate that primiparous sows were not increasing RR to compensate for their greater RT throughout lactation. Average daily ear, shoulder, rump and tail temperature were also not different for each parity during lactation. According to Renaudeau et al. (2001), elevated peripheral skin temperatures are a reflection of increased blood flow for dissipation of body heat at the skin's surface. These patterns of skin temperature suggest that first parity sows are not increasing skin vasodilation to a greater extent than older sows. Primiparous sows, therefore, may be changing their metabolism rather than thermoregulation to more effectively cope with these heat stress conditions during lactation. In comparison, Williams (2009) found that respiration rate and shoulder temperature for primiparous

sows increased at farrowing and decreased at weaning back to gestational levels. This discrepancy in results between the two trials may be attributed to the more extreme environmental conditions at the farrowing facility as compared with the controlled environmental chambers.

Ear, shoulder, tail and rump temperatures as well as RR for each parity were different in the morning compared with the afternoon because ambient temperature was greater in the afternoon (Table 5). Primiparous sows had lower morning skin temperatures and RR, but showed a greater increase in these measurements throughout the day as compared with multiparous sows. These results indicate that the first parity sows are conserving heat in the morning, but vasodilating and increasing respiration rate to a greater extent in the afternoon. Interestingly, there was no parity by time interaction for RT (Table 5). This indicates that there is not a significant difference between morning to afternoon RT measurements for each parity, possibly due to the constant metabolic heat load from lactation. In contrast, Gourdine et al. (2007) reported that RT in lactating sows had diurnal fluctuations and was greater in the afternoon compared with the morning.

Results from the previous trial performed in the Brody Environmental Chambers (Williams, 2009) agree with the thermal data findings from the current study. At the time of farrowing, there was an increase in RT. After weaning, there was a decrease in RT. However, the specific patterns for RR and skin temperatures found in the current trial were not observed in the previous study. For example, Williams (2009) found that shoulder temperatures and respiration rate increase markedly during lactation, but then decreased back to gestational levels after weaning. This may be due to the fact that the

previous trial was performed within environmentally controlled chambers. In comparison, the current study was a field trial which provided more realistic fluctuations in ambient temperature throughout the day and night.

There was an effect of parity on sow body weight at late gestation, the week before farrowing and at weaning. These results are supported by Mullan and Williams (1989) who found that gilts are smaller than multiparous sows because they have not reached full maturity. All sows lost weight between the week before farrowing and weaning due to loss in fetal and placental mass and negative energy balance caused by heat stress and milk production (Table 6). Parity did not affect weight loss from when sows were moved into farrowing to weaning or from gestation to weaning. First parity sows actually lost more weight during lactation and between gestation and weaning than multiparous sows when you compare the weight loss as a percentage of their total body weight. Neil et al. (1996) found that primiparous sows have a lower voluntary feed intake and, therefore, have greater weight losses during lactation than older sows.

There was no effect of parity on litter weights at processing or weaning, number of piglets born alive or number of piglets weaned. These data suggest that despite differences in weight loss during lactation, multiparous and primiparous sows may be able to produce similar quantities of milk for their nursing piglets that allows them to reach similar weaning weights. In conditions without heat stress, offspring born to primiparous sows are lighter at birth (Tummaruk et al., 2004) and weaning (Holyoake, 2006) than offspring from multiparous sows. First parity sows may alter their metabolism during lactation to cope with the strain of heat stress, which in turn, affects milk production. Feed intake was not taken into consideration during this trial; therefore, components of metabolism and energy balance that may have played a role in this study can only be hypothesized. Also, sow body weight was not measured at the time of farrowing; therefore, it is unclear whether the body weight loss in sows between when they were moved to farrowing through weaning is due to loss in fetal mass, negative energy balance or both of these factors. Since there were few sows of first parity used during this trial, our statistical power may have also been too low to detect differences in milk yield between first parity and older sows during lactation.

This study demonstrated that sows have an increase in RT during lactation. First parity sows, in particular, had a large increase in internal body temperature and greater body weight loss during lactation. The greater RT of the primiparous sows during lactation, therefore, may not affect their ability to produce milk. An increase in RT was also observed for first parity sows in environmental chambers (Williams, 2009). This pattern, therefore, occurs in controlled heat stress, thermoneutral and real-world heat stress conditions. Further research needs to be conducted to more specifically determine the thermoregulatory and metabolic behavior of different parity sows during lactation.

Component	Lactation diet	Gestation/Breeding diet
Corn	79.4	69.4
Soybean meal (48%)	15.0	15.0
Soy hulls	-	10.0
Choice white grease	1.00	1.00
Dicalcium phosphate	2.25	2.30
Limestone	1.00	1.00
Salt	0.50	0.50
Vitamin premixes	0.50	0.50
Trace mineral premix	0.15	0.20
Zinc premix	0.10	0.10
Biotin premix	0.10	0.10

Table 2. Composition of lactation and gestation/breeding diets (% as-fed basis).


Figure 3. Proc Summary averages for farrowing room ambient temperatures (C°) expressed as day of lactation (DOL; A; d 0 = farrowing) for parity 1 (P1) and \geq parity 2 (P2 or >) sows and day relative to weaning (DRW; B: d 0 = weaning).



Figure 4. Least squares means for rectal temperature (C°) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) and day relative to weaning (DRW; B; d 0 = weaning).



Figure 5. Least squares means for respiration rate (BPM) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) and day relative to weaning (DRW; B: d 0 = weaning).



Figure 6. Least squares means for ear temperature (C°) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) and day relative to weaning (DRW; B: d 0 = weaning).



Figure 7. Least squares means for shoulder temperature (C°) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) and day relative to weaning (DRW; B: d 0 = weaning).



Figure 8. Least squares means for rump temperature (C°) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) and day relative to weaning (DRW; B: d 0 = weaning).



Figure 9. Least squares means for tail temperature (C°) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) and day relative to weaning (DRW; B: d 0 = weaning).

		l	Measurement			
Effect	RT	Ear	RR	Shoulder	Rump	Tail
Parity	<0.019	NS	NS	NS	NS	NS
DOL	< 0.001	< 0.002	< 0.001	< 0.01	< 0.008	< 0.001
Parity by DOL	<0.05	NS	<0.03	NS	NS	NS
Time	< 0.001	< 0.06	< 0.001	< 0.001	< 0.001	< 0.001
Parity by time	<0.11	< 0.05	< 0.05	<0.02	<0.009	<0.03
DOL by time	<0.001	<0.001	<0.06	<0.003	<0.006	<0.001
Parity by DOL by time	NS	NS	NS	NS	NS	NS

Table 3. P-values for rectal temperature (RT; °C), ear temperature (°C), respiration rate (RR in BPM), shoulder temperature (°C), rump temperature (°C) and tail temperature (°C) of parity one and ≥ parity two sows analyzed as day of lactation (DOL) with effects of parity, time, DOL and interactions between these effects.

Table 4. P-values for rectal temperature (RT; °C), ear temperature (°C), respiration rate (RR in BPM), shoulder temperature (°C), rump temperature (°C) and tail temperature (°C) of parity one and \geq parity two sows analyzed as day relative to weaning (DRW) with effects of parity, time, DRW and interactions between these effects.

			Measurement			
Effect	RT	Ear	RR	Shoulder	Rump	Tail
Parity	< 0.02	NS	NS	NS	NS	NS
DRW	< 0.001	< 0.008	< 0.001	< 0.001	< 0.001	< 0.001
Parity by DRW	NS	NS	<0.08	NS	NS	<0.03
Time	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Parity by time	NS	NS	NS	NS	NS	NS
DRW by time	<0.001	<0.002	<0.007	<0.001	<0.001	<0.001
Parity by DRW by time	NS	NS	NS	NS	NS	NS

Table 5. Least squares means rump skin temperature minute (BPM), respect	and P-values for in , tail skin temperat tively, for lactating	tteraction of parity by t ture, ear skin temperatt sows as analyzed by d	ime with rectal temports and respiration rates and respiration rates and of lactation (DOL)	erature, shoulder sk e, expressed in °C).	in temperature, and breaths per
Measurement	AN	V	Id	Λ	$P<^2$
1	P1 ¹	P2 ¹	P1	$P2^{I}$	
Rectal temperature, °C	38.9 ± 0.1	38.7 ± 0.1	39.1 ± 0.1	38.8 ± 0.1	NS
Shoulder skin temp, °C	34.1 ± 0.1	34.4 ± 0.1	35.4 ± 0.1	35.1 ± 0.1	0.02
Rump skin temp, °C	34.7 ± 0.1	34.9 ± 0.1	36.0 ± 0.1	35.8 ± 0.1	0.009
Tail skin temp, °C	35.5 ± 0.1	35.6 ± 0.1	36.2 ± 0.1	36.0 ± 0.1	0.03
Ear skin temp, °C	35.5 ± 0.1	35.6 ± 0.1	35.9 ± 0.1	35.6 ± 0.1	0.04
Respiration rate, BPM	53 ± 3	58 ± 2	67 ± 3	66 ± 2	0.05
¹ P1 denotes parity one sows a 0900 h (AM) and once at 1500 ² Overall type I error rate (P va	and P2 denotes ≥ p 0 h (PM) on alterna ilue) for parity by t	arity two sows. Sow b ting days. ime.	ody temperature data	was collected twic	e daily: once at

Table 6. Least squares means and P-values for in weaning, sow weight differences betweer kg) as well as number of piglets born aliv	teraction of parity with sow these phases, piglet litter w e and number of piglets we:	body weights during gestation eights at processing and wean med throughout the trial.	ı, farrowing and ing (expressed in
Measurement	P1 ¹	P2 ¹	P< ²
Sow body weight gestation (G)	191.0 ± 5.2	232.1 ± 4.6	0.001
Sow body weight farrowing (F)	203.3 ± 5.3	249.3 ± 4.7	0.001
Sow body weight weaning (W)	172.7 ± 6.8	207.7 ± 6.0	0.002
Sow weight difference F-G	12.3 ± 1.1	$17.1 \pm .98$	0.005
Sow weight difference W-F	30.6 ± 4.6	41.7 ± 4.0	0.089
Sow weight difference W-G	18.3 ± 5.0	24.4 ± 4.4	NS
Litter weight processing	16.7 ± 2.3	20.0 ± 2.0	NS
Number born alive	11.9 ± 1.6	12.9 ± 1.4	NS
Litter weight weaning	50.6 ± 8.4	57.1 ± 7.4	NS
Number weaned	10.0 ± 1.6	11.8 ± 1.4	NS
¹ P1 denotes parity one sows and P2 denotes \geq parigestation (G), moved from gestation to farrowing (gestation and farrowing denoted as G-F, between f denoted as W-G. Litter weights were measured at t	ty two sows. Sow weights (k _i) F) and at the time of weaning arrowing and weaning denote he time of processing (≥3 d a	g) were measured when sows were (W). Sow weight difference be as F-W and between weaning fiter birth) and at weaning.	ere moved into tween and gestation
² Overall type 1 error rate (P value) for parity.			

CHAPTER 4

EFFECT OF PARITY AND STATUS ON BODY TEMPERATURE, RESPIRATION RATE AND ENERGY BALANCE OF SOWS HOUSED AT 24 TO 27°C DURING LACTATION

SUMMARY

Heat stress during the summer negatively affects lactating sows. The objective was to examine how the performance, body temperatures and respiration rate of different parity sows are affected during lactation when the sows are housed within the same environment. Primiparous (P1) and multiparous (P \geq 2) Landrace or Landrace x Large White sows were studied while housed in an evaporatively-cooled (EC) farrowing facility. There were effects of day of lactation (DOL; P < 0.001) and parity (P < 0.01) on rectal temperature (RT). Rectal temperature increased after farrowing $(38.3 \pm 0.1^{\circ}C \text{ on})$ day -1 to 39.3 ± 0.1 °C on day 0) and remained elevated during lactation (38.8 ± 0.1 to $39.4 \pm 0.1^{\circ}$ C). Rectal temperature was greatest in P1 sows when analyzed relative to DOL (39.1 \pm 0.1 and 38.8 \pm 0.1 for P1 and P \geq 2 sows, respectively) and day relative to weaning (DRW; 39.4 \pm 0.1 and 38.9 \pm 0.1°C for P1 and P \geq 2 sows, respectively). The RT decreased after weaning $(39.3 \pm 0.1^{\circ}C \text{ on day } -1 \text{ to } 39.0 \pm 0.1^{\circ}C \text{ on day } 0)$ and continued to decrease until day 4 (38.5 \pm 0.1°C). The respiration rate (RR; P > 0.34) and ear temperature (P > 0.15) were similar for all parities in the DOL analysis. Parity one sows also had similar RR compared with $P \ge 2$ sows for the DRW analysis (P > 0.16). Ear temperature, however, for P1 sows was greater than that of $P \ge 2$ sows when

analyzed as DRW (P < 0.03). Shoulder temperatures were greater for P1 than P \ge 2 sows when analyzed by DOL (P < 0.005) and by DRW (P < 0.04).

Pregnant sows housed beside lactating sows had lesser RT than lactating sows for the DOL analysis (P < 0.001; 38.3 \pm 0.1 and 38.9 \pm 0.1°C, respectively) as well as the DRW analysis (P < 0.001; 38.4 \pm 0.1 and 39.1 \pm 0.1°C, respectively). Pregnant sows had lower ear temperatures compared with lactating sows when analyzed by DOL (P < 0.001) and DRW (P < 0.001). Pregnant sows also had lesser shoulder temperatures than lactating sows for both the DOL (P < 0.004) and DRW analysis (P < 0.001). Respiration rate was also different between pregnant and lactating sows when analyzed by DOL (P < 0.01) and DRW (P < 0.02). Lactating sows had greater RR overall compared to pregnant sows (52 \pm 2 BPM compared to 45 \pm 2 BPM, respectively).

There was a trend for a parity by DOL interaction for energy balance (EB; P < 0.06) during lactation. The main effect of parity was not significant for EB (P > 0.80). Average EB for all sows increased from day 0 (-8.4 ± 1.1 Mcal ME) to day 5 (-1.5 ± 1.1 Mcal ME), but then decreased to day 9 (-4.5 ± 1.1 Mcal ME) and achieved neutrality by day 13 (P < 0.001). There was an effect of parity on maintenance (P < 0.001) and total requirements (P < 0.001) for all lactating sows relative to DOL, but no effect of parity on lactation requirements (P > 0.53). There was an effect of parity by DOL on feed energy intake (ME_I; P < 0.01).

These results confirm that younger (P1) sows have greater RT than older ($P \ge 2$) sows during lactation. This phenomenon could be caused by differences in metabolism between first parity and older sows or because first parity sows have never experienced lactation before, and therefore, may accept the higher rectal temperature more readily than older sows. This study also provided evidence that lactating sows have greater rectal, ear and shoulder temperatures, as well as respiration rates compared to pregnant sows.

INTRODUCTION

The previous experiment performed during summer 2008 (Chapter 3) demonstrated that RT of sows increased at the time of farrowing. The study also showed that different parity sows differed in terms of their body temperatures during lactation. The rise in RT during lactation is in agreement with studies by King et al. (1972) who found that farrowing causes an increase in rectal temperature (about 1°C) that remains high throughout lactation, perhaps because of greater metabolic demand. This increase in RT during lactation may make it more difficult for the sow to overcome heat stress.

The previous trial also showed that P1 sows differed from $P \ge 2$ sows because of a greater RT of P1 sows throughout lactation. Primiparous sows did not increase their RR as much as multiparous sows as lactation progressed, although they did have greater RT. These results agree with Kelley and Curtis (1978), who found that there was a reduction in respiration rate of sows housed in a heat stress environment after farrowing and attributed this to a partial acclimation to the heat stress. Sows of different parities also had different ear, shoulder, rump and tail temperatures during lactation. The finding that different parity sows have different body temperatures, yet similar respiration rate during lactation may be a novel concept in swine research.

Data from the previous trial indicated that P1 and $P \ge 2$ sows had similar piglet weaning weights despite differences in sow body weight from late gestation through weaning. Feed intake and piglet growth rate, however, were not taken into consideration during the previous trial. Both aspects could affect the metabolism of the sow. Litter weight gain is a particularly important measurement in commercial swine operations because it reflects the sow's level of milk production. Low litter weights have been associated with decreased milk production in sows exposed to heat stress (Renaudeau and Noblet, 2001). Heat stress was also shown to reduce feed intake in lactating sows and reduce body weight gain in piglets (Quiniou and Noblet, 1999). Weekly sow and piglet litter weights as well as sow feed intake were recorded during this trial to estimate milk production and EB.

The objective of this trial was to collect temperature and metabolic data on sows during lactation in order to compare the effect of parity on thermoregulation within the same farrowing room. The hypothesis was that sows of different parity would have different body temperatures during lactation under the same environmental conditions. First parity sows, for example, should have a greater RT than older sows and this difference in thermoregulation should also affect EB and litter growth. We also included a control group of pregnant sows that did not farrow. These sows were used to verify that farrowing (and not an alternative influence within the room) caused an increase in RT.

MATERIALS AND METHODS

Animals and Facilities

All animal procedures were reviewed and approved by the University of Missouri Animal Care and Use Committee. Primiparous (P1) and multiparous (P \ge 2) pregnant and lactating Landrace or Landrace x Large White sows of Genes Diffusion, Inc. (n = 19) that were artificially inseminated with Landrace x Large White or Large White pooled semen were studied. The trial occurred between October and November 2010 (35 days) within the evaporatively-cooled farrowing room of the University of Missouri Swine Research Complex (Columbia, Missouri). There were first parity (n = 7), second parity (n = 4) and sixth parity (n = 2) sows that farrowed during the trial. First parity (n = 3), third parity (n = 1), sixth parity (n = 1) and seventh parity (n = 1) pregnant sows were used as nonfarrowing controls. There were also four sows in late lactation that were housed within the evaporatively-cooled farrowing room during the trial, but were not used in the data analysis.

Experimental Design

Sows were moved from the gestation barn to the farrowing room a week before their expected farrowing dates. Body temperature measurements began the day that they were moved into the farrowing room. The sows farrowed at different times within a span of a week. Weaning occurred on day 31 of the trial. The sows remained in the farrowing room throughout lactation until four days after weaning, when they were moved back to the gestation barn and thermal measurements were no longer collected. The farrowing room temperature was set to 26°C and fluctuated between 22.3 ± 3.3 °C and 26.2 ± 2.0 °C. Hobo Data Loggers (Onset Computer Corp.; Bourne, MA) were placed at sow standing level in the middle walking aisle of the farrowing room and also outside the barn. Sows were housed in individual 2.1 m x 1.5 m (including creep area) metal farrowing crates with plastic slatted flooring. Sows and piglets had *ad-libitum* access to water by nipple valve waterers. Sows were fed 1.8 kg of a standard corn-soybean meal-based diet (Table 2) once daily between 0800 and 0900 h. After parturition, feed offered to lactating sows was increased by 0.9 kg per day in increments depending on feed consumption. Sows that consumed the morning meal in its entirety were offered additional feed in the afternoon. Sows that failed to consume the previous meal in its entirely were offered less feed.

Body Temperature and Body Weight Measurements

Thermal measurements were collected once daily at 1400 h. Thermal data included rectal temperatures collected using a calibrated Cole Parmer thermometer model 8110-20 with a thermistor probe (Cole Parmer; Vernon Hills, IL) and crate, shoulder and ear temperatures collected using a calibrated Raytek Raynger (Raytek Corp.; Santa Cruz, CA) infrared thermometer. Respiration rate for each sow was measured using a timer and counting the number of breaths per minute (BPM) using flank movement. Feed offered and feed refused as well as sow and litter weights were measured to estimate energy balance (Mcal ME). To determine the dry vs. wet matter content of the feed given to the sows, samples of uneaten feed were collected daily. These samples were bagged and placed into a -20°C freezer until further weighing. At the end of the trial, these samples were thawed and subsequently weighed to determine the total weight and dry matter weight. The samples were placed into a drying oven for 72 h, after which they were reweighed to determine the dry matter weight. Sow body weights were collected the day after farrowing, after farrowing (one, two, and three weeks) and at weaning (day 31) using a calibrated Rockshaft Scale Cart (Mosdal Scale Systems Inc.; Broadview, MT). Piglet litter weights were measured on the day of processing (≤ 3 days after birth), one week after processing, two weeks after processing, three weeks after processing and at weaning using a calibrated Mosdal Smart Cart (Mosdal Scale Systems Inc.; Broadview, MT).

Energy Balance

Energy balance (EB; Mcal ME) was estimated using energy requirements during lactation. Metabolizable energy of intake (ME_I or feed energy) was calculated by multiplying the energy in the feed (3.67 kcal/kg) by the feed consumed by the sow. During lactation, maintenance requirements (ME_M) were estimated using the equation 110 kcal ME per kg of body weight^{0.75} (Noblet et al., 1990). Lactation requirements (ME_{Milk}) were calculated: (2540 * piglet average daily gain) * ((78.7 * piglet body weight) + 153) * (number of piglets in litter)/1000). The total energy requirements were calculated as ME_M + ME_{milk}. Sow energy balance for lactation (EB_L) was determined according to the following formulas (National Research Council, 1981) and expressed as Mcal of ME/d: EB_L= ME_I - ME_M - ME_{Milk}

Statistical Analyses

Thermal data were analyzed as repeated measures using Proc Mixed of SAS with the day of lactation (DOL) timeline of -7 to 20 days relative to farrowing on day 0 and a day relative to weaning (DRW) timeline of -12 to 4 relative to weaning on day 0. The SAS statistical model for the DOL analysis included the effects of: parity, DOL and parity by DOL. The statistical model for the DRW analysis included the effects of parity, DRW and parity by DRW. To compare the body temperatures and respiratory rate of control (pregnant) with farrowing/lactating sows, each farrowed sow was paired with a contemporary control sow of the same or similar parity and matched with their farrowing date as well. Data were analyzed via Proc Mixed of SAS with the same DOL and DRW timeline as in the previous analysis. The statistical model for the DOL analysis included the effects of: status (pregnant or farrowing/lactating), DOL, parity, DOL by status, DOL by parity, parity by status and DOL by parity by status. The statistical model for the DRW analysis included the effects of: status (pregnant or farrowing/lactating), DRW, parity, DRW by status, DRW by parity, parity by status and DRW by parity by status. Energy balance data were analyzed as repeated measures using Proc GLM of SAS with a DOL timeline of 0 to 19 days relative to farrowing on day 0. The statistical model included the effects of: parity, sow within parity, DOL and parity by DOL. The EB data were also analyzed via Proc Mixed of SAS using the best covariance parameter based on fit statistics. The statistical model included the effects of parity, DOL and parity by DOL. Sow and litter weights were analyzed using Proc GLM of SAS with a model including the effect of parity. Ambient temperatures outside and within the farrowing room were analyzed using Proc Summary to find the average daily temperatures throughout the trial. For all SAS analyses, sows were classified as P1 and P \geq 2 parity (all sows \geq parity two sows were combined into one group). A type I error rate of P < 0.05 was considered significant. Data are expressed as least squares means \pm SEM.

RESULTS

The ambient temperature within the farrowing room and outside showed similar patterns with regard to increases and decreases in temperature; however, the magnitude of this response was different in each environment (Figure 10). The outdoor temperature did have a small effect on the indoor farrowing temperature, as reflected by similar patterns of temperature change. The farrowing room temperature did not fluctuate to as great of a degree throughout the day or from day to night when compared with the outdoor temperature, perhaps because the EC room had a minimum temperature setpoint.

For the DOL analysis, there were effects of parity (P < 0.01) and day of lactation (P < 0.001) on RT (Tables 7 and 9). The RT increased after farrowing $(38.3 \pm 0.1^{\circ}C)$ on day -1 to 39.3 ± 0.1 °C on day 0) and remained elevated during lactation (38.8 ± 0.1 to 39.4 ± 0.1 °C). During lactation, RT was greatest in P1 sows (39.1 ± 0.1 and 38.8 ± 0.1 for P1 and P \geq 2 sows, respectively; Figure 12A; Tables 7 and 9). For the DRW analysis, there was also an effect of parity (P < 0.007) and DRW (P < 0.001) on RT (Tables 7 and 9). The RT decreased after weaning $(39.3 \pm 0.1^{\circ}C \text{ on day } -1 \text{ to } 39.0 \pm 0.1^{\circ}C \text{ on day } 0)$ and continued to decline until the end of the trial (38.5 \pm 0.1°C on day 4). Rectal temperatures were greatest in P1 sows for the DRW analysis $(39.4 \pm 0.1 \text{ and } 38.9 \pm 0.1^{\circ}\text{C}$ for P1 and P \geq 2 sows, respectively; Figure 12B; Tables 8 and 10). Despite greater RT during lactation, P1 sows did not have greater respiration rate (RR) than $P \ge 2$ sows based on DOL (P > 0.34; 54 \pm 2 and 50 \pm 2 BPM for P1 and P \geq 2 sows, respectively; Figure 14A; Tables 7 and 9). The P1 sows also had similar RR with $P \ge 2$ sows for the DRW analysis (P > 0.16; 53 \pm 2 and 49 \pm 2 BPM for P1 and P \geq 2 sows, respectively; Figure 14B; Tables 8 and 10). Shoulder temperatures were greater for P1 sows when analyzed by DOL (P < 0.005; 36.5 \pm 0.1 and 36.0 \pm 0.1°C for P1 and P \geq 2 sows, respectively; Figure 15A; Tables 7 and 9) and by DRW (P < 0.04; 36.3 ± 0.1 and $36.0 \pm 0.1^{\circ}$ C for P1

and $P \ge 2$ sows, respectively; Figure 15B; Tables 8 and 10). There was an effect of parity by DOL on crate temperature (P < 0.006; Figure 11A; Tables 7 and 9). However, there was no effect of parity by DRW on crate temperature (P > 0.74; Figure 11B; Tables 8 and 10). There was also no effect of ear temperature on parity for the DOL analysis (P > 0.15; Figure 13A; Tables 7 and 9); however, there was an effect of parity on ear temperature based on DRW (P < 0.03; Figure 13B; Table 7). Ear temperature for P1 sows was greater than that of P \ge 2 sows (37.2 \pm 0.1 and 36.9 \pm 0.1°C for P1 and P \ge 2 sows, respectively; Table 9). There was also an effect of DRW on RR as well as crate, ear and shoulder temperatures (P < 0.001; Tables 8 and 10).

Pregnant sows had lesser RT than farrowing/lactating sows for the DOL analysis (P < 0.001; 38.3 ± 0.1 and $39.0 \pm 0.1^{\circ}$ C, respectively; Figure 16A and Table 11) as well as the DRW analysis (P < 0.001; 38.4 ± 0.1 and $39.1 \pm 0.1^{\circ}$ C, respectively; Figure 16B and Table 12). There was an effect of parity on RT for DOL (P < 0.007; P1 sows had RT of $38.8 \pm 0.1^{\circ}$ C while P ≥ 2 sows had RT of $38.5 \pm 0.1^{\circ}$ C; Table 11) and DRW (P < 0.01; P1 sows had RT of $38.9 \pm 0.1^{\circ}$ C while P ≥ 2 sows had RT of $38.5 \pm 0.1^{\circ}$ C; Table 11) and DRW (P < 0.01; P1 sows had RT of $38.9 \pm 0.1^{\circ}$ C while P ≥ 2 sows had RT of $38.5 \pm 0.1^{\circ}$ C; Table 11) and DRW (P < 0.01; Tables 12). There was an effect of DOL by status and DRW by status on RT (P < 0.001; Tables 11 and 12). For the DOL analysis, pregnant and farrowed sows had similar RT on day -7 (38.4 ± 0.2 and $38.3 \pm 0.1^{\circ}$ C, respectively), but at the time of farrowing and throughout lactation, the RT for the farrowing sows was greater than that of the pregnant sows (39.2 ± 0.1 and $38.2 \pm 0.2^{\circ}$ C, respectively on day 0). For the DRW analysis, pregnant and farrowing sows had different RT before weaning (38.01 ± 0.2 and $39.1 \pm 0.1^{\circ}$ C, respectively on day -6), but after weaning their RT were similar (38.4 ± 0.1 and

 38.5 ± 0.1 °C for pregnant and farrowed sows, respectively on day 4). Pregnant sows had lesser ear temperatures compared with lactating sows when analyzed by DOL (P < 0.001; 36.1 ± 0.1 and 37.1 ± 0.1 °C, respectively; Figure 17A and Table 11) and DRW

(P < 0.001; 36.0 \pm 0.1 and 36.9 \pm 0.1°C, respectively; Figure 17B and Table 12). There was also a DOL by status effect on ear temperature (P < 0.03; Table 11). Pregnant sows also had lesser shoulder temperatures than lactating sows for both the DOL (P < 0.004; 34.8 \pm 0.1 and 35.9 \pm 0.1°C, respectively; Figure 18A and Table 11) and DRW analysis (P < 0.001; 35.1 \pm 0.1 and 36.3 \pm 0.1°C, respectively; Figure 18B and Table 12). Interestingly, RR was different between pregnant and lactating sows when analyzed by DOL (P < 0.01; 45 \pm 2 and 52 \pm 2 BPM, respectively; Table 11) and DRW (P < 0.02; 43 \pm 3 and 52 \pm 2 BPM, respectively; Table 12). There was no effect of parity by status, DOL by parity by status or DRW by parity by status on any measurements (Tables 11 and 12).

There was an effect of parity on maintenance (P < 0.001; Table 13) and total requirements (P < 0.001; Figure 19A and Table 13) for all lactating sows relative to DOL, but no effect of parity on lactation requirements (P > 0.53; Table 13). There was also an effect of DOL on maintenance, lactation and total requirements, as well as feed energy intake (ME_I) and energy balance (EB; P < 0.001; Table 13). There was an effect of parity by DOL on ME_I (P < 0.01; Figure 19A and Table 13). The ME_I for P1 sows increased from day 0 to day 6 (5.4 to 13.4 ± 1.4 Mcal ME), decreased from day 7 to day 12 and then increased until the end of lactation (20.0 \pm 1.5 Mcal ME on day 19). In comparison, the ME_I for P \geq 2 sows increased from day 0 to day 11 (5.5 to 21.4 \pm 1.5 Mcal ME) and then slowly decreased until the end of lactation (15.9 \pm 1.6 on day 19).

Average EB for all sows increased from day 0 (-8.4 \pm 1.1 Mcal ME) to day 5 (-1.5 \pm 1.1 Mcal ME), but then decreased to day 9 (-4.5 \pm 1.1 Mcal ME) and then achieved neutrality by day 13 (P < 0.001; Table 13). Although there was no effect of parity on EB (P > 0.80), there was a trend for parity by DOL to have an effect on EB (P < 0.06; Figure 19B and Table 13).

Parity had an effect on sow weight (P < 0.001; Table 13). The P1 sows had lesser body weights throughout the trial compared with P \ge 2 sows (190 ± 7.0 and 260 ± 8.0 kg for P1 and P \ge 2 sows, respectively at the first time of weighing compared with 180 ± 7.0 and 247 ± 8.0 kg for P1 and P \ge 2 sows, respectively at the final weighing; Table 13). However, parity did not have an effect on litter weights (P > 0.10; Table 13).

DISCUSSION

The small variability in indoor farrowing room temperature as compared with outdoor temperature minimized the effect of heat stress on the pigs and provided an ideal environment to focus on the effect of farrowing and lactation on rectal, ear, and shoulder temperatures as well as respiration rate of sows. The results from this trial confirmed our hypothesis and also the outcome from the previous trial: younger sows have greater RT during lactation than older sows, even in conditions without heat stress. Gourdine et al. (2007) also reported greater RT in primiparous compared with multiparous sows during lactation; however, this result is poorly documented within the literature. This phenomenon could be caused by differences in metabolism or thermoregulation between first parity and older sows. Primiparous sows may have greater metabolic demand than older sows because primiparous sows are partitioning energy towards both milk production and body growth (Flowers and Day, 2002). Another explanation for these observations is that first parity sows are experiencing their first lactation; therefore, first parity sows may not be as physiologically prepared in terms of thermoregulatory efficiency for heat dissipation. This trial also confirmed the findings from the previous trial that there is an increase in rectal and skin temperatures at the time of farrowing and throughout lactation (King et al., 1972; Williams, 2009); this response is independent of heat stress.

The patterns of skin (ear and shoulder) temperatures and respiratory rate in primiparous sows were not similar throughout the trial, indicating that the first parity sow may not use skin vasodilation and respiratory rate to the same extent during lactation. For example, first parity sows had greater shoulder temperature, but similar ear temperature and RR to older sows. In previous studies, skin temperatures at the flank increased linearly with rectal temperatures during lactation in primiparous (Rosero et al., 2012) and multiparous sows (Quiniou and Noblet, 1999) to allow for greater conductive heat loss. Difference in skin temperature patterns between different parity sows, however, is not well documented. The findings in the current trial may be a function of greater skin vasodilation at the shoulder rather than ear or merely a reflection of their greater RT, and therefore, higher body heat content.

The similar RR for each parity indicated that first parity sows are not trying to cool themselves using respiratory evaporative methods, despite having greater RT. Rosero et al. (2012) found that first parity sows have lesser RR compared to second and third parity sows when all sow diets were supplemented with fat and the sows were

housed at 27°C during lactation. The notion that different parity sows have different patterns of RR during lactation regardless of heat stress or dietary treatment, however, seems to be a novel concept in the swine industry. These younger sows, therefore, may not be as physiologically affected by the heat stress compared with older sows, either due to body size, metabolism or endocrine differences. In agreement with Hendrix et al. (1978), respiration rate for all sows decreased at the time of farrowing. This may due to metabolic rate being greater in late pregnancy as compared with lactation or because the pregnancy is limiting the size of breath a sow can take. More detailed metabolic and oxygen consumption studies may be able to better answer these questions. There was a significant drop in rectal, ear and shoulder temperatures as well as respiration rate at the time of weaning; this may be a reflection of the loss of heat load due to piglet weaning (Noblet and Etienne, 1987). Respiration rate, however, subsequently increased a few days after weaning. In contrast, Williams (2009) found that RR decreased in heat stressed primiparous sows at the time of weaning from about 70 to 25 BPM and showed a further decrease to about 20 BPM for the remaining 6 days of the trial after weaning. The pattern found in the current trial may indicate the sow's shift in thermoregulatory set-point after lactation or it may have been caused by the sows becoming agitated due to oncoming estrus behavior.

The trial also demonstrated that there are differences between patterns of rectal, ear, and shoulder temperatures, as well as respiration rate of lactating and gestating sows. The results from the present study indicate that there was nearly a 1°C difference between RT of pregnant and lactating sows. This finding is in agreement with King et al. (1972) who established that the sow has an average pre-farrowing rectal temperature of ~38.3°C and post-farrowing temperature of ~39.3°C. King et al. (1972) also noted that the increase in RT that occurred at farrowing remains in effect throughout lactation, which also agrees with the present study. Regardless of lactating or pregnancy status, primiparous sows showed greater rectal, ear and shoulder temperatures as well as respiration rate throughout the trial compared to older sows. This indicates that the primiparous sows have different body temperatures and respiration rate than multiparous sows during both pregnancy and lactation.

Before farrowing and after weaning, the skin temperatures between pregnant and lactating sows were similar. Ear and shoulder temperatures during lactation, however, were greater in lactating sows compared with pregnant sows. This increase in skin temperatures in lactating sows also reflects a simultaneously rise in rectal temperature (Rosero et al., 2012; Quiniou and Noblet, 1999). The increase in heat load at this time must cause sows to have greater vasodilation in an attempt to lose this excess heat from lactation.

Lactating sows had a negative energy balance during a majority of lactation. According to Dourmad et al. (2000), a negative energy balance occurs when energy intake is less than what is consumed by physical activity, metabolic requirements and maintenance. A negative energy balance is expected during lactation because of the extremely high energy requirements for milk production. Although the average EB throughout the study was similar for both parities, there was a trend (P < 0.06) for parity by DOL interaction. There was a relationship between feed intake and EB (Figure 19A and B) for both parities. As feed intake increased, EB improved. In comparison, as feed intake decreased, EB became more negative. Primiparous sows showed a greater incidence of negative energy balance compared with multiparous sows during midlactation because of a prolonged period of reduced feed intake (from day 7 to day 17 of lactation; Figure 19A). This reduced feed intake may be a consequence of the P1 sows' greater RT compared with multiparous sows during lactation - the hyperthermia associated with lactation may be reducing the sow's appetite.

Maintenance requirements were greater for older compared with P1 sows because multiparous sows weigh more than P1 sows. These results agree with Beyer et al. (1994), who reported an increase in maintenance requirements as parity increased. The lactation requirements were similar for both parities. This indicated that the sows were producing similar quantities of milk throughout lactation. The difference in total requirements can be attributed to the difference in maintenance requirements based on body weight (BW) of different parity sows. The EB for sows was not greatly affected by their lactation, maintenance or total energy requirements. Instead, feed energy intake was the factor that had the greatest influence on EB for different parity sows. According to National Research Council (1981), feed energy intake or ME₁ represents the total amount of energy from the feed available to meet net energy requirements after fecal, urine and gas losses. Although the ME₁ for primiparous sows was on average, not different than that from older sows (Table 13), younger sows were consuming less feed at some times during lactation.

For an unknown reason, primiparous sows did not consume adequate feed during the second and third weeks of lactation (Figure 19A) as compared with older sows. These results are supported by Eiseen et al. (2000) who reported lesser feed intakes of first and second parity sows during lactation compared to older sows. The deficit in feed consumption caused a decrease in energy balance at these points in lactation (Figure 19B). This depression in feed intake as lactation progressed may have been a function of different nutrient partitioning mechanism in different parity sows (Flowers and Day, 2002). Multiparous sows may partition energy towards decreasing the heat load caused by lactation; in turn, they were able to consume more feed because they effectively minimized their heat load. In contrast, primiparous sows may partition more energy towards growth than towards decreasing the heat load from lactation; therefore they consume less feed during certain parts of lactation to avoid overheating. This may also explain why first parity sows had greater RT and skin temperatures than older sows.

Parity not only affects the partitioning of nutrients towards metabolism, but it also may play a role in the amount of milk produced during lactation. The amount of milk produced by a sow can be estimated by measuring piglet litter size and weights (Noblet and Etienne, 1989). Although first parity sows had lesser BW throughout the trial as compared with older sows, both parities had similar piglet litter weights during lactation. This indicates that, despite lower feed intake and lesser BW, first parity sows were able to produce similar quantities of milk for their piglets throughout lactation compared with older sows. According to Flowers and Day (2002), nutrients are used for milk production at the expense of other physiological processes, such as growth and reproduction, in thermoneutral conditions. During periods of heat stress, however, the nutrient partitioning processes for each parity may be different. Older sows may partition less nutrients towards milk production in order to minimize metabolic heat load. In comparison, first parity sows may continue to partition great quantities of nutrients towards milk production rather than minimizing heat load during lactation. This study provides a better understanding of the differences in thermoregulation and metabolism between different parity sows during lactation and how they can affect subsequent piglet performance. Management techniques to determine feed and environmental requirements for sows of different ages during lactation as well as between lactating and non-lactating sows should be taken into consideration in order to prevent losses in productivity. These data are essential to understanding the challenges encountered by first parity sows due to the metabolic demands of lactation.



Figure 10. Comparison of outdoor and farrowing room ambient temperatures (°C).The data were collected by hobo loggers within the farrowing room and outside (143 collections per day). At hobo logger reading 1200, ambient temperature in the EC room was set to 26°C.



Figure 11. Least squares means for crate temperature (°C) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 12. Least squares means for rectal temperature (RT; °C) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 13. Least squares means for ear temperature (°C) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 14. Least squares means for respiration rate (RR in BPM) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 15. Least squares means for shoulder temperature (°C) for parity one and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 16. Least squares means for rectal temperature (RT; °C) of pregnant parity one (P1), pregnant ≥ parity two (P2), farrowed parity one (P1) or farrowed ≥ parity two (P2) sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).


Figure 17. Least squares means for ear temperature (°C) of pregnant parity one (P1), pregnant \geq parity two (P2), farrowed parity one (P1) or farrowed \geq parity two (P2) sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 18. Least squares means for shoulder temperature (°C) of pregnant parity one (P1), pregnant ≥ parity two (P2), farrowed parity one (P1) or farrowed ≥ parity two (P2) sows in the farrowing facility expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 19. Least squares means comparison for feed energy intake (FEI; A) as well as energy balance (EB in Mcal ME; B) for first and \geq parity two sows in the farrowing facility expressed as day of lactation (DOL, d 0 = farrowing).

Table 7. Least squares m (RR) and shoulder and parity by DOL	teans and P-value temperature of d	s for crate temperatur ifferent parity sows an	e, rectal temperature alyzed as day of lact	e (RT), ear tempera ation (DOL) with e	ature, respiration rate affects of parity, DOL
Measurement	P1 ¹	P2 or greater ¹	Parity P < ³	DOL P < ³	Parity by DOL P < ³
Crate temperature, ^o C	26.1 ± 0.1	26.1 ± 0.1	NS	NS	0.006
Rectal temperature, °C	39.1 ± 0.1	38.8 ± 0.1	0.01	0.001	NS
Shoulder skin temp, °C	36.5 ± 0.1	36.0 ± 0.1	0.005	0.01	NS
Ear skin temp, °C	37.2 ± 0.1	36.9 ± 0.1	NS	0.001	NS
Respiration rate, BPM	54 ± 2	50 ± 2	NS	0.003	NS
¹ P1 and P2 or greater denc ² Sow body temperature da	otes parity one and ata was collected o	$d \ge parity 2 sows, response of the second $	ectively. r.		

³Overall type I error rate (P value) for interaction of parity, DOL or parity by DOL with various measurements

Table 8. Least squares m (RR) and shoulde parity, DRW and _f	neans and P-value ar temperature of parity by DRW.	s for crate temperatur different parity sows a	e, rectal temperature analyzed as day rela	e (RT), ear temper: tive to weaning (L	ature, respiration rate DRW) with effects of
Measurement	P1 ¹	P2 or greater ¹	Parity P < ³	DOL P < ³	Parity by DOL P < ³
Crate temperature, ^o C	25.9 ± 0.1	25.8 ± 0.1	NS	0.001	NS
Rectal temperature, °C	39.4 ± 0.1	38.9 ± 0.1	0.007	0.001	NS
Shoulder skin temp, ^o C	36.3 ± 0.1	36.0 ± 0.1	0.04	0.001	NS
Ear skin temp, °C	37.2 ± 0.1	36.9 ± 0.1	NS	0.001	NS
Respiration rate, BPM	54 ± 2	50 ± 2	NS	0.003	NS
¹ P1 and P2 or greater dend ² Sow body temperature da	otes parity one and ata was collected o	d ≥ parity 2 sows, response daily at 1400 hour	ectively. r.		

³Overall type I error rate (P value) for interaction of parity, DRW or parity by DRW with various measurements.

oy punty,	514145, 2020	j status, puittj	Measurement	on of pully of	j status.
Effect	Crate	RT	Ear	RR	Shoulder
DOL	<0.001	<0.001	<0.009	<0.03	<0.005
Parity	NS	<0.007	<0.06	<0.009	<0.004
DOL by parity	<0.005	NS	NS	NS	NS
Status	<0.05	<0.001	<0.001	<0.02	<0.001
DOL by status	NS	<0.001	<0.03	NS	NS
Parity by status	NS	NS	NS	<0.08	NS
DOL by parity by status	NS	NS	NS	NS	NS

Table 9. P-values for crate temperature (°C), rectal temperature (RT; °C), ear temperature (°C), respiration rate (RR in BPM) and shoulder temperature (°C) for farrowed and pregnant sows analyzed as day of lactation (DOL) with effects of DOL, parity, DOL by parity, status, DOL by status, parity by status, and DOL by parity by status.

			Measurement		
Effect	Crate	RT	Ear	RR	Shoulder
DRW	<0.001	<0.001	< 0.001	< 0.001	<0.001
Parity	NS	<0.01	<0.01	<0.01	<0.002
DRW by parity	NS	NS	NS	NS	NS
Status	NS	<0.001	< 0.001	<0.01	<0.001
DRW by status	<0.001	<0.001	<0.03	NS	NS
Parity by status	NS	NS	NS	NS	NS
DRW by parity by status	<0.09	NS	NS	NS	NS

Table 10. P-values for crate temperature (°C), rectal temperature (RT; °C), ear temperature (°C), respiration rate (RR in BPM) and shoulder temperature (°C) for farrowed and pregnant sows analyzed as day relative to weaning (DRW) with effects of DRW, parity, DRW by parity, status, DRW by status, parity by status, and DRW by parity by status.

Measurement		Status			Parity	
	Pregnant	Farrowed	P< ³	$P1^2$	$P2^{2}$	P< ³
Crate temperature, ^o C	25.6 ± 0.2	26.1 ± 0.2	0.05	$25.8 \pm .2$	25.9 ± 0.2	NS
Rectal temperature, °C	38.3 ± 0.1	39.0 ± 0.1	0.001	$38.8 \pm .1$	38.5 ± 0.1	0.007
Shoulder temperature, °C	35.1 ± 0.1	36.3 ± 0.1	0.001	$35.4 \pm .2$	35.9 ± 0.2	0.06
Ear temperature, $^\circ C$	36.1 ± 0.1	37.1 ± 0.1	0.02	$36.7 \pm .1$	36.4 ± 0.1	0.009
Respiration rate, BPM	45 ± 2	52 ± 2	0.001	53 ± 2	44 ± 2	0.004

²Overall type I error rate (P value) for interaction of status or parity with various measurements.

Measurement		Status			Parity	
	Pregnant	Farrowed	P< ³	P1 ²	$P2^{2}$	P<3
Crate temperature, °C	25.6 ± 0.2	25.9 ± 0.2	0.05	25.8 ± 0.2	25.8 ± 0.2	NS
Rectal temperature, ^o C	38.4 ± 0.1	39.1 ± 0.1	0.001	38.9 ± 0.1	38.5 ± 0.1	0.01
Shoulder temperature, ^o C	34.8 ± 0.1	35.9 ± 0.1	0.001	35.6 ± 0.2	35.0 ± 0.2	0.01
Ear temperature, $^{\circ}C$	36.0 ± 0.1	36.9 ± 0.1	0.02	36.6 ± 0.1	36.2 ± 0.1	0.01
Respiration rate, BPM	43 ± 3	52 ± 2	0.001	52 ± 2	43 ± 2	0.002

Table 12. Least squares means and P-values for crate temperature (RT; ^o C), rectal temperature (^o C), shoulder temperature (^o C),	ear temperature (^o C) and respiration rate (RR in BPM), for pregnant and farrowed sows as analyzed by day relative to	weaning (DRW) with status or parity.
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³Overall type I error rate (P value) for interaction of status or parity with various measurements.

Table 13. Least squares means and P-values for interaction of parity with sow body weights one, two, three, four and five (kg) and piglet body weights one, two, three and four (kg). Least squares means and P-values for interaction of parity, day of lactation (DOL) and parity by DOL on maintenance requirements (Mcal ME), lactation requirements (Mcal ME), total requirements (Mcal ME), feed energy or ME_I (Mcal ME) and energy balance (Mcal ME).

Measurement	P1 ¹	$P2^1$	Parity	$\frac{\text{DOL}}{\mathbf{P}}$	Parity by DOL $P < 4$
Sow body weight one $(kg)^2$	220 + 9.0	266 + 9.0	0.001	1 <	DOLIS
Sow body weight one (kg)	220 ± 7.0	200 ± 9.0	0.001		
Sow body weight two (kg)	190 ± 7.0	260 ± 8.0	0.001		
Sow body weight three (kg)	183 ± 6.0	256 ± 7.0	0.001		
Sow body weight four (kg)	181 ± 7.0	250 ± 8.0	0.001		
Sow body weight five (kg)	180 ± 7.0	247 ± 8.0	0.001		
Litter weight one (kg) ³	16.5 ± 0.9	16.0 ± 1.0	NS		
Litter weight two (kg)	28.1 ± 2.0	29.4 ± 3.0	NS		
Litter weight three (kg)	47.1 ± 3.0	50.1 ± 3.0	NS		
Litter weight four (kg)	63.8 ± 4.0	65.2 ± 4.0	NS		
Maintananaa naguinamanta	55 0 1	70+02	0.001	0.001	NC
(Mcal ME/d)	5.5 ± 0.1	7.0 ± 0.2	0.001	0.001	IND
Lactation requirements (Mcal ME/d)	10.3 ± 0.1	11.0 ± 0.1	NS	0.001	NS
Total requirements (Mcal ME/d)	15.8 ± 0.1	18.0 ± 0.1	0.04	0.001	NS
ME_I or feed energy (Mcal ME/d)	13.6 ± 0.1	15.4 ± 0.1	NS	0.001	0.01
Energy balance (Mcal ME/d	-2.2 ± 1.1	-2.6 ± 1.2	NS	0.001	0.06

¹P1 and P2 or greater denote parity one and \geq parity 2 sows, respectively.

²Sow weights (kg) were measured when sows were moved into gestation, the day after farrowing, 1 week after farrowing, 2 weeks after farrowing and at weaning.

³Litter weights (kg) were measured at the time of processing (\leq 3 day after birth), 1 week after processing, 2 weeks after processing and at weaning.

⁴Overall type I error rate (P value) for interaction between parity, DOL or parity by DOL and various measurement.

CHAPTER 5

THERMOREGULATION OF DIFFERENT PARITY SOWS WITHIN FORCED AIR AND EVAPORATIVELY-COOLED FARROWING ROOMS

SUMMARY

Heat stress decreases feed intake, thereby negatively affecting growth, reproduction and thermoregulation of lactating sows. The objective of this experiment was to evaluate the parity response to summer heat stress in both forced air (FA) and evaporatively-cooled (EC) farrowing facilities and determine if EC facilities effectively minimize the effect of heat stress on lactating sows. One trial and a replicate were conducted to study primiparous (P1) and multiparous (P \geq 2) Landrace or Landrace x Large White sows while housed in FA or EC ventilated farrowing facilities. The first study took place between June and August 2010 (n = 36), and the replicate occurred between July and August 2011 (n = 28). Thermal measurements, which included crate, rectal, shoulder, and ear temperatures (°C), as well as respiration rate (RR in BPM) were collected throughout the trial. For the day of lactation (DOL) analysis, there were effects of parity (P < 0.001) and DOL (P < 0.001) on rectal temperature (RT). Rectal temperature increased after farrowing (38.3 ± 0.1°C on d -2 to 38.9 ± 0.1°C on day 0) and remained elevated during lactation (38.8 ± 0.1 to 39.0 ± 0.1°C). For the day relative to

weaning (DRW) analysis, there was an effect of DRW by time on RT (P < 0.03). Rectal temperatures in the morning and afternoon were similar on day -12 ($38.9 \pm 0.1^{\circ}$ C), but by the day of weaning, RT in the morning were less than in the afternoon ($38.9 \pm 0.1^{\circ}$ C) compared with $39.2 \pm 0.1^{\circ}$ C, respectively).

There was also a parity by time effect for ear temperature (P < 0.026) and shoulder temperatures (P < 0.024). There was a treatment by time effect for ear (P < 0.028) and shoulder temperatures (P < 0.048). Sows housed in the FA room had lesser ear temperatures in the morning than sows in the EC room (35.1 ± 0.1 and $35.6 \pm 0.2^{\circ}$ C, respectively). By the afternoon, however, sows in the FA had similar ear temperature to sows in the EC room (36.1 ± 0.1 and $36.1 \pm 0.2^{\circ}$ C, respectively). Similarly, sows housed in the FA room had lesser shoulder temperature in the morning than sows in the EC room (34.4 ± 0.1 and $34.8 \pm 0.1^{\circ}$ C, respectively), but in the afternoon, sows in the FA had similar shoulder temperature to sows in the EC room ($35.6 \pm 0.1^{\circ}$ C).

There was no effect of parity (P > 0.59), parity by DOL (P > 0.43) or treatment (P > 0.59) on RR (Table 13). The RR for P1 sows was similar to that of older sows (64 ± 2 and 62 ± 2 BPM for P1 and P ≥ 2 , respectively; Figure 25A and Table 13). There was, however, an effect of treatment by DOL (P < 0.001) and parity by treatment by time (P < 0.01) for RR (Figure 25A and Table 13). For the DRW analysis, there was an effect of treatment by DRW on RR (P < 0.02). Sows in the EC and FA room had similar RR on day -12 (63 ± 3 BPM), but the sows in the EC room had lower RR in late lactation compared with sows in the FA room (65 ± 3 and 77 ± 3 BPM for EC and FA sows on day 0, respectively).

The P1 sows had lesser body weights (BW) throughout the trial compared with

 $P \ge 2$ sows (204 ± 5.0 and 264 ± 3.0 kg for P1 and $P \ge 2$ sows, respectively at the first time of weighing compared with 173 ± 6.0 and 230 ± 4.0 kg for P1 and $\ge P2$ sows, respectively at the final weighing). There was a trend for sows in the EC room to be heavier at the time of weaning than sows in the FA room (P < 0.09; 208 ± 5.0 and 195 ± 5.0 kg, respectively). There was no effect of treatment on sow weight one or treatment by parity on sow weight one or two. There were also no effects of parity, treatment or treatment by parity on piglet weights, number of piglets born or number of piglets weaned.

Primiparous sows had different rectal and skin temperatures during lactation than multiparous sows. Despite greater RT, primiparous sows did not show a drastic increase in RR throughout lactation to compensate for the metabolic effects of lactation as well as heat stress. This may be due to that fact that first parity sows have never experienced lactation before and may not be physiologically prepared for lactation or that first parity sows have different concentrations of growth hormone (GH) and insulin-like growth factor (IGF-1) throughout lactation compared with older sows. Primiparous sows may be partitioning their nutrients differently, therefore, than multiparous sows. Although EC did not lessen the body temperatures and RR of sows throughout the entire lactation period, it did lessen RR in sows during late lactation.

INTRODUCTION

Previous studies performed at the Swine Research Complex (Columbia, MO) determined that sows of different parities were different in terms of physiological parameters such as rectal, ear, and shoulder temperature. First parity sows had greater rectal temperatures (RT) throughout lactation compared with older sows. Primiparous sows did not, however, increase their respiration rate (RR) greatly to compensate for this rise in internal body temperature. There were also differences in the extent of skin vasodilation during certain times of the day between primiparous and multiparous sows. The first objective of this study was to confirm the phenomenon that first parity sows do not compensate for greater RT by increasing RR and skin vasodilation to the same extent as older sows in order to reduce heat load during lactation and heat stress.

Heat stress during the summer combined with the metabolic heat load of lactation can detrimentally affect sow and piglet performance. These problems can be reduced through adequate water supply, drippers, sprinklers, evaporative cooling pads and proper feeding regimes. Ventilation within the farrowing room is also a key factor for increasing sow heat loss during lactation and can be used to minimize the effect of heat stress on the animals. Older farrowing facilities employ forced-air ventilation systems in which there is an air pressure difference created by fans on opposite sides of the barn that allows for air exchange. These exhaust fans create a slight negative pressure or vacuum in the facility, causing the outside air to enter the barn through designed ceiling inlets (MWPS-32, 1990). This air is then pulled out of the facility by the fans on the side of the building; this fast air movement allows for sow cooling by convective methods.

Modern farrowing facilities employ evaporatively-cooled ventilation systems in which water drips down between ridged pads, located on the side of the facility. The cooling pad uses evaporation to remove the heat from the outside air as it enters the facility. This cooler air is then pulled over the sows and back out of the facility through fans located on the opposite side of the room. In the swine industry, there is a current effort to modify many of the older forced-air farrowing facilities to evaporatively-cooled farrowing facilities due to potential benefits of modern ventilation techniques. According to Zulovich (2002), evaporative cooling can reduce incoming air temperature by at least 8°C when the outside air is dry (relative humidity < 55%). Improving the farrowing room ventilation, therefore, may reduce negative reproductive and health effects as well as increase feed intake, thereby improving sow and piglet performance. The second objective of this trial was to determine the differences in parity response to summer heat stress in both forced air (FA) and evaporatively-cooled (EC) farrowing facilities and whether EC facilities effectively minimize the effect of heat stress on lactating sows.

MATERIALS AND METHODS

Animals and Facilities

All animal procedures were reviewed and approved by the University of Missouri Animal Care and Use Committee. The farrowing facility at the University of Missouri Swine Research Complex has two different types of ventilated rooms within it: one forced air (FA) ventilated room and one evaporatively-cooled (EC) ventilated room. Within the EC room, the evaporative cooling pad and fans were controlled by an ECC-1 Supra 16-stage environmental system (Phason; Winnipeg, Manitoba, Canada). Primiparous and multiparous pregnant Landrace or Landrace x Large White sows of Genes Diffusion, Inc. that were artificially inseminated with Landrace x Large White or Large White pooled semen were studied during this trial. This trial took place in two replicates: the first replicate occurred between June and August 2010 (n = 36) and the second replicate occurred between July and August 2011 (n = 28) within the FA and EC farrowing rooms. In the first replicate, there were first parity (n = 7), second parity (n = 4), fourth parity (n = 2), fifth parity (n = 1), sixth parity (n = 2) and seventh parity (n = 2) sows in the FA facility and first parity (n = 5), second parity (n = 5), third parity (n = 3), fourth parity (n = 1), fifth parity (n = 2) and seventh parity (n = 2) sows in the EC facility. There were also pregnant sows and gilts (n = 18) housed within these two farrowing rooms that served as controls. In the second replicate, there were first parity (n = 4), second parity (n = 4), third parity (n = 4), sixth parity (n = 1) and eight parity (n = 1) sows housed in the FA facility and first parity (n = 4), second parity (n = 1), third parity (n = 4), fourth parity (n = 1), fifth parity (n = 2), seventh parity (n = 1) and eighth parity (n = 1) sows housed in the EC facility. During the second replicate, there were pregnant sows and gilts (n = 33) housed in both rooms as non-farrowing controls. A second parity sow within the EC room developed mastitis during lactation and was subsequently removed from the trial.

Experimental Design

Sows were moved from the gestation barn to their specified farrowing rooms one week before their expected farrowing dates. Body temperature measurements began the day that they were moved into the farrowing rooms (day 0). The sows in both rooms farrowed at different times within a span of one week. The sows remained in their respective farrowing rooms throughout lactation until the day of weaning, when they were moved back to the gestation barn and thermal measurements were no longer collected. Calibrated hobo data loggers (Onset Computer Corp.; Bourne, MA) were placed at sow standing level in the middle walking aisle of each farrowing room and outside the barn to collect temperature and humidity data (47 data collections per 24 hours). Hobo logger data were combined for the two replicates. Average outdoor high and low ambient temperature (Ta, °C) for the first trial and replicate replicates were 31.4 ± 3.6 and 20.5 ± 3.2 °C. Average daily high and low Ta were 30.2 ± 2.8 and 23.9 ± 2.0 °C within the FA farrowing room and 28.7 ± 1.4 and 24.5 ± 1.3 °C within the EC farrowing room. Humidity data were only collected for the replicate during the summer of 2011. Average daily high and low relative humidity were 88.5 ± 7.8 and $59.8 \pm 22.6\%$ within the FA farrowing room and 90.5 ± 7.1 and $70.4 \pm 10.7\%$ within the EC farrowing room.

Water drippers, available only in the FA room, were turned on during days in which the ambient temperature reached above 32°C within that room. These drippers allowed for cool water to fall onto the sows' shoulder or head for skin evaporation. In both rooms, sows and piglets had *ad-libitum* access to water by nipple valve waterers. Sows in both rooms were housed in individual metal farrowing crates (2.1 m x 1.5 m, including creep area) throughout the trial. In the FA farrowing room, sows were housed on plastisol-covered (Tenderfoot[®]; Tandem Products, Inc., Minneapolis, MN, USA), iron slatted floors while in EC farrowing room, sows were housed on plastic slatted flooring. All sows were fed 1.8 kg of a standard corn-soybean meal-based diet (Table 2) once daily between 0800 and 0900 h. After parturition, feed offered to lactating sows was increased by 0.9 kg per day in increments depending on feed consumption. Sows that consumed the

morning meal in its entirety were offered additional feed in the afternoon. Sows that failed to consume the previous meal in its entirely were offered less feed.

Body Temperature and Body Weight Measurements

Temperature data was collected twice daily at 0900 h (AM) and 1500 h (PM) on Monday, Wednesday and Friday. Thermal data included rectal temperatures collected by a Cole Parmer thermometer model 8110-20 with a calibrated thermistor probe (Cole Parmer; Vernon Hills, IL) and crate, floor, shoulder and ear temperatures collected using a calibrated Raytek Raynger (Raytek Corp.; Santa Cruz, CA) infrared thermometer. Floor temperature was measured for this trial in order to determine whether conduction of heat between the sow and the floor was affecting sow thermoregulation. Respiration rate for each sow was measured using a timer and by counting the number of breaths per minute (BPM) using flank movement. Sow body weights were collected when sows were moved into farrowing and at weaning using a calibrated Rockshaft Scale Cart (Mosdal Scale Systems Inc.; Broadview, MT). Piglet litter weights were measured mosdal Smart Cart (Mosdal Scale Systems Inc.; Broadview, MT).

Statistical Analyses

Thermal data were analyzed as repeated measures with Proc Mixed of SAS (SAS Institute Inc., Cary, NC) using the day of lactation (DOL) timeline of -6 to 14 days relative to farrowing on day 0. The statistical model included the effects of treatment (FA or EC), parity, sow nested within treatment and parity, DOL, time (time of day), and interactions of these main effects. Data were also analyzed by day relative to weaning

(DRW), using the timeline -12 to 0 days relative to weaning on day 0. The statistical model included the effects of treatment (FA or EC), parity, sow nested within treatment and parity, DRW, time, and interactions of these main effects. Odd numbered days were assigned the nearest even number (i.e. day -5 was assigned day -4) to ensure that each sow had similar DOL or DRW. Piglet and sow weights were analyzed using Proc GLM of SAS with a model including the effects of: parity, treatment and parity by treatment. Average daily ambient temperatures outside and within each farrowing room were analyzed using Proc Summary. The summer 2010 trial and its replicate (summer 2011 trial) were combined for all analyses because preliminary analyses did not detect a significant effect of trial/replicate on thermal measurement. Sows were classified as P1 and $P \ge 2$ parity (all sows \ge parity 2 were combined into one group). A type I error rate of P<0.05 was considered significant. Data are expressed as least squares means \pm SEM

RESULTS

There were effects of parity (P < 0.001), time (P < 0.001) and day of lactation (DOL; P < 0.001) on rectal temperature (RT) for the DOL analysis (Table 14). The RT for both parities increased after farrowing ($38.3 \pm 0.1^{\circ}$ C on day -2 to $38.9 \pm 0.1^{\circ}$ C on day 0) and remained elevated during lactation (38.9 ± 0.1 to $39.0 \pm 0.1^{\circ}$ C). The average RT for P1 sows was greater than that of P ≥ 2 sows throughout the trial (P < 0.001; $38.8 \pm 0.1^{\circ}$ C compared with $38.6 \pm 0.1^{\circ}$ C, respectively; Figure 24A and Table 14). Average RT for all parities was lesser in the morning than in the afternoon ($38.6 \pm 0.1^{\circ}$ C) and the trial (P < 0.001) and the trial

and $38.8 \pm 0.1^{\circ}$ C, respectively; Figure 24A and Table 14). There was no difference between the RT of sows in the FA compared with the EC room (P > 0.65; $38.7 \pm 0.1^{\circ}$ C; Table 14). There was also no effect of parity by treatment on RT (P > 0.25) or treatment by time on RT (P < 0.83; Table 14). For the DRW analysis, there were effects of parity (P < 0.008), time (P < 0.001) and DRW (P < 0.001) on RT (Table 15). The average RT for P1 sows was greater than that of P ≥ 2 sows (P < 0.001; $38.8 \pm 0.1^{\circ}$ C compared with $38.6 \pm 0.1^{\circ}$ C, respectively; Figure 24B and Table 15). There was also an effect of DRW by time on RT (P < 0.03; Table 15). Rectal temperatures in the morning and afternoon were similar on day -12 ($38.9 \pm 0.1^{\circ}$ C), but by the day of weaning, RT in the morning were less than in the afternoon (38.9 ± 0.1 compared with $39.2 \pm 0.1^{\circ}$ C, respectively; Figure 24B and Table 15).

When analyzed by DOL, there was an effect of DOL and time on RR as well as ear, shoulder, and crate temperatures (P < 0.001; Table 14). There was no effect of parity (P > 0.59), parity by DOL (P > 0.43) or treatment (P > 0.59) on RR (Table 14). The RR for P1 sows was similar to that of older sows (64 ± 2 and 62 ± 2 BPM for P1 and P \ge 2, respectively; Figure 26A and Table 14). There was, however, an effect of treatment by DOL (P < 0.001) and parity by treatment by time (P < 0.01) for RR (Figure 26A and Table 14). Sows in the FA and EC rooms had similar RR before farrowing (68 ± 4 and 76 ± 4 BPM), but FA sows had greater RR by late lactation than EC sows (76 ± 4 and 63 ± 5 BPM on day 14). The RR for P1 sows in the EC room increased to a greater extent than the RR of P1 sows in the FA room throughout the day (50 ± 4 to 82 ± 4 BPM for AM and PM in EC compared to 52 ± 4 to 72 ± 4 for AM and PM in FA). However, the RR for P \ge 2 sows in the FA room increased to a greater extent than the RR of P \ge 2 sows in the EC room (48 ± 2 to 70 ± 2 BPM for AM and PM in EC compared to 53 ± 3 to 79 ± 3 for AM and PM in FA). For the DRW analysis, there was an effect of treatment (P < 0.001) and time (P < 0.001) on RR (Table 15). Sows in the FA room had greater RR throughout the trial compared with sows in the EC room (60 ± 2 and 70 ± 2 BPM, respectively; Figure 26B and Table 15). There was also an effect of treatment by DRW on RR (P < 0.02; Table 15). Sows in the EC and FA room had similar RR on day -12 (63 ± 3 BPM), but the sows in the EC room had lower RR in late lactation compared with sows in the FA room (65 ± 3 and 77 ± 3 BPM for EC and FA sows on day 0, respectively).

There was a parity by time effect for ear (P < 0.026) and shoulder temperature (P < 0.024) for the DOL analysis (Figure 28A and B; Table 14). Ear temperature for P1 sows were lower than P \geq 2 sows in the morning (35.1 ± 0.1 and 35.5 ± 0.1°C, respectively), but P1 sows had a similar ear temperature to P \geq 2 sows by the afternoon (36.2 ± 0.1 to 36.1 ± 0.1°C, respectively). The P1 sows had similar shoulder temperature to P \geq 2 sows in the morning (34.5 ± 0.2 and 34.7 ± 0.1°C, respectively), but greater shoulder temperature in the afternoon (35.7 ± 0.2 and 35.4 ± 0.1°C, respectively). When analyzed by DRW, there was an effect of DRW (P < 0.001) and time (P < 0.001) on shoulder and ear temperatures (Table 15).

There was a treatment by time effect on ear temperature for the DRW analysis (P < 0.03; Table 15). Surprisingly, sows housed in the FA room had a lesser ear temperature in the morning than sows in the EC room (35.3 ± 0.2 and $36.0 \pm 0.2^{\circ}$ C, respectively). By the afternoon, however, sows in the FA room had a similar ear temperature to sows in the EC room ($36.6 \pm 0.2^{\circ}$ C). There was also an effect of treatment

by DRW on shoulder temperature (P < 0.03; Table 15). There was a treatment by time effect for ear (P < 0.03; Figures 29A and Table 14) and shoulder temperatures (P < 0.05; Figures 29B and Table 14) for the DOL analysis. Sows housed in the FA room had a lesser ear temperature in the morning than sows in the EC room $(35.1 \pm 0.1 \text{ and } 35.6 \pm 0.2^{\circ}\text{C}$, respectively). By the afternoon, however, sows in the FA had a similar ear temperature to sows in the EC room $(36.1 \pm 0.1 \text{ and } 36.1 \pm 0.2^{\circ}\text{C}$, respectively). Similarly, sows housed in the FA room had lesser shoulder temperature in the morning than sows in the EC room ($36.1 \pm 0.1 \text{ and } 36.1 \pm 0.2^{\circ}\text{C}$, respectively). Similarly, sows housed in the FA room had lesser shoulder temperature in the morning than sows in the EC room ($34.4 \pm 0.1 \text{ and } 34.8 \pm 0.1^{\circ}\text{C}$, respectively), but in the afternoon, sows in the FA had similar shoulder temperature to sows in the EC room ($35.6 \pm 0.1^{\circ}\text{C}$).

There was an effect of DOL by time on crate temperature (P < 0.023; Figure 23A and Table 14). There was also an effect of treatment on crate temperature (P < 0.001; Table 14). Crate temperature in the EC room was lower than that in the FA room throughout the trial (26.0 \pm 0.1 and 27.0 \pm 0.1°C, respectively). For the DRW analysis, there was an effect of treatment (P < 0.001), time (P < 0.001) and DRW by time on crate temperature (P < 0.001; Figure 23B and Table 15).

Parity had an effect on sow weight one and two (P < 0.001; Table 16). The P1 sows had lesser BW throughout the trial compared with P \ge 2 sows (204 ± 5.0 and 264 ± 3.0 kg for P1 and P \ge 2 sows, respectively at the first time of weighing compared to 173 ± 6.0 and 230 ± 4.0 kg for P1 and \ge P2 sows, respectively at the final weighing; Table 16). There was also a trend for treatment to have an effect on sow weight two (weight at the time of weaning; P < 0.09; Table 17). Sows in EC room tended to be heavier at the time of weaning than sows in the FA room (208 ± 5.0 and 195 ± 5.0 kg,

respectively). However, there was no effect of treatment on sow weight one or treatment by parity on sow weight one or two (Table 17). There were also no effects of parity, treatment or treatment by parity on piglet weights, number of piglets born or number of piglets weaned (Tables 16 and 17).

DISCUSSION

Average ambient temperature was lower in the EC room compared with the FA room for both trials, indicating that the EC rooms effectively cooled the incoming outside air to a greater extent than the FA room (Figures 20 and 21). The ambient temperature in the FA room was more sensitive to the fluctuations of outside ambient temperature than the EC room. The temperature in the EC room was more consistent throughout the day and night because the ECC-1 Supra 16-stage environmental system was set to 26°C during the trial. The FA room had a lower ambient temperature at night and in the morning compared with the EC room. In the afternoon, however, the FA room had a greater ambient temperature than the EC room.

As the outdoor temperature increased or decreased, the temperature in the FA room subsequently changed, but the FA room did not have as extreme fluctuations in temperature as outdoors. As ambient temperature within the FA farrowing room increased during the day, there was less temperature difference between the sow skin surface and the ambient air; therefore, less heat could be released as sensible heat. In this circumstance, a greater quantity of heat is instead released as latent heat – the heat released by a fluid in the process of its change of state by evaporation (or condensation)

under equilibrium conditions (Mercer, 2001). This latent heat energy can alter the thermoregulatory behavior of the sows within the farrowing room. Crate temperatures in the EC room were consistently lower than those in the FA room; this is also a reflection of the effectiveness of the EC room in cooling the outside air as well as the latent heat phenomenon.

The humidity within the EC farrowing room was more consistent and, on average, greater than that within the FA room (Figure 22). This is because the evaporative cooling method increases moisture and humidity within the room as the outdoor ambient air evaporates the water in the pads (Randall et al., 1983). High humidity makes it more difficult for sows to dissipate heat through panting and skin evaporation (Curtis, 1983). These high humidity levels, therefore, may have been a contributing factor for why sows housed in the EC room had similar body temperatures to those sows housed in the FA room throughout the trial.

Farrowing was associated with an increase in RT for all parities, as found in the previous studies. The increase in RT during lactation, however, was greater in primiparous than in multiparous sows. Once again, first parity sows had greater RT throughout lactation compared with older sows, as supported by Gourdine et al. (2007; Figure 24). These primiparous sows did not increase their RR to compensate for the rise in internal body temperature (Figure 26). Although the average ambient temperature in the FA room was greater than that in the EC room throughout the trial, there were no differences between RT of sows housed in the FA or EC room. This result could be attributed to different skin vasodilation techniques used by the sows within the FA room, different cooling systems available within the FA room compared with the EC room.

higher relative humidity during the summer in Missouri or a combination of these factors. The sows in the FA room may have increased skin vasodilation to a greater extent throughout the day as lactation progressed to cope with this increased room temperature. Also, the drippers within the FA room may have also played an important role in reducing body temperature in the afternoon through skin evaporation. According to Zulovich (2002), the evaporative cooling process is most effective when RH is less than 55%. If the RH was too high during portions of the study, then the EC ventilation system may not have been as effective in alleviating the effect of heat stress on sows. Despite the greater average afternoon temperature in the FA compared with the EC room, the cooler night and morning temperatures as well as the water drippers may have been sufficient enough to effectively reduce the effect of heat stress on sows in the FA room.

Interestingly, RR for all parity sows in the EC room were lower in late lactation and near the time of weaning compared with sows in the FA room (Figure 26A and B), suggesting that the EC treatment did, in fact, help to alleviate heat load during this time. In comparison, RR for the sows housed in the FA room increased as lactation progressed (Figure 26A and B), even though there was no differences in rectal or skin temperatures. This increase in RR reflects the fact that sows tend to be more susceptible to heat stress during late lactation, when they have the highest levels of milk production (King, 2000). The evaporative cooling mechanisms in the EC farrowing room, however, must help to reduce heat load during late lactation when milk production is greatest because sows had lesser RR in the EC compared to the FA room at this time.

For all sows, shoulder temperature increased after farrowing and remained elevated throughout lactation. Ear temperatures for all sows also increased at the time of

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farrowing. This may be due to the higher body heat content at the time of farrowing or may be due to sows increasing their skin vasodilation to lose the excess heat gained during lactation. Primiparous sows had a greater increase in shoulder and ear temperatures as well as RR from the morning to the afternoon compared with multiparous sows. These parity differences in skin temperatures and RR suggests that primiparous sows may be vasoconstricting and reducing RR at night and through the morning to a greater extent as well as vasodilating in the afternoon to a greater extent than multiparous sows. This means that first parity sows are conserving heat more at night, but trying to dissipate heat in the afternoon to a greater extent than older sows. Sows in the FA and EC rooms had similar RR two days before farrowing, but FA sows had greater RR by late lactation than EC sows. Similarly, sows housed in the FA room had a greater increase in RR as well as ear and shoulder temperatures from the morning to afternoon compared with the sows housed in the EC room. Sows in the FA room may be vasoconstricting and reducing RR at night and through the morning to a greater extent than sows in the EC room. This could have also been a reflection of the lower night and morning ambient temperatures within the FA compared to EC farrowing room (Figures 20 and 21).

In agreement with Mullan and Williams (1989), primiparous sows weighed less than multiparous sows throughout the study because they had not reached full maturity. All sows lost weight between the week before farrowing and weaning because of the loss in fetal and placental mass and negative energy balance caused by heat stress and milk production (Table 16; Gourdine et al., 2007). Interestingly, sows in the EC room tended to have greater body weights than sows housed in the FA room at the time of weaning. This may be a reflection of decreased feed intake in the warmer environment, causing an overall reduction in sow body weight. There was no effect of parity on litter weights at processing or weaning, number of piglets born alive or number of piglets weaned. These data suggest that despite differences in body weight during lactation, primiparous sows may be able to produce similar quantities of milk compared with older sows (Flowers and Day, 2002), thereby allowing their nursing piglets to reach similar weaning weights. This is in contrast to King (2000), who reports that first parity sows produce less milk compared with older sows.

For an unknown reason, primiparous sows had different rectal and skin temperatures during lactation than multiparous sows. In contrast, Rosero et al. (2012) and Quiniou and Noblet (1999) found that both primiparous sows and multiparous sows show a similar increase in rectal and skin temperatures during lactation. Despite greater RT, primiparous sows had similar RR as older sows throughout lactation. This may be due to the fact that first parity sows are metabolically naïve as compared with the older sows and have never experienced lactation before. More likely, however, is that first parity sows respond differently to heat stress because of different circulating concentrations of growth hormone (GH) and insulin-like growth factor (IGF-1) throughout lactation compared with older sows. According to Lucy (2008), GH and IGF-I are coupled and their concentrations are elevated during lactation; therefore, these hormones may play a role in nutrient partitioning at this time. Primiparous sows may be partitioning their nutrients differently than multiparous sows. In particular, older sows may be partitioning energy towards reducing the heat load produced during lactation, thereby negatively effecting milk production. In contrast, younger sows may have higher levels of GH and

IGF-I compared with multiparous sows because they are still growing. Machlin et al. (1968) reported that the circulating GH concentrations in growing pigs decrease with increased live weight or age. Taylor et al. (2004) found that plasma concentrations of IGF-I were higher in primiparous than in the multiparous dairy cows from one week before calving to twelve weeks after calving. These greater concentrations of IGF-I and GH may also allow for greater milk production by the first parity sow. This was reflected by the fact that litter weights for the first parity sows were not different from those of older sows at the time of weaning. This phenomenon may also explain their greater RT during lactation.

These data are essential to understanding the challenges encountered by first parity sows caused by the metabolic demands of lactation, particularly under heat stressed conditions. Management techniques to determine feed and environmental requirements for sows of different ages during lactation should be taken into consideration in order to prevent losses in productivity within sow herds. Although the sows housed in the EC room did have lesser rectal or skin temperatures throughout lactation compared to sows housed in the FA room, respiration rate for sows housed in the EC room was reduced during late lactation. Producers should, therefore, consider modifying the farrowing room environments to either indirect evaporative cooling pads or to add more direct evaporative cooling methods (such as drippers or sprinklers) within FA farrowing rooms to prevent lactating sows from overheating, especially during late lactation. Further molecular studies are necessary to elucidate the hormonal mechanisms in which first parity sows differ from older sows in response to heat stress.



Figure 20. Outdoor and evaporatively-cooled (EC; A) or forced-air (FA; B) farrowing room ambient temperatures (°C) throughout summer 2010 trial. The data were collected by hobo loggers within the farrowing room and outside (47 collections per day).



Figure 21. Outdoor and evaporatively-cooled (EC; A) or forced-air (FA; B) farrowing room ambient temperatures (°C) throughout summer 2011 trial. The data were collected by hobo loggers within the farrowing room and outside (47 collections per day).



Figure 22. Evaporatively-cooled (EC) and forced-air (FA) farrowing room relative humidity (%) throughout summer 2011 trial. The data were collected by hobo loggers within the farrowing room and outside (47 collections per day).



Figure 23. Least squares means for crate temperature (°C) for parity one (P1), and \geq parity two (P2 or >) sows in evaporatively-cooled (EC) or forced-air (FA) farrowing facilities expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 24. Least squares means for rectal temperature (RT; °C) for parity one (P1), and \geq parity two (P2 or >) sows in evaporatively-cooled (EC) or forced-air (FA) farrowing facilities expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 24. Least squares means for ear temperature (°C) for parity one (P1), and \geq parity two (P2 or >) sows in evaporatively-cooled (EC) or forced-air (FA) farrowing facilities expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 26. Least squares means for respiration rate (RR in BPM) for parity one (P1), and \geq parity two (P2 or >) sows in evaporatively-cooled (EC) or forced-air (FA) farrowing facilities expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).



Figure 27. Least squares means for shoulder temperature (°C) for parity one (P1), and \geq parity two (P2 or >) sows in evaporatively-cooled (EC) or forced-air (FA) farrowing facilities expressed as day of lactation (DOL; A; d 0 = farrowing) or day relative to weaning (DRW; B; d 0 = weaning).


Figure 28. Least squares means for ear temperature (°C; A) or shoulder temperature (°C; B) for parity one (P1), and \geq parity two (P2 or >) sows in in the morning (AM) and afternoon (PM) within the farrowing facilities expressed as day of lactation (DOL; A; d 0 = farrowing).



Figure 29. Least squares means for ear temperature (°C; A) or shoulder temperature (°C; B) for all sows in in the morning (AM) and afternoon (PM) within the evaporatively-cooled (EC) or forced-air (FA) farrowing facilities expressed as day of lactation (DOL; A; d 0 = farrowing).

			Measure	ement	
Effect –	Crate	RT	Ear	RR	Shoulder
DOL	< 0.005	< 0.001	<0.009	< 0.001	<0.001
Parity	NS	<0.009	NS	NS	NS
Treatment	<0.001	NS	NS	NS	NS
Parity by treatment	NS	NS	NS	< 0.07	NS
Parity by DOL	NS	NS	NS	NS	NS
Treatment by DOL	NS	NS	NS	< 0.001	NS
Parity by treatment by DOL	NS	NS	NS	NS	NS
Time	<0.001	<0.001	< 0.001	< 0.001	<0.001
Parity by time	NS	NS	< 0.03	NS	< 0.02
Treatment by time	NS	NS	< 0.03	NS	< 0.05
Parity by treatment by time	NS	NS	NS	< 0.01	NS
DOL by time	< 0.02	NS	NS	NS	NS
Parity by DOL by time	NS	NS	NS	NS	<0.04
Treatment by DOL by time	NS	NS	NS	NS	NS
Parity by treatment by DOL by time	NS	NS	NS	NS	NS

Table 14. P-values for crate temperature (°C), rectal temperature (RT; °C), ear temperature (°C), respiration rate (RR in BPM) and shoulder temperature (°C) for first parity and ≥ parity two sows analyzed as day of lactation (DOL) with effects of DOL, parity, time, treatment and interactions between these effects.

Effe et			Measuremen	ıt	
Effect	Crate	RT	Ear	RR	Shoulder
DRW	< 0.001	<0.001	<0.001	< 0.001	<0.001
Parity	NS	<0.008	NS	NS	NS
Treatment	< 0.001	NS	<0.09	< 0.001	NS
Parity by treatment	NS	NS	NS	<0.07	NS
Parity by DRW	NS	NS	NS	NS	NS
Treatment by DRW	NS	<0.03	NS	< 0.02	<0.03
Parity by treatment by DRW	NS	NS	NS	NS	NS
Time	< 0.001	<0.001	< 0.001	< 0.001	<0.001
Parity by time	NS	NS	< 0.03	NS	< 0.02
Treatment by time	NS	NS	< 0.03	NS	NS
Parity by treatment by time	NS	NS	NS	NS	NS
DRW by time	< 0.001	NS	< 0.001	NS	< 0.001
Parity by DRW by time	NS	NS	NS	NS	NS
Treatment by DRW by time	NS	NS	NS	NS	NS
Parity by treatment by DRW by time	NS	<0.03	NS	NS	NS

Table 15. P-values for crate temperature (°C), rectal temperature (RT; °C), ear temperature (°C), respiration rate (RR in BPM) and shoulder temperature (°C) for first parity and ≥ parity two sows analyzed as day relative to weaning (DRW; B) with effects of DRW, parity, time, treatment and interactions between these effects.

sow body weight two (kg), piglets weaned.	litter weight one	(kg), litter weig	ht two (kg), nun	aber of piglets b	orn alive and nui	nber of
Measurement	P1 ¹	$P2^{1}$	EC	FA	Parity P< ⁴	Trt P < ⁴
Sow body weight one (kg) ²	204 ± 5.0	264 ± 3.0	237 ± 5.0	231 ± 4.0	0.001	NS
Sow body weight two $(kg)^2$	173 ± 6.0	230 ± 4.0	208 ± 5.0	195 ± 5.0	0.001	0.09
Litter weight one (kg) ³	13.4 ± 1.0	14.8 ± 1.0	13.7 ± 1.0	14.5 ± 1.0	NS	NS
Litter weight two (kg) ³	53.7 ± 3.0	54.3 ± 2.0	54.8 ± 2.0	53.3 ± 2.0	NS	NS
Number of piglets born alive	9.1 ± 1	9.7 ± 1	9.8 ± 1	9.0 ± 1	NS	NS
Number of piglets weaned	8.9 ± 1	9.1 ± 1	9.2 ± 1	8.8 ± 1	NS	NS
¹ P1 and P2 or greater denote parity ² Sow weights (kg) were measured	<pre>one and > parity when sows were</pre>	two sows, resp moved into farr	ectively. owing and at we	aning.		
³ Litter weights (kg) were measured	at the time of pr	ocessing ($\leq 3 ds$	ays after birth) a	nd at weaning.	2400	
Overall type I error rate (r value)	IOF INCLACTION DE	stween parity or	ureaument and V	allous illeasurei	licitis.	

Table 16. Least squares means and P-values for effect of parity and treatment (trt; FA or EC) on sow body weight one (kg),

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Table 17. Least squares means an sow body weight two (kg) piglets weaned.	ld P-values for int), litter weight one	eraction of parity by t (kg), litter weight tw	reatment (trt; FA o 'o (kg), number of _]	r EC) on sow bod piglets born alive a	y weight one (kg), and number of
	P1	1	P	51	
Measurement	EC	FA	EC	FA	Parity by Trt P< ⁴
Sow body weight one (kg) ²	208 ±8.0	200 ± 7.0	266 ± 5.0	263 ± 5.0	NS
Sow body weight two (kg) ²	182 ± 9.0	165 ± 9.0	235 ± 6.0	225 ± 6.0	NS
Litter weight one (kg) ³	12.9 ± 1.0	13.9 ± 1.0	14.6 ± 1.0	15.0 ± 1.0	NS
Litter weight two (kg) ³	52.2 ± 4.0	55.2 ± 4.0	57.3 ± 2.0	51.3 ± 3.0	NS
Number of piglets born alive	9.6 ± 1	8.7 ± 1	10 ± 1	9.3 ± 1	NS
Number of piglets weaned	9.1 ± 1	8.6 ±1	9.3 ± 1	8.9 ± 1	NS
¹ P1 and P2 or greater denote parit ² Sow weights (kg) were measurec ³ L itter weights (kg) were measure	ty one and ≥ parity I when sows were ed at the time of n	√ 2 sows, respectively moved into farrowin rocessing (< 3 days a	, g and at weaning. ffer hirth) and at we	eaning	
⁴ Overall type I error rate (P value)) for interaction b	etween parity or treat	ment and various n	neasurements.	

CHAPTER 6

CONCLUSIONS AND FUTURE DIRECTIONS FOR RESEARCH

CONCLUSIONS

These trials demonstrated that the rectal and skin temperatures of sows during lactation are different than those during gestation and after weaning. Increases in rectal temperature for all parity sows were observed at the time of farrowing perhaps caused by an increase in metabolic heat load at this time (Messias de Bragança et al., 1998; Prunier et al., 1997). In particular, rectal temperatures began to increase a few days before farrowing and continued to rise until a few days after farrowing for all trials. As lactation progressed, however, rectal temperatures gradually decreased. These findings agree with results from the previous trial performed in the Brody Environmental Chambers (Williams, 2009), in which sows showed an increase in rectal temperature due to farrowing, but showed a decline in rectal temperatures throughout lactation. There was a further decrease in rectal temperatures at the time of weaning. After weaning, however, sows did not achieve rectal temperatures as low as what was observed during gestation. This indicated that the sows may have physiologically adapted to heat stress during lactation by modifying their thermoregulatory set-point. The current study also established that primiparous sows had a greater increase in rectal temperature during lactation compared with multiparous sows, which is also supported by work from Gourdine et al. (2007). In fact, the rectal temperatures for primiparous sows remained higher throughout lactation compared to older sows.

The specific patterns of RT, RR and skin temperatures in the current study were not observed in the previous study by Williams (2009), most likely because the Williams study was performed within more stable temperature conditions in environmentally controlled chambers. In comparison, the current field trial provided more realistic temperature and humidity fluctuations throughout the day and night. This caused more variation in skin temperature between morning and afternoon temperatures for all parities, although overall, these skin temperatures did not increase to a great extent during lactation to compensate for the higher internal body temperatures. More specifically, ear and shoulder temperatures remained relatively consistent throughout lactation, despite variation on a daily basis. This is also in agreement with Williams (2009), who found sows that were heat stressed during lactation did not show an overall decrease or increase in shoulder temperatures throughout lactation. In contrast, earlier studies by Quiniou and Noblet (1999) found that flank skin temperatures increased simultaneously with the increase in RT at the time of farrowing.

Surprisingly, respiration rate decreased or remained constant over time during lactation for the current trials, despite the sows' higher rectal temperatures. In the study by Williams (2009), however, respiration rate actually increased as lactation progressed. This discrepancy may be because the primiparous sows in the previous study were not acclimated to the head load of lactation, while the multiparous sows in the current study had already experienced lactation. Immediately after weaning, there was a substantial decrease in skin temperatures as well as respiration rate. However, these temperatures normalized a few days after weaning. These patterns may result from the removal of heat load due to weaning the piglets (Noblet and Etienne, 1987).

During lactation, primiparous sows had similar respiration rate to multiparous sows, meaning they did not increase their respiratory rate to a great extent in order to compensate for their higher rectal temperatures. This reinforces the possibility that the primiparous sows acclimated to the heat stress and re-established their biological set point during lactation. One hypothesis to explain this difference in thermoregulatory ability between first parity and older sows is that first parity sows may have different circulating concentrations of growth hormone (GH) and insulin-like growth factor I (IGF-1) during lactation compared with older sows because they have still not reached their mature size (Flowers and Day, 2002). First parity sows may be partitioning their nutrients differently than older sows; in particular, they may be putting more nutrients towards growth and milk yield than reducing heat stress. This concept was supported by the fact that primiparous sows had similar litter weights as compared with multiparous sows in all trials, despite their lesser body weights.

Both control (non-lactating) and lactating sows exhibited an increase in rectal temperature throughout the trial as well as an increase in rectal temperature, skin temperature (both ear and shoulder) and respiration rate from the morning to the afternoon measurements. There was, however, a difference in the magnitude of these body temperatures and respiration rate between control and lactating sows. These results indicate that non-lactating control sows were sensitive to summer heat stress, even though they did not have an additional heat load caused by lactation. However, control sows did not show the same increase in body temperatures as lactating sows, proving that

the heat load of lactation caused a more extreme increase in body temperatures and respiration rate than just heat stress alone.

Ambient temperature was reduced in the EC room compared with the FA room. However, there was no difference between rectal temperatures of sows housed in the FA or EC room. This indicates that the sows in the FA room must be able to cope with this higher temperature by increasing their skin vasodilation and respiration rate to a greater extent between the morning and afternoon in order to keep their body temperature stable. The drippers within the FA room may have been enough to allow for effective cooling of the sows housed in that farrowing room (Randall et al., 1983). The EC room had greater humidity levels throughout the trials compared to the FA room due to the indirect evaporative cooling pads; therefore, the similar RT for sows housed in both rooms may be due to the lactating sows' inability to dissipate heat effectively in an environment with high humidity (Curtis, 1983).

FUTURE DIRECTIONS FOR RESEARCH

Future research should focus on confirming and fully understanding the notion that first parity sows behave differently, both physiologically and metabolically, than older sows due to heat stress during lactation. It would be beneficial to perform a trial to measure the thermoregulatory and metabolic aspects of different parity sows during lactation on a larger scale. An additional trial performed on a commercial swine farm would be able to confirm that even on a large scale, primiparous sows show different thermoregulatory behaviors compared with multiparous sows during lactation. Although these field trials performed at the University of Missouri Swine Research Complex confirm the notion that primiparous and multiparous sows show different thermoregulatory and metabolic patterns during lactation, the temperature was variable and unpredictable each day of the trial and between the morning and afternoon. Therefore, it may also be helpful to perform a trial comparing the thermoregulatory mechanisms of different parity sows within an environmental chamber held at a constant temperature.

Studies should also focus on developing novel methods for producers to manage different parity sows in order to minimize the effect of heat stress on sow health, metabolism and reproduction as well as litter performance. In the most recent study, the sows in the EC farrowing room did not seem to benefit in terms of reduced rectal temperature from that ventilation system as compared to sows housed in the FA room throughout the majority of lactation. Therefore, further research needs to be conducted to investigate whether high humidity limits the effectiveness of the EC facility, which may explain the discrepancy in the previous study.

The interaction between feeding levels, metabolism and thermoregulation of different parity sows is still not fully understood. The current studies proved that primiparous sows have a different pattern of feed intake throughout lactation as compared with multiparous sows. Primiparous sows also showed similar piglet weights, and therefore, milk production as compared with multiparous sows during lactation. These results may be attributed to differences in metabolic or endocrine mechanisms between different parity sows. Performing more detailed studies in regards to the timing of endocrine mechanisms during lactation in different parity sows would be beneficial to determine the relationship between heat stress, parity and milk production. Once the underlying biological mechanisms of the thermoregulatory and metabolic patterns between different parity sows during lactation are better understood, researchers will be able to make recommendations to producers in regards to the most cost-effective method to manage sows during heat stress conditions and lactation.

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VITA

Whitney Martin was born in San Diego, CA and spent the early part of her childhood as a "military brat," traveling to a new location every few years. Once her dad retired from the military, she spent the rest of her youth living in Northern Virginia. Other than visiting her grandparents' farm a few times a year, she had no previous livestock experience before college. She completed her undergraduate degree in 2010 with a BS in Animal Science from Virginia Tech. Throughout her college experiences, she became fascinated not only with livestock species, but also with reproduction. During her junior year, she participated in the Miller Summer Internship Program in Animal Sciences at the University of Missouri, under the supervision of Dr. Matthew Lucy. It was during that time that her passion for research and pigs, in particular, flourished. This experience solidified her decision to attend graduate school with a focus in reproductive physiology in swine. She will complete a MS in Animal Science with an emphasis in swine reproductive physiology from the University of Missouri in May 2012 under the guidance of Dr. Matthew Lucy. Upon graduation, Whitney plans to pursue a career in the animal biologicals/pharmaceutical industry.