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Evaluation of Nutritional Factors Affecting Sow Reproductive Longevity

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EVALUATION OF NUTRITIONAL FACTORS AFFECTING SOW REPRODUCTIVE LONGEVITY

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EVALUATION OF NUTRITIONAL FACTORS AFFECTING SOW REPRODUCTIVE LONGEVITY

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Sow reproductive longevity is an important trait for swine operations from a production and economic standpoint. Previous research has shown that a sow needs to produce 3 litters before she covers the costs associated with introducing her to the operation. A literature review of research conducted related to sow longevity is discussed in Chapter 1. Chapters 2 and 3 present data from the University of Nebraska – Lincoln's long-term sow longevity research. The research looks at the effects of energy restriction with soy hulls during gilt development on sow reproductive longevity through 4 parities. Chapter 2 presents data from replications 16-18 where 383 gilts were fed developmental dietary treatments from d 112 to 209 of age and then tracked through 4 parities. Chapter 3 presents data from replications 14-15 where 256 gilts were fed dietary treatments from d 114 to 226 d of age and then again tracked through 4 parities. While some results differed between the two chapters, the overall result was similar: energy restriction during gilt development results in delayed age at puberty but does not have a negative impact on reproductive performance and longevity.

Keywords: energy restriction, gilt development, reproductive performance, sow longevity

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ABSTRACT

Sow longevity is an important economical trait for swine production systems. Sows are removed from breeding herds for a variety of reasons but identifying observational traits as well as implementing beneficial management techniques is important to rearing gilts to maximize their potential longevity. This review looks at those traits as well as possible management techniques. Energy is an important component of diets for all stages of a gilt's life. This review also defines energy and looks at its importance in swine and how requirements are met.

Keywords: energy, gilt development, puberty, sow longevity

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1. INTRODUCTION

For swine production systems to be productive, many factors must be considered, one of which is sow longevity. Sow longevity refers to how long a sow remains in the herd producing piglets. To recover the costs of bringing a sow into the herd, she needs to produce at least three litters. There are numerous factors that go into maximizing a sow's longevity to ensure she produces those three litters and beyond. These factors range from observing characteristics of gilts, choosing the most promising replacement gilts, and implementing different management techniques to provide gilts and sows the best opportunities to maximize their longevity. This review focuses mainly on characteristics and practices during pre- and post-pubertal development to maximize sow longevity and defining how energy affects sow longevity.

2. LONGEVITY

2.1. Importance

One of the most important factors for ensuring high production and a positive impact on the economics and survivability of swine production systems is sow longevity. The longer a sow remains in the breeding herd, the greater her overall total production. When she is removed early, she produces fewer litters, and thus fewer piglets. It has been shown that litter size increases through the fourth parity; thus, ensuring sows remain in the herd until at least their fourth parity or longer is in the best interest of maximizing pig production (Patterson and Foxcroft, 2019). Sow longevity can be specifically defined in a number of ways, including sow age, parity the sow is removed, and lifetime productivity (Stalder et al., 2004).

2.2. Reasons for Removal

Sows are removed from the breeding herd for a variety of reasons, but finding the optimal time for removal is important in helping maximizing longevity as well as overall production of the herd. Examples of reasons for removal include reproductive issues, old age, disease, low production, and lameness. Although removal of a sow from the breeding herd is sometimes obvious, other times that is not the case. In those instances where it may not be completely necessary, it is important for producers to consider the effects a sow’s removal will have on the production system. From a profitability standpoint, a sow needs to produce three litters before her costs are recovered (Mote et al, 2009; Patterson and Foxcroft, 2019; Segura-Correa et al, 2019). Occasionally, sows are removed simply due to old age. In a study by Mote et al. in 2009, they showed that higher-parity sows, those in parities 6 and greater, were oftentimes culled due to old age, despite their level of production. Also, sows culled due to old age produced 8 litters on average, while most were still producing at or above herd average when culled (Mote et al, 2009). Without looking at production values, those sows that were culled may have been high producers, and thus unnecessarily removed from the breeding herd, decreasing overall production and decreasing longevity.

2.3. Replacement Costs: Economic

Early sow removal from the breeding herd impacts the economics of production in two ways. First, sows produce fewer number of piglets. Secondly, there is the cost to replace the sow. The costs of replacement gilts come from the purchase price or cost of raising the gilt, gilt development regimen, and acclimating the gilt to the barn and program (Stalder et al., 2004). Estimates from Aae (2018) stated that the costs of raising a gilt equate to $627 USD. This includes breeding the sow to produce the gilt, rearing the gilt, and vaccinations (Aae, 2018). While roughly $171 USD can be recovered from marketing the sow that was replaced, there is still a cost of $456 USD for the replacement gilt (Aae, 2018). If a sow farm with 1,000 sows replaces in excess of 10% of their sows than required, that is an unneeded cost of $45,000 USD (Aae, 2018).

2.4. Replacement Costs: Biosecurity

Beyond the economic cost of gilt replacement, introducing a new gilt into the breeding herd also brings a disease risk. Therefore, minimizing the number of replacement gilts required can lower the risk of introducing a disease into the breeding herd. Introduction of a disease will hurt production, ranging from decreased production to requiring the entire herd to be depopulated. Maximizing biosecurity measures and minimizing unnecessary introductions are ways to help minimize this risk when introducing replacement gilts.

3. PRE-PUBERTAL DEVELOPMENTAL PERIOD

Many factors are involved to maximize a sow's longevity in the breeding herd. Some of which occur during the developmental period. While characteristics and milestones during this period can help predict longevity, different management techniques can also increase or decrease longevity. Successful gilt management techniques are integral to incorporate into the management system of a breeding herd, as the techniques used early on have an influence on a gilts lifetime production and longevity (Patterson and Foxcroft, 2019). Therefore, observing and documenting characteristics for interpretation as well as ensuring best management practices are beneficial to maximizing longevity.

3.1. Observational Traits

There are certain traits or characteristics that producers should document to predict a sow's longevity. These traits could indicate she would be a long-time producer, or they could be suggestive of problems that may occur throughout her reproductive years.

3.1.1. Birth weight. One predictive characteristic of longevity is a gilt's birth weight. Low birth weight piglets not only have a reduced chance of surviving early after birth, but are also less productive later in life. This is important to document as selecting for larger litter sizes over time has resulted in lower individual piglet birth weights (Yuan et al., 2015). Gilts with low birth weights can exhibit decreased growth, decreased pig production, and reduced longevity (Patterson and Foxcroft, 2019). Piglets with low birth weights are less likely to survive or exhibit adequate growth. Within a commercial pig production system, the greatest incidence of death occurs before weaning (Fix et al., 2010). Small piglets consume less colostrum, have less hepatic glycogen stored, more easily develop hypothermia, and are at an increased risk of being laid on (Magnabosco et al., 2015). Magnabosco et al. (2015) showed that decreased survivability and reduced growth rates to market weight in smaller birth weight piglets (< 1.1 kg) reduced their probability of entering the breeding herd.

In addition to decreased probability of selection for breeding, lower birth weight piglets are also less productive compared to higher birth weight piglets. A study by Magnabosco et al. (2016) showed that low birth weight (less than 1 kg) had a negative effect on a sow's production and longevity. In the lightest birth weight class, piglets averaged 828.5 ± 9.6 g at birth and produced fewer piglets compared to the other 7 birth weight classes throughout three parities, even though there was not a difference in farrowing rates. Therefore, it is important to consider a gilt's birth weight before selecting her as a replacement gilt.

3.1.2. Age at Puberty. Another trait to record is age at puberty. Age at puberty is important as it is moderately heritable (Tart et al., 2013) and can be used as an early predictor for sow retention and longevity (Patterson and Foxcroft, 2019). Gilts with a younger age at first estrus are younger when they mate and farrow and have been shown to have longer longevity (Tart et al., 2013). The younger a gilt's age at puberty, the more likely she is to produce litters throughout parity three (Patterson and Foxcroft, 2019). While a younger age at puberty has been shown to be reproductively beneficial, the opposite has been shown to be true as age at puberty increases. Gilts with a higher age at puberty are more likely to develop reproductive issues leading to culling (Roongsitthichai et al., 2013). An older age at puberty delays the age at which a gilt farrows her first litter, and an older age at first litter has been related to the gilt remaining in the breeding herd for a shorter duration (Serenius and Stalder, 2007). Overall, age at puberty has been proven to be an important early indicator of a gilt's reproductive performance. Age at puberty by 220 days is indicative of increased production and longevity compared to a later age at puberty (Patterson and Foxcroft, 2019).

Determining age at puberty is more labor intensive than recording a birth weight at one time point. It involves using a boar to check for estrus on a daily basis, typically beginning around 140 days of age (Miller et al., 2011). The methods used for estrus detection require a significant amount of manpower, and thus is not readily employed in commercial farms or seed-stock operations (Tart et al., 2013). Therefore, while age at puberty is an observational trait, it involves more work than simply identifying the day and recording it for selection practices, and thus starts to fall into a management technique.

3.2. Management

Beyond simply observing a gilt's characteristics during her developmental period to predict longevity, additional management techniques can be incorporated to help maximize her longevity. Positive gilt management techniques can prove crucial for developing a gilt for reproductive success and longevity (Patterson and Foxcroft, 2019).

3.2.1. Litter Size: One management technique used is to rear litters specifically for replacement females where they nurse in a smaller litter which is achieved through cross fostering. A smaller litter size contributes to greater piglet growth, benefitting reproductive organ development, which ultimately contributes to greater production and longevity (Patterson and Foxcroft, 2019). This was shown in a study by Flowers (2009) where gilts were raised in lactation litters of either less than or equal to 7 pigs (small litter) or greater than or equal to 10 pigs (large litter). Data were collected on 3,180 gilts through 6 parities in a commercial setting. Sows raised in small litters produced litters with 11 piglets born throughout six parities; whereas, those raised in a large litter averaged 10.5 piglets per litter (Flowers, 2009). Sows that had been raised in a small litter were also more likely to remain in production at the end of parity 6 when compared to those raised in a large litter (35% vs 17%, respectively; Flowers, 2009).

3.2.2. Early Boar Exposure: Another management technique used to help maximize longevity is exposing gilts early to boars. The same study by Flowers (2009) looked at this in comparing boar exposure starting at 140 d of age vs starting at 170 d of age.

Thirty-three percent of gilts exposed starting at 140 d were still in the herd at the end of parity 6 compared with only 16% of those that had started exposure at 170 d.

A note on the two management techniques just discussed, smaller litter size and early boar exposure were shown to be additive in Flowers (2009) study. Forty-five percent of sows that were from a small litter size and exposed to boars early were still in production after 6 parities, and sows from large litters and exposed to boars later only had 10% remaining in production (Flowers, 2009).

3.2.3. Mammary Development: An important trait to help ensure sow longevity is adequate milk yield. If sows do not produce enough milk for their litter poor growth rates of piglets will occur. Sows have a greater chance of being culled due to poor litter growth rate. To help ensure adequate milk yield, some nutritional management techniques can be used. While some nutritional management techniques can have negative effects on mammary development, other strategies can stimulate mammary development, resulting in increased weight in mammary tissue (27% to 52% increase; Farmer, 2018). There are three stages identified for rapid mammary development, the first is from 90 d of age until puberty (Farmer, 2018). Prior to 90 d, mammary development is gradual, but after, it increases 4- to 6-fold (Sorensen et al., 2002). The next stage of rapid mammary development is during the final third of gestation and the third stage is during lactation (Farmer, 2018).

During the first stage of mammary development, it has been shown that feed restriction can decrease mammary development (Farmer, 2018). A study showed that restricting feed intake during the first stage of mammary development by 20% resulted in a 26% decrease in parenchymal tissue weight and 42% for extraparenchymal tissue weight (Farmer et al., 2004). In contrast, ad libitum access during this same time has the opposite effect, significantly increasing the weight of mammary parenchymal tissue anywhere from 36% to 52% (Farmer, 2018). Ad libitum access to feed has thus been shown to help increase mammary development of gilts prior to puberty (Farmer et al., 2004). While feed restriction from d 90 to puberty negatively impacts mammary development, ad libitum access to feed during this time positively impacts mammary development. Restricting crude protein does not appear to affect mammary development (Farmer, 2018).

3.2.4. Energy Restriction: One management technique still being investigated is energy restriction of gilts during the pre-pubertal developmental period. It has been shown in other species that supplying adequate nutrients while only restricting energy between weaning and puberty can increase an animal's longevity (Johnson et al., 2011). Therefore, researchers have begun investigating how energy intake of pigs during the developmental period affects reproductive longevity. A study (Johnson et al., 2011) restricted energy intake by 25% compared to ad libitum access to feed of gilts during pre-pubertal development from 123 d of age until breeding. They showed that the energy-restricted gilts had increased age at puberty compared to pigs with ad libitum access to feed during the same period (Miller et al., 2011). While age at puberty increased (Miller et al., 2011), no difference was seen in production traits such as number born alive, number weaned, and litter weaning weight (Johnson et al., 2011). The benefit of prepubertal energy restriction is that because reproductive performance and longevity are unchanged, production costs from feed can be lowered (Johnson et al., 2021).

3.2.5. Implementation of Techniques: For these management techniques, implementation can vary depending on the operation. Cross-fostering for smaller litters for those identified as possible replacement gilts is something most producers could easily implement. Early boar exposure on the other hand may be more difficult to accomplish. Possible issues with this implementation include the human resources needed to expose gilts consistently and the biosecurity risk of moving the boar frequently. Providing ad libitum access to feed to ensure mammary development is one approach that could also be easy to implement as most operations already do this. Energy intake restriction during development contradicts the results observed for mammary development as a result of providing ad libitum access to feed early in development. Additional research is needed to examine how energy restriction affects mammary development specifically. Producers should evaluate whether the saved costs from the energy restriction (reduced feed intake) is something they value before implementing that management technique into their operation. The feasibility of adding these different management techniques, as well as their added benefits or cost is something different operations need to consider prior to implementation.

4. POST-PUBERTAL PERIOD

4.1. Mammary Development

As previously mentioned, rapid mammary development occurs during three main stages. The first, 90 d after birth until puberty. The other two stages occur after puberty, during gestation and lactation. During the second stage of rapid mammary development (the last third of gestation) increasing dietary energy intake can have a negative effect on mammary development, while increasing dietary CP has no affect. This was shown in a study by Weldon et al. (1991) where dietary energy was provided at either 5.8 or 10.5 Mcal ME/d. Sows provided the greater energy intake had decreased mammary development. These investigators also fed either 216 or 330 g CP/d and showed no effect on mammary development (Weldon et al., 1991).

The final stage of rapid mammary development (during lactation) has been shown to be affected by both dietary energy and CP consumption. Kim et al. (1999) showed that during lactation, maximal mammary development was observed after a 28 d lactation with the sow consuming 16.9 Mcal of ME/day and 55 g of lysine/day on average throughout lactation. While nutrition is important for mammary development in all stages, during lactation suckling by piglets is also extremely important. Teat suckling increases mammary development during lactation, not only for that current lactation, but also the subsequent lactation (Farmer, 2019). Initial suckling is incredibly important as without it, mammary glands can irreversibly shrink after only three days (Farmer, 2019).

From the current data available, it is recommended that during the second stage of mammary development to avoid over feeding dietary energy as it can have negative effects on mammary development. For the final stage of rapid mammary development, during lactation, it was shown that the most development occurred in response to a lactation consumption of 16.9 Mcal ME/day and 55 g lysine/day (Kim et al, 1999). Beyond these dietary recommendations, producers should ensure suckling by piglets for a minimum of the first three days after parturition to ensure mammary development for that lactational period as well as future lactations. All these recommendations to maximize mammary development are important for sow longevity, as without adequate milk production, a sow could be removed early from the herd due to reduced litter performance.

4.2. Lactation Feed Intake

Another factor that can help maximize a sow's longevity is feed intake during lactation. A study by Knauer et al. (2010) showed that the more feed a sow consumed during lactation the greater the probability she remained in the breeding herd for four parities. This could also be inferred from a study where sows were fed either 3 kg (L) or 6 kg (H) of their lactation diet a day (Kirkwood et al., 1987). Those in the L group had greater weight and backfat losses compared to those in the H group, resulting in more frequent anestrus, a longer duration to rebreed, and a decreased pregnancy rate (Kirkwood et al., 1987). Poor reproductive performance leads to a greater chance of culling and thus shorter longevity.

5. ENERGY

5.1. Energy Defined

Energy is an important component of swine diets that needs to be accounted for to ensure pigs are producing optimally. Energy is commonly described as gross energy (GE), digestible energy (DE), metabolizable energy (ME), and net energy (NE). Gross energy is the starting point, the total amount of energy produced and measured from complete oxidation of a source (Hall et al., 2013). Subtracting the GE in the animal's feces from the dietary GE they consumed gives you DE. Subtracting the GE found in the animal's urine as well as the gases from fermentation from DE gives you ME (Noblet and van Milgen, 2004). Finally, subtracting heat increment energy (H_iE) from ME results in net energy (NE) which is divided out into NE for maintenance and production (NE_m and $NE_{p,}$ respectively; National Research Council, 2012). A diagram of this flow of dietary energy (Saha and Pathak, 2021) is depicted in **Figure 1.1**. One thing to note with ME is that in pigs, since their production of gasses is relatively minute, the energy losses due to gasses is ignored in the equation (Kil et al., 2013).

5.2. Energy Importance

Pigs consume feed, giving them dietary energy, which is absorbed and used, or excreted as feces, urine, or heat (Kil et al., 2013). In growing pigs, the dietary energy absorbed is first used for maintenance, accounting for approximately one third of that absorbed, and the remaining two thirds is stored in the form of proteins and lipids (Kil et al., 2013; Lizardo et al., 2002). The energy used for maintenance involves fueling and maintaining simple biological mechanisms including blood flow, tissue breakdown and replacement, ion balance, breathing, muscle tension, homeostasis, and physical activity such as movement and the consumption of food (Kil et al., 2013). Because energy is involved in fueling all these functions simply for survival, it is extremely important to ensure pigs are consuming adequate amount of energy.

5.3. Energy Requirements

Depending on gender, age, weight, and stage of production, pigs have different energy requirements. The Nutrient Requirements of Swine, published by the National Research Council (2012), has tables taking these things into account to help determine how much energy pigs need. For example, the "estimated effective ME intake" for a growing pig changes drastically from 5 to 135 kg; **Table 1.1** shows these requirements for different weight ranges according to the National Research Council (2012).

Beyond these standard requirements, temperatures below and above their lower and upper critical temperature limits, as well as activity level, affect energy requirements. Formulas are available in the National Research Council (2012) to account for these differences.

The precise amount of energy needed for a pig depends on body weight and stage of life. There has been debate regarding the most accurate equation for determining metabolizable energy for maintenance (ME_m). Birkett and de Lange (2001) state that for a growing-finishing pig, their requirements for ME_m ranges from 191 to 216 kcal/kg $BW^{0.60}$, with the mean being 197 kcal/kg $BW^{0.60}$. For gestating and lactating sows, 100 and 110 kcal ME/kg $BW^{0.75}$, respectively. These values stated are for maintenance and do not account for the different energy needs for different physiological states such as growth, pregnancy, lactation, and sexually-active boars. For example, a lactating sow cannot consume enough dietary energy to support what is needed for maintenance and to produce milk, thus she relies on mobilizing body tissue to support those needs (Dourmad et al., 2008).

5.4. Meeting Energy Requirements

Metabolizable energy is the energy value used for ensuring pigs are meeting their energy requirements. In swine, different processes utilize ME at different efficiencies. The approximate average efficiencies are: 80% for maintenance ($\mathbf{k_m}$) and fat deposition ($\mathbf{k_f}$), 75% for weight gain occurring during growth ($\mathbf{k_g}$), 70% for milk production ($\mathbf{k_l}$), and 60% for protein deposition ($\mathbf{k_p}$; Noblet et al., 1994), as well as 87% for milk production from body reserves($\mathbf{k_{rm}}$), 80% for body mobilization ($\mathbf{k_r}$) and 50% for uterine growth ($\mathbf{k_c}$; Dourmad et al., 2008). When energy consumption from feed is lower than the energy required, pigs will mobilize body reserves to help meet that need. The amount mobilized depends on how significant the deficit is. This mainly occurs in lactating sows as mentioned, and energy use from body reserves is more efficient than from consuming energy. Thus, ensuring adequate energy supplies during pregnancy for lipid and protein deposition is important for the sow to build those body reserves. It is also important to avoid excessive buildup as that can increase farrowing problems (Dourmad et al., 2008).

6. CURRENT INDUSTRY AVERAGES

In today's industry, gilts are typically developed on ad libitum access to a corn-soybean meal-based diet through breeding age (Johnson et al., 2011). As they grow and develop, it is typical to see gilts reach puberty somewhere between 190 and 230 days of age (Knox et al., 2015). Ideally, gilts are bred at second or third estrus around day 230 while weighing 300 lbs with satisfactory backfat to help achieve high reproductive performance and longevity (Knox et al., 2015). Once bred, their gestation length averages 115 days. Over time, industry averages have changed due to selection practices and changes in genetics. Over a ten-year span, the number of live pigs born per litter on average has increased from 10.2 pigs/litter to 11.4 pigs/litter (Fix et al., 2010). Also, individual piglet weight within these larger litters has tended to decrease (Yuan et al., 2015). Piglets weigh 2 to 3 lbs at birth on average, or 0.9 to 1.4 kg (National Pork Board, 2021). Because of these larger litters and smaller piglets, maximizing mammary development as mentioned previously is extremely important for maximizing growth and production. During lactation, gilts and sows often lose body weight (decreased body condition) due to the high demands of milk production and lower appetites (Cozannet et al., 2018; Lawlor and Lynch, 2007). At the end of lactation, most farms wean piglets between 18 and 21 days of age, although there are farms that wean outside this range (Knox et al., 2013). After weaning, gilts and sows typically have a wean to estrus interval of 5 days, with 6 days being more common than 4 days (Knox et al., 2013). Depending on the severity of body condition loss during lactation, the wean-to-estrus interval could be lengthened. While these are averages of what is seen in the industry today, there are differences among different genetic lines and each farm has their own preferred targets.

7. CONCLUSION

Overall, numerous studies have investigated sow longevity, but there are still unanswered questions. It is known that a sow needs to produce three litters before she returns the cost of bringing her into the breeding herd. Therefore, producers should select for traits and implement management techniques to increase the likelihood of gilts reaching that third parity and beyond. These traits and techniques include avoiding low birth weight piglets as replacement gilts, identifying age at puberty, raising litters specifically for replacement gilts with smaller litter sizes, starting boar exposure early, ensuring adequate mammary development, and maximizing lactational feed intake. Identifying these traits and implementing these management techniques can help producers maximize sow longevity.

Energy is an important component in swine diets. Understanding a pigs energy requirements is crucial for maintenance and optimizing production. The National Research Council (2012) has a vast amount of information available to determine energy requirements as well as the energy contents of feedstuffs to ensure diets are composed to meet those requirements. Key factors in determining energy requirements include gender, age, weight, and stage of production or physiological state. Research is ongoing in relation to energy restrictions during pre-pubertal development on sow longevity. Known key factors regarding sow longevity include birth weight, age at puberty, litter nursing size, onset of boar exposure, and mammary development.

Swine production systems are continuously growing, adapting, and developing. Research is ongoing to maximize production from all aspects to continue this growth. Growth in one area puts pressure on other areas to grow. This was seen with the increase in litter size, and thus the pressure to maximize mammary development and milk production to support that increase. Research is a continuous necessity to help maximize all aspects of swine production.

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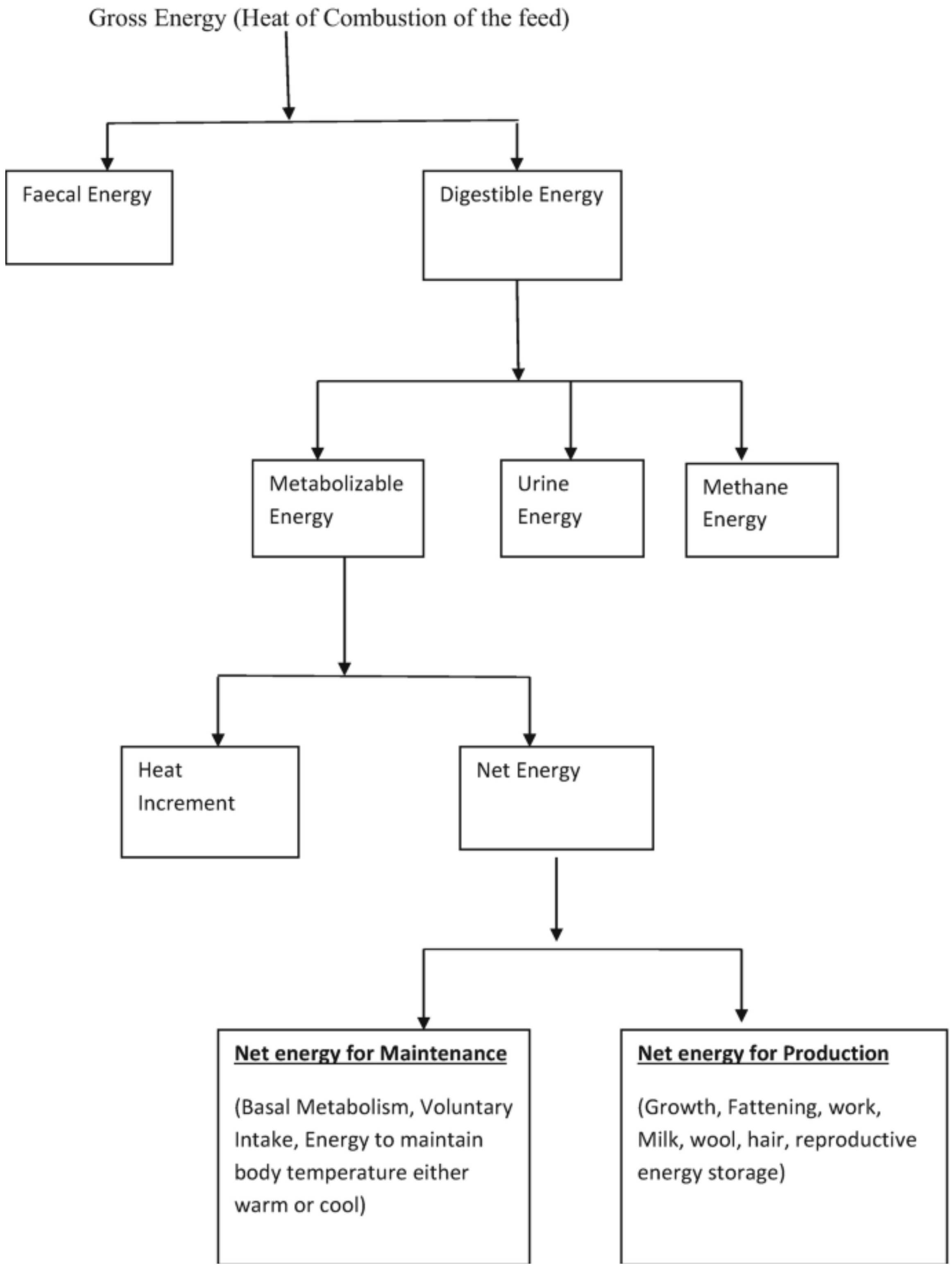
Table 1.1. Dietary Estimated Effective ME Intake of Growing Pigs with Ad Libitum Access to Feed (90% dry matter)

	Body Wight Range (kg)						
Item	5-7	7-11	11-25	25-50	50-75	75-100	100-135
Estimated effective ME intake (kcal/day)	904	1,592	3,033	4,959	6,989	8,265	9,196

Figure 1.1. Partitioning of feed energy



CHAPTER II. EVALUATION OF 2-PHASE DIETS OF AD LIBITUM ACCESS, ENERGY RESTRICTION THROUGH SOY HULLS, AND AD LIBITUM ACCESS PLUS DURING GILT DEVELOPMENT ON REPRODUCTIVE PERFORMANCE AND LONGEVITY

ABSTRACT

Three dietary treatments were randomly assigned to 383 gilts from d 112 to 209 of age to determine the effects on reproductive performance and longevity. Treatments included ad libitum access to a typical corn-soybean meal diet (AL, n = 120), 25% energy restriction using soy hulls (R, n = 144), and the ad libitum access diet with increased crude protein, lysine, and other amino acids (AL+, n = 119). Daily estrus detection through use of boar exposure was used to determine age at puberty (AP). Gilts were removed for lameness, failure to express estrus, and randomly culled. A total of 313 gilts were selected for breeding. At farrowing and weaning of each parity, sow weight, backfat, and longissimus muscle (LM) depth were measured. Litter birth traits analyzed through 4 parities included total number born (TNB), number born alive (NBA), number of stillborn (SB), number of mummies (Mum) and litter birth weight (LBW). Litter weaning traits included number of pigs weaned (NW), litter weaning weight (LWW), and piglet average weaning weight (Avg WW). Lifetime productivity traits were analyzed including number of litters, lifetime number born alive, and lifetime number weaned. No treatment difference for probability to express estrus was detected. Gilts receiving the R treatment had delayed AP compared to AL and AL+ gilts ($P < 0.01$). Sows fed the R regimen had lower values for all sow traits except LM depth at weaning where no difference was detected and lactational ADFI where they had greater values. No effect of treatment was detected for litter birth traits or lifetime productivity traits. For litter weaning traits only Avg WW was affected (R sows greater than AL and AL+ sows). Parity affected sow traits where weight increased with parity, backfat was greatest at parity 1, and LM depth greatest at parity 4. Parity 4 sows lost the least during lactation for all measurements. Lactational ADFI was least at parity 1 followed by parities 3, 2, and 4. Parity effects were detected for litter birth and weaning traits including TNB (P = 0.01), NBA (P = 0.02), LBW (P < 0.01), NW (P = 0.01), and LWW (P < 0.01). Parity 1 sows had the lowest values for all litter traits except NW where parity 4 had the lowest values. Treatment × parity effects were observed for farrowing weight, backfat, and LM depth (P < 0.01), weaning weight (P = 0.04) and backfat (P < 0.01), backfat and LM depth changes over lactation (P = 0.01 and P = 0.02, respectively), and lactational ADFI (P < 0.05). Most interactions saw greater differences between treatments at earlier parities and less differences between treatments at later parities.

Keywords: birth, development, energy restriction, gilt, lactation, longevity, production, weaning

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INTRODUCTION

Sow longevity is an important trait for the success of a breeding operation. It takes 3 litters before a sow recovers her costs (Mote et al., 2009; Patterson and Foxcroft, 2019; Segura-Correa et al., 2019), thus ensuring she produces a minimum of 3 litters is important for the economic success of an operation. Litter size has also been shown to increase through the fourth parity, so ensuring a sow produces 4 litters is important for pig production and ultimately the profitability of the operation (Patterson and Foxcroft, 2019). Thus, determining and implementing management techniques to help maximize a sow's longevity to ensure she reaches 4 or more parities is important for swine production overall. The objective of this experiment was to determine the effects of energy restriction from d 112 to 209 of age on sow longevity and reproductive performance through 4 parities.

MATERIALS AND METHODS

Gilt Population

Gilts for this experiment were derived from the University of Nebraska selection Line 45 (L45X). The formation of this line is described by Johnson et al. (1999), Ruíz-Flores and Johnson (2001), and Hsu and Johnson (2014). The L45X dams were bred through artificial insemination to boars of an industry maternal line (L_M). Gilts resulting from these crosses (L45X × L_M) were randomly selected for the project.

Gilt Management

The gilts used for this experiment were born into replications (rep) during September, 2016 (rep 16); September and October, 2017 (rep 17); and March and April, 2018 (rep 18). Weaning occurred at approximately 21 d post-farrowing. After weaning, gilts were moved to a nursery where they were housed in pens of 30 and managed similarly. From the nursery they were moved to a grower barn and were fed and managed similarly on a standard industry diet.

The experiment began with 383 gilts (127 to 128 gilts per rep) at approximately d 112 of age. At the start of the experiment, gilts were randomly assigned to pens of 8. Pens were 1.6 × 5.4 m^2 with the floor divided into 2/3 solid surface and 1/3 slatted surface.

This resulted in 0.36 m^2 feed space and 1.08 m^2 total floor space per gilt. The developmental period of the experiment ended with 369 gilts (121 to 124 gilts per rep) at approximately 209 d of age.

Dietary Regimens

Prior to beginning the experiment, all gilts were fed the same diets during the nursery period as described by Miller et al. (2011). At approximately d 112, each pen began receiving the experimental diets and randomly assigned to 1 of the 3 developmental regimens. The first regimen was ad libitum access (AL) to a 2-phase corn-soybean meal diet. The second regimen was a 2-phase diet using soy hulls to restrict energy intake (R) to 75% of that of the AL regimen. The final regimen was a 2-phase ad libitum access plus diet (AL+) which was similar to the AL regimen but with increased protein, lysine, and other amino acids, with a Lysine:ME ratio similar to the R regimen, and ME similar to the AL regimen. Diets were formulated to meet or exceed all other nutrient requirements in accordance to the NRC (2012). The experimental diets are presented in **Tables 2.1** and **2.2**. Feeders were weighed bi-weekly. The dietary phase change occurred after 55 d on the phase 1 diet (54 to 56 d). Pigs received the phase 2 diet for 42 d. Pigs consumed dietary treatments for an average of 97 d (96 to 98 d).

Breeding and Lactation Management

A total of 369 gilts remained at the end of the developmental period. Eight gilts were removed for displaying irregular estrus prior to 210 d of age. Twenty-three gilts did not display estrus by 210 d of age and were removed. Twenty gilts were removed due to lameness after development. Five gilts were randomly culled, 1 due to accidently being shipped and 4 to match the number of gilts to the available breeding spaces. A total of 313 gilts remained and were selected for breeding.

Gilts were moved to the breeding barn and placed in pens of 8. Gilts were checked once a day with a boar for estrus. When estrus was observed they were artificially inseminated each day with pooled semen from a terminal boar line. Gilts that were removed due to lameness, poor health, presenting as open, and not exhibiting estrus during breeding were tracked and accounted for. These numbers are available in **Table 2.3** for gilts through 4 parities, as well as numbers for the gilt developmental period.

During breeding, gestation, and lactation, gilts were fed, managed, and had backfat and longissimus muscle (LM) depth measured as described by Johnson et al. (2021). Cross-fostering of the sow's piglets was implemented after birth without regard to which dietary treatment sows had been developed on. Parity 1 litters were weaned at approximately 21 d. Number of pigs weaned and total litter weaning weight were recorded for each litter.

Sows for parities 2 through 4 were also managed as described by Johnson et al. (2021). Litters for parities 2, 3, and 4 were all weaned at approximately d 20 post-farrowing.

Traits and Data Analysis

Data were analyzed using the Fit Model procedure (JMP Pro 15). Multiple comparisons were completed using the Tukey HSD All Pairwise Comparisons procedure

(JMP Pro 15). Traits analyzed related to puberty, sow traits, litter birth traits, litter weaning traits, and lifetime productivity.

Puberty traits were analyzed two ways. First as a binomial trait where the gilts that exhibited estrus during the developmental period were coded as 1 and those who did not coded as 0. Secondly, age at puberty was analyzed for gilts that expressed pubertal estrus during the developmental period. Both approaches were analyzed with treatment as a fixed effect and rep and pen as random effects. The gilts birth litter and sire were originally added to the model as random effects but then removed due to random effect variance components being zero.

Sow traits analyzed were sow weight, sow backfat thickness, and sow LM depth. These measurements were taken at farrowing and weaning. The changes between farrowing and weaning were also calculated. Average daily feed intake (ADFI) was also measured for sows during each parity. These traits were all analyzed with a repeated measures model that included fixed effects for treatment and parity as well as a 2-way interaction for these 2 effects. The sow's birth litter and sire as well as rep and pig (sow herself) were included as random effects.

Litter birth traits analyzed included total number born, number born alive, number of stillborn pigs at birth, number of mummified pigs at birth, and total litter birth weight. These traits were analyzed the same as sow traits.

Litter weaning traits that were analyzed included number weaned, total litter weaning weight, and piglet average weaning weight. These traits were analyzed the same as sow traits except weaning age and number nursed were included as covariates to control for differences within these categories. Number born alive was also included as a covariate for piglet average weaning weight.

Lifetime productivity traits were included as the per sow means for number of litters produced, total number of pigs born alive, and total number weaned. The mean total weaning weight was not included as weaning weights for rep 18 parity 3 were unavailable. These were all calculated based on the 313 gilts that had been selected as breeders. Out of those 313 gilts, 273 farrowed at least 1 litter. These traits were analyzed with treatment as a fixed effect and rep as a random effect.

RESULTS

Puberty Traits

When analyzed as a binomial trait, there was no difference ($P > 0.10$) in the probability of gilts to express estrus during the developmental period based on treatment. Developmental dietary treatment was shown to have an effect on AP where gilts fed the R regimen had delayed ($P < 0.0001$) AP compared to the AL and AL+ regimens (d 168 vs 160 and 158, respectively). The LS means and SEM for the probability to express estrus and AP are listed in **Table 2.4**. Based on the pairwise comparisons for AP between treatments, R gilts had delayed AP compared to both the AL ($P < 0.01$) and AL+ ($P < 0.0001$) gilts, but no difference ($P > 0.10$) was shown between the AL and AL+ gilts.

Sow Traits

Weight, backfat and LM depth measurements were recorded for sows at farrowing and weaning through 4 parities, as well as during lactation. Dietary treatment was shown to have an effect on all sow traits except LM depth at weaning (*P* > 0.10). Parity was shown to have an effect on all sow traits. There was a treatment × parity interaction for all sow traits except LM depth at weaning (*P* > 0.10) and a trend was shown for weight change during lactation (*P* < 0.10). The tests of fixed effects for this data are shown in **Table 2.5**.

Sows that had received the R regimen during development weighed less (212 kg; *P* < 0.0001) compared to the AL and AL+ (228 and 226 kg, respectively) sows at farrowing. There was a difference (*P* < 0.0001) shown between each parity, where with each successive parity, sows had greater farrowing weights. Looking within parity, the R sows weighed less (228 kg; *P* < 0.0001) than both the AL and AL+ (212 and 226 kg, respectively) sows only during parity 1 (**Figure 2.1**).

Farrowing backfat thickness for sows fed the R regimen was less (1.89 cm; *P* < 0.0001) than those who received the AL and AL+ (2.26 and 2.20 cm, respectively) treatments. Within a parity, R sows only had less (1.82 cm; *P* < 0.0001) backfat at parity 1 compared to both AL and AL+ (2.26 and 2.20 cm, respectively; **Figure 2.2**) sows. Across parities and regardless of treatment, sows at parity 1 had greater (2.09 cm; *P* < 0.0001) backfat when compared to the other 3 parities. Parity 2 sows also had greater (1.84 cm; *P* < 0.0001) backfat compared to parities 3 and 4 (1.70 and 1.65 cm, respectively).

Sow LM depth at farrowing was inconsistent across parities when comparing different treatments (**Figure 2.3**). The R sows had decreased (5.61 cm; *P* < 0.01 and *P* < 0.0001, respectively) LM depth overall compared to AL (5.89 cm) and AL+ (5.95 cm) sows at farrowing. A parity effect was observed where parities 2 and 4 had greater (5.89

and 5.91 cm, respectively; $P < 0.05$) LM depth than parity 3 (5.77 cm). A treatment × parity interaction was shown ($P < 0.0001$) for R sows having less LM depth than AL sows at parity 1 (5.61 cm vs 5.88 cm) and AL+ sows at parities 1 and 2 (5.95 and 5.98 cm, respectively), but no difference at other parities. Parity 1 R sows also had less ($P < 0.05$) LM depth than R sows at parities 2 and 4 (5.85 and 6.02 cm, respectively). No difference was shown ($P > 0.10$) between AL and AL+ sows no matter the parity. While not always significant, R sows appeared to have greater LM depth from parity 1 to 4 while AL and AL+ sows appeared to have greater depths at parities 1 and 2 and less depth at parity 3 with an intermediate depth at parity 4. Longissimus muscle depth for R sows was less (5.61 vs 5.85 and 6.02 cm; $P < 0.0001$) at parity 1 compared to parities 2 and 4, respectively.

When comparing sow weights at weaning, there was a treatment effect where R sows weighed less (185 kg; $P < 0.0001$) than AL and AL+ sows (196 and 192, respectively; **Figure 2.4**). With each subsequent parity, sows had greater ($P < 0.0001$) body weight at weaning from parity 1 through 4 (191, 214, 226, and 251 kg, respectively). A treatment × parity interaction was shown ($P < 0.01$) with R sows increasing weight more significantly through 4 parities than AL and AL+ sows.

Weaning backfat for sows developed on the R treatment was less (1.52 cm; $P < 0.0001$) than those fed the AL and AL+ treatments (1.81 and 1.73 cm, respectively; **Figure 2.5**). A parity effect was observed where sows at parity 1 had more (1.68 cm; $P < 0.0001$) backfat than sows at parities 2, 3 and 4 (1.48, 1.44, 1.53 cm, respectively). Parity 4 sows also had greater ($P < 0.05$) backfat than parity 3 sows.

Longissimus muscle depth at weaning for sows was similar (*P* > 0.10) across treatments. A parity effect was shown (*P* < 0.0001; **Figure 2.6**) where parity 1 sows had the lowest (5.41 cm; *P* < 0.05) LM depth, parity 4 sows had the greatest (5.76 cm; *P* < 0.001) LM depth, and parities 2 and 3 had similar (5.52 and 5.56 cm, respectively; *P* > 0.10) LM depths.

A treatment effect was shown (*P* < 0.01) for weight change over lactation. Restricted energy sows lost less body weight (-15.03 kg; *P* < 0.01) than AL+ sows (-22.63 kg) and tended to lose less (*P* < 0.10) than AL sows (-19.88 kg). A parity effect was also detected (*P* < 0.0001) for lactational weight change. Parity 4 sows lost less (-6.56 kg; *P* < 0.0001) than parities 1, 2 and 3 sows (-19.18, -19.04, and -18.76 kg, respectively; **Figure 2.7**).

Backfat change over lactation was less (*P* < 0.001) for R sows (-0.29 cm) compared to AL and AL+ sows (-0.46 and -0.47 cm, respectively). Parity 4 sows lost the lowest (-0.10 cm; *P* < 0.0001; **Figure 2.8**) amount of backfat over lactation, followed by parity 3 sows (-0.24 cm; *P* < 0.01). Parity 1 and 2 sows lost the greatest amount of backfat during lactation with no difference (-0.41 and -0.35 cm, respectively; *P* > 0.10) between those parities.

Lactational LM depth change was affected (*P* < 0.001) by treatment. Restricted energy sows lost less (-0.21 cm; *P* < 0.01) than AL and AL+ sows (-0.44 and -0.50 cm, respectively). Parity greatly affect (*P* < 0.0001) lactational LM depth change. Parity 1 and 2 sows lost more (-0.38 and -0.36 cm, respectively; *P* < 0.01) LM depth during lactation than parity 3 and 4 sows (-0.18 and -0.12 cm, respectively; **Figure 2.9**).

Sow ADFI during lactation was affected ($P < 0.0001$) by developmental treatment. Sows developed on the R regimen had greater (5.04 vs 4.41 and 4.30 kg, respectively; **Figure 2.10**) ADFI than AL and AL+ sows. A parity affect was shown ($P < 0.0001$) with a difference between all parities. Parity 1 sows consumed the least (4.58, 5.14, 5.49, and 6.23 kg, respectively) followed by parity 3, parity 2, and parity 4 sows. A treatment × parity interaction was detected ($P < 0.05$). Restricted energy sows at parity 1 had greater lactational ADFI compared to AL and AL+ sows, but by later parities there was no difference between treatment within a parity. These results are shown in **Table 2.6**.

Litter birth traits

Treatment was shown to have no effect ($P > 0.10$) on any of the litter birth traits. Parity had an effect on all the litter birth traits analyzed except Mum ($P > 0.10$). Parity 1 sows farrowed fewer (15.4 piglets; $P < 0.05$) total piglets than both parity 2 and 3 sows (16.3 and 17.0 piglets, respectively). Parity 4 sows farrowed fewer (16.0 piglets; $P < 0.05$) total piglets than parity 3 sows. For NBA, parity 1 and 4 sows farrowed fewer (14.0 and 13.9, respectively; $P < 0.05$) alive piglets than parity 2 and 3 sows (14.9 and 15.1 piglets). Parity 1 and 2 sows farrowed a fewer (1.45 and 1.36 piglets, respectively; $P < 0.05$) number of stillborn piglets than parity 3 and 4 sows (1.96 and 2.09 piglets, respectively). Litter birth weight was least ($P < 0.05$) for parity 1 sows (18.75 kg) compared to parity 2, 3, and 4 sows (22.46, 23.09, and 19.73 kg, respectively), while parity 4 sows had lower litter birth weights than parity 2 and 3 sows. There was shown to be no interaction between treatment and parity for any of the litter birth traits. These results are shown in **Table 2.7**.

Litter weaning traits

Treatment was shown to have an effect on piglet Avg WW ($P < 0.05$), but not on any other litter weaning traits. Restricted energy sows had greater (5.85 vs 5.64 and 5.65 kg, respectively) piglet Avg WW than AL and AL+ sows. While not significant, LWW was numerically least for AL sows, followed by AL+ and R sows (63.03, 65.05, and 65.71 kg, respectively). Parity affected all litter weaning traits. Parity 4 sows weaned the fewest (10.89 piglets; $P < 0.05$) number of piglets compared to parity 1, 2, and 3 sows (11.35, 11.91, and 11.46 piglets, respectively). Parity 1 sows also weaned fewer ($P < 0.01$) piglets than parity 2 sows. Litter weaning weight was least ($P < 0.01$) for parity 1 sows (64.59 kg) compared to parity 2, 3, and 4 sows (76.47, 69.27, and 68.68 kg, respectively). Parity 2 sow LWWs were also less ($P < 0.0001$) than parity 3 and 4 sows. Average WW was least ($P < 0.0001$) for parity 1 sows (5.71 kg) compared to parity 2, 3, and 4 sows (6.46, 6.07, and 6.37 kg, respectively). Parity 3 sows Avg WW was less ($P < 0.001$) than parity 2 and 4 sows. There was no treatment × parity interaction shown. These results are shown in **Table 2.8**.

Lifetime productivity traits

The lifetime productivity traits were calculated from the 313 gilts that had been selected for breeding. Of those, 273 produced at least 1 litter, with 157 producing 4 litters (**Figure 2.11**). The total number of pigs born alive ranged from 0 to 58 (**Figure 2.12**).

Zero occurred 41 times, 40 times for those gilts failing to produce at least 1 litter, and 1 time for a gilt farrowing all stillborn piglets. The total number weaned ranged from 0 to 58 (**Figure 2.13**). For the means measured on the lifetime productivity traits, those fed the ad libitum access regimen had numerically lower values compared to those that had received the restricted and ad libitum access plus diet regimens, though no statistical differences ($P > 0.10$) were shown between treatments (**Table 2.9**).

DISCUSSION

Treatment effects

Age at puberty can be used as a predictor for future longevity, and an AP before 220 d is associated with longer longevity (Patterson and Foxcroft, 2019). Based on the results of this experiment, there was no treatment difference for the probability to express estrus by 210 d, but it was shown that the restricted energy treatment during the developmental period resulted in a delayed age at puberty. Den Hartog and Noordewier (1984) implemented energy restrictions for a greater length of time, d 84 to 266 of age, and showed that those with energy intake had an earlier AP with daily gilt exposure to a boar beginning at approximately d 168 of age. Newton and Mahan (1992) did not expose gilts to boars and did not see a difference in the proportion that expressed estrus or in AP for gilts restricted energy to 50% or 75% of ad libitum access from approximately d 135 to 270 of age. A different experiment by Newton and Mahan (1993) did expose gilts daily to boars beginning at approximately d 159 of age and again did not see a difference in AP with restricted feed intake from approximately d 150 to 240 of age. Patterson et al. (2002) conducted 2 experiments, with daily boar exposure beginning at approximately d 135 of age, where energy was restricted to either approximately 87 or 78% and from d 96 or 88 until puberty for experiments 1 and 2, respectively and did not detect a difference in AP based on treatment. Klindt et al. (2001b) did not observe a delay in AP due to energy restriction from approximately d 91 to 175 of age and began daily boar exposure at approximately d 175 of age. The authors used 4 treatment groups with energy restricted to 50%, 62.5% 75%, and 87.5% of that of ad libitum access. Age at puberty was earliest for the 50% group, followed by 87.5%, then 62.5% and 75%. This nonlinear relationship does not agree with our findings for a delayed AP due to energy restriction. This could be due to management after d 175 where gilts in this study by Klindt et al. (2001b) were allowed ad libitum access to feed. Those with the most energy restriction consumed the greatest amount and thus had compensatory gain which could have affected AP. The authors also did not have a control group without a restriction to compare to which could also have affected their results. A different experiment by Klindt et al. (2001a) again did not detect a delay in AP, this time from a 74% energy restriction from d 91 to 175 of age and boar exposure starting at approximately d 176 of age. Other previous research (Miller et al., 2011) showed a difference based on 25% energy restriction through limited feed intake for both the probability to express estrus and age at puberty. The reason for this experiment not showing a treatment difference for the probability to express pubertal estrus could be due to less statistical power.

Sow traits of weight, backfat, and LM depth at farrowing, weaning, and change during lactation were all shown to be affected by treatment except sow weaning LM depth. The differences were always observed in parity 1 with sows fed the R treatment having lower values than the AL and(or) AL+ sows. This would be due to slower growth during development due to the energy restriction. By parity 2, sows developed on the restricted energy treatment no longer had lower values compared to those fed the AL and AL+ regimens. Newton and Mahan (1993) also showed a treatment effect from limit feeding on farrowing and weaning weights of sows. Klindt et al. (2001) euthanized gilts at d 30 of gestation so traits at farrowing and weaning were not available; however, weight and backfat at the start of breeding and at pregnancy decreased linearly with decreased energy during development which is suggestive that those traits at parity 1 farrowing and weaning would have been similar.

Sow weight and backfat at farrowing, weaning, and change during lactation were also examined by Johnson et al. (2021), though less differences were detected between treatments. They had also investigated a 25% energy restriction compared to ad libitum access, though their restriction was through limit feeding rather than using soy hulls. While they detected differences for farrowing weight and weaning backfat based on treatment, as with this experiment, they did not observe differences in farrowing backfat, weaning weight, lactational weight change, and lactational backfat change observed in this experiment. The authors did not look at LM depths. This could be due to the timeframe and duration that the treatments were applied. While they applied the energy restriction for a greater duration (112 d vs our 97 d), they initiated treatments at a later age (123 d vs our 112 d). Presumably, starting the energy restriction at an earlier age had a greater effect on development in terms of weight and backfat which was shown by greater differences between treatments at parity 1.

Litter birth traits were not affected by developmental dietary treatment. This is in agreement with a previous study (Johnson et al., 2021) where no effect was shown based on the developmental 25% energy restriction. Stalder et al. (2000) similarly observed no difference for total number born, number born alive, or litter birth weight for parity 1 sows.

The only litter weaning trait affected by treatment was piglet average weaning weight (R-regimen piglets weighed more). No effect was shown by Stalder et al. (2000) for total number weaned or litter weaning weight for parity 1 sows receiving different energy levels. While not significant, a numerical difference was shown for LWW based on treatment where AL sows had the smallest weight litters, followed by AL+ and R sows (63.03, 65.05, and 65.71 kg, respectively). It is interesting to note that while R sows weaned the greatest average weight piglets, they lost the least amount of weight, backfat thickness, and LM depth during lactation compared to AL and AL+ sows. While losing the least amount of those during lactation is not predictive of weaning the greatest average weight piglets, this could be explained by R sows having greater ADFI during lactation compared to the AL and AL+ sows.

Lifetime productivity was also not affected by treatment. Again, this is in agreement with Johnson et al. (2021) that showed no treatment effect on lifetime productivity, but those fed the AL regimen had numerically smaller lifetime productivity values for each trait.

Parity effects

There was shown to be a parity effect on all sow traits except farrowing LM depth. For weight this was expected as sows weigh more with each parity as they are still growing. Newton and Mahan (1993) detected a similar result regarding weight through 3 parities. In this experiment, parity 4 sows lost less weight compared to parities 1-3. Again, Newton and Mahan (1993) showed similar results in that the latest parity they looked at, parity 3, lost the least amount over lactation. Parity 1 sows had the greatest amount of backfat, but also lost the most over lactation compared to other parities. The sows presumably lost more as they had more available and mobilized it to support lactation. Longissimus muscle depth was similar across parities at farrowing; however, there was a difference at weaning between parity 1 and 4, presumably due to older sows having more developed musculature.

Parity effects were observed for litter birth traits except number of mummies, as well as for all litter weaning traits. Parity 1 sows almost always produced litters with lower birth and weaning traits. This agrees with what was shown by Newton and Mahan (1993) as well as Johnson et al. (2021), though the former did not show an effect on the number of stillborn and did not look at the number of mummies.

CONCLUSION

A 2-phase 25% energy restriction diet and an ad libitum access plus diet were evaluated against a typical corn-soybean meal diet fed during gilt development on subsequent sow longevity. No differences between the ad libitum access plus diet and the ad libitum access diet were shown for any trait analyzed. While the energy restricted diet did not affect the probability to express estrus by 210 d, it did delay the age at puberty of those that did express estrus. Gilt developmental treatment and parity interacted to affect most of the sow traits (weight, backfat, and LM depth) analyzed at farrowing, weaning, and change over lactation, as well as lactational ADFI. Parity affected litter birth and weaning traits including TNB, NBA, LBW, NW, LWW, and avg WW. Treatment did not have an effect on any of the lifetime productivity traits. Overall, no effect on longevity was observed as a result of feeding the ad libitum access plus diet during gilt development. The energy-restricted diet delayed age at puberty, but did not affect longevity measured by lifetime productivity traits. During development the restricted energy diet offers an opportunity to decrease diet costs as soy hulls are typically a cheaper feed ingredient than corn and soybean meal. Before implementing this diet to cut costs, a cost analysis should be done to determine if it would be cheaper in the long run as R sows increased ADFI during lactation. Overall, feeding the energy restricted diet offers an opportunity to save money in terms of feed costs during development, while still maintaining the same reproductive performance and longevity.

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Table 2.1. Composition of Phase 1 of ad libitum (AL), restricted (R), and ad libitum plus (AL+) diets fed during development to gilts (approximately d 112 to 167)

	Diet		
Item	AL	R	AL+
Ingredient, %			
Corn	72.52	39.59	70.38
Soybean meal, 47.5% CP	21.53	17.79	23.35
Soybean hulls		40.00	
Tallow	3.00		3.00
Dicalcium phosphate	1.37	1.72	1.37
Limestone	0.68		0.68
Salt	0.50	0.50	0.50
F-G-N Vitamin Premix[1]	0.25	0.25	0.25
TM Premix[2]	0.15	0.15	0.15
L-Lys-HCL			0.15
L-Thr			0.09
DL-Met			0.05
L-Trp			0.03
Total	100.00	100.00	100.00
Calculated analysis			
ME, kcal/kg	3,406	2,705	3,408
CP, %	13.72	12.68	14.34
Lysine, %	0.70	0.70	0.86
Ca, %	0.67	0.71	0.68
P, %	0.60	0.60	0.61

[1]Diet AL, R and AL+ supplied per kilogram of diet: vitamin A (as retinyl acetate), 5,500 IU; vitamin D (as cholecalciferol), 550 IU; vitamin E (as α-tocopherol acetate), 30 IU; vitamin K (as menadione dimethylpyrimidinol bisulfite), 4.4 mg; riboflavin, 11.0 mg; d-pantothenic acid, 22.05 mg; niacin, 33.0 mg; and vitamin B12, 33.0 mg.

[2]Diet AL, R and AL+ supplied per kilogram of diet: Zn (as ZnSO4), 127 mg; Fe (as $FeSO_4 \cdot H_2O$), 128 mg; Mn (as MnO), 30 mg; Cu (as $CuSO_4 \cdot 5H_2O$), 11 mg; I [as $Ca(IO_3) \cdot H_2O$], 0.26 mg; Se (as Na_2SeO_3), 0.3 mg.

Table 2.2. Composition of Phase 2 of ad libitum (AL), restricted (R), and ad libitum plus (AL+) diets fed during development to gilts (approximately d 167 to 209)

	Diet		
Item	AL	R	AL+
Ingredient, %			
Corn	76.32	43.17	74.66
Soybean meal, 47.5% CP	17.66	14.13	19.00
Soybean hulls		40.00	
Tallow	3.00		3.00
Dicalcium phosphate	1.46	1.80	1.46
Limestone	0.66		0.66
Salt	0.50	0.50	0.50
F-G-N Vitamin Premix[1]	0.25	0.25	0.25
TM Premix[2]	0.15	0.15	0.15
L-Lys-HCL			0.15
L-Thr			0.09
DL-Met			0.05
L-Trp			0.03
Total	100.00	100.00	100.00
Calculated analysis			
ME, kcal/kg	3,408	2,706	3,408
CP, %	12.36	11.39	12.81
Lysine, %	0.61	0.61	0.76
Ca, %	0.67	0.72	0.68
P, %	0.60	0.60	0.60

[1]Diet AL, R and AL+ supplied per kilogram of diet: vitamin A (as retinyl acetate), 5,500 IU; vitamin D (as cholecalciferol), 550 IU; vitamin E (as α-tocopherol acetate), 30 IU; vitamin K (as menadione dimethylpyrimidinol bisulfite), 4.4 mg; riboflavin, 11.0 mg; d-pantothenic acid, 22.05 mg; niacin, 33.0 mg; and vitamin B12, 33.0 mg.

[2]Diet AL, R and AL+ supplied per kilogram of diet: Zn (as ZnSO4), 127 mg; Fe (as $FeSO_4 \cdot H_2O$), 128 mg; Mn (as MnO), 30 mg; Cu (as $CuSO_4 \cdot 5H_2O$), 11 mg; I [as $Ca(IO_3) \cdot H_2O$], 0.26 mg; Se (as Na_2SeO_3), 0.3 mg.

Table 2.3. Number of gilts at beginning (112 d) and end (209 d) of developmental period. Outcomes of breedings and litters through 4 parities[1]

	Number at			Culled/died			
Trt[2]	112 d	209 d	AP	No AP	Late AP	D/L	Ran
AL	120	113	108	5	1	9	1
R	144	140	129	11	3	3	3
AL+	119	116	109	7	4	8	1
Total	383	369	346	23	8	20	5

		Culled					
	Breeders	B/O	NE	DG	F/L/I	Litters	DPW
	Parity 1						
AL	97	9	2	0	3	83	2
R	120	10	3	0	2	105	2
AL+	96	5	3	0	3	85	1
Total	313	24	8	0	8	273	5
	Parity 2						
AL	81	2	10	1	3	65	1
R	103	2	8	0	2	91	5
AL+	84	7	6	0	1	70	2
Total	268	11	24	1	6	226	8
	Parity 3						
AL	64	5	3	2	2	52	1
R	86	6	5	1	0	74	3
AL+	68	4	2	1	0	61	1
Total	218	15	10	4	2	187	5
	Parity 4						
AL	51	6	1	0	0	44	1
R	71	7	2	0	0	62	0
AL+	60	6	1	2	0	51	0
Total	182	19	4	2	0	157	1

[1]No AP = no estrus exhibited, Late AP = delayed or irregular estrus which prevented breeding at second estrus, D/L = died or exhibited lameness, Ran = randomly culled, B/O = bred, but determined open, NE = no estrus exhibited during the breeding period, DG = died during gestation, F/L/I = foot or leg structure, lameness, or injury, DPW = farrowed litter, but died while lactating

[2]AL = ad libitum, R = restricted energy intake, AL+ = ad libitum plus

Table 2.4. LS means, tests of fixed effects, and random effect variance components for the probability to express pubertal estrus and age at puberty for gilts based on developmental treatment

Item[1]	Probability to express pubertal estrus	Age at puberty, d
	LS mean ± SEM	
AL	0.90 ± 0.025	160.06 ± 1.61
R	0.91 ± 0.023	167.97 ± 1.47
AL+	0.95 ± 0.025	157.75 ± 1.59
	Tests of fixed effects, Prob > F	
Treatment	0.44	<0.01
	Radom effect variance components	
Rep	0.001	0.000
Pen	0.000	0.003
Residual	0.073	281.171

[1]AL = ad libitum access, R = restricted energy, AL+ = ad libitum access plus

Table 2.5. Tests of fixed effects, Tukey HSD all pairwise comparisons, and random effect variance components for sow weight, backfat and LM depth at farrowing (FW, FB, FLD) and weaning (WW, WB, WLD), as well as weight, backfat and LM depth change during lactation from farrowing to weaning (WC, BC, LDC)

Item[1]	FW, kg	FB, cm	FLD, cm	WW, kg	WB, cm	WLD, cm	WC, kg	BC, cm	LDC, cm
	Tests of fixed effects, Prob > F								
Treatment (T)	<0.01	<0.01	<0.01	<0.01	<0.01	0.81	<0.01	<0.01	<0.01
Parity (P)	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
T × P	<0.01	<0.01	<0.01	<0.01	<0.01	0.98	0.09	0.01	0.02
	Tukey HSD all pairwise comparisons, Prob > |t|								
AL vs R	<0.01	<0.01	<0.01	<0.01	<0.01	0.99	0.07	<0.01	0.01
AL vs AL+	0.85	0.51	0.64	0.15	0.31	0.89	0.45	0.99	0.70
R vs AL+	<0.01	<0.01	<0.01	0.02	<0.01	0.80	<0.01	<0.01	<0.01
P1 vs P2	<0.01	<0.01	0.20	<0.01	<0.01	0.04	1.00	0.15	0.94
P1 vs P3	<0.01	<0.01	0.77	<0.01	<0.01	<0.01	0.99	<0.01	<0.01
P1 vs P4	<0.01	<0.01	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P2 vs P3	<0.01	<0.01	0.03	<0.01	0.53	0.79	1.00	<0.01	<0.01
P2 vs P4	<0.01	<0.01	0.98	<0.01	0.22	<0.01	<0.01	<0.01	<0.01
P3 vs P4	<0.01	0.60	0.02	<0.01	0.01	<0.01	<0.01	<0.01	0.65
	Random effect variance components								
Replication	0.36	0.01	0.00	1.35	0.00	0.00	95.25	0.005	0.003
Litter	3.19	0.00	0.01	30.92	0.00	0.01	15.74	0.003	0.003
Sire	15.92	0.02	0.02	0.00	0.02	0.03	10.10	0.002	0.000
Pig	96.79	0.04	0.08	135.88	0.03	0.07	18.18	0.002	0.007
Residual	252.47	0.10	0.19	141.01	0.07	0.20	197.64	0.084	0.262

[1]AL = ad libitum, R = restricted energy, AL+ = ad libitum plus, P1 – P4 = parity 1 – 4

Table 2.6. LS means, tests of fixed effects, prob > F, and random effect variance components for sow lactational ADFI

Item[1]	Lactational ADFI, kg
	LS means ± SEM
AL	4.41 ± 0.16
R	5.04 ± 0.15
AL+	4.30 ± 0.16
P1	4.58 ± 0.13
P2	5.49 ± 0.13
P3	5.14 ± 0.14
P4	6.23 ± 0.14
	Tests of fixed effects, Prob > F
Treatment (T)	<0.01
Parity (P)	<0.01
T × P	0.01
	Random effect variance components
Replication	0.03
Litter	0.05
Sire	0.04
Pig	0.20
Residual	0.93

[1]AL = ad libitum, R = restricted energy, AL+ = ad libitum plus, P1 – P4 = parity 1 – 4

Table 2.7. LS means, tests of fixed effects, prob > F, and random effect variance components for litter birth traits[1]

Item[2]	TNB	NBA	SB	Mum	LBW,kg[3]
	LS means ± SEM				
AL	15.52 ± 0.42	13.99 ± 0.40	1.53 ± 0.24	0.69 ± 0.14	18.76 ± 0.70
R	15.69 ± 0.38	14.37 ± 0.36	1.34 ± 0.22	0.44 ± 0.13	18.74 ± 0.67
AL+	15.00 ± 0.42	13.52 ± 0.40	1.47 ± 0.24	0.44 ± 0.14	18.75 ± 0.70
P1	15.40 ± 0.27	13.96 ± 0.25	1.45 ± 0.15	0.52 ± 0.11	18.75 ± 0.59
P2	16.26 ± 0.29	14.92 ± 0.26	1.36 ± 0.16	0.49 ± 0.11	22.46 ± 0.60
P3	17.01 ± 0.31	15.09 ± 0.28	1.96 ± 0.17	0.55 ± 0.12	23.09 ± 0.64
P4	15.95 ± 0.33	13.90 ± 0.31	2.09 ± 0.18	0.66 ± 0.12	19.73 ± 0.63
	Tests of fixed effects, Prob > F				
Treatment (T)	0.40	0.24	0.81	0.11	1.00
Parity (P)	<0.01	<0.01	<0.01	0.34	<0.01
T × P	0.50	0.23	0.45	0.82	0.44
	Random effect variance components				
Replication	0.00	0.00	0.00	0.02	0.76
Litter	0.00	0.00	0.00	0.00	0.30
Sire	0.83	0.46	0.16	0.02	0.80
Pig	1.48	1.50	1.03	0.07	3.78
Residual	11.01	10.51	3.29	0.78	12.79

[1]TNB = total number born, NBA = number born alive, SB = number of stillborn pigs at birth, Mum = number of mummified pigs at birth, LBW,kg = litter birth weight in kg
[2]AL = ad libitum, R = restricted energy diet, AL+ = ad libitum plus, P1 – P4 = parity 1 – 4
[3]Weight data for rep 18 parity 3 was missing and thus not included

Table 2.8. LS means, tests of fixed effects, prob > F, and random effect variance components for litter weaning traits[1]

Item[2]	NW	LWW,kg[3]	Avg WW, kg[3]
	LS means ± SEM		
AL	11.24 ± 0.37	63.03 ± 1.72	5.64 ± 0.26
R	11.29 ± 0.36	65.71 ± 1.61	5.85 ± 0.26
AL+	11.52 ± 0.37	65.05 ± 1.70	5.65 ± 0.26
P1	11.35 ± 0.33	64.60 ± 1.30	5.71 ± 0.26
P2	11.91 ± 0.34	76.47 ± 1.34	6.46 ± 0.26
P3	10.46 ± 0.35	69.27 ± 1.52	6.07 ± 0.26
P4	10.89 ± 0.35	68.68 ± 1.45	6.37 ± 0.26
	Tests of fixed effects, Prob > F		
Treatment (T)	0.55	0.32	0.04
Parity (P)	<0.01	<0.01	<0.01
T × P	0.36	0.70	0.24
Wean age	0.13	<0.01	<0.01
NN	<0.01	0.02	<0.01
NBA			<0.01
	Random effect variance components		
Replication	0.29	3.00	0.19
Litter	0.00	0.00	0.01
Sire	0.01	3.12	0.03
Pig	0.51	20.93	0.06
Residual	2.79	127.76	0.33

[1]NW = number of piglets weaned, LWW, kg = litter weaning weight in kg, Avg WW, kg = piglet average weaning weight in kg

[2]AL = ad libitum, R = restricted energy diet, AL+ = ad libitum plus, P1 – P4 = parity 1 – 4, NN = number nursed after crossfostering, NBA = number born alive

[3]Weight data for rep 18 parity 3 was missing and thus not included

Table 2.9. LS means, tests of fixed effects, and random effect variance components for the number of litters, total number of pigs born alive and total number weaned for each female selected as a breeder based on developmental regimen

Item[1]	Number of litters	Total number pigs born alive	Total number weaned
	LS means		
AL	2.52 ± 0.15	36.54 ± 2.38	27.78 ± 1.79
R	2.77 ± 0.14	40.41 ± 2.14	30.98 ± 1.61
AL+	2.78 ± 0.15	40.34 ± 2.40	31.99 ± 1.80
	Tests of fixed effects, Prob > F		
Treatment	0.38	0.41	0.22
	Random effect variance components		
Replication	0.04	6.42	0.34
Residual	2.27	551.33	310.87

[1]AL = ad libitum access, R = restricted energy, AL+ = ad libitum plus

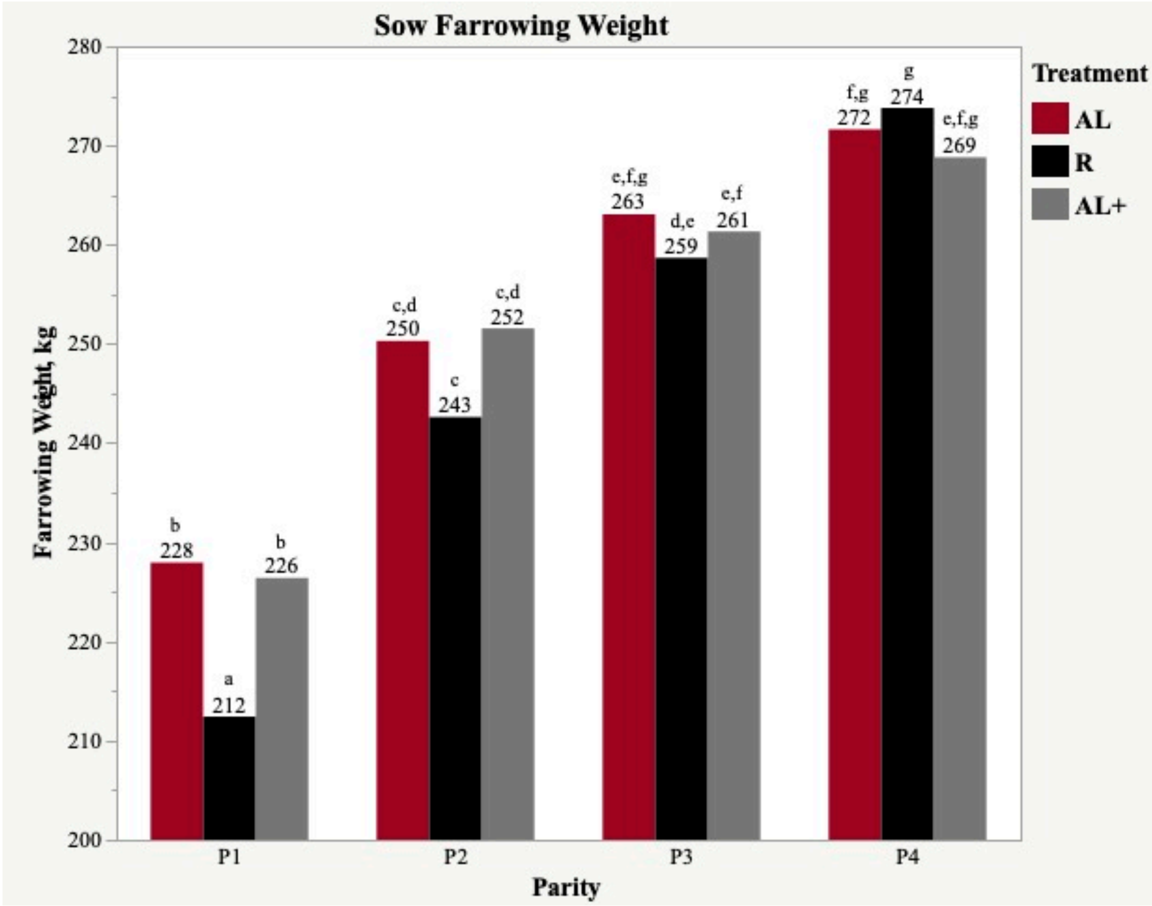

Figure 2.1. Weight of sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum plus (AL+) regimens at farrowing for parities 1 through 4 (LS means; SEM ranged 2.03 to 2.88 kg). The tests of fixed effects and random effects variance components for the data in this figure is presented in **Table 2.5**.

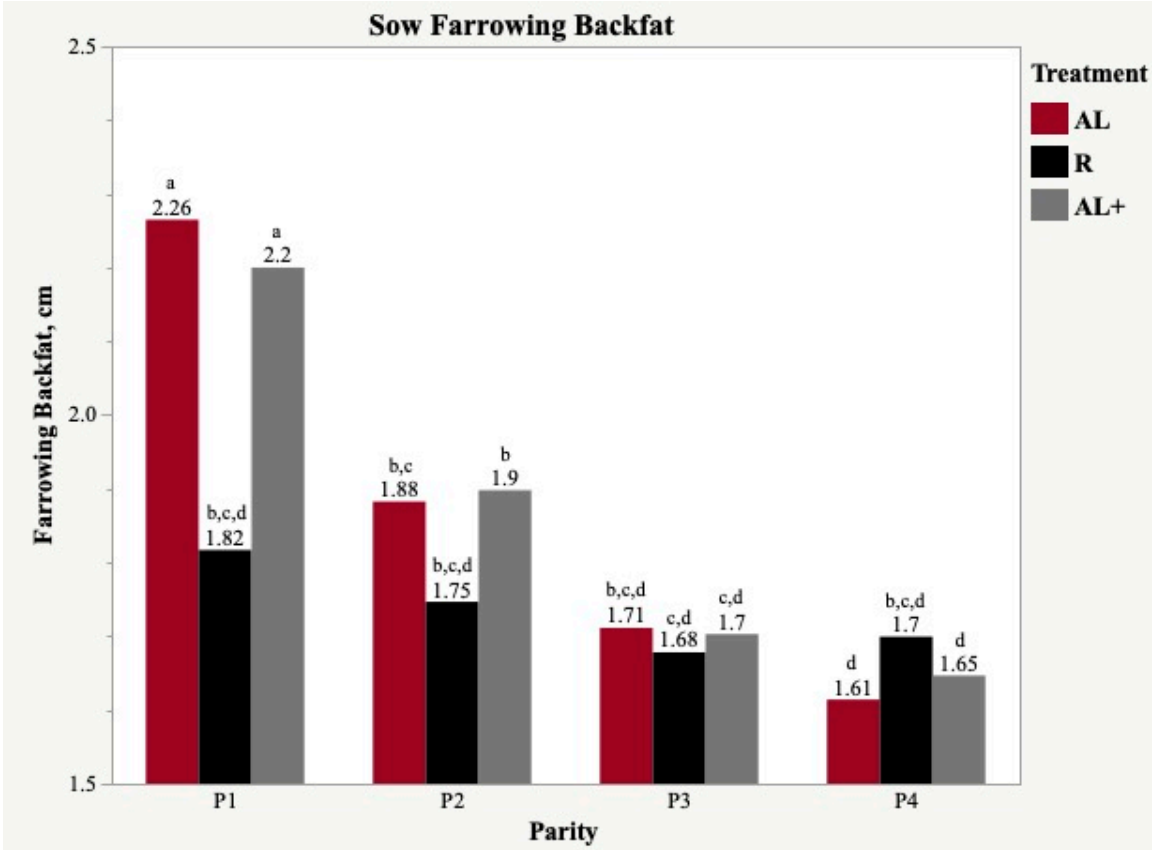

Figure 2.2. Backfat of sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum plus (AL+) regimens at farrowing for parities 1 through 4 (LS means; SEM ranged 1.61 to 2.26 cm). The tests of fixed effects, pairwise comparisons, and random effect variance components for the data in this figure is presented in **Table 2.5.**

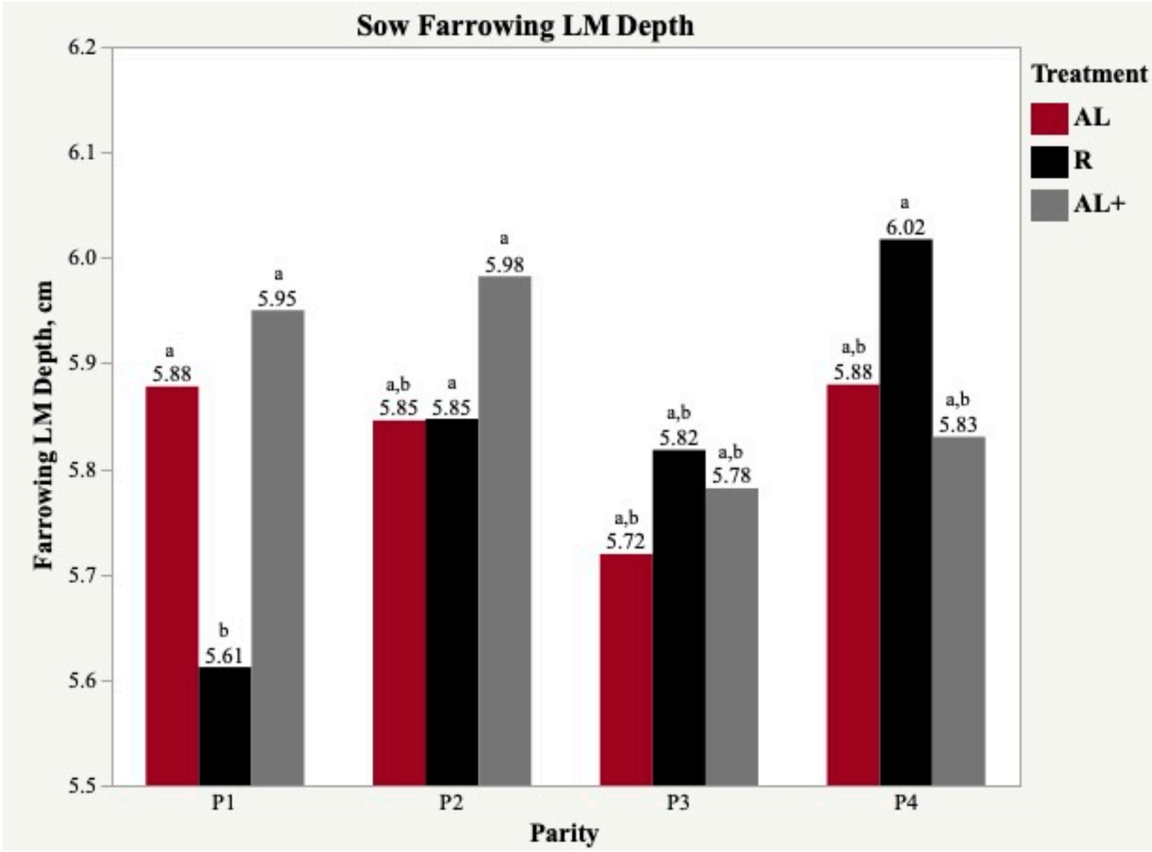

Figure 2.3. LM depth of sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum plus (AL+) regimens at farrowing for parities 1 through 4 (LS means; SEM ranged 0.06 to 0.08 cm). The tests of fixed effects, pairwise comparisons, and random effect variance components for the data in this figure is presented in **Table 2.5.**

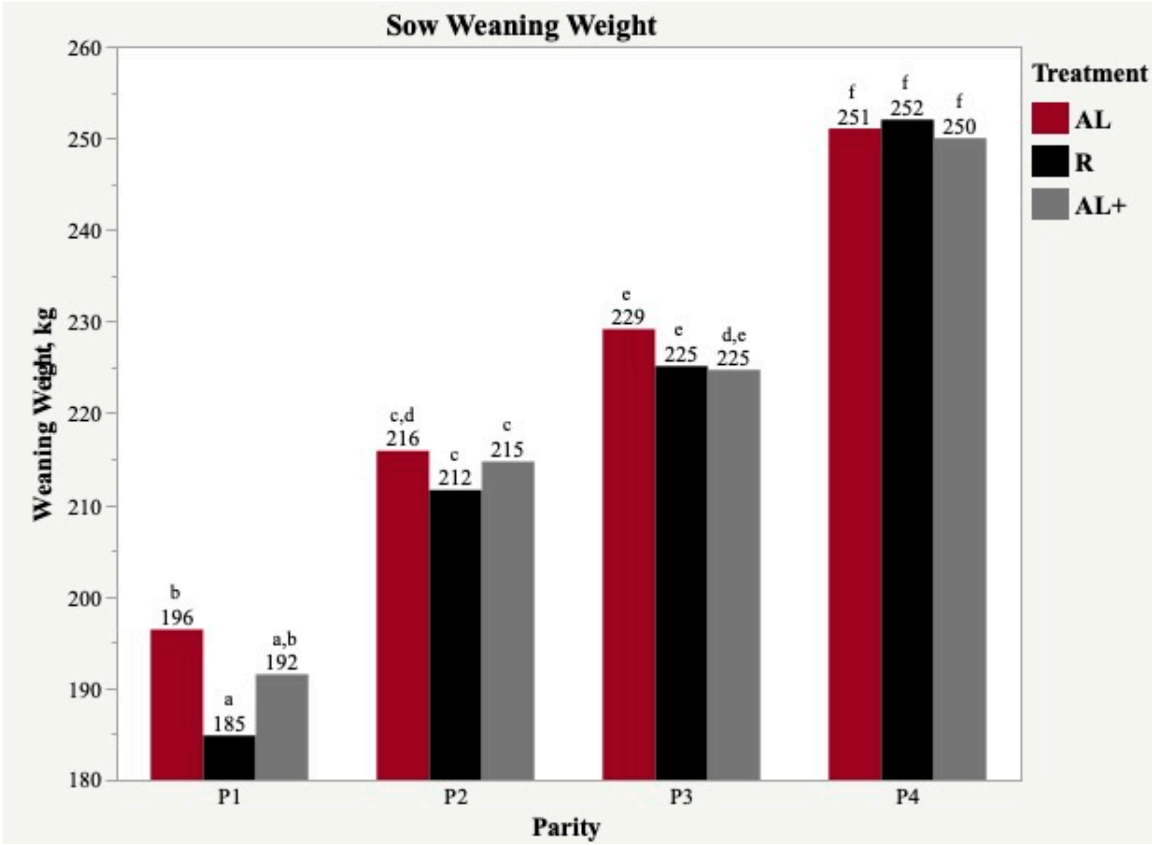

Figure 2.4. Weight of sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum plus (AL+) regimens at weaning for parities 1 through 4 (LS means; SEM ranged 1.96 to 2.63 kg). The tests of fixed effects, pairwise comparisons, and random effect variance components for the data in this figure is presented in **Table 2.5.**

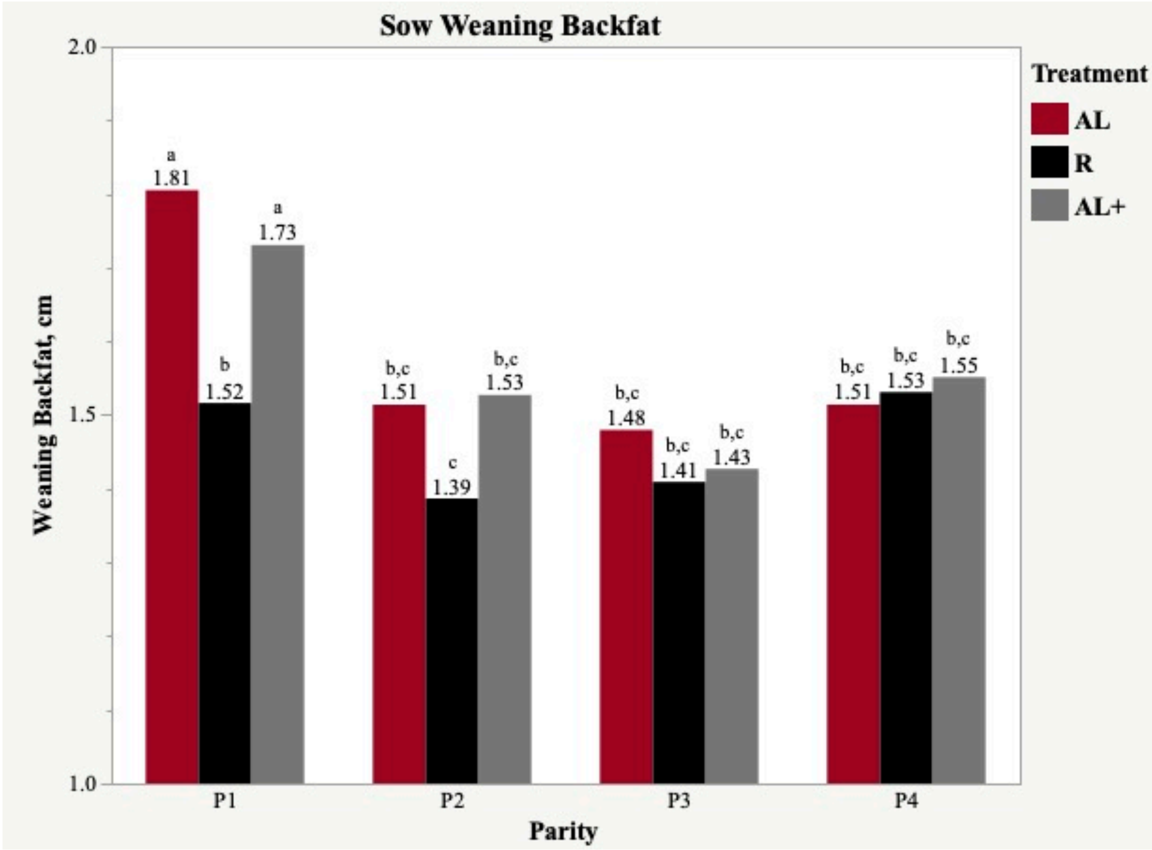

Figure 2.5. Backfat of sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum plus (AL+) regimens at weaning for parities 1 through 4 (LS means; SEM ranged 0.04 to 0.05 cm). The tests of fixed effects, pairwise comparisons, and random effect variance components for the data in this figure is presented in **Table 2.5.**

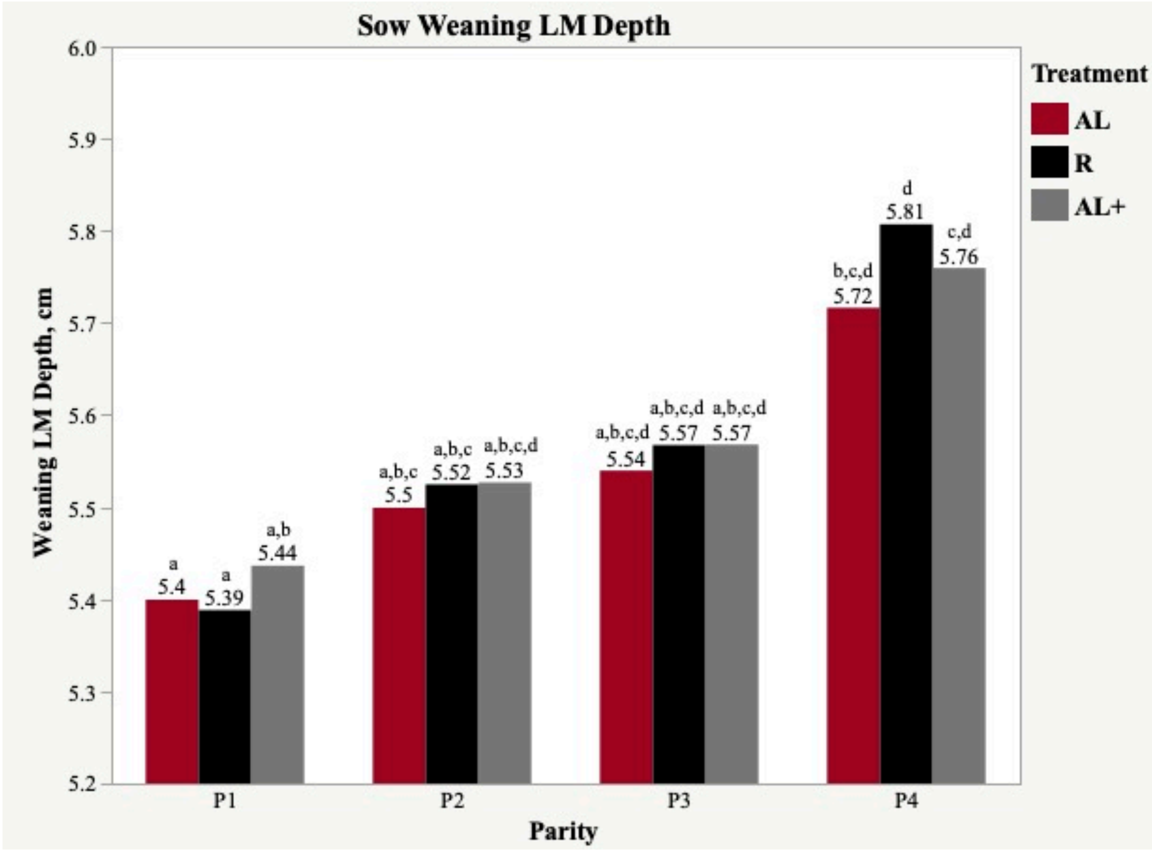

Figure 2.6. LM depth of sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum plus (AL+) regimens at weaning for parities 1 through 4 (LS means; SEM ranged 0.06 to 0.08 cm). The tests of fixed effects, pairwise comparisons, and random effect variance components for the data in this figure is presented in **Table 2.5.**

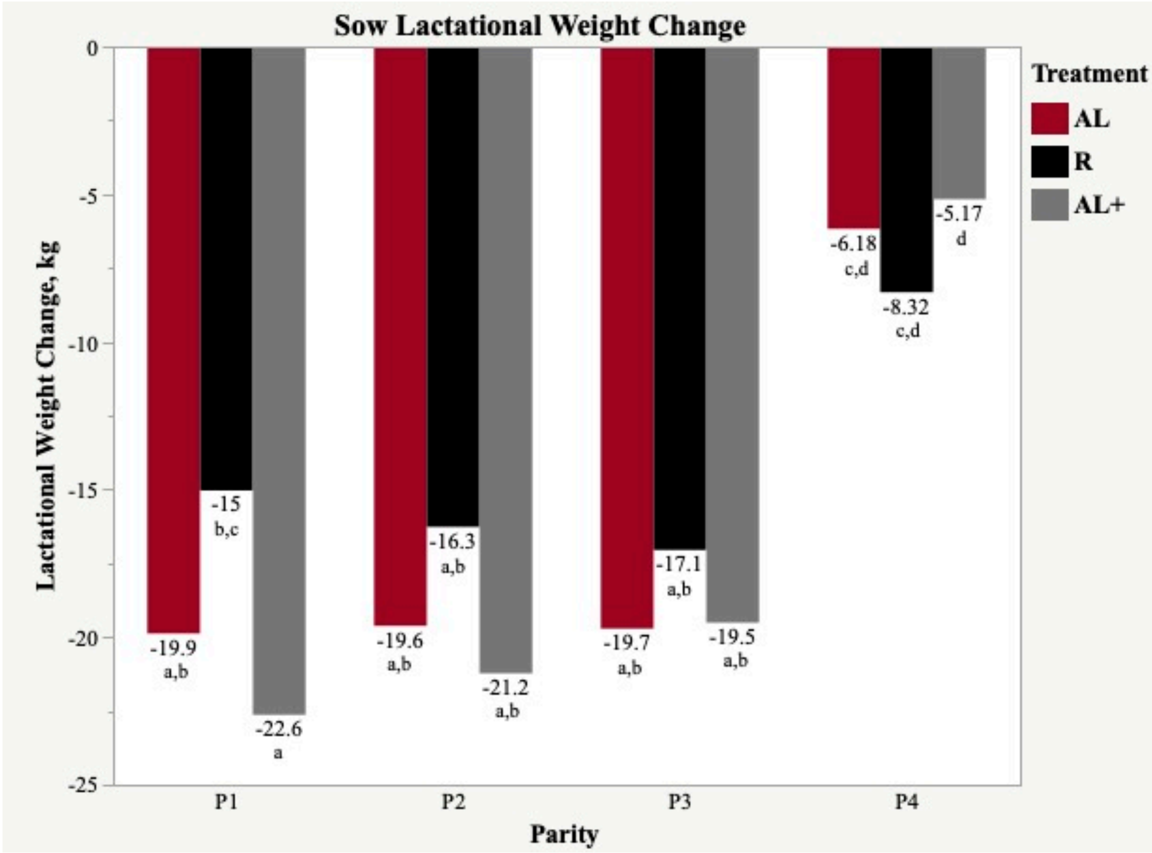

Figure 2.7. Weight change of sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum plus (AL+) regimens from farrowing to weaning for parities 1 through 4 (LS means; SEM ranged 5.88 to 6.15 kg). The tests of fixed effects, pairwise comparisons, and random effect variance components for the data in this figure is presented in **Table 2.5.**

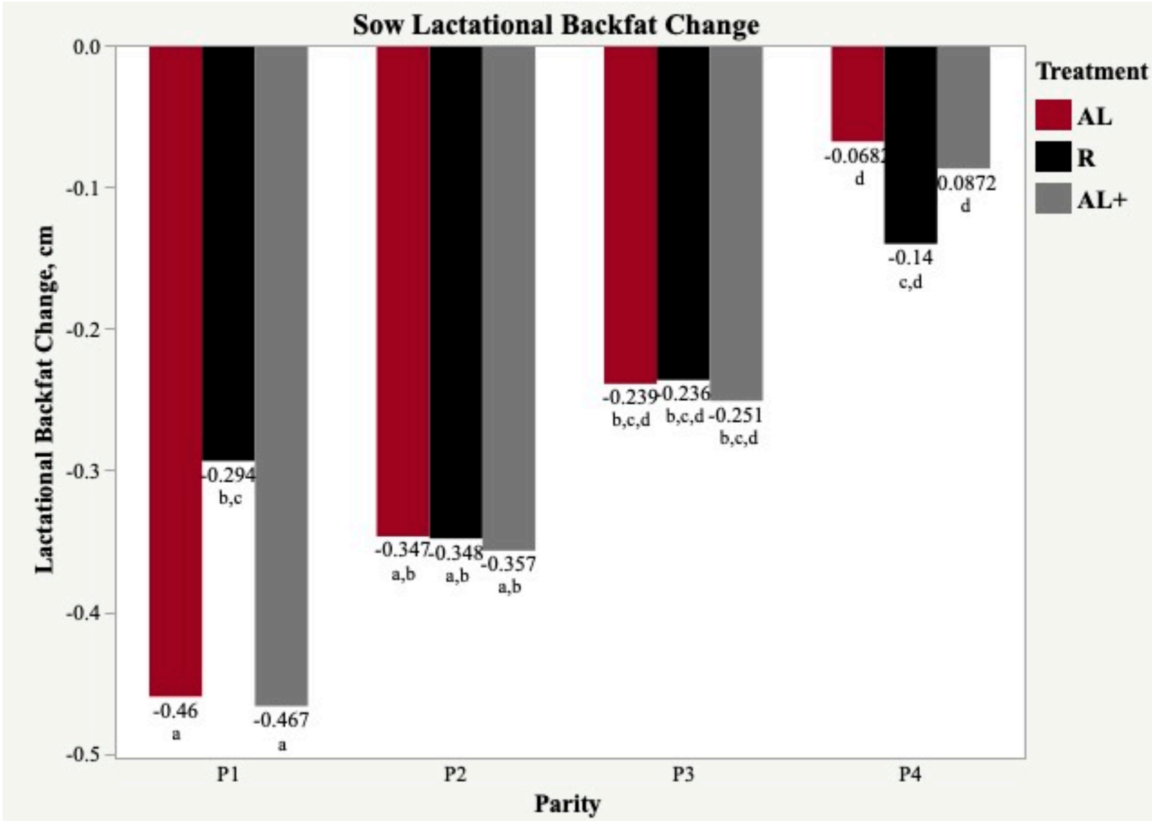

Figure 2.8. Backfat change of sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum plus (AL+) regimens from farrowing to weaning for parities 1 through 4 (LS means; SEM ranged 0.051 to 0.063 cm). The tests of fixed effects, pairwise comparisons, and random effect variance components for the data in this figure is presented in **Table 2.5.**

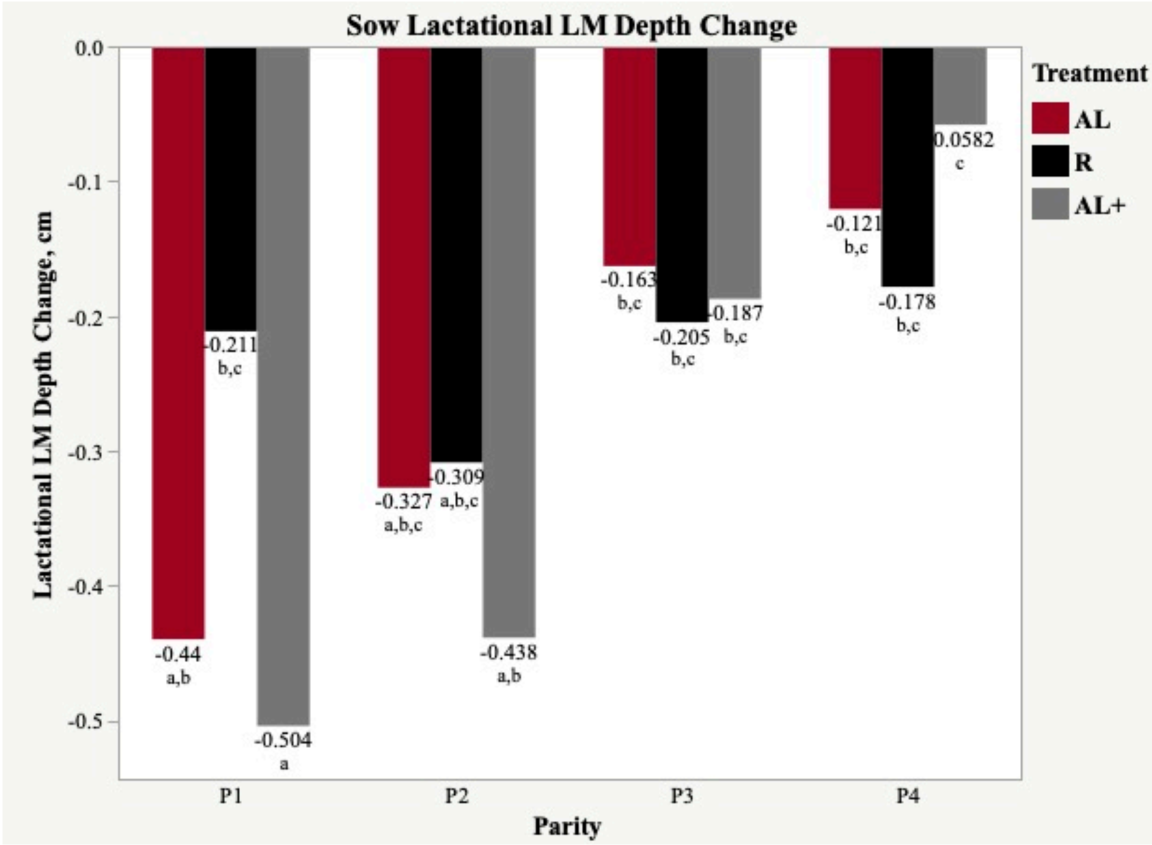

Figure 2.9. LM depth change of sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum plus (AL+) regimens from farrowing to weaning for parities 1 through 4 (LS means; SEM ranged 0.061 to 0.088 cm). The tests of fixed effects**,** pairwise comparisons, and random effect variance components for the data in this figure is presented in **Table 2.5.**

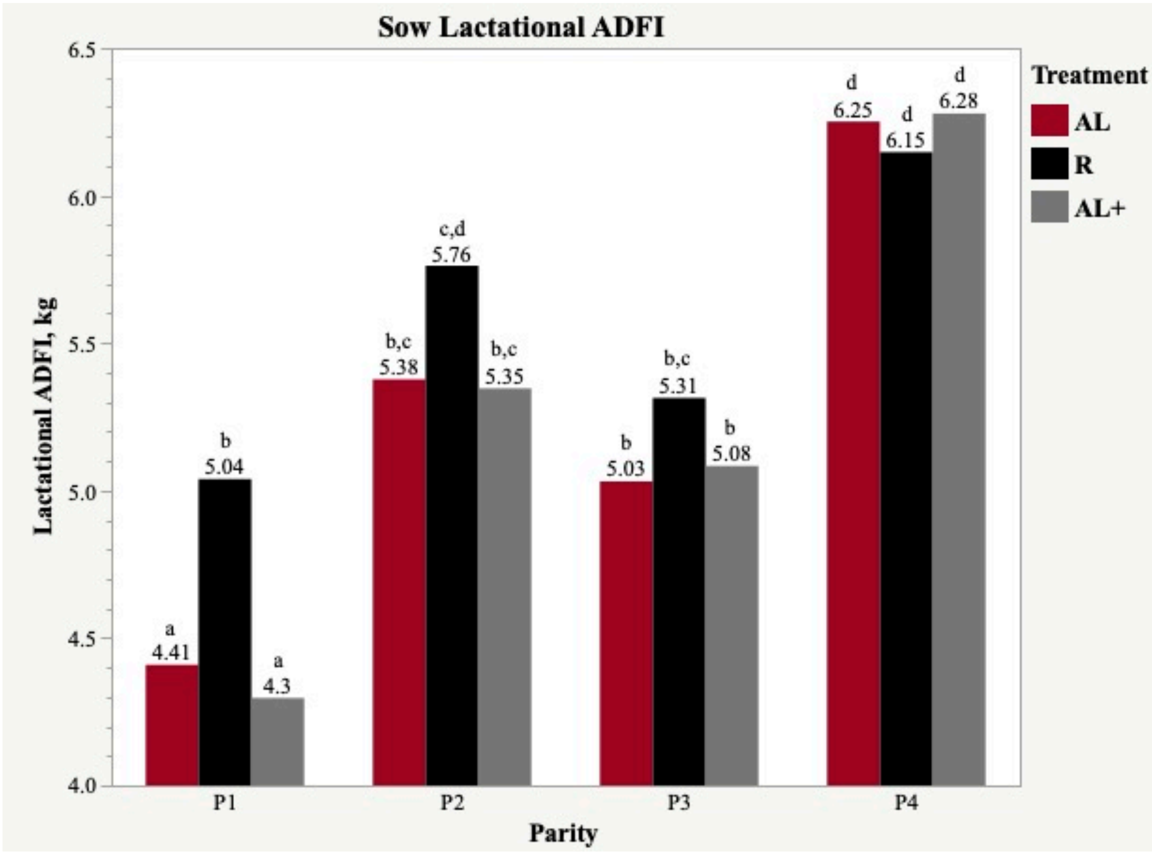

Figure 2.10. Lactational ADFI for sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 0.153 to 0.198 kg). The tests of fixed effects**,** pairwise comparisons, and random effect variance components for the data in this figure is presented in **Table 2.6.**

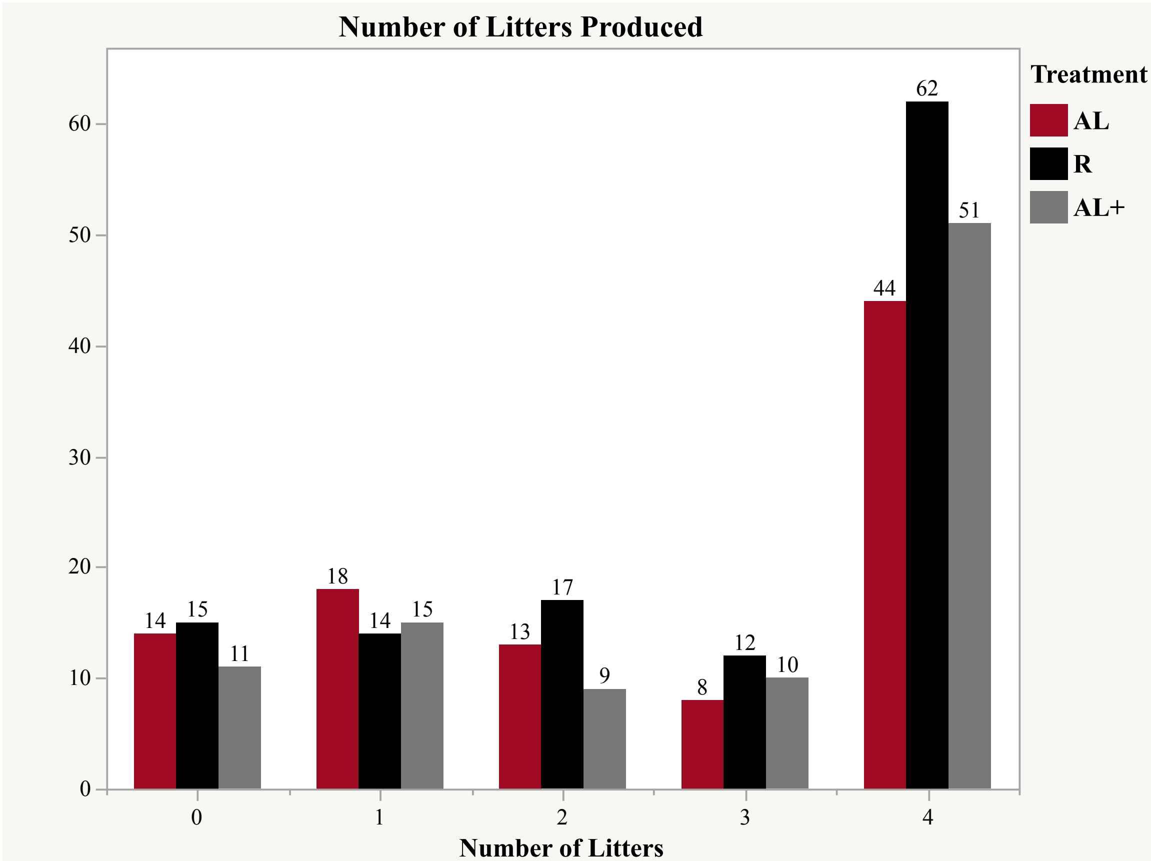

Figure 2.11. Total number of litters produced broken up by developmental treatment

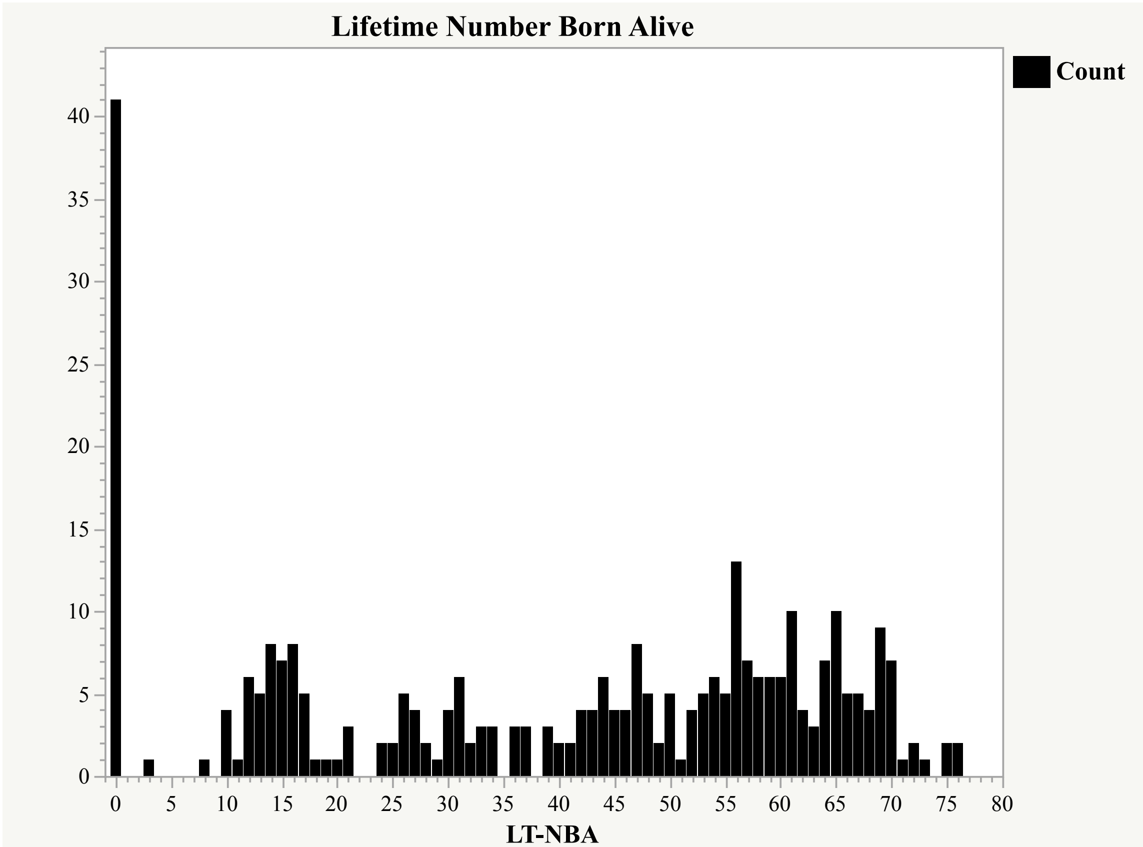

Figure 2.12. Lifetime number of pigs born alive

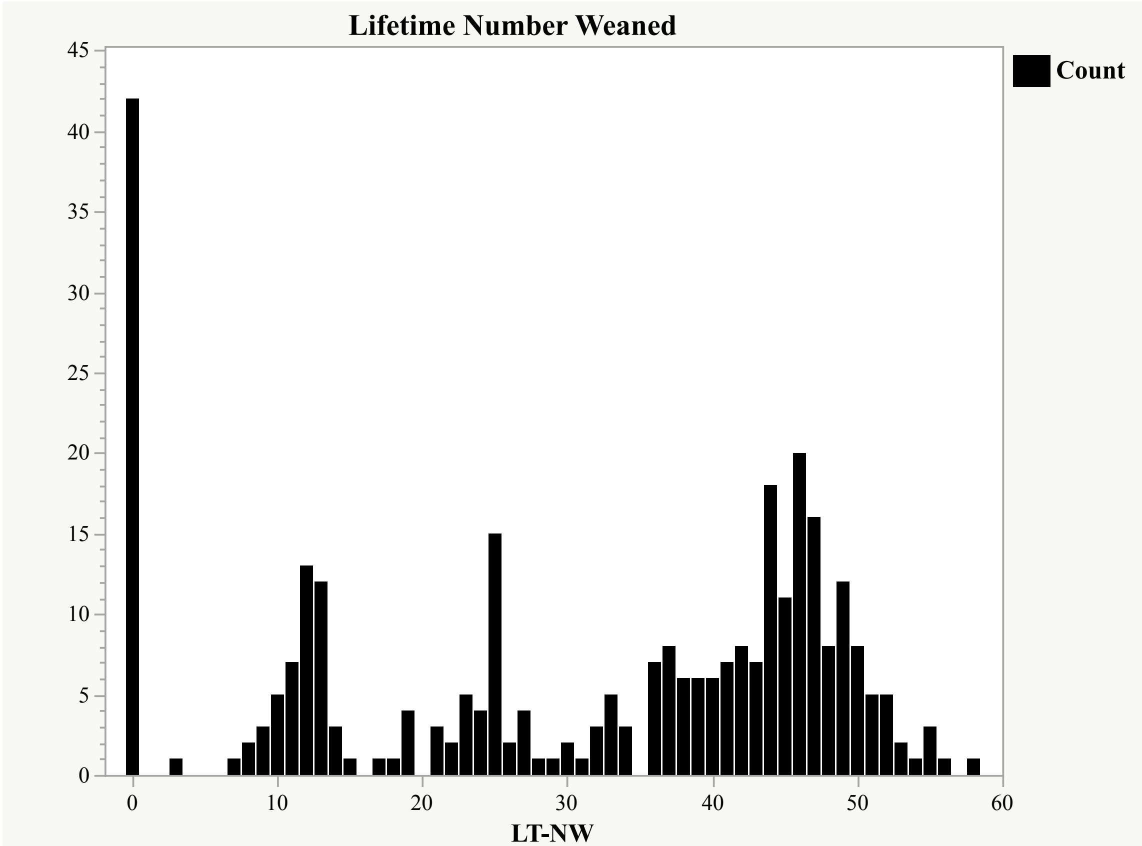

Figure 2.13. Lifetime number of pigs weaned distribution

CHAPTER III. EVALUATION OF 3-PHASE DIETS OF AD LIBITUM ACCESS, ENERGY RESTRICTION THROUGH SOY HULLS, AND AD LIBITUM ACCESS PLUS DURING GILT DEVELOPMENT ON REPRODUCTIVE PERFORMANCE AND LONGEVITY

ABSTRACT

Three different dietary treatments were randomly assigned during development from d 114 to 226 d of age to 256 gilts. Treatments were a corn-soybean meal diet with ad libitum access (AL, n = 96), the AL diet with corn and soybean meal replaced by soy hulls to restrict energy by 25% (R, n = 80), and the AL diet with increased protein and lysine (AL+, n = 80). Age at puberty (AP) was determined via once daily estrus detection. Reasons for gilt removal included failure to express estrus, lameness and structural problems, and sickness. Two gilts died due to unknown causes. A total of 242 gilts remained at the end of the developmental period and 223 of those were selected as breeders. Sow traits measured at farrowing and weaning included weight, backfat, and longissimus muscle (LM) depth. Average daily feed intake (ADFI) was measured during lactation. Litter birth traits taken included total number born (TNB), number born alive (NBA), number of stillborn piglets (SB), number of mummified piglets (Mum), and litter birth weight (LBW). Litter weaning traits recorded included number weaned (NW) and litter weaning weight (LWW). All traits were recorded through 4 parities. Overall lifetime productivity traits included lifetime number of litters, lifetime number born alive, and lifetime number weaned. AP was delayed for R treatment gilts ($P < 0.01$) while no treatment effect was shown for the probability to express estrus. Treatment effects were also shown where R gilts had less weight and backfat at weaning and farrowing ($P < 0.01$) and had greater ($P < 0.01$) lactational ADFI. Treatment effects did not exist for most litter birth and weaning traits. No treatment effect existed for any of the lifetime productivity traits. Parity effects existed for all sow, litter birth, and litter weaning traits except TNB and Mum ($P > 0.10$). Weight increased with parity and parity 4 sows generally had greater values for all sow traits at farrowing and weaning. Lactational ADFI was least at parity 1 and greatest at parity 4. Parity 1 sows generally had lower values for SB, LBW, LWW, and Avg WW. Treatment × parity interaction only existed for farrowing weight ($P = 0.01$), farrowing backfat ($P < 0.01$), and weaning backfat ($P < 0.01$). At parity 1 differences based on treatment were detected in sow traits, where R sows differed from AL and AL+ sows, while at later parities they were similar.

Keywords: birth, development, energy restriction, gilt, lactation, longevity, production, weaning

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INTRODUCTION

Success for a breeding option depends on not only sow production, but also sow longevity. There are economic costs associated with bringing a new gilt into the breeding herd, and she needs to produce at least 3 litters before those costs are recovered (Mote et al., 2009; Patterson and Foxcroft, 2019; Segura-Correa et al., 2019). While it takes approximately 3 litters to recover costs, sows tend to increase litter size through 4 litters, thus taking advantage of that and ensuring a sow not only reaches 3 litters, but 4, helps maximize profit (Patterson and Foxcroft, 2019). This experiment looked at a possible management technique to help ensure a sow produces at least 4 parities. Specifically, the objective was to determine the effects of three, 3-phase diets fed during gilt development from d 114 to 226 (phase 1: d 114-156; phase 2: d 156-198; phase 3: d 198-226) on subsequent reproductive traits and sow longevity through 4 parities. Diets consisted of an ad libitum access diet, a 25% energy restricted using soy hulls, and an ad libitum access diet with increased protein and amino acids.

MATERIALS AND METHODS

Gilt Population

The University of Nebraska selection Line 45 (L45X) was used as the resource population for this experiment. Gilts used in this experiment were from a cross of this line. The selections and formation in developing the L45X line is described by Johnson et al. (1999), Ruíz-Flores and Johnson (2001), and Hsu and Johnson (2014). The cross included breeding the L45X dams with semen from boars belonging to an industry maternal line (L_M) and using resulting gilts for this experiment.

Gilt Management

The gilts chosen for this study were born into replications (rep) during August, 2015 (rep 14) and December, 2015 and January, 2016 (rep 15). Gilts were weaned at approximately 21 d after farrowing. Following weaning, gilts were moved to a nursery and maintained in pens of 30 gilts per pen. All gilts were managed the same, receiving industry standard nursery diets. After the nursery period, gilts were moved to a different barn to grow and mature and again managed similarly and received industry standard diets.

A total of 256 gilts began the experiment (128 gilts per rep) at approximately d 114. To begin the experiment, gilts were assigned to pens of 8 randomly. Pens were 1.6 ×

5.4 m^2 with the floor consisting of 2/3 solid surface and 1/3 slatted surface. Gilts each had 0.36 m^2 feed space and 1.08 m^2 total floor space. The gilt developmental period ended with 242 gilts (117 and 125 gilts from reps 14 and 15, respectively) at approximately 226 d of age.

Dietary Regimens

As previously mentioned, prior to the start of the experiment gilts were managed similarly receiving industry standard diets. To begin the experiment gilts were randomly assigned to pens of 8 and 1 of 3 treatments. They began receiving dietary treatments at approximately d 114. The treatments were all 3-phase regimens. First was an ad libitum access regimen (AL) to a typical corn/soybean meal feed. Second was a corn/soybean meal feed with soy hulls added in place of corn and soybean meal to achieve a 25% energy restriction (R) of the AL diet. The third diet was formulated similar to the AL diet but had increased levels of protein and lysine as well as other amino acids with the Lysine:ME ratio similar to the R diet and total ME similar to the AL diet (AL+). All other nutrients in the diet met or exceeded requirements as stated by the NRC (2012). The treatment diets are shown in **Tables 3.1**, **3.2** and **3.3**. During the developmental period on treatment, start and end feeder weights were recorded, and feed added every 2 wk. The first dietary phase change occurred after 42 d on the phase 1 diet. The second phase change occurred after 42 d on the phase 2 diet. Gilts received the phase 3 diet for 28 d. Gilts were fed dietary treatments for a total of 112 d.

Breeding and Lactation Management

A total of 242 gilts remained at the completion of the gilt developmental period. After the developmental period, 18 were removed for lameness and 1 removed for a belly rupture. The remaining 223 gilts were selected and moved to the breeding barn. These data are available in **Table 3.4**.

In the breeding barn they were again placed into pens of 8 gilts per pen but irrespective of developmental treatment. During the breeding period, gestation, and lactation, gilts were managed according to industry standards and fed the same diets. Diets and management practices were as described by Johnson et al. (2021).

They were checked for exhibiting signs of estrus once daily with boar exposure. If they exhibited estrus, they were bred using artificial insemination each day it was exhibited with semen that was pooled from boars belonging to a commercially-available terminal sire line. Removals were tracked and recorded and categorized as being due to failure to express estrus during the breeding period, lameness or poor health, not being pregnant whether through ultrasound check or aborting, or dying during the gestational period. These removals were tracked through 4 parities and are available in **Table 3.4**. Sows had their piglets cross-fostered after birth without regard to which dietary treatment sows had received during development. Weaning ages for parities 1, 2, 3, and 4 were 20, 19, 20, and 20, respectively.

Traits and Data Analysis

JMP Pro 15 was used to analyze the data with the Fit Model procedure. Tukey HSD All Pairwise Comparisons procedure (JMP Pro 15) was used to complete multiple comparisons. Traits analyzed were categorized into puberty, sow traits, litter birth traits, litter weaning traits, and lifetime productivity.

The first category analyzed was puberty. It was described as the probability to express estrus during the developmental period, where those that did express estrus were assigned 1 and those that did not were assigned 0. Those that did express estrus during that time were analyzed for age at puberty (AP). For these analyses, treatment was included as a fixed effect and rep and pen were included as random effects.

The second category analyzed was sow traits. This included sow weight, sow backfat, and sow longissimus muscle (LM) depth measured at farrowing and weaning. The lactational change calculated as the difference between the trait at weaning and farrowing was also calculated. A note for sow LM depth is that that data were not available for rep 14, and thus only rep 15 data related to sow LM depth for all timepoints were analyzed. During lactation, sow average daily feed intake (ADFI) was also measured. The model to analyze the sow traits included treatment and parity as fixed effects as well as a 2-way interaction between them. Random effects were included as rep, birth litter, sire, and pig.

The third category analyzed was litter birth traits. This included total number born (TNB), number born alive (NBA), number of stillborn piglets (SB), number of mummies (Mum), and total litter birth weight (LBW). The model to analyze these traits was the same as the model used for sow traits.

The fourth category analyzed was litter weaning traits. This included number weaned (NW), total litter weaning weight (LWW), and average piglet weaning weight (Avg WW). The model used to analyze these traits was the same as the model used for the sow traits with the following modifications. For all 3 traits, weaning age and number nursed (NN) were also included in the model as covariates. For Avg WW the number of piglets born alive was added as a covariate.

The final category analyzed was lifetime productivity traits which included the total number of litters produced, the total number of pigs born alive, and the total number weaned. The analysis of these traits included treatment as a fixed effect and rep as a random effect. These traits were calculated based on the 223 gilts that had been selected for breeding. Out of the 223 gilts, 186 farrowed 1 or more litters.

RESULTS

Puberty Traits

Puberty was analyzed as a binomial trait looking at the probability of the gilt to express estrus during development. Probability to express estrus was not affected ($P >$ 0.10) by treatment. Treatment did affect ($P < 0.01$) AP. The all pairwise comparison did not detect a difference ($P > 0.10$) between the AL and AL+ regimens but did detect a difference where the R regimen sows had delayed (d 165; $P < 0.01$) AP compared to both the AL and AL+ regimen sows (d 156 for both). **Table 3.5** provides the LS means, tests of fixed effects, and random effect variance components for both the probability to express estrus and AP.

Sow Traits

Sow traits of weaning and backfat were recorded at farrowing and weaning through parity 4. Differences were calculated to determine change during that timeframe.

Longissimus muscle depth measurements were also taken at those timepoints, but only for Rep 15 sows. Tests of fixed effects, pairwise comparisons, and estimates of random effect variance components for sow traits are given in **Table 3.6**.

Treatment, parity, and treatment × parity effects were all detected ($P < 0.001$, $P < 0.0001$, and $P = 0.0001$, respectively) for sow weight at farrowing. Overall, sows receiving the R regimen weighed less (220 kg; $P < 0.01$) than sows receiving the AL and AL+ regimens (230 and 229 kg, respectively; **Figure 3.1**). Sows weighed more ($P < 0.0001$) with each subsequent parity for parities 1 through 4 (226, 241, 260, and 284 kg, respectively). The treatment × parity effect was detected for all pairwise comparisons except when comparing treatments within the same parity, besides parity 1 where AL vs R was significant ($P < 0.01$) and AL+ vs R showed a trend ($P > 0.10$).

Farrowing backfat was affected ($P < 0.0001$) by development treatment. Sows receiving the R regimen had less (1.78 cm; $P < 0.0001$) backfat than both the AL and AL+ sows. The AL sows had greater (2.23 cm; $P = 0.01$) backfat than the AL+ sows (2.07 cm). Both parity 1 and 4 sows had greater (2.03 and 2.07 cm, respectively; $P < 0.0001$) backfat than parity 2 and 3 sows (1.61 and 1.70 cm, respectively; **Figure 3.2**). Parity 3 sows had greater ($P = 0.01$) backfat than parity 2 sows.

No treatment effect was detected ($P > 0.10$) for sow farrowing LM depth. A parity effect was observed ($P < 0.0001$) for LM depth and all pairwise comparisons between parities were significant except when comparing parities 3 and 4 (5.66 and 5.78 cm; $P > 0.10$). Parity 2 sows had noticeably smaller (5.09 cm; $P < 0.0001$) LM depths than all other parities. Parity 1 sows had greater (5.43 cm; $P < 0.0001$) depth than parity 2 sows but less ($P < 0.001$) depth than parity 3 and 4 sows (**Figure 3.3**).

Comparing weaning weights, R sows weighed less (194 kg; *P* < 0.01) than AL sows (194 kg), but not compared to AL+ sows (189 kg; *P* > 0.10). Sow weight at weaning increased (*P* < 0.0001) with each parity from parity 1 through 4 (189, 213, 234, and 257 kg, respectively; **Figure 3.4**).

Weaning backfat was greatest (1.70 cm; *P* < 0.01) for AL sows, followed by AL+ sows (1.55 cm), and lowest (1.37 cm; *P* < 0.01) for R sows. There was a difference (*P* < 0.0001) detected between all parities except between parities 1 and 3 (1.54 and 1.55 cm, respectively; *P* > 0.10). Parity 2 sows had the least amount of backfat at weaning while parity 4 sows had the greatest amount (1.44 and 1.86 cm, respectively; **Figure 3.5**).

Weaning LM depth was not affected (*P* > 0.10) by treatment, but was affected (*P* < 0.0001) by parity. Parity 1 and 2 sows had less (4.91 and 4.92 cm, respectively; *P* < 0.0001) LM depth than parity 3 and 4 sows (5.53 and 5.69 cm, respectively; **Figure 3.6**). No difference (*P* > 0.10) was detected for LM depth between parity 1 and 2 sows or (*P* > 0.10) between parity 3 and 4 sows.

Weight change during lactation was not affected (*P* > 0.10) by treatment. A parity effect was shown (*P* < 0.0001) and parity 1 sows (-17.66 kg) lost more weight during lactation than parity 2, 3, and 4 sows (-6.78, -5.34, and -8.30 kg, respectively; **Figure 3.7**).

A treatment effect for backfat change during lactation was detected (*P* < 0.05). Restricted energy sows lost less (-0.40 cm; *P* < 0.05) backfat compared to both AL and AL+ sows (-0.52 and -0.51 cm, respectively. No difference (*P* > 0.10) was detected between AL and AL+ sows. Similar to lactational weight change, parity 1 sows lost a greater amount (-0.47 cm; $P < 0.0001$) of backfat during lactation than parity 2, 3, and 4 sows (-0.16, -0.15, and -0.21 cm, respectively; **Figure 3.8**).

Lactational LM depth change was not affected ($P > 0.10$) by treatment but was affected ($P < 0.0001$) by parity. Parity 1 sows lost a greater amount (-0.54 cm; $P < 0.0001$) of LM depth during lactation compared to parities 2, 3, and 4 (-0.19, -0.16, and -0.13 cm, respectively; **Figure 3.9**).

Both treatment and parity affected ($P < 0.01$ and $P < 0.0001$, respectively; **Table 3.7**) sow lactational ADFI. Sows fed the R regimen consumed more (4.63 vs 4.11 and 4.06 kg, respectively; **Figure 3.10**) per day on average during lactation than AL and AL+ sows. Parity 1 sows had the least (4.27 kg) lactational ADFI while parity 4 sows had the greatest (5.87 kg). No difference (5.45 and 5.54 kg, respectively) was observed between parity 2 and 3 sows. No treatment × parity interaction ($P > 0.10$) was detected.

Litter birth traits

A tendency for a treatment effect was observed for number of stillborn piglets and litter birth weight. Sows fed the R regimen tended ($P < 0.10$) to produce fewer stillborn piglets than AL sows (0.98 vs 1.69 piglets). Restricted-regimen sows also tended ($P < 0.10$) to have greater birth weight litters than AL sows (20.40 vs 18.90 kg, respectively). Parity affected number born alive, number of stillborn piglets, and litter birth weight. Parity 1 sows tended (14.62 piglets; $P < 0.10$) to produce more alive piglets than parity 2 and 4 sows (13.74 and 13.65 piglets, respectively). The number of stillborn piglets was less ($P < 0.05$) for parity 1 sows (1.38 piglets) compared to parity 3 and 4 sows (1.87 and 1.96 piglets, respectively). Litter birth weight was also less ($P < 0.05$) for parity 1 sows

(19.53 kg) compared to parity 2, 3, and 4 sows (21.01, 20.72, and 21.08 kg, respectively). No treatment × parity interactions were observed for any litter birth traits. The LS means, tests of fixed effects, and estimates for random effect variance components for the litter birth traits are shown in **Table 3.8**.

Litter weaning traits

Treatment was shown to affect piglet Avg WW ($P < 0.05$) and tended to affect LWW ($P = 0.10$). Sows fed the R regimen had a greater (5.95 kg; $P < 0.05$) Avg WW than sows fed the AL and AL+ regimens (5.63 and 5.64 kg, respectively). Restricted-energy sows tended (70.56 kg; $P < 0.10$) to produce greater LWWs than AL+ sows (65.84 kg). Parity affected all litter weaning traits. Parity 3 and 4 sows produced fewer (10.70 piglets for both; $P < 0.05$) piglets at weaning than parity 1 and 2 sows (11.81 and 11.23 piglets, respectively). Parity 1 sows produced more ($P < 0.01$) piglets at weaning compared to parity 2 sows. Parity 1 sows had a lower (67.64 kg; $P < 0.05$) LWW than parity 2 sows (71.32 kg). Parity 3 sows had a lighter (66.99 kg; $P < 0.05$) LWW than parity 2 and 4 sows (71.32 and 71.00 kg, respectively). For Avg WW, parity 1 sows had lighter (5.74 kg; $P < 0.0001$) weights than parity 2, 3, and 4 sows (6.36, 6.26, and 6.65 kg, respectively). Parity 4 sows had the greatest ($P < 0.001$) LWWs compared to the other 3 parities. No treatment × parity interaction was detected. These tests of fixed effects as well as LS means and estimates for random effect variance components are shown in **Table 3.9**.

Lifetime productivity traits

The traits for lifetime productivity were calculated based on the 223 gilts that were selected for breeding. Out of the 223 gilts, 186 produced 1 or more litters, while 105 of them produced 4 litters (**Figure 3.11)**. The total number born alive per gilt ranged from 0 to 75 (**Figure 3.12**). The total number of piglets weaned per sow ranged from 0 to 54 (**Figure 3.13**). LS means were calculated for traits for lifetime productivity (**Table 3.10**), and while those fed the AL+ regimen had numerically greater values compared to those receiving the AL and R regimens, there was no difference shown among treatments.

DISCUSSION

Treatment effects

Age at puberty is an important trait to identify as it can be used to help predict future reproductive longevity, and thus help predict if a gilt will have a positive impact on the operation in the future. The ideal AP is prior to 220 d of age as that is a predictor for longer longevity (Patterson and Foxcroft, 2019). No difference was observed for the probability to express estrus based on developmental treatment. When looking at AP, it was delayed for those gilts fed the R regimen ($P < 0.01$).

The delayed AP agrees with what was observed by Miller et al. (2011) where a similar 25% energy restriction was used, but through limiting intake rather than using soy hulls. They had also shown a difference for the probability to express estrus, which was not observed in this analysis. This could be due to sample size. Our sample size was much smaller at the beginning of the developmental period than theirs (256 gilts vs. 655

gilts, respectively). Our per treatment sample size was even smaller as we divided our total sample size into 3 treatments; whereas, they divided theirs into only 2 treatments.

Patterson et al. (2002) completed 2 experiments with restricted energy and detected no difference in AP. Experiment 1 began at d 96 and restricted energy to 87% (LL diet) of that of the maximum growth potential diet (LP diet) and lasted until puberty; whereas experiment 2 began at d 88 and restricted energy to 78% (RL diet), again lasting until puberty. This disagrees with the findings of the present study. Looking at the actual ME consumed, experiment 1 gilts consumed 8.5 and 8.3 Mcal/day for the LP and LL diets, respectively, representing a 98% energy restriction. Experiment 2 gilts consumed 7.6 and 7.2 Mcal/day for the LP and RL diets, respectively, representing a 95% energy restriction. So while they formulated diets to certain energy restrictions, actual consumptions resulted in a lesser degree of energy restriction for both experiments, which can explain why they did not find a difference in AP based on energy restriction.

Newton and Mahan (1993) restricted feed intake and did not observe a difference in AP. They had restricted total feed intake; whereas, we restricted only energy intake. They also did not begin their restriction until 150 d of age and we began at 114 d of age. Presumably they did not observe a difference in AP as we did in our study due to beginning the restriction at a later age, suggesting AP is affected by manipulations earlier in life more than those closer to when it occurs.

A different study by Newton and Mahan (1992) restricted energy intake to 50 and 75% of that of ad libitum access. They again did not detect a difference in AP, or in the proportion that attained puberty. While they began their treatments earlier than their previous experiment discussed, at 135 d, it again was not as early as we initiated our experiment, thus possibly accounting for no difference in AP.

Klindt et al. (2001b) implemented treatments with energy restriction from d 91 to 175 of age at 4 different levels and did not see a consistent delay in AP. Their treatments restricted energy to 50%, 62.5%, 75%, and 87.5% of ad libitum access, but did not include an ad libitum access treatment group. Those with the greatest amount of energy restriction had the earliest AP, followed by those with the least amount of energy restriction, and the two in between groups had the latest AP. Management after d 175 could have impacted these results as gilts were allowed ad libitum access to feed and those with the greatest amount of energy restriction consumed the greatest amount of feed during that time, compensating for the previous restricted intake.

In a different experiment, Klindt et al. (2001a) again did not see a delay in age at puberty. They again fed treatments from d 91 to 175 of age, but had 3 treatment groups consisting of an ad libitum group, a control group where they received ad libitum access until they reached 100 kg at which time they received 90% of ad libitum intake, and a restricted group which received 74% of ad libitum intake.

Den Hartog and Noordewier (1984) observed similar results to ours for probability to express estrus and AP. While their energy levels were different in that they had 4 different levels, they were similar in that they implemented boar exposure and detected no effect on spontaneous estrus, or probability to express estrus, based on energy level (intake). They also showed that sows that had received greater energy level diets reached puberty sooner than those that had received lower energy level diets. Their treatment length was greater than ours, beginning at approximately d 84 and ending at d

266 and the present study began at d 114 and ended at d 226. This could suggest that the length of energy restriction is not as significant as the ages during which energy restriction is implemented.

Sow traits were not consistently affected by treatment. Weight at farrowing and weaning were affected by treatment with those fed the R regimen weighing less. This is expected, especially in those earlier parities and agrees with results shown by Newton and Mahan (1993). Sow backfat at weaning and farrowing was also affected by treatment where those fed the R regimen had less backfat than those fed the AL regimen at both timepoints as well as the AL+ regimen at farrowing. Again, this was expected due to the energy restriction. Klindt et al. (2001a) did not detect a difference in weight or backfat at the end of pregnancy (farrowing), but that could be due to compensatory gains because sows that received the restricted regimen weighed less and had less backfat at prior timepoints including at 175 d of age, puberty, and at the beginning of pregnancy. Johnson et al. (2021) observed similar results for backfat at weaning, but only detected trends for farrowing weight and backfat and did not find that a 25% energy restriction during development affected weaning weight. This could be due to their treatment timeframe being later as they implemented treatments from d 123 to 235 (we implemented them from d 114 to 226). In the present study LM depth at farrowing tended to be less for those fed the R diet compared to those fed the AL diet, but no difference was detected at weaning. The failure to see differences for LM depth as we did with sow weight and backfat may be due to only having LM depth data for rep 15 sows.

Most litter birth traits were not affected by treatment, though a trend was observed for both number of stillborn piglets and litter birth weight. Johnson et al. (2021) did not see an effect of treatment from a 25% energy restriction on any of the litter birth traits. Further research should be done to see if those trends have any merit.

Examining litter weaning traits based on treatment, a trend was detected for litter weaning weight where sows developed on the R regimen tended to produce greater LWWs than those fed the AL+ regimen. Johnson et al. (2021) examined litter weaning weight and did not find a treatment effect. Their sample size was much larger. Average piglet weaning weight was affected by treatment where sows receiving the R regimen weaned heavier individual piglets than sows receiving the AL and AL+ regimens.

None of the lifetime productivity traits were affected by treatment, agreeing with Johnson et al. (2021). They determined sows receiving the AL regimen had numerically smaller values for total number of litters produced, total number of pigs born alive, and total number weaned compared to the R regimen, but in our present study those fed the AL+ regimen had numerically larger values for each trait compared to the AL and R regimens. Further research may be able to find statistical differences.

Parity effects

All sow traits were affected by parity except LM depth at farrowing. Longissimus muscle depth at all measurements was only available for Rep 15, and thus a smaller sample size. Regardless of treatment, farrowing LM depths were decreased during parity 2 compared to all other parities. This is important to note as it would have been expected to see a slight increase as parity increased as sows were getting heavier with age. The decrease at parity 2 cannot be explained relative to parity effects.

Approximately half of the litter birth traits were affected by parity. Number born alive tended to be greater for parity 1 sows compared to parities 2 and 4. Parity 1 sows also produced fewer stillborn piglets compared to parities 3 and 4 and had lower litter birth weights than parities 2, 3, and 4. Total number born and number of mummies were not affected by parity. Johnson et al. (2021) detected some similar results where Mum was not affected by parity and parity 2 sows had greater LBWs than parity 1 sows.

All litter weaning traits were affected by parity, agreeing with Johnson et al. (2021) and Newton and Mahan (1993). Number weaned was lower for parities 3 and 4 than parities 1 and 2, similar to Johnson et al. (2021), and in the present study parity 1 sows weaned the greatest number, whereas in that study parity 2 sows weaned the greatest number. Newton and Mahan (1993) determined different results where parity 3 sows weaned more than parity 1 and 2 sows. Litter weaning weights were lower for parity 1 sows compared to parity 2, and parity 3 sows had lower LWWs than parity 2 and 4 sows. Both Johnson et al. (2021) and Newton and Mahan (1993) had similar results for LWWs when comparing parities 1 and 2, but Johnson et al. (2021) determined parity 3 sows produced greater LWWs than parity 4 sows while Newton and Mahan (1993) determined parity 3 sows produced lower LWWs than parity 2 sows. Average piglet weaning weight was lower for parity 1 sows compared to parities 2, 3, and 4, which parity 4 sows having the greatest Avg WWs.

CONCLUSION

Three treatments were fed in 3 phases (as presented in **Tables 3.1, 3.2,** and **3.3**) to gilts during development from d 114 to 226 of age consisting of a typical corn-soybean meal diet fed with ad libitum access (AL), a 25% energy restriction compared to the ad libitum access diet through use of soy hulls (R), and the ad libitum access diet with increased protein, lysine, and other amino acids (AL+). Sows fed the AL and AL+ treatments remained similar for most all traits analyzed while those fed the R treatment differed for a lot of the traits. Specifically, those fed the R treatment had delayed age at puberty and had lower weights and less backfat at farrowing and weaning. No treatment effects were detected for the lifetime productivity traits for total number of litters, total number born alive, and total number weaned. Parity affected all sow traits and litter weaning traits, as well as most of the litter birth traits. Sow traits of weight, backfat, and longissimus muscle depth were generally greater for parity 4. Values were generally lower for number of stillborn, litter birth weight, litter weaning weight, and average weaning weight at parity 1. Treatment × parity interactions were only observed for farrowing weight, farrowing backfat, and weaning backfat, where differences based on treatment were generally greater at parity 1 and less at later parities. Overall, the ad libitum access plus diet produced similar results and did not find any benefit in terms of production and longevity traits over the ad libitum access diet. The restricted-energy diet delayed age at puberty but produced similar results for production and longevity traits to the ad libitum access and ad libitum access plus diets. With this we can conclude that restricting energy has the possibility to cut costs during development using soy hulls while still producing similar results in terms of productivity and longevity.

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Table 3.1. Composition of phase 1 diets for ad libitum (AL), restricted (R), and ad libitum plus (AL+) diets fed during gilt development (approximately d 114 to 156)

	Diet		
Item	AL	R	AL+
Ingredient, %			
Corn	72.52	39.59	70.38
Soybean meal, 47.5% CP	21.53	17.79	23.35
Soybean hulls		40.00	
Tallow	3.00		3.00
Dicalcium phosphate	1.37	1.72	1.37
Limestone	0.68		0.68
Salt	0.50	0.50	0.50
F-G-N Vitamin Premix[1]	0.25	0.25	0.25
TM Premix[2]	0.15	0.15	0.15
L-Lys-HCL			0.15
L-Thr			0.09
DL-Met			0.05
L-Trp			0.03
Total	100.00	100.00	100.00
Calculated analysis			
ME, kcal/kg	3,406	2,705	3,408
CP, %	13.72	12.68	14.34
Lysine, %	0.70	0.70	0.86
Ca, %	0.67	0.71	0.68
P, %	0.60	0.60	0.61

[1] Diet AL, R and AL+ supplied per kilogram of diet: vitamin A (as retinyl acetate), 5,500 IU; vitamin D (as cholecalciferol), 550 IU; vitamin E (as α-tocopherol acetate), 30 IU; vitamin K (as menadione dimethylpyrimidinol bisulfite), 4.4 mg; riboflavin, 11.0 mg; d-pantothenic acid, 22.05 mg; niacin, 33.0 mg; and vitamin B12, 33.0 mg.

[2]Diet AL, R and AL+ supplied per kilogram of diet: Zn (as ZnSO4), 127 mg; Fe (as $FeSO_4 \cdot H_2O$), 128 mg; Mn (as MnO), 30 mg; Cu (as $CuSO_4 \cdot 5H_2O$), 11 mg; I [as $Ca(IO_3) \cdot H_2O$], 0.26 mg; Se (as Na_2SeO_3), 0.3 mg.

Table 3.2. Composition of phase 2 diets for ad libitum (AL), restricted (R), and ad libitum plus (AL+) diets fed during development to gilts (approximately d 156 to 198)

	Diet		
Item	AL	R	AL+
Ingredient, %			
Corn	76.32	43.17	74.66
Soybean meal, 47.5% CP	17.66	14.13	19.00
Soybean hulls		40.00	
Tallow	3.00		3.00
Dicalcium phosphate	1.46	1.80	1.46
Limestone	0.66		0.66
Salt	0.50	0.50	0.50
F-G-N Vitamin Premix[1]	0.25	0.25	0.25
TM Premix[2]	0.15	0.15	0.15
L-Lys-HCL			0.15
L-Thr			0.09
DL-Met			0.05
L-Trp			0.03
Total	100.00	100.00	100.00
Calculated analysis			
ME, kcal/kg	3,408	2,706	3,408
CP, %	12.36	11.39	12.81
Lysine, %	0.61	0.61	0.76
Ca, %	0.67	0.72	0.68
P, %	0.60	0.60	0.60

[1]Diet AL, R and AL+ supplied per kilogram of diet: vitamin A (as retinyl acetate), 5,500 IU; vitamin D (as cholecalciferol), 550 IU; vitamin E (as α-tocopherol acetate), 30 IU; vitamin K (as menadione dimethylpyrimidinol bisulfite), 4.4 mg; riboflavin, 11.0 mg; d-pantothenic acid, 22.05 mg; niacin, 33.0 mg; and vitamin B12, 33.0 mg.

[2] Diet AL, R and AL+ supplied per kilogram of diet: Zn (as ZnSO4), 127 mg; Fe (as $FeSO_4 \cdot H_2O$), 128 mg; Mn (as MnO), 30 mg; Cu (as $CuSO_4 \cdot 5H_2O$), 11 mg; I [as $Ca(IO_3) \cdot H_2O$], 0.26 mg; Se (as Na_2SeO_3), 0.3 mg.

Table 3.3. Composition of phase 3 diets for ad libitum (AL), restricted (R), and ad libitum plus (AL+) diets fed during development to gilts (approximately d 198 to 226)

	Diet		
Item	AL	R	AL+
Ingredient, %			
Corn	80.13	47.16	78.60
Soybean meal, 47.5% CP	13.79	10.05	15.00
Soybean hulls		40.00	
Tallow	3.00		3.00
Dicalcium phosphate	1.54	1.89	1.54
Limestone	0.64		0.64
Salt	0.50	0.50	0.50
Breeding Swine Vitamin Premix[1]	0.25	0.25	0.25
TM Premix[2]	0.15	0.15	0.15
L-Lys-HCL			0.15
L-Thr			0.09
DL-Met			0.05
L-Trp			0.03
Total	100.00	100.00	100.00
Calculated analysis			
ME, kcal/kg	3410	2707	3412
CP, %	11.01	9.96	11.41
Lysine, %	0.51	0.51	0.66
Ca, %	0.67	0.73	0.68
P, %	0.60	0.60	0.60

[1]Diet AL, R and AL+ supplied per kilogram of diet: vitamin A (as retinyl acetate), 6,600 IU; vitamin D (as cholecalciferol), 660 IU; vitamin E (as α-tocopherol acetate), 66 IU; vitamin K (as menadione dimethylpyrimidinol bisulfite), 4.4 mg; riboflavin, 11.0 mg; d-pantothenic acid, 22.05 mg; niacin, 33.0 mg; and vitamin B12, 22.05 mg.

[2] Diet AL, R and AL+ supplied per kilogram of diet: Zn (as ZnSO4), 127 mg; Fe (as $FeSO_4 \cdot H_2O$), 128 mg; Mn (as MnO), 30 mg; Cu (as $CuSO_4 \cdot 5H_2O$), 11 mg; I [as $Ca(IO_3) \cdot H_2O$], 0.26 mg; Se (as Na_2SeO_3), 0.3 mg.

Table 3.4. Number of gilts at beginning (114 d) and end (226 d) of developmental period. Outcomes of breedings and litters through 4 parities[1]

	Number at			Culled/died			
Trt[2]	114 d	226 d	AP	No AP	Late AP	D/L	Cull
AL	96	92	94	0	0	3	1
R	80	75	78	0	0	7	0
AL+	80	75	80	0	0	8	0
Total	256	242	252	0	0	18	1

		Culled					
	Breeders	B/O	NE	DG	F/L/I	Litters	DPW
	Parity 1						
AL	88	10	2	1	4	71	0
R	68	6	4	1	3	54	1
AL+	67	0	3	2	1	61	1
Total	223	16	9	4	8	186	2
	Parity 2						
AL	71	6	6	1	1	57	1
R	53	1	5	0	0	47	1
AL+	60	2	6	1	1	50	2
Total	184	9	17	2	2	154	4
	Parity 3						
AL	56	3	0	1	1	51	1
R	46	5	2	1	0	38	0
AL+	48	2	1	0	1	44	2
Total	150	10	3	2	2	133	3
	Parity 4						
AL	50	8	1	0	1	40	0
R	38	6	2	0	0	30	0
AL+	42	4	1	1	1	35	0
Total	130	18	4	1	2	105	0

[1]No AP = no estrus exhibited, Late AP = delayed or irregular estrus which prevented breeding at second estrus, D/L = died or exhibited lameness, Cull = culled for belly rupture, B/O = bred, but determined open, NE = no estrus exhibited during the breeding period, DG = died during gestation, F/L/I = foot or leg structure, lameness, or injury, DPW = farrowed litter, but died while lactating or prior to breeding after weaning
[2]AL = ad libitum, R = restricted energy intake, AL+ = ad libitum plus

Table 3.5. LS means, tests of fixed effects, and random effect variance components for the probability to express pubertal estrus and age at puberty for gilts based on developmental dietary treatment

Item[1]	Probability to express pubertal estrus	Age at puberty, d
	LS mean ± SEM	
AL	0.98 ± 0.013	156.07 ± 1.90
R	0.98 ± 0.014	164.60 ± 2.09
AL+	1.00 ± 0.014	155.82 ± 2.06
	Tests of fixed effects, Prob > F	
Treatment	0.39	<0.01
	Random effect variance components	
Rep	0.000	41.892
Pen	0.000	0.001
Residual	0.015	340.329

[1]AL = ad libitum access, R = restricted energy, AL+ = ad libitum plus

Table 3.6. Tests of fixed effects, all pairwise comparisons, and estimates for random effect variance components for sow weight, backfat and LM depth at farrowing (FW, FB, FLD) and weaning (WW, WB, WLD), as well as weight, backfat and LM depth change during lactation from farrowing to weaning (WC, BC, LDC)[1]

Item[2]	FW, kg	FB, cm	FLD, cm	WW, kg	WB, cm	WLD, cm	WC, kg	BC, cm	LDC, cm
	Tests of fixed effects, Prob > F								
Treatment (T)	<0.01	<0.01	0.10	0.01	<0.01	0.71	0.27	0.02	0.62
Parity (P)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
T × P	0.01	<0.01	0.14	<0.01	<0.01	0.14	0.90	0.10	0.29
	Tukey HSD all pairwise comparisons, Prob > |t|								
AL vs R	<0.01	<0.01	0.13	<0.01	<0.01	0.70	0.82	0.02	0.84
AL vs AL+	0.81	0.01	0.21	0.20	0.01	0.86	0.52	0.99	0.59
R vs AL+	<0.01	<0.01	0.94	0.31	<0.01	0.95	0.25	0.05	0.94
P1 vs P2	<0.01	<0.01	<0.01	<0.01	<0.01	1.00	<0.01	<0.01	<0.01
P1 vs P3	<0.01	<0.01	<0.01	<0.01	0.99	<0.01	<0.01	<0.01	<0.01
P1 vs P4	<0.01	0.51	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P2 vs P3	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.86	0.95	0.98
P2 vs P4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.87	0.43	0.89
P3 vs P4	<0.01	<0.01	0.28	<0.01	<0.01	0.10	0.46	0.20	0.98
	Random effect variance components								
Replication	34.20	0.00	0.00	22.76	0.00	0.00	0.00	0.001	0.00
Litter	0.00	0.01	0.02	10.40	0.01	0.00	4.84	0.001	0.00
Sire	54.00	0.01	0.00	42.64	0.01	0.00	0.00	0.002	0.01
Pig	102.18	0.04	0.07	173.00	0.04	0.13	16.96	0.003	0.00
Residual	107.72	0.06	0.14	110.12	0.04	0.27	234.99	0.059	0.23

[1]LM depth measurements only available for Rep 15

[2]AL = ad libitum, R = restricted energy, AL+ = ad libitum plus, P1 – P4 = parity 1 – 4

Table 3.7. LS means, tests of fixed effects, prob > F, and random effect variance components for sow lactational ADFI

Item[1]	Lactational ADFI, kg
	LS means ± SEM
AL	4.11 ± 0.13
R	4.63 ± 0.14
AL+	4.06 ± 0.14
P1	4.27 ± 0.09
P2	5.45 ± 0.09
P3	5.54 ± 0.10
P4	5.87 ± 0.11
	Tests of fixed effects, Prob > F
Treatment (T)	<0.01
Parity (P)	<0.01
T × P	0.17
	Random effect variance components
Replication	0.00
Litter	0.06
Sire	0.01
Pig	0.21
Residual	0.72

[1]AL = ad libitum, R = restricted energy, AL+ = ad libitum plus, P1 – P4 = parity 1 – 4

Table 3.8. LS means, tests of fixed effects, prob > F, and estimates for random effect variance components for litter birth traits[1]

Item[2]	TNB	NBA	SB	Mum	LBW,kg
	LS means				
AL	15.92 ± 0.49	14.23 ± 0.46	1.69 ± 0.23	0.57 ± 0.12	18.90 ± 0.56
R	16.24 ± 0.55	15.27 ± 0.51	0.98 ± 0.26	0.49 ± 0.14	20.40 ± 0.62
AL+	15.83 ± 0.53	14.36 ± 0.49	1.47 ± 0.25	0.36 ± 0.13	19.29 ± 0.60
P1	16.00 ± 0.35	14.62 ± 0.33	1.38 ± 0.16	0.47 ± 0.09	19.53 ± 0.43
P2	15.25 ± 0.37	13.74 ± 0.35	1.52 ± 0.17	0.40 ± 0.10	20.01 ± 0.45
P3	15.74 ± 0.39	13.88 ± 0.37	1.87 ± 0.18	0.41 ± 0.10	20.72 ± 0.47
P4	15.59 ± 0.43	13.65 ± 0.40	1.96 ± 0.20	0.47 ± 0.11	21.08 ± 0.50
	Tests of fixed effects, Prob > F				
Treatment (T)	0.82	0.21	0.10	0.37	0.09
Parity (P)	0.26	0.03	0.01	0.83	<0.01
T × P	0.60	0.61	0.47	0.17	0.66
	Random effect variance components				
Replication	0.00	0.00	0.00	0.01	0.00
Litter	0.45	0.28	0.13	0.00	1.55
Sire	0.64	0.70	0.02	0.02	1.02
Pig	1.62	1.01	0.67	0.08	1.57
Residual	11.62	10.39	2.67	0.68	13.02

[1]TNB = total number born, NBA = number born alive, SB = number of stillborn pigs at birth, Mum = number of mummified pigs at birth, LBW,kg = litter birth weight in kg
[2]AL = ad libitum, R = restricted energy diet, AL+ = ad libitum plus, P1 – P4 = parity 1 – 4

Table 3.9. LS means, tests of fixed effects, prob > F. and estimates for random effect variance components for litter weaning traits[1]

Item[2]	NW	LWW,kg	Avg WW, kg
	LS means ± SEM		
AL	11.80 ± 0.21	66.51 ± 1.54	5.63 ± 0.09
R	11.93 ± 0.24	70.56 ± 1.75	5.95 ± 0.10
AL+	11.70 ± 0.23	65.84 ± 1.66	5.64 ± 0.10
P1	11.81 ± 0.15	67.64 ± 1.05	5.74 ± 0.07
P2	11.23 ± 0.16	71.32 ± 1.12	6.36 ± 0.07
P3	10.70 ± 0.16	66.99 ± 1.18	6.26 ± 0.08
P4	10.70 ± 0.18	71.00 ± 1.29	6.65 ± 0.08
	Tests of fixed effects, Prob > F		
Treatment (T)	0.76	0.09	0.02
Parity (P)	<0.01	<0.01	<0.01
T × P	0.29	0.12	0.29
Wean age	<0.01	<0.01	<0.01
NN	<0.01	0.53	<0.01
NBA			<0.01
	Random effect variance components		
Replication	0.00	0.00	0.00
Litter	0.10	9.53	0.03
Sire	0.05	0.00	0.03
Pig	0.50	35.24	0.14
Residual	2.09	108.32	0.29

[1]NW = number of piglets weaned, LWW, kg = litter weaning weight in kg, Avg WW, kg = piglet average weaning weight in kg

[2]AL = ad libitum, R = restricted energy diet, AL+ = ad libitum plus, P1 – P4 = parity 1 – 4, NN = number nursed after crossfostering, NBA = number born alive

Table 3.10. LS means, tests of fixed effects, and random effect variance components for number of litters, total number of pigs born alive and total number weaned for each female selected as a breeder based on developmental regimen

Item[1]	Number of litters	Total number pigs born alive	Total number weaned
	LS means ± SEM		
AL	2.49 ± 0.17	34.69 ± 2.49	27.50 ± 1.93
R	2.49 ± 0.19	35.84 ± 2.83	27.79 ± 2.20
AL+	2.84 ± 0.19	40.03 ± 2.85	31.04 ± 2.21
	Tests of fixed effects, Prob > F		
Treatment	0.32	0.35	0.43
	Random effect variance components		
Replication	0.00	0.00	0.00
Residual	2.47	544.01	327.90

[1]AL = ad libitum access, R = restricted energy, AL+ = ad libitum plus

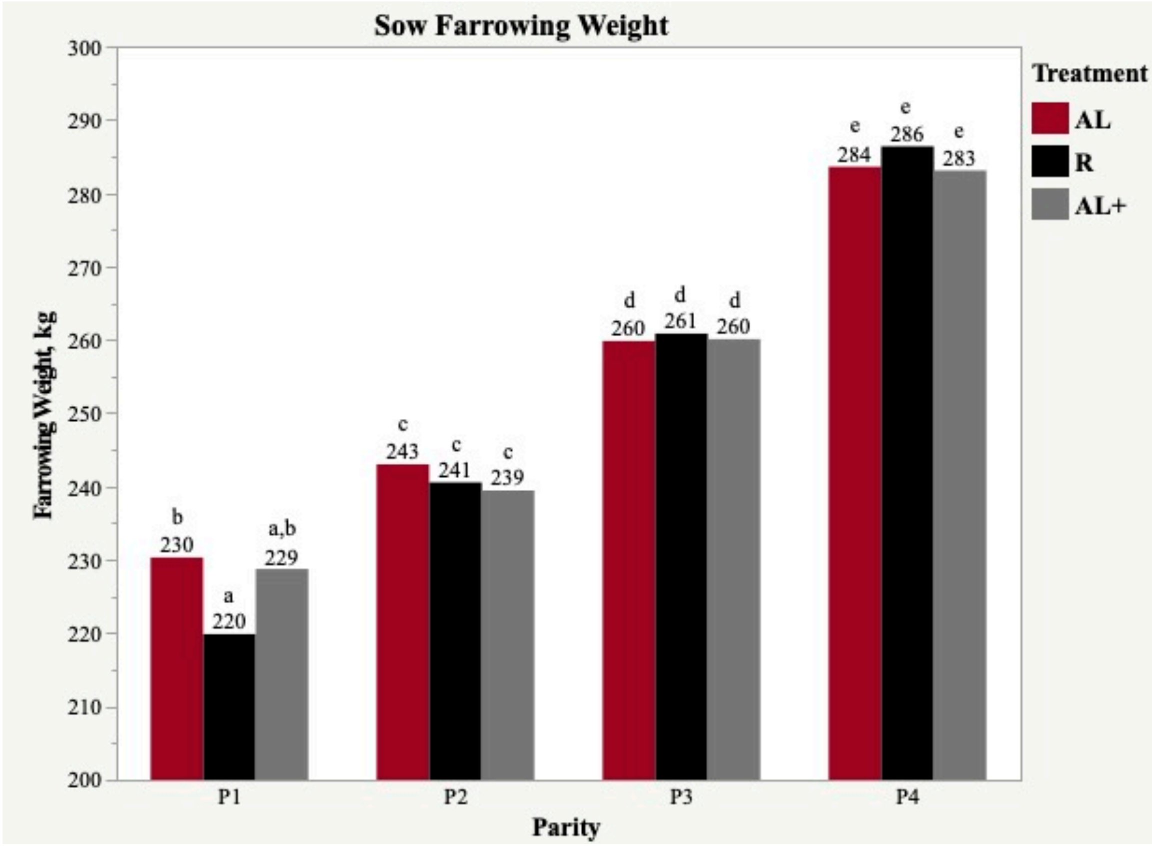

Figure 3.1. Sow farrowing weight for those developed on the ad libitum access (AL), restricted energy (R), and ad libitum access plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 4.80 to 5.10 kg). The tests of fixed effects, pairwise comparisons, and estimates for random effect variance components for the data in this figure are presented in **Table 3.6**.

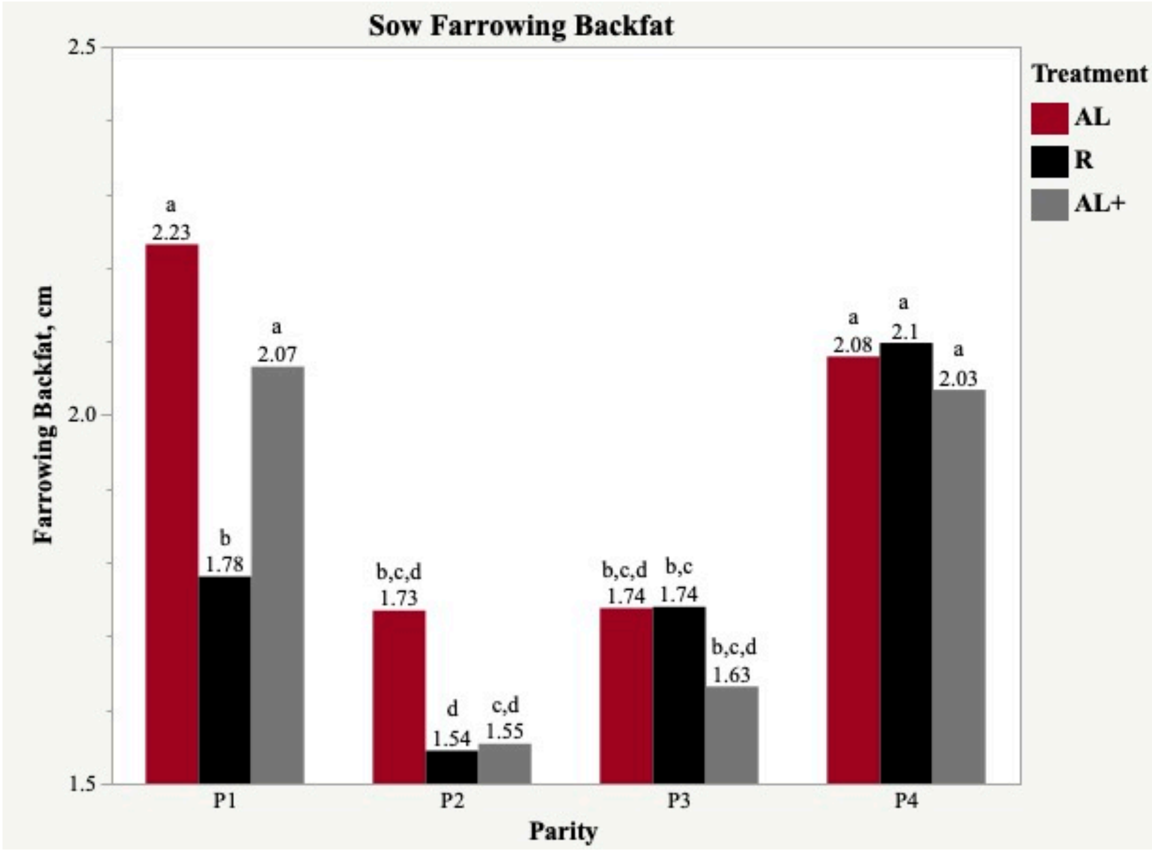

Figure 3.2. Sow farrowing backfat for those developed on the ad libitum access (AL), restricted energy (R), and ad libitum access plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 0.051 to 0.066 cm). The tests of fixed effects, pairwise comparisons, and estimates for random effect variance components for the data in this figure are presented in **Table 3.6.**

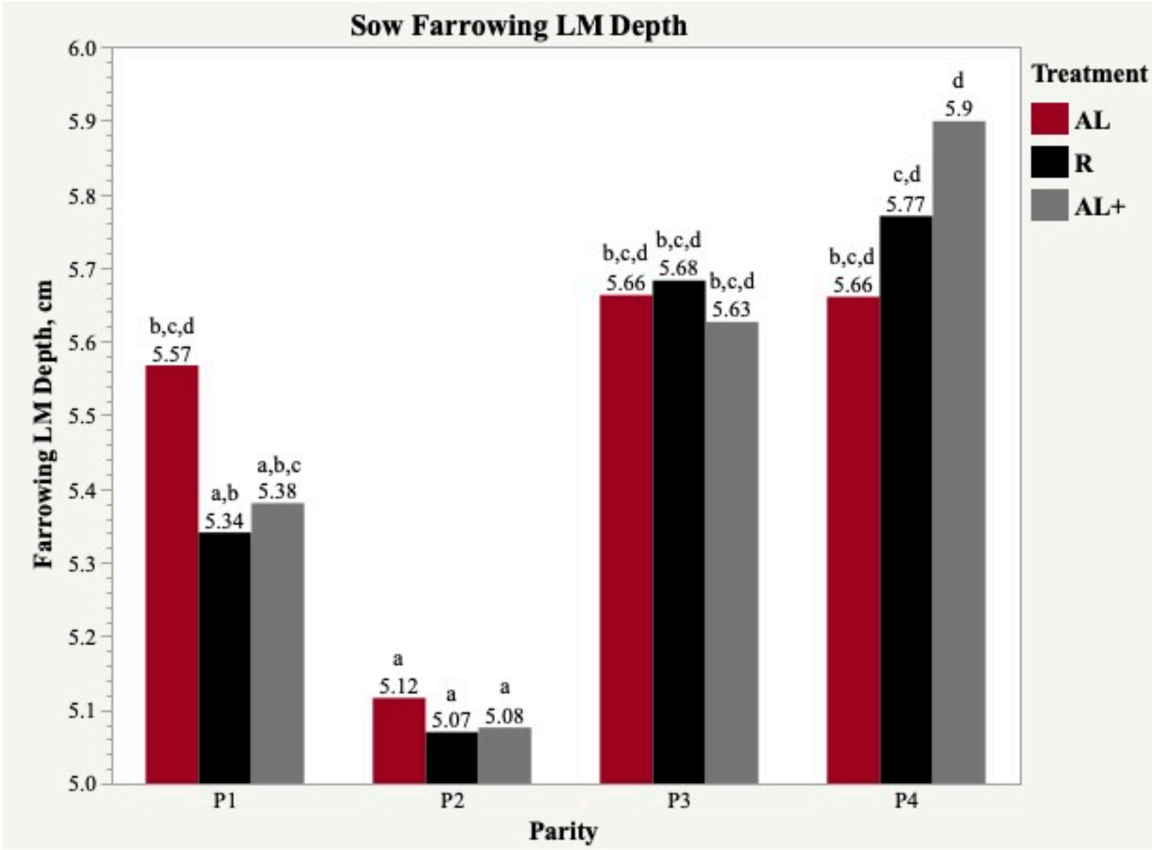

Figure 3.3. Sow farrowing LM depth for those developed on the ad libitum access (AL), restricted energy (R), and ad libitum access plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 0.081 to 0.110 cm). The tests of fixed effects, pairwise comparisons, and estimates for random effect variance components for the data in this figure are presented in **Table 3.6**.

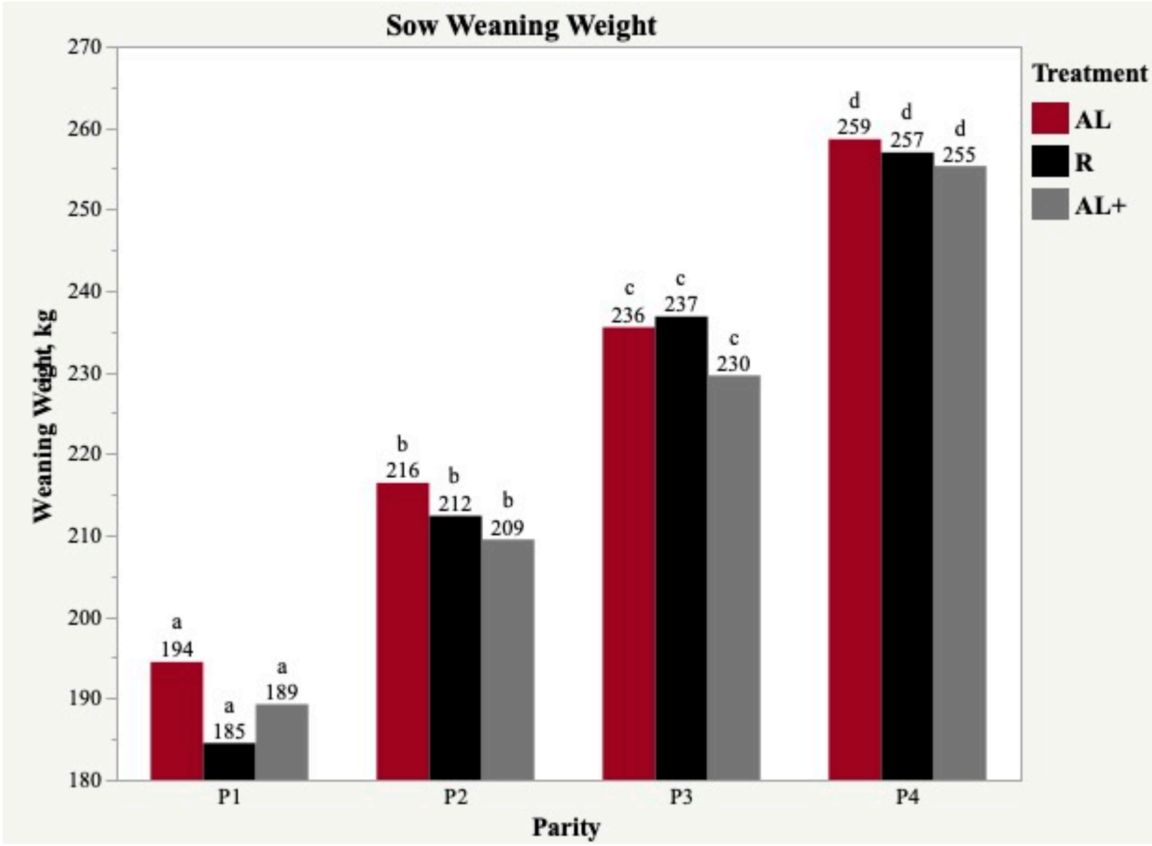

Figure 3.4. Sow weaning weight for those developed on the ad libitum access (AL), restricted energy (R), and ad libitum access plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 4.27 to 4.67 kg). The tests of fixed effects, pairwise comparisons, and estimates for random effect variance components for the data in this figure are presented in **Table 3.6**.

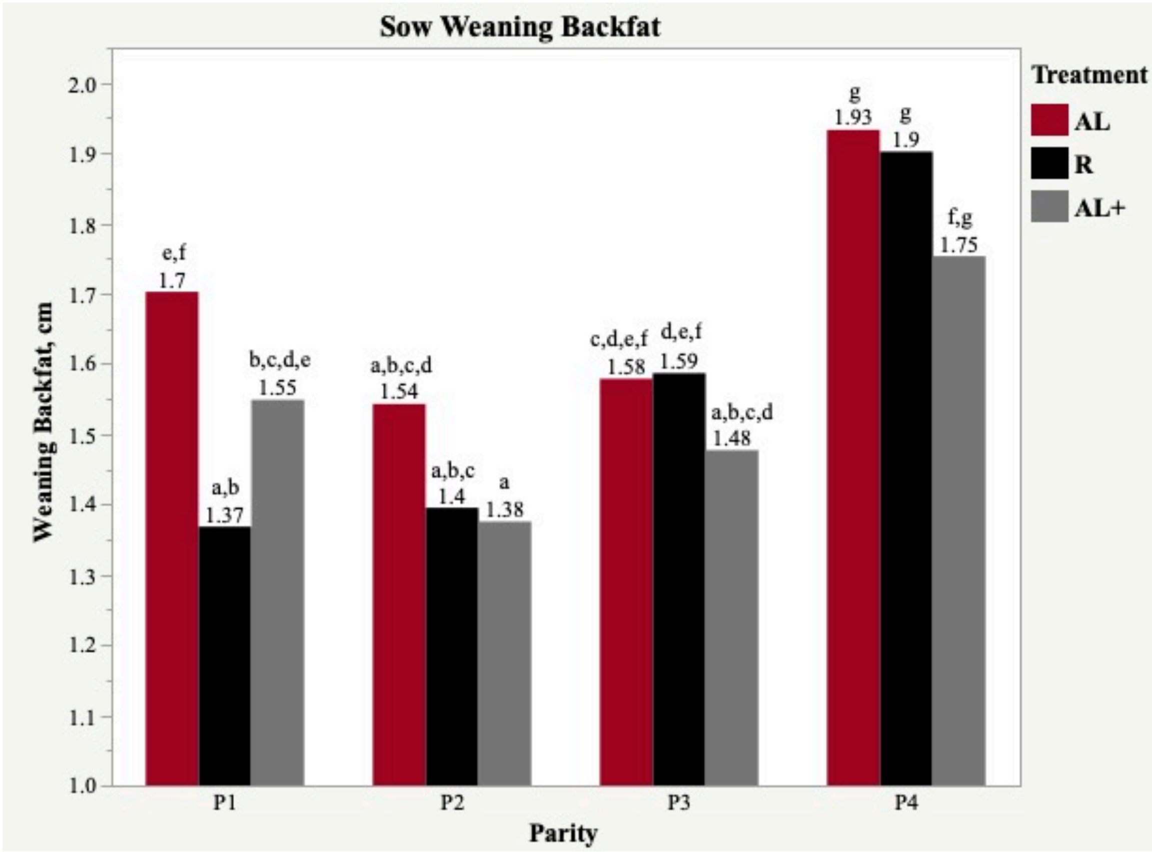

Figure 3.5. Sow weaning backfat for those developed on the ad libitum access (AL), restricted energy (R), and ad libitum access plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 0.066 to 0.075 cm). The tests of fixed effects, pairwise comparisons, and estimates for random effect variance components for the data in this figure are presented in **Table 3.6**.

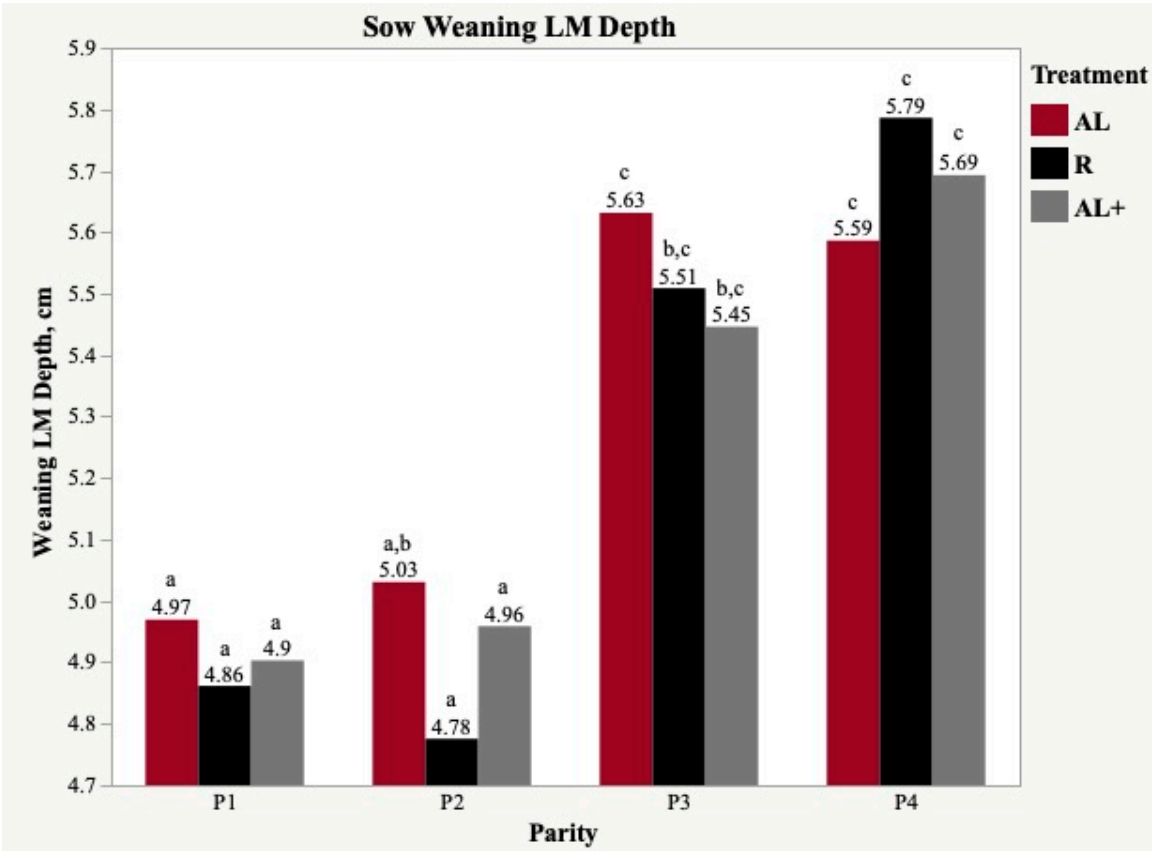

Figure 3.6. Sow weaning LM depth for those developed on the ad libitum access (AL), restricted energy (R), and ad libitum access plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 0.087 to 0.117 cm). The tests of fixed effects, pairwise comparisons, and estimates for random effect variance components for the data in this figure are presented in **Table 3.6**.

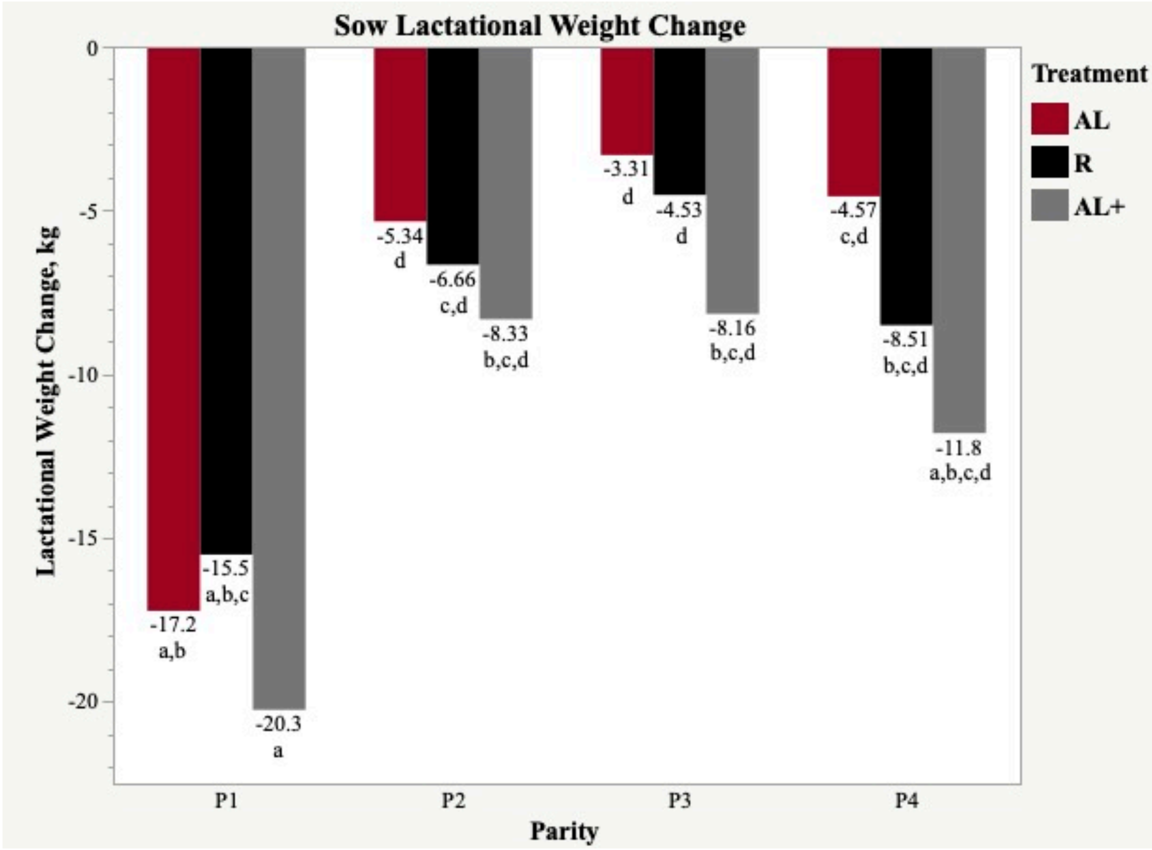

Figure 3.7. Sow weight change from farrowing to weaning for those developed on the ad libitum access (AL), restricted energy (R), and ad libitum access plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 1.93 to 2.94 kg). The tests of fixed effects, pairwise comparisons, and estimates for random effect variance components for the data in this figure are presented in **Table 3.6**.

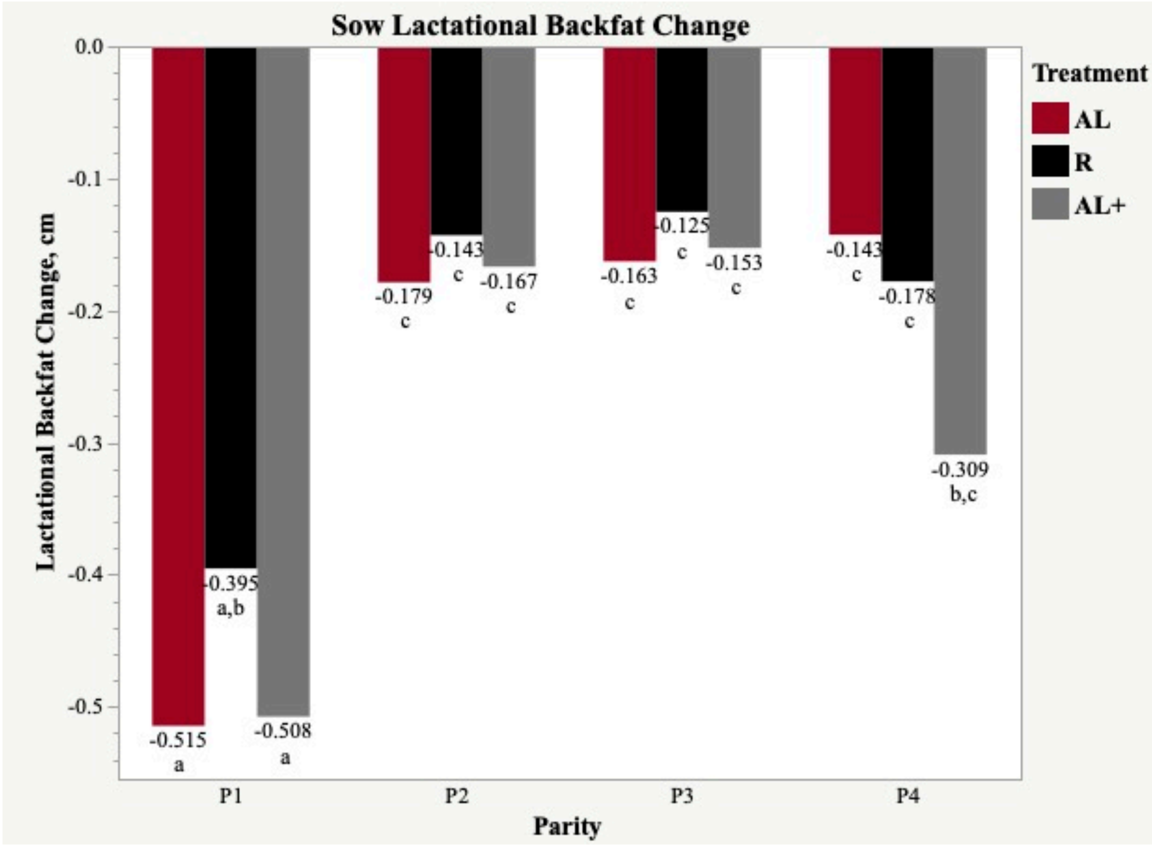

Figure 3.8. Sow backfat change from farrowing to weaning for those developed on the ad libitum access (AL), restricted energy (R), and ad libitum access plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 0.039 to 0.052 cm). The tests of fixed effects, pairwise comparisons, and estimates for random effect variance components for the data in this figure are presented in **Table 3.6**.

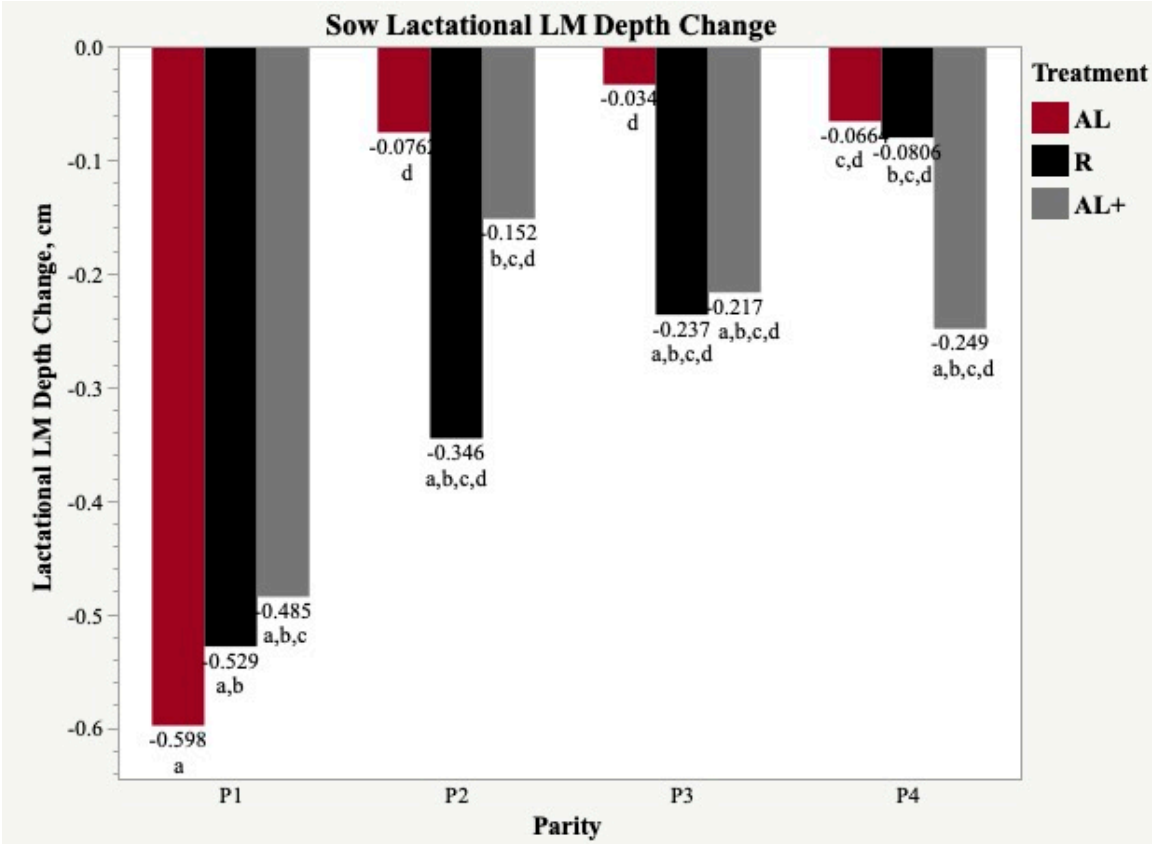

Figure 3.9. Sow LM depth change from farrowing to weaning for those developed on the ad libitum access (AL), restricted energy (R), and ad libitum access plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 0.085 to 0.120 cm). The tests of fixed effects, pairwise comparisons, and estimates for random effect variance components for the data in this figure are presented in **Table 3.6**.

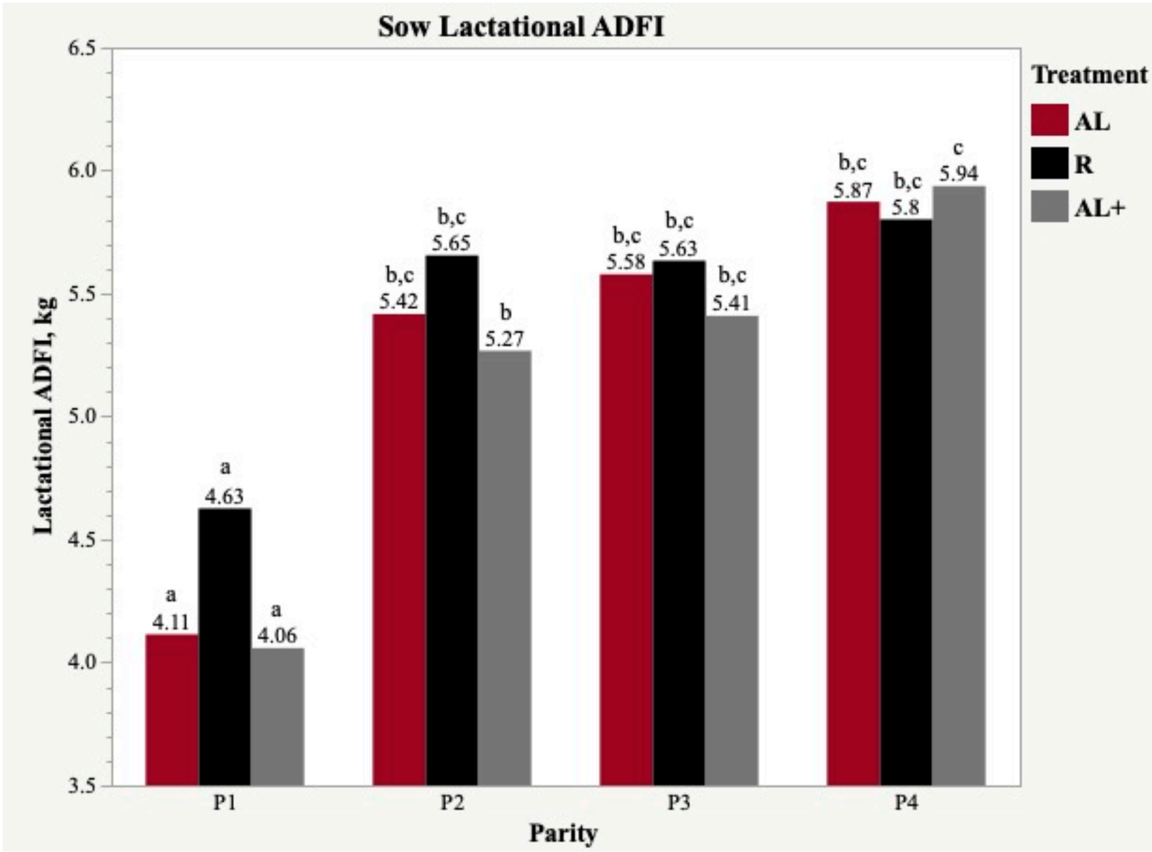

Figure 3.10. Lactational ADFI for sows developed on the ad libitum access (AL), restricted energy (R), and ad libitum access plus (AL+) regimens for parities 1 through 4 (LS means; SEM ranged 0.126 to 0.183 kg). The tests of fixed effects**,** pairwise comparisons, and random effect variance components for the data in this figure is presented in **Table 3.7.**

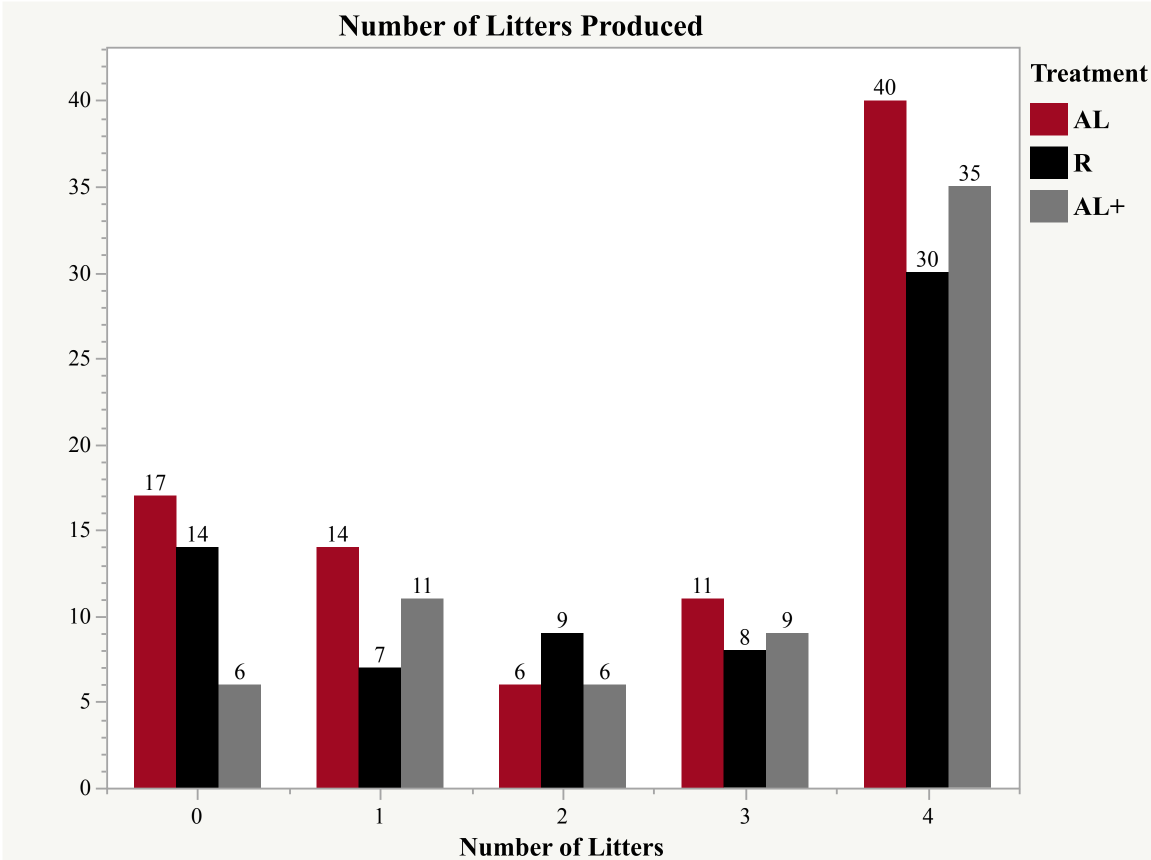

Figure 3.11. Total number of litters produced by breeders broken up by developmental treatment

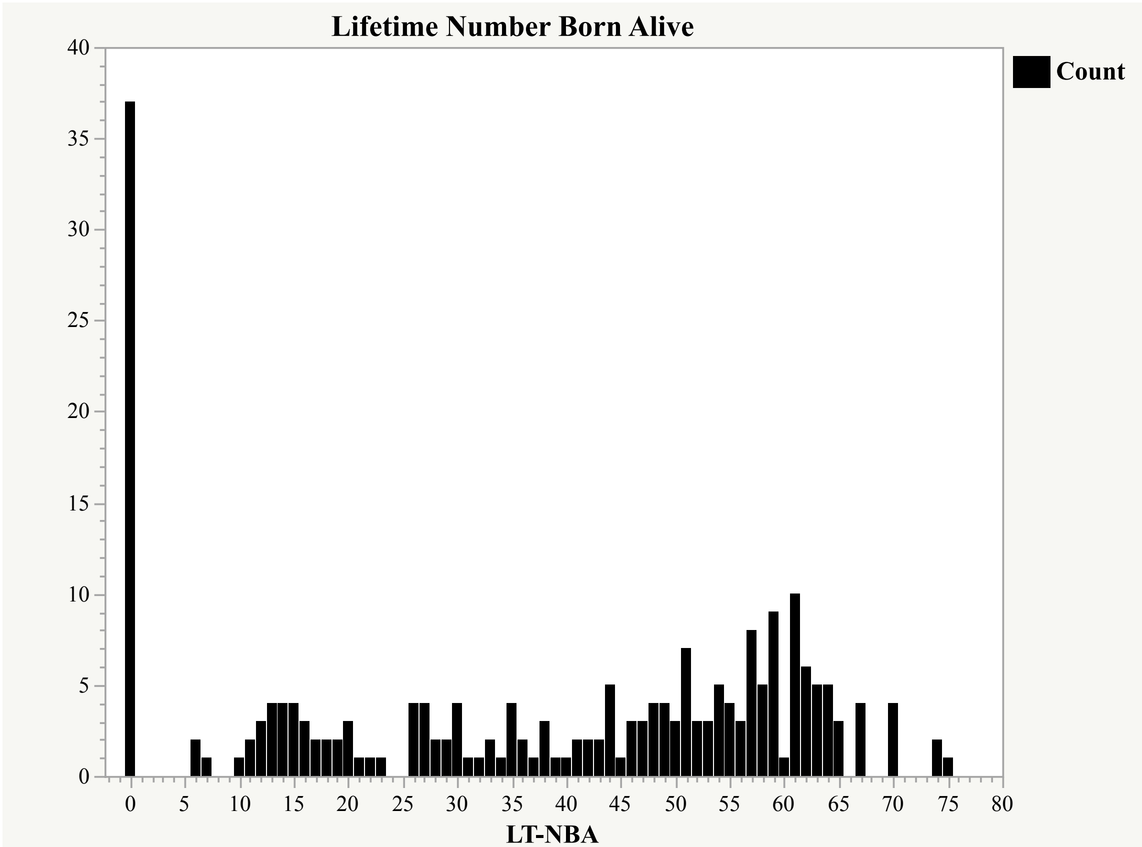

Figure 3.12. Distribution of lifetime number of pigs born alive by breeders

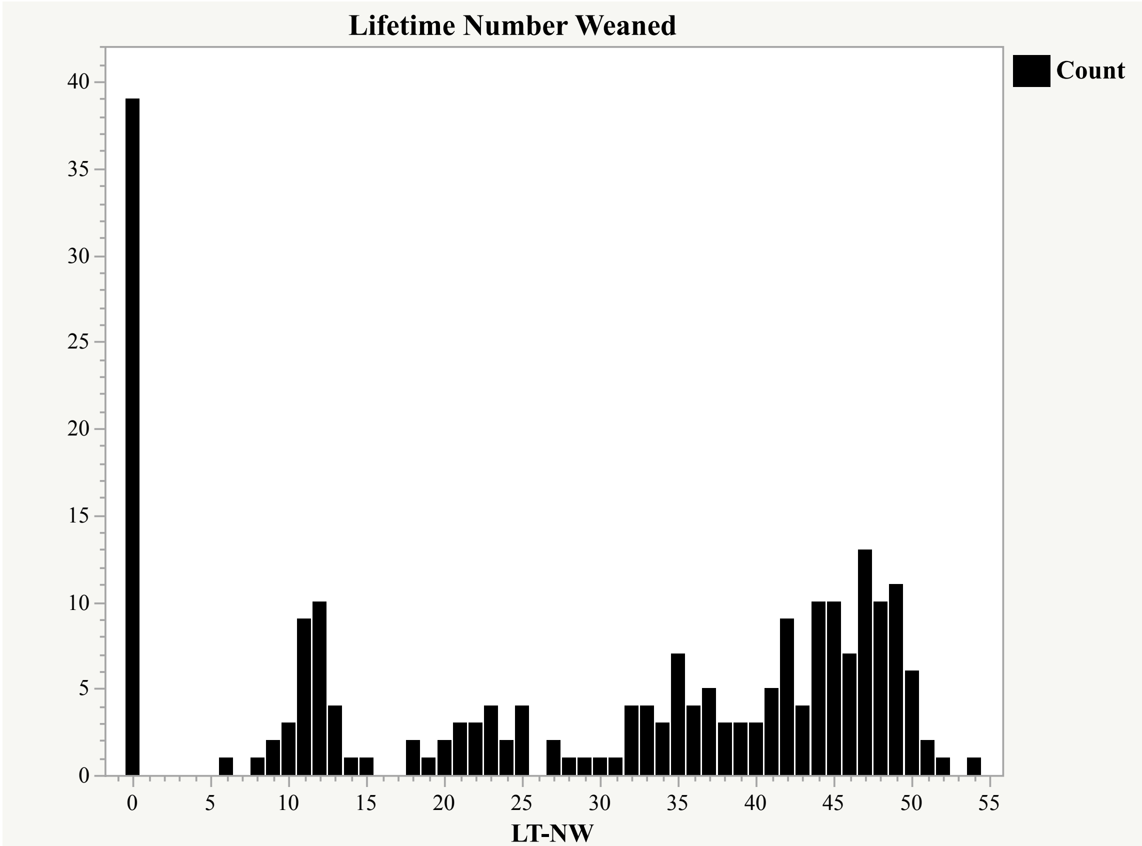

Figure 3.13. Lifetime number of pigs weaned distribution