

2019

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Recommended Citation

Gourley, K. M.; Swanson, A. J.; Woodworth, J. C.; DeRouchey, J. M.; Tokach, M. D.; Dritz, S. S.; and Goodband, R. D. (2019) "Effect of Feeding Duration of Increased Lysine and Energy Prior to Farrowing on Sow Performance and Colostrum Quality," *Kansas Agricultural Experiment Station Research Reports*: Vol. 5: Iss. 8. <https://doi.org/10.4148/2378-5977.7832>

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Funding Source

Appreciation is expressed to Minnesota Pork Board for financial support, Brent Frederick, Paul Cline, and the Christensen Farms Team for technical support and use of facilities, and the Kansas State University graduate students and professors that provided labor during this project.

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Effect of Feeding Duration of Increased Lysine and Energy Prior to Farrowing on Sow Performance and Colostrum Quality¹

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Summary

A total of 467 sows were used in a study to evaluate the effect of feeding duration of increased lysine (Lys) and energy prior to farrowing on sow and litter performance, piglet survival, and colostrum quality. Sows were blocked by body weight and parity category on d 106 of gestation, and allotted to one of three dietary treatments: 1) 4.5 lb/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until d 113 of gestation, then 6 lb/d lactation feed (28 g SID Lys and 9.4 Mcal ME) until parturition; 2) 4.5 lb/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until d 113 of gestation, then 8.3 lb/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition; or 3) 8.3 lb/d lactation feed (40 g SID Lys and 13.3 Mcal ME) from d 107 of gestation until parturition. Data were analyzed for treatment within parity effects using the GLIMMIX procedure of SAS. Increasing the duration of feeding additional standardized ileal digestible (SID) Lys and energy increased ($P < 0.05$) sow weight gain from d 106 to 113. Sow backfat gain from d 106 to 113 of gestation increased ($P < 0.05$) in gilts and sows fed 8.3 lb/d of the lactation diet starting on d 107 vs. the control diet. There was no evidence ($P > 0.05$) for difference in female body weight (BW) or backfat loss from d 113 of gestation until weaning between treatments. Average total born and born alive piglet birth weight was greater ($P < 0.05$) in gilts fed 8.3 lb/d lactation diet starting on d 107 or 113 vs. control, with no evidence ($P > 0.05$) for difference in average piglet birth weight in sows or weaning weight in gilts and sows. Piglet mortality after cross-foster to weaning was decreased ($P < 0.05$) in sows fed 8.3 lb/d lactation diet starting on d 113 vs. control or increased lactation diet starting on d 107, but not in gilts. However, litter gain from 48 h to weaning was decreased ($P < 0.05$) in gilts fed 8.3 lb/d lactation diet starting on d 107 compared to control, with no difference in sows. For colostrum composition, fat and total solids were decreased ($P < 0.05$) in sows fed 8.3 lb/d of the lactation diet starting on d 107 compared to the control, with no difference observed in gilts. There was no evidence for difference ($P > 0.05$) in colostrum protein or lactose concentrations

¹ Appreciation is expressed to Minnesota Pork Board for financial support, Brent Frederick, Paul Cline, and the Christensen Farms Team for technical support and use of facilities, and the Kansas State University graduate students and professors that provided labor during this project.

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due to dietary treatment. Colostrum immunoglobulin G was increased ($P < 0.05$) in gilts and sows fed 8.3 lb/d of the lactation diet starting on d 113 compared to control. Piglet colostrum intake and colostrum yield were not different ($P > 0.05$) due to dietary treatment fed pre-farrow. For subsequent female performance, there was no evidence for difference ($P > 0.05$) among treatments in the wean-to-estrus interval, percentage of females in estrus by d 7, farrowing rate, or subsequent litter characteristics. In summary, providing high Lys and energy intake from d 107 or 113 to farrowing increased piglet birth weight in gilts; however, litter gain to weaning was reduced when gilts started on high lactation feed intake at d 107 compared to gilts not fed increased Lys and energy. Providing high Lys and energy intake from d 113 increased pre-weaning piglet survival in sows. Colostrum intake and yield, and subsequent reproductive performance were unaffected by dietary treatments. In conclusion, *ad libitum* feeding of a lactation diet when gilts are loaded into the farrowing house may be adequate to meet the additional Lys and energy requirements for fetal growth. However, further research is needed to determine why a reduced litter growth occurred in gilts fed increased Lys and energy prior to farrowing.

Introduction

In recent years, a large emphasis has been placed on understanding the requirements of high-producing sows. While several studies have been conducted to evaluate changing nutrient requirements in late gestation (d 90 to parturition) and lactation, few studies have focused on the few days immediately prior to lactation. The transition period has been loosely defined as the last 10 d of gestation to the first 10 d of lactation,³ with most studies involving transition diets starting to be fed between d 104 and 109 of gestation.^{4,5} Currently in U.S. swine production, it is not common to feed a specific transition diet. However, nutrient partitioning changes rapidly in the last 10 d prior to parturition with fetal growth (22.7%), mammary growth (16.8%), and colostrum production (16.1%) representing the majority of the total required SID Lys in late gestation.⁶

The exponential fetal growth rate increases the amino acid and energy requirements in late gestation.³ When nutrients for fetal growth cannot be met, the sow will mobilize protein and lipid pools to satisfy the requirement. Researchers⁶ used a factorial approach to model the metabolizable energy (ME) and SID Lys requirements of sows during transition and lactation. Relative to d 104 of gestation, ME and SID Lys requirements increased by 60 and 149% at d 115 of gestation, respectively. These researchers predicted that the ME and SID Lys requirement on the last day of gestation is approximately 13.3 Mcal of ME and 35 g of SID Lys. This is a significant increase in energy and Lys required compared to what is typically provided in production today. There-

³ Theil, P. K. 2015. Transition feeding of sows. In: C. Farmer, editor, The gestating and lactating sow. Wageningen Academic Publishers. The Netherlands. P. 147-167.

⁴ Garrison, C., E. van Heugten, J. G. Wiegert, and M. T. Knauer. 2017. 236 Got Colostrum? Effect of diet and feeding level on piglet colostrum intake and piglet quality. J. Anim. Sci. 95(Suppl2):113-113. Doi:10.2527/asasmw.2017.12.236.

⁵ Feyera, T, C. K. Hojgaard, J. Vinther, T. S. Bruun, and P. K. Theil. 2017. Dietary supplement rich in fiber fed to late gestating sows during transition reduces rate of stillborn piglets. J. Anim. Sci. (in press).

⁶ Feyera, T, P. K. Theil. 2017. Energy and lysine requirements and balances of sows during transition and lactation: A factorial approach. Livest. Sci. 201(Supplement C): 50-57. doi: <https://doi.org/10.1016/j.livsci.2017.05.001>.

fore, in the last few days prior to parturition, the sow may be in a negative lysine and energy balance if not supplied increased nutrient concentrations as she partitions an exponentially increasing amount of nutrients to the fetus and colostrum production. A recent review⁷ analyzed the results of multiple trials utilizing bump feeding strategies and showed that increased gestation feed starting around d 90 of gestation hardly ever achieved more than 20 g/d of SID Lys, which would be less than the recommended 35 g/d in late gestation as suggested.⁶

Although the previous studies provide some data to begin understanding the transition period, to our knowledge no large study (>100 sows) has evaluated the significantly increased SID Lys and energy supplied immediately prior to parturition that is suggested to be most beneficial for sow productivity. Additionally, most of the data sets lack experiments conducted in field settings.⁸ Thus, the objective of the current experiment was to determine the impact of different feeding durations of increased lysine and energy immediately prior to farrowing on colostrum production, sow and litter performance, and piglet survival.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment.

A total of 467 sows (Large white × Landrace) were used in a late gestation and lactation study at a commercial sow farm in southern Minnesota (Christensen Farms, Sleepy Eye, MN). On d 106 of gestation, sows were weighed, blocked by body weight and parity category (gilts and sows) and allotted to 1 of 3 dietary treatments. Treatments consisted of: 1) 4.5 lb/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until d 113 of gestation, then 6 lb/d lactation feed (28 g SID Lys and 9.4 Mcal ME) until parturition; 2) 4.5 lb/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until d 113 of gestation, then 8.3 lb/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition; and 3) 8.3 lb/d lactation feed (40 g SID Lys and 13.3 Mcal ME) from d 107 of gestation until parturition (Figures 1 and 2). Diets were formulated to meet or exceed nutrient requirements (Table 1) and were manufactured in Sleepy Eye, MN. Feed samples of each diet were collected twice each week from the feeders at the farm. Samples were pooled and used for chemical analysis.

At loading into the farrowing crates (approximately d 113 of gestation), sows were weighed and backfat thickness was measured using a Renco probe (last rib, 4 inches from the midline). Sows were hand-fed their respective dietary treatments until parturition, at which point they were fed the lactation diet *ad libitum* until weaning. Sows were induced (2cc, Lutalyse, Zoetis Inc., Kalamazoo, MI) on the afternoon of d 115 of gestation if signs of parturition had not begun.

⁷ Gonçalves, M. A. D., S. S. Dritz, M. D. Tokach, J. H. Piva, J. M. DeRouchey, J. C. Woodworth, and R. D. Goodband. 2016b. Fact sheet – Impact of increased feed intake during late gestation on reproductive performance of gilts and sows. *J Swine Health Prod.* 24:264–266.

⁸ Garrison, C. E. 2017. Late gestation feeding strategies to improve piglet colostrum intake and piglet quality. MS Thesis. North Carolina State University.

At birth, the time each piglet was born was recorded, the umbilical cord was cut to 2 inches, the piglet was dried using desiccant and paper towels, identified with an ear tag, and weighed. Stillborn and mummified fetuses were also weighed and birth time recorded. Within 3 hours from the initiation of parturition, a 50 mL sample of colostrum was collected from multiple teats and the number of functional teats was recorded. Colostrum samples were split into two subsamples, 15 mL for colostrum immunoglobulin G (IgG) analysis, and 35 mL for nutrient analysis (preserved with an 18% Bronopol pellet). Samples were stored at -20°F until analysis. At 24 h after the birth of the first pig, piglets were individually reweighed to calculate colostrum intake. After 24 h, pigs were cross-fostered within treatment to equalize litter size. All piglet mortalities were weighed, and the date recorded. Fall-behind piglets, removed due to weight loss or injury between d 3 and d 10 of age, were weighed and moved off test to a nurse sow. At weaning (d 20 ± 3), all piglets were individually weighed.

At weaning, sows were weighed, backfat measurements recorded, then moved to gestation crates and checked twice daily for signs of estrus using a boar and back pressure test. Wean-to-first service interval and d 30 conception rate were collected on 419 of the 423 sows that were weaned. Subsequent litter characteristics were collected on 363 females.

Colostrum intake was calculated using the equation⁹ where colostrum intake = $-106 + 2.26 \text{ WG} + 200 \text{ BWB} + 0.111 \text{ D} - 1,414 \text{ WG/D} + 0.0182 \text{ WG/BWB}$, where WG is 24 h piglet weight gain in grams, D is duration of colostrum suckling in minutes, and BWB is body weight at birth. Colostrum yield was calculated as the sum of the colostrum intake of the pigs in the litter. If a piglet died before 24 h, the assumption was that there was no colostrum intake by that piglet.

Economics were calculated using the following values: weaned pig value of \$32 per pig, gestation feed cost of \$184.64/ton, and lactation feed cost of \$237.40/ton. Feed cost from d 107 to farrow was calculated using the daily intake of gestation or lactation feed, and multiplying by the cost per lb for each respective diet. Weaned pig revenue was the value of a weaned pig multiplied by the number of pigs weaned per litter. Income over additional feed cost (IOFC) was calculated by subtracting feed cost from weaned pig revenue. Additional feed cost per weaned pig is calculated as the additional feed cost from d 107 to farrow divided by the number of pigs weaned.

Chemical Analysis

Four samples (1 per week) of gestation diet, or 8 samples (1 per week) of lactation from within the weekly pooled samples were sent to a commercial laboratory (Ward Labo-

⁹ Theil, P. K., C. Flummer, W. L. Hurley, N. B. Kristenen, R. L. Labouriau, and M. T. Sorensen. 2014. Mechanistic model to predict colostrum intake based on deuterium oxide dilution technique data and impact of gestation and pre-farrowing diets on piglet intake and sow yield of colostrum. *J. Anim. Sci.* 92: 5507-5519. doi:10.2527/jas2014-7841.

ratories, Kearney, NE) and analyzed in duplicate for crude protein (AOAC 990.03, 2006), Ca, and P.^{10,11}

Colostrum samples were sent to a commercial laboratory (Stearns DHIA Lab, Sauk Centre, MN) and analyzed in duplicate for fat, protein, lactose, and total solids (Combi-Foss milk analyzer, Foss Analytics, Denmark). Immunoglobulin G concentration was analyzed in duplicate using the Porcine IgG ELISA Quantitation Kit (Bethyl Laboratories, Montgomery, TX).

Statistical Analysis

Data were analyzed using generalized linear mixed models where dietary treatment within parity category (gilt or sow) was a fixed effect, with random effect of block. Statistical models were fit using the GLIMMIX procedure of SAS (Version 9.4, SAS Institute, Inc., Cary, NC).

Sow body weight, backfat depth, litter weights, mean piglet body weights, litter gains, colostrum quality (fat, protein, lactose, and solids), colostrum yield, colostrum intake, and economics were fitted using a normal distribution. Total born, litter counts, and wean-to-estrus interval were fit using a negative binomial distribution. Percentage born alive, stillborns, mummies, survivability, fallbacks, mortality, estrus by d 7, and subsequent farrowing rate were fitted using a binomial distribution. Colostrum IgG concentration was analyzed using a log transformation.

Covariates were used if they significantly improved the model fit. Residuals and the Bayesian Information Criterion (BIC) were used as an indication of improved model fit. Total born was used as a covariate for total born litter weight and mean piglet birth weight. Born alive was used as a covariate for born alive and 24 h litter weight and mean piglet birth and 24 h weight. Teat-to-pig ratio was used as a covariate for 24 h litter gain, colostrum yield and intake. Litter size after cross foster was used as a covariate for litter weight and piglet weight after cross foster and at weaning.

Results and Discussion

Chemical analyses of crude protein, Ca, and P in treatment diets were similar to formulated values (Table 2).

Sow BW and backfat depth on d 106 and gestation length were similar ($P > 0.05$; Table 3) across treatments which validates the sow randomization. At the time of loading into the farrowing house (d 113 ± 2), a treatment within parity category effect was observed where gilts that received 8.3 lb/d lactation diet starting on d 107 were 11 lb heavier ($P < 0.05$) than control gilts, with gilts that received 8.3 lb/d lactation diet starting on d 113 intermediate. Sows that received 8.3 lb/d lactation diet starting on d 107 were heavier ($P < 0.05$) than sows fed control or those that received 8.3 lb/d

¹⁰ Campbell, C. R. and C. O. Plank. 1991. Sample Preparation. In: C. O. Plank, editor, Plant analysis reference procedures for the southern region of the United States. Southern Cooperative Series Bulletin #368. p. 1-11.

¹¹ Kovar, J. L. 2003. Method 6.3 Inductively coupled plasma spectroscopy. In: J. Peters, editor, Recommended methods of mature analysis publication A3769. Univ. of Wisconsin Extension, Madison, WI. p. 41-43.

lactation diet starting on d 113. As a result, a main effect of treatment was observed for sow weight change from d 106 to loading where gilts and sows fed 8.3 lb/d lactation diet starting on d 107 gained more weight ($P < 0.05$) than females that received 8.3 lb/d lactation diet starting on d 113, and both treatments gained more weight than control gilts or sows. This was expected due to the increased Lys and energy provided to females beginning at d 107 or d 113 compared to the standard farm feeding levels. Previous studies⁷ that evaluated increased feeding strategies starting on d 90 of gestation suggested that an additional 16.6 g/d SID Lys and 9.6 Mcal/d ME resulted in an additional 15 lb of BW gain. While the dietary treatments in the current study would have been fed for a shorter duration, the much higher levels of SID Lys (40 g/d) and ME intake (13.3 Mcal/d) resulted in similar BW gain as those where feed intake was increased from d 90 of gestation to farrowing.

Backfat thickness at the time of loading was increased ($P < 0.05$) in gilts that received lactation diet starting on d 107 compared to those starting on d 113, with control gilts intermediate. There was no evidence for difference in backfat thickness in sows at time of loading. However, a main effect of treatment on backfat change from d 106 to loading was observed where gilts and sows that received 8.3 lb/d lactation diet starting on d 107 had increased ($P < 0.05$) backfat gain compared to control gilts and sows, but this change was small (0.50 mm). This demonstrates that the increased nutrient supply that resulted in increased body weight was partially allocated towards sow body fat.

There was no evidence for difference ($P > 0.05$) in sow body weight at weaning or sow weight loss from loading to weaning, regardless of dietary treatment. However, there was numerically greater body weight loss during lactation in gilts and sows that received an 8.3 lb/d lactation diet starting on d 107 compared to control gilts and sows. Additionally, there was no difference ($P > 0.05$) in female body weight change from d 106 to weaning, indicating that the additional weight gain observed peripartum was subsequently lost during the lactation period. There was no evidence for difference ($P > 0.05$) in backfat loss from loading until weaning. As a result, a main effect of treatment was observed for sow backfat thickness at weaning, where gilts and sows that received lactation diet starting on d 107 had increased ($P < 0.05$) backfat compared to the control or those that received 8.3 lb/d lactation diet starting on d 113. This demonstrated that the additional backfat that females gained peripartum resulted in increased backfat at weaning.

Individual lactation feed intake was unable to be measured with the automated feeding system on this commercial sow farm. Thus, it is unknown if increased backfat and body weight negatively affected lactation feed intake as previous studies would suggest.⁷

There was a treatment within parity effect for total born litter weight, born alive litter weight, and 24 h litter weight, where gilts fed 8.3 lb/d lactation diet starting on d 113 had heavier ($P < 0.05$; Table 4) litters compared to control gilts, with gilts fed 8.3 lb/d lactation diet starting on d 107 being intermediate. Sows that received 8.3 lb/d lactation diet starting on d 107 had heavier ($P < 0.05$) litters compared to sows fed 8.3 lb/d lactation diet starting on d 107, and control sows were intermediate. A treatment within parity effect was observed for mean piglet body weight for total born and born alive piglets, where gilts fed 8.3 lb/d lactation diet starting on d 107 or 113 had heavier

($P < 0.05$) piglets compared to control gilts. There was no evidence ($P > 0.05$) for difference in average piglet body weight in sow litters. At 24 h, although the average pig body weight was numerically higher in pigs from gilts that received lactation diet starting on d 107 or d 113, there was no evidence statistically ($P > 0.05$). Litter gain from birth to 24 h was similar regardless of dietary treatment. Born alive birth weight CV was lowered ($P < 0.05$) in gilts fed 8.3 lb/d lactation diet starting on d 113 compared to those fed control, with no difference observed in sow litters. This demonstrates less variation in birth weight in gilts that were fed additional SID Lys and ME for 3 d prior to farrowing.

There was no evidence for difference ($P > 0.05$) in total born, born alive, stillborn, and litter size at 24 h, regardless of dietary treatment. A treatment within parity effect was observed for percent mummified fetuses due to gilts fed the control having reduced ($P < 0.05$) mummies compared to gilts fed control diet or those that received lactation diet starting on d 107, with no difference observed in sows. This difference is likely due to random chance because the majority of mummified fetuses are established earlier in pregnancy (d 30 to 100). Thus, changing feed intake in the last 3 or 8 d prior to parturition should not affect mummified fetuses. Survivability, calculated as: [total born – (stillborn + mummified + 24 h mortality)]/total born, was increased in gilts fed 8.3 lb/d lactation diet starting on d 113 compared to those fed control. This is likely a result of decreased mummified fetuses, and numerically lower stillborn rate in gilt litters fed 8.3 lb/d lactation diet starting on d 113. No evidence of influence on survival of piglets born alive to 24 h was noted ($P > 0.05$) regardless of dietary treatment.

Pigs were cross-fostered up to 48 h within dietary treatments to equalize litter size (Table 5). Litter weight, litter count, and average pig body weight after cross-fostering were similar ($P > 0.05$) across dietary treatments. There was no evidence for difference ($P > 0.05$) in litter weight, individual piglet body weight, or litter count at weaning regardless of dietary treatment. However, litter gain from 48 h to weaning was decreased ($P < 0.05$) in gilts that received 8.3 lb/d lactation diet starting on d 107 compared to the control, with no difference in sows. This was an unexpected result because earlier studies¹² suggested that an increase in piglet birth weight also results in an increase in piglet weaning weight. One potential explanation for the reduction in litter gain in the current study is that increased weight gain of sows prior to farrowing may have had a negative effect on lactation feed intake, which resulted in less milk production and consequently less piglet growth. Further research is needed to determine the cause of the decreased piglet growth in response to increased lysine and energy prior to farrowing.

Wean age was similar across all dietary treatments and averaged 20.7 d. There was no evidence for difference in the percent of pigs recorded as fallbacks, regardless of treatment. Mortality after cross-fostering to weaning was lower ($P < 0.05$) in sows that received 8.3 lb/d lactation diet starting on d 113 compared to control sows, with no evidence for difference in gilts. This resulted in a higher ($P < 0.05$) percentage of pigs

¹² Bergstrom, J., M. L. Potter, M. T. Tokach, S. C. Henry, S. S. Dritz, J. L. Nelssen, R. D. Goodband, J.M. DeRouchey. 2009. Effects of piglet birth weight and litter size on the preweaning growth performance of pigs on a commercial farm. Kansas Agricultural Experiment Station Research Reports. 10.4148/2378-5977.6800.

weaned from sows that received 8.3 lb/d lactation diet starting on d 113 compared the control sows or sows that received lactation diet starting on d 107, again with no change in gilts fed different treatments.

For colostrum composition, fat, and total solids were decreased ($P < 0.05$) in sows that received the lactation diet starting on d 107 compared to the controls, with no difference observed in gilts (Table 6). There was no evidence for difference ($P > 0.05$) in colostrum protein or lactose concentrations due to dietary treatments. Immunoglobulin G, which provides passive immunity to the piglet, was increased ($P < 0.05$) in gilts and sows that received 8.3 lb/d lactation diet starting on d 113 compared to the control, which could support why an increase in piglet survival at weaning was observed in sows fed the additional lactation diet. Piglet colostrum intake and colostrum yield were not different ($P > 0.05$) due to dietary treatment fed pre-farrow.

There was no evidence for difference ($P > 0.05$) in wean-to-estrus interval, percentage of females in estrus by d 7, or farrowing rate regardless of dietary treatment that had been fed in the previous transition period (Table 7). In addition, total born or percentage born alive, stillborn, or mummified were similar ($P > 0.05$) across dietary treatments that had been fed in the previous transition period.

Economic analysis showed sow feed cost from d 107 to farrowing was increased ($P < 0.05$) as the duration of feeding 8.3 lb/d of lactation feed increased (Table 8). This was expected due to feeding an increased amount of a higher cost diet. Because litter counts at weaning were similar across treatments, there was no difference ($P > 0.05$) in weaned pig revenue or income over feed cost. However, feed cost per weaned pig was higher ($P < 0.05$) as the duration of feeding 8.3 lb/d of lactation feed increased. This demonstrates that the additional feed cost from feeding lactation diet for 8 or 3 d prior to farrowing was not recovered in the current trial because there was no increase in litter count at weaning.

In summary, feeding increased Lys and energy 8 or 3 d prior to farrowing increased weight gain and backfat depth of gilts and sows peripartum. The additional weight and backfat gain pre-farrowing did not result in statistically significant weight or backfat loss during the lactation period. Average piglet body weight for total born and born alive pigs was increased in gilts fed increased Lys and energy starting at 8 or 3 d before parturition. However, litter gain to weaning was reduced in gilts fed increased Lys and energy starting at d 107 of gestation compared to the control gilts. There was reduced mortality of piglets from sows that consumed increased Lys and energy starting on d 113 of gestation. Colostrum intake and yield, and subsequent reproductive performance were unaffected by dietary treatments. It can be concluded that *ad libitum* feeding a lactation diet when gilts are loaded into the farrowing house (approximately d 113 of gestation) may be adequate to meet the additional Lys and energy requirements for fetal growth, as measured by increased piglet birth weight in gilts. However, further research is needed to determine why reduced litter growth occurred in gilts fed increased Lys and energy prior to farrowing.

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Table 1. Diet composition¹

Item	Gestation	Lactation
Ingredient, %		
Corn	44.90	47.29
Soybean meal	4.53	25.14
DDGS ²	23.00	5.00
Bakery meal	10.00	15.00
Soybean hulls	12.20	--
Corn oil	1.23	2.90
Dicalcium P, 18.5%	1.88	1.86
Limestone	0.66	0.61
Lysine-HCl	0.26	0.34
Salt	0.27	0.23
L-Threonine	0.06	0.12
DL-Methionine	0.02	0.06
Vitamin and mineral premix	0.87	1.31
Choline chloride, 70%	0.13	0.13
Total	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	0.62	1.06
Methionine:lysine	36	29
Methionine and cysteine:lysine	54	54
Threonine:lysine	64	64
Tryptophan:lysine	18	18
Valine:lysine	70	70
Isoleucine:lysine	63	63
Total lysine, %	0.77	1.21
Crude protein, %	14.0	18.3
Metabolizable energy, kcal/lb	1,457	1,598
Net energy, kcal/lb	831	1,151
Calcium, %	0.85	0.85
Phosphorus, %	0.74	0.72

¹Diets were fed according to treatment as follows: 1) 4.5 lb/d gestation feed until d 113 of gestation, then 6 lb/d lactation feed until parturition; 2) 4.5 lb/d gestation feed until d 113 of gestation, then 8.3 lb/d lactation feed until parturition; and 3) 8.3 lb/d lactation feed from d 107 of gestation until parturition.

²Dried distillers grain with solubles.

Table 2. Chemical analysis of the diets (as-fed basis)¹

Item, %	Gestation	Lactation
Dry matter	89.1	88.9
Crude protein	14.9	19.0
Ca	0.90	0.92
P	0.73	0.71

¹Diet samples were collected twice weekly from the feeders (4 or 8 weeks for gestation and lactation, respectively). Nutrient analysis was conducted in duplicate on the weekly pooled samples (Ward Laboratories, Kearney, NE).

Table 3. Effects of increased dietary lysine and energy feeding duration before farrowing on sow performance within parity category¹

Response	Gilts				Sows			
	Control (1)	d 113 (2)	d 107 (3)	SEM	Control (1)	d 113 (2)	d 107 (3)	SEM
Count, n	46	46	45	--	113	110	112	--
Gestation length, d	115.7	115.7	115.8	0.12	115.7	115.8	115.8	0.08
Sow body weight, lb								
d 106	493.6	493.1	495.0	7.44	609.7	608.4	608.1	4.80
Loading ²	499.4 ^b	501.4 ^{ab}	512.5 ^a	7.44	616.3 ^b	616.1 ^b	627.0 ^a	4.81
Weaning	401.4	399.9	406.3	8.65	510.0	514.8	519.2	5.82
Sow weight change, lb								
d 106 to loading ³	4.7 ^c	8.9 ^b	15.7 ^a	1.92	5.1 ^c	7.3 ^b	19.3 ^a	1.22
Loading to weaning	-96.2	-102.5	-108.9	5.94	-104.5	-100.6	-108.8	4.03
d 106 to weaning	-91.3	-93.6	-92.3	6.21	-98.8	-93.2	-88.7	4.17
Sow backfat, mm								
d 106	20.0	19.0	20.4	0.55	18.1	18.0	17.7	0.35
Loading ²	20.5 ^{ab}	19.8 ^b	21.3 ^a	0.58	18.3	18.5	18.4	0.37
Weaning ⁴	12.7 ^b	12.8 ^b	14.2 ^a	0.51	13.7 ^b	13.4 ^b	13.9 ^a	0.34
Sow backfat change, mm								
d 106 to loading ⁵	0.3	0.7	0.9	0.23	0.2	0.5	0.6	0.15
Loading to weaning	-7.9	-6.9	-7.4	0.58	-4.6	-4.8	-4.5	0.38
d 106 to weaning	-7.2	-6.2	-6.3	0.56	-4.4	-4.4	-3.9	0.37

¹A total of 467 sows were used from d 106 of gestation until weaning. Sows were weighed, blocked by body weight and parity category, and allotted to treatment on d 106 of gestation. Loading occurred at d 113 (± 2 d) of gestation. Weaning occurred at d 18 to 24 of lactation. Diets were fed according to treatment as follows 1) 4.5 lb/d gestation feed until d 113 of gestation, then 6 lb/d lactation feed until parturition; 2) 4.5 lb/d gestation feed until d 113 of gestation, then 8.3 lb/d lactation feed until parturition; and 3) 8.3 lb/d lactation feed from d 107 of gestation until parturition.

²Significant treatment within parity differences. Values within parity category without a common superscript differ ($P < 0.05$).

³All treatment means significantly different from each other ($P < 0.05$).

⁴Treatment main effect: 3 vs. 1 or 2 ($P < 0.05$).

⁵Treatment main effect: 1 vs. 3 ($P < 0.05$).

Table 4. Effects of increased dietary lysine and energy feeding duration before farrowing on litter performance within parity category¹

Response	Gilts				Sows			
	Control (1)	d 113 (2)	d 107 (3)	SEM	Control (1)	d 113 (2)	d 107 (3)	SEM
Litter weight, lb								
Total born, ^{2,5} 0 h	40.0 ^b	42.5 ^a	42.2 ^{ab}	0.73	48.9 ^{ab}	48.1 ^b	49.8 ^a	0.61
Born alive, ^{2,6} 0 h	36.8 ^b	39.7 ^a	39.3 ^{ab}	0.68	45.0 ^{ab}	44.6 ^b	46.3 ^a	0.54
24 h ^{2,6}	38.5 ^b	41.2 ^a	40.5 ^{ab}	0.80	45.9 ^{ab}	46.0 ^b	47.4 ^a	0.61
Mean piglet body weight, lb								
Total born, ^{2,5} 0 h	2.85 ^b	3.02 ^a	2.99 ^a	0.052	3.17	3.13	3.23	0.039
Born alive, ^{2,6} 0 h	2.88 ^b	3.09 ^a	3.06 ^a	0.052	3.23	3.21	3.32	0.040
24 h ⁶	3.16	3.31	3.28	0.055	3.50	3.49	3.57	0.041
Total born birth weight CV, %	22.2	19.3	22.0	1.29	23.7	23.0	23.7	0.84
Born alive birth weight CV, ² %	18.4 ^b	16.1 ^a	16.4 ^{ab}	0.83	20.0	19.4	19.9	0.53
Litter gain 0 to 24 h of live pigs, ^{3,7} lb	2.83	2.37	2.36	0.540	2.71	3.06	2.59	0.356
Litter gain 0 to 24 h, ^{4,7} lb	1.80	1.20	1.23	0.371	0.72	1.65	0.92	0.211
Litter size at birth								
Total born, n	14.4	14.2	14.0	0.56	15.8	15.4	15.7	0.37
Born alive, %	90.1	92.8	91.4	1.10	90.4	89.9	90.8	0.83
Stillborn, %	6.9	6.1	5.5	1.01	6.9	6.5	5.8	0.69
Mummified, ² %	3.0 ^a	1.0 ^b	3.1 ^a	0.70	2.6	3.4	3.1	0.48
Litter size at 24 h, n	12.3	12.8	12.3	0.52	13.5	13.1	13.6	0.34
Survival from birth to 24 h, %	95.9	97.1	96.6	0.80	94.9	95.3	96.1	0.59
Survivability, ^{2,8} %	86.0 ^b	90.0 ^a	88.1 ^{ab}	1.41	85.5	85.5	87.1	0.98

¹A total of 467 sows were used from d 106 of gestation until weaning. Sows were weighed, blocked by body weight and parity category, and allotted to treatment on d 106 of gestation. Loading occurred at d 113 (± 2 d) of gestation. Weaning occurred at d 18 to 24 of lactation. Diets were fed according to treatment as follows: 1) 4.5 lb/d gestation feed until d 113 of gestation, then 6 lb/d lactation feed until parturition; 2) 4.5 lb/d gestation feed until d 113 of gestation, then 8.3 lb/d lactation feed until parturition; and 3) 8.3 lb/d lactation feed from d 107 of gestation until parturition.

²Significant treatment within parity differences. Values within parity category without a common superscript differ ($P < 0.05$).

³Litter gain of live pigs = (litter weight at 24 h) – (born alive litter birth weight – birth weight of piglets that died in 24 h).

⁴Litter gain = (litter weight at 24 h) – (born alive litter birth weight).

⁵Total born used as a covariate.

⁶Number born alive used as a covariate.

⁷Teat:pig used as a covariate.

⁸Survivability = [total born – (stillborn + mummified + 24 h mortality)]/total born.

Table 5. Effects of increased dietary lysine and energy feeding duration before farrowing on litter performance within parity category¹

Response	Gilts				Sows			
	Control (1)	d 113 (2)	d 107 (3)	SEM	Control (1)	d 113 (2)	d 107 (3)	SEM
Count, n	42	43	41	--	99	98	100	--
Litter weight, lb								
After cross foster ²	43.6	44.5	45.2	0.88	46.1	47.2	47.6	0.73
Weaning ⁵	161.4	157.9	155.2	3.30	167.9	172.6	170.7	2.65
Average piglet body weight, lb								
After cross foster ²	3.26	3.35	3.39	0.063	3.45	3.53	3.56	0.056
Weaning ⁵	13.18	13.22	12.79	0.224	14.47	14.41	14.44	0.180
Litter gain, ^{3,4,5} lb	119.4 ^a	113.5 ^{ab}	110.0 ^b	3.11	121.8	125.4	122.9	2.43
Litter count, n								
After cross foster ²	13.3	13.5	13.3	0.56	13.6	13.2	13.7	0.36
Weaning	12.3	12.1	12.2	0.54	11.7	11.9	11.9	0.34
Fallbacks, ⁶ %	2.9	2.9	2.4	0.66	5.3	3.7	4.9	0.63
Mortality, ⁴ %	5.0	7.5	5.1	1.14	8.1 ^a	5.4 ^b	7.1 ^{ab}	0.79
Weaned, ^{4,7} %	92.4	90.2	92.0	1.33	86.6 ^b	90.9 ^a	88.3 ^b	1.06
Wean age, d	20.8	20.9	20.7	0.23	20.8	20.6	20.6	0.15

¹A total of 423 sows were weaned from an initial 467 sows that farrowed. Sows were removed due to poor milking or a health challenge—becoming nurse sows. Pigs stayed with birth sow until 24 h, then were cross-fostered within treatment to equalize litter size. Diets were fed according to treatment as follows: 1) 4.5 lb/d gestation feed until d 113 of gestation, then 6 lb/d lactation feed until parturition; 2) 4.5 lb/d gestation feed until d 113 of gestation, then 8.3 lb/d lactation feed until parturition; and 3) 8.3 lb/d lactation feed from d 107 of gestation until parturition.

²Piglets were cross-fostered within treatment between 24 and 48 h. Weights are adjusted to reflect the addition or subtraction of fostered piglets.

³Litter gain = litter weaning weight – litter weight after cross foster.

⁴Significant treatment within parity differences. Values within parity category without a common superscript differ ($P < 0.05$).

⁵Count after cross-foster used as a covariate.

⁶Fallbacks were pigs removed due to weight loss or injury and moved to a nurse sow. This occurred between d 3 and d 10 of age.

⁷Percentage weaned = litter count at weaning/litter count after cross foster.

Table 6. Effects of increased dietary lysine and energy feeding duration before farrowing on colostrum quality and yield within parity category

Response	Gilts				Sows			
	Control (1)	d 113 (2)	d 107 (3)	SEM	Control (1)	d 113 (2)	d 107 (3)	SEM
Count, n	46	46	45	--	113	110	112	--
Fat, ² %	5.4	5.4	5.3	0.21	4.7 ^a	4.6 ^{ab}	4.4 ^b	0.13
Protein,%	14.8	14.9	15.1	0.27	15.3	14.9	15.1	0.17
Solids, ² %	24.7	25.3	25.1	0.36	24.6 ^a	24.1 ^{ab}	24.0 ^b	0.22
Lactose, %	3.2	3.1	3.2	0.05	3.1	3.2	3.2	0.03
IgG, ³ mg/mL	107	125	105	1.6	114	131	126	1.3
Colostrum yield, ^{4,6} lb	11.8	11.8	11.7	0.52	13.2	13.5	13.3	0.28
Colostrum intake, ^{5,6} g	445	437	436	17.0	461	480	460	11.0

¹A total of 467 sows were used from d 106 of gestation until weaning. Diets were fed according to treatment as follows: 1) 4.5 lb/d gestation feed until d 113 of gestation, then 6 lb/d lactation feed until parturition; 2) 4.5 lb/d gestation feed until d 113 of gestation, then 8.3 lb/d lactation feed until parturition; and 3) 8.3 lb/d lactation feed from d 107 of gestation until parturition. Fifty mL of colostrum was collected within 3 h from the onset of parturition from multiple teats. Samples were sent to a commercial laboratory (Stearns DHIA Lab, Sauk Centre, MN) and analyzed in duplicate for fat, protein, lactose, and total solids (Combi-Foss milk analyzer, Foss Analytics, Denmark). Immunoglobulin G concentration was analyzed in duplicate using the porcine colostrum immunoglobulin G (IgG) ELISA Quantitation Kit (Bethyl Laboratories, Montgomery, TX).

²Significant treatment within parity differences. Values within parity category without a common superscript differ ($P < 0.05$).

³Main effect of treatment: treatment 1 vs. treatment 2 ($P < 0.05$).

⁴Total colostrum intake for the litter.

⁵Average colostrum intake of a piglet calculated as: $-106 + 2.26 \text{ WG} + 200 \text{ BWB} + 0.111 \text{ D} - 1,414 \text{ WG/D} + 0.0182 \text{ WG/BWB}$, where WG is 24 h piglet weight gain in grams, D is duration of colostrum suckling in minutes, and BWB is body weight at birth.

⁶Teat:pig ratio used as a covariate.

Table 7. Effects of increased dietary lysine and energy feeding duration before farrowing on subsequent reproductive performance within parity category¹

Response	Gilts				Sows			
	Control (1)	d 113 (2)	d 107 (3)	SEM	Control (1)	d 113 (2)	d 107 (3)	SEM
Count, n	37	43	40	--	98	99	102	--
Wean to estrus interval, d	5.0	5.0	5.3	0.59	4.9	4.9	4.9	0.35
In estrus by d 7, %	86.2	88.4	90.0	5.81	94.8	93.8	96.0	2.45
Farrowing rate, %	92.1	80.0	87.5	6.34	90.8	90.8	91.3	3.01
Count, n	33	33	35	--	86	89	91	--
Subsequent litter								
Total born, n	13.5	13.6	14.5	0.64	14.9	15.8	15.7	0.41
Born alive, %	96.2	93.3	95.0	1.27	91.6	92.8	93.5	0.86
Stillborn, %	3.2	4.8	2.9	1.06	6.6	6.2	4.9	0.75
Mummified, %	0.6	1.9	2.2	0.66	1.8	0.9	1.6	0.38

¹A total of 419 sows were recorded for a wean to estrus interval, and 363 sows from that group had subsequent farrowing data. Diets were fed according to treatment as follows: 1) 4.5 lb/d gestation feed until d 113 of gestation, then 6 lb/d lactation feed until parturition; 2) 4.5 lb/d gestation feed until d 113 of gestation, then 8.3 lb/d lactation feed until parturition; and 3) 8.3 lb/d lactation feed from d 107 of gestation until parturition.

Table 8. Effects of increased dietary lysine and energy feeding duration before farrowing on economics within parity category¹

Response	Gilts				Sows			
	Control (1)	d 113 (2)	d 107 (3)	SEM	Control (1)	d 113 (2)	d 107 (3)	SEM
Feed cost d 107 to farrow, ² \$	4.84	6.15	9.73	0.099	4.85	6.26	9.65	0.065
Weaned litter revenue, ³ \$	391.6	386.9	383.5	7.58	373.1	382.3	381.3	4.95
IOFC, ⁴ \$	386.7	380.0	373.7	7.58	368.3	376.0	371.6	4.96
Feed cost /weaned pig, ^{2,5} \$	0.401	0.517	0.826	0.0154	0.423	0.533	0.826	0.0101

¹A total of 423 sows were weaned from an initial 472 sows that farrowed. Sows were removed due to poor milking, health challenge, or becoming nurse sows. Weaned pig value = \$32/pig. Gestation feed = \$184.64/ton. Lactation feed = \$237.40/ton.

²All treatment means were significantly different from each other ($P < 0.05$).

³Weaned pig revenue = (litter count at weaning $\times$ \$32/weaned pig).

⁴Income over additional feed cost (IOFC) = (weaned litter revenue – feed cost d 107 to farrow).

⁵Feed cost/weaned pig = (feed cost d 107 to farrow/ litter count at weaning).

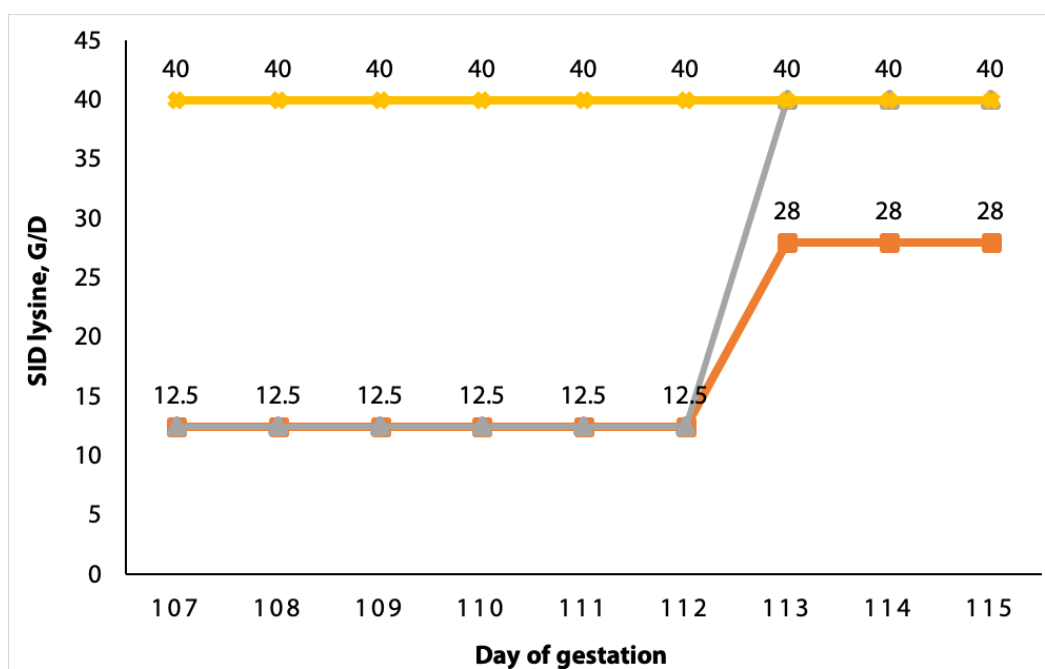


Figure 1. Standardized ileal digestible (SID) lysine (Lys) intake (g/d) for each dietary treatment. Treatment 1 (orange) received 4.5 lb/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until d 113 of gestation, then 6 lb/d lactation feed (28 g SID Lys and 9.4 Mcal ME) until parturition; Treatment 2 (gray) received 4.5 lb/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until d 113 of gestation, then 8.3 lb/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition; and Treatment 3 (yellow) received 8.3 lb/d lactation feed (40 g SID Lys and 13.3 Mcal ME) from d 107 of gestation until parturition.

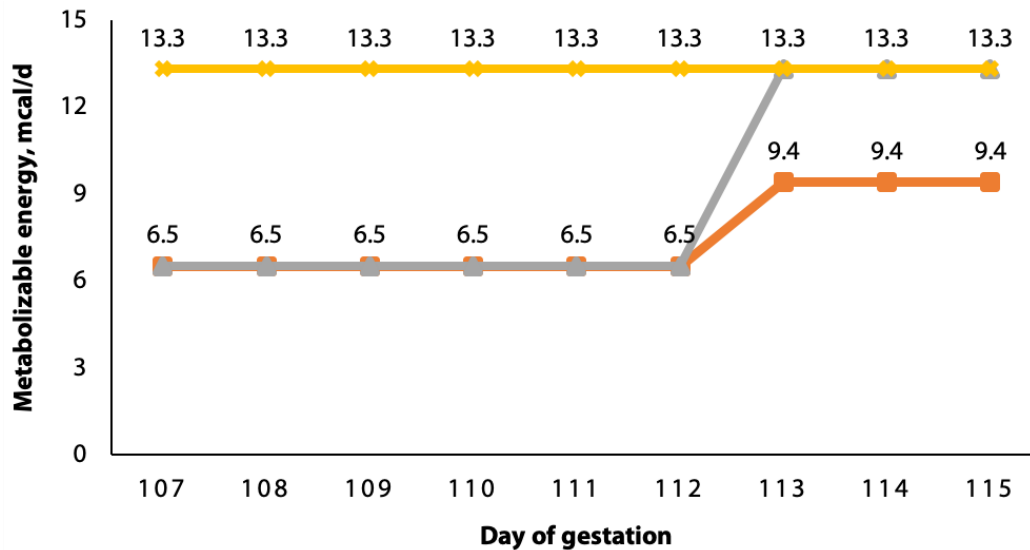


Figure 2. Metabolizable energy (ME) intake (Mcal/d) for each dietary treatment. Treatment 1 (orange) received 4.5 lb/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until d 113 of gestation, then 6 lb/d lactation feed (28 g SID Lys and 9.4 Mcal ME) until parturition; Treatment 2 (gray) received 4.5 lb/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until d 113 of gestation, then 8.3 lb/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition; and Treatment 3 (yellow) received 8.3 lb/d lactation feed (40 g SID Lys and 13.3 Mcal ME) from d 107 of gestation until parturition.