# Determining the impact of increasing standardized ileal digestible lysine for primiparous and multiparous sows during lactation[1,2]

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**ABSTRACT:** Two experiments were conducted to evaluate the effects of increasing dietary SID Lys in lactation on sow and litter performance. In Exp. 1, a total of 111 primiparous sows (Line 241; DNA Genetics, Columbus, NE) were allotted to 1 of 4 dietary treatments on d 110 of gestation. Dietary treatments included increasing dietary standardized ileal digestible (SID) Lys (0.80, 0.95, 1.10, and 1.25%). During lactation, there were no differences in ADFI or sow BW at weaning (d 21), resulting in no differences in BW loss. However, backfat loss during lactation decreased (linear, $P = 0.046$) as SID Lys increased. There were no differences in litter weaning weight, litter gain from d 2 to weaning, percentage of females bred by d 7 after weaning, d 30 conception rate, farrowing rate or subsequent litter characteristics. In Exp. 2, a total of 710 mixed parity sows (Line 241; DNA Genetics) were allotted to 1 of 4 dietary treatments at d 112 of gestation. Dietary treatments included increasing SID Lys (0.75, 0.90, 1.05, and 1.20%). Sow BW at weaning increased (quadratic, $P = 0.046$), and sow BW loss from post-farrow to weaning or d 112 to weaning decreased (quadratic, $P \leq 0.01$) as SID Lys increased. Sow backfat loss increased (linear, $P = 0.028$) as SID Lys increased. Conversely, longissimus muscle depth loss decreased (linear, $P = 0.002$) as SID Lys increased. Percentage of females bred by d 7 after weaning increased (linear, $P = 0.047$) as SID Lys increased in parity 1 sows, with no difference in parity 2 or 3+ sows. Litter weight at d 17 and litter gain from d 2 to 17 increased (quadratic, $P = 0.01$) up to 1.05% SID Lys with no improvement thereafter. For subsequent litter characteristics, there were no differences in total born, percentage born alive, stillborn, or mummies. In conclusion, our results suggest that increasing dietary SID Lys can reduce sow protein loss in lactation. The optimal level of dietary SID Lys required by the sow may vary based on response criteria and parity.

**Key words:** gilt, lactation, lysine, reproduction, sow



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## INTRODUCTION

Over the past 2 decades, genetic improvement has increased productivity of the sow herd. Therefore, nutrient requirement estimates need to be reevaluated to ensure optimum performance. In lactation, nutrients need to support both sow maintenance and litter growth (Dourmad et al., 2008). Milk production represents about 75% of total nutrient requirements in lactation (Noblet et al., 1990), thus as litter size increases, it becomes challenging to meet the sow's requirement.

Inadequate nutrient intake during lactation can increase sow body protein mobilization (Yang et al., 2000). Excessive body protein mobilization can decrease subsequent litter size due to reduced follicular development (Clowes et al., 2003) or embryonic survival (Vinsky et al., 2006). However, recent research

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has demonstrated that primiparous sows may be more resistant to the negative effects of lactational catabolism from reduced feed intake (Patterson et al., 2011).

Lysine is the first limiting amino acid in corn and soybean meal-based swine diets. Because primiparous sows consume less feed than multiparous sows (Koketsu et al., 1996), maternal growth accounts for a larger percentage of daily nutrient intake. Early literature has shown decreased BW loss but no difference in litter performance when Lys increased from 0.67 to 1.0% in the diet of lactating gilts (Boomgaardt et al., 1972; Dourmad et al., 1998), with varying results in sows depending on response criteria (Boyd et al., 2000). However, with modern genetics and greater productivity levels, requirements to reduce mobilization of body protein reserves, maximize litter growth, and maintain reproductive function in high producing multiparous sows needs to be reevaluated. Therefore, the objective of these experiments was to determine the effect of increasing standardized ileal digestible (SID) Lys on the performance of 1) lactating primiparous sows and their litters, and 2) mixed parity sows and their litters under commercial conditions.

## MATERIALS AND METHODS

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in these experiments.

### *Experiment 1*

A total of 111 primiparous sows (Line 241, DNA Genetics, Columbus, NE) were used over 4 consecutive farrowing groups. The trial was conducted at the Kansas State University Teaching and Research Center in Manhattan, KS from January to April, 2016. At d 110 of gestation, sows were weighed and moved to the farrowing house. Females were blocked by weight and expected farrowing date and randomly allotted to 1 of 4 treatments within those blocks. Dietary treatments were corn-soybean meal-based and consisted of increasing SID Lys (0.80, 0.95, 1.10, or 1.25%). Treatments were formed by increasing both crystalline Lys and soybean meal such that there was an increase in L-Lys HCl of 0.12% between each treatment with soybean meal increasing to meet the remainder of the SID Lys target for each treatment. Other feed-grade AA were added as needed to maintain a similar minimum ratio to Lys. All other nutrients met or exceeded the NRC (2012) requirement estimates (Table 1).

From d 110 to 113 of gestation, sows were fed 2.7 kg/d of the gestation diet (14.1% CP, 0.56% SID Lys, 1,472 ME/kg). Starting on d 113, sows received 2.7 kg/d of dietary treatment until farrowing. Postpartum, sows were allowed ad libitum access to feed, recorded by weighing the amount placed in a feed hopper and the amount remaining at weaning (d 21 ± 3). Sow BW and back fat depth (measured 10 cm from the midline of the last rib) were measured on d 0, d 10 post-farrowing, and at weaning. Cross fostering occurred irrespective of dietary treatment until 48 h postpartum in an attempt to equalize litter size (minimum of 10 pigs per litter for group 1 and 12 pigs per litter for groups 2 to 4). Litters were weighed on d 2 and 10 post-farrowing and at weaning.

At weaning (average of 18.7 d post farrowing and range of 15 to 23), sows were moved to a breeding barn, housed individually, and checked daily for signs of es-

**Table 1.** Diet composition (as-fed basis), Exp. 1[1]

| | Standardized ileal digestible Lys, % | | | |
|---|---|---|---|---|
| Ingredient, % | 0.80 | 0.95 | 1.10 | 1.25 |
| Corn | 68.17 | 65.64 | 63.00 | 60.38 |
| Soybean meal, 46.5% CP | 25.58 | 27.89 | 30.21 | 32.49 |
| Choice white grease | 2.00 | 2.00 | 2.00 | 2.00 |
| Limestone | 1.30 | 1.28 | 1.28 | 1.25 |
| Monocalcium P, 21% P | 1.80 | 1.78 | 1.75 | 1.75 |
| Salt | 0.50 | 0.50 | 0.50 | 0.50 |
| L-Lys-HCl | --- | 0.12 | 0.24 | 0.36 |
| DL-Met | --- | 0.01 | 0.07 | 0.14 |
| L-Thr | --- | 0.06 | 0.13 | 0.20 |
| L-Trp | --- | --- | --- | 0.02 |
| L-Val | --- | 0.09 | 0.18 | 0.28 |
| Trace mineral premix[2] | 0.15 | 0.15 | 0.15 | 0.15 |
| Sow vitamin premix[3] | 0.25 | 0.25 | 0.25 | 0.25 |
| Vitamin premix[4] | 0.25 | 0.25 | 0.25 | 0.25 |
| Total | 100 | 100 | 100 | 100 |
| Calculated analysis | | | | |
| Standardized ileal digestible (SID) AA, % | | | | |
| Lys | 0.80 | 0.95 | 1.10 | 1.25 |
| Ile:Lys | 80 | 72 | 65 | 61 |
| Leu:Lys | 173 | 151 | 135 | 123 |
| Met:Lys | 32 | 29 | 31 | 34 |
| Met & Cys:Lys | 63 | 56 | 56 | 56 |
| Thr:Lys | 69 | 67 | 67 | 67 |
| Trp:Lys | 23 | 21 | 19 | 19 |
| Val:Lys | 89 | 87 | 87 | 87 |
| Total Lys, % | 0.93 | 1.08 | 1.24 | 1.40 |
| ME, kcal/kg | 3,313 | 3,315 | 3,318 | 3,322 |
| CP, % | 17.8 | 18.9 | 20.1 | 21.3 |
| Ca, % | 0.90 | 0.90 | 0.90 | 0.90 |
| P, % | 0.75 | 0.75 | 0.75 | 0.75 |
| Available P, % | 0.45 | 0.45 | 0.45 | 0.45 |

[1]Diets were fed from d113 of gestation to weaning.

[2]Provided per kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulfate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[3]Provided per kg premix: 4,409 IU vitamin A; 44 mg biotin; 992 mg vitamin B6; 331 mg folic acid; 110,229 mg choline; 9,921 mg L-carnitine.

[4]Provided per kg premix: 4,409,171 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 15 mg vitamin B12; 1,764 mg menadione; 3,307 mg riboflavin; 11,023 mg pantothenic acid, 19,841 mg niacin.

trus using a boar. The wean-to-estrus interval (WEI) was determined as the number of days between weaning and when sows were first observed to show a positive response to the back-pressure test. Conception rate was determined based on confirmation of pregnancy by ultrasound test at approximately d 30 post breeding.

After weaning, no dietary treatments were applied, and females were fed a common gestation diet with 0.56% SID Lys according to their body condition. Thin, ideal, and fat sows were fed 2.1, 2.0, or 1.9 kg/d, respectively. Subsequent performance (total born, number born alive, stillborn, and mummies) was collected from sows on the subsequent farrowing. Diets were manufactured at the Kansas State University O.H. Kruse Feed Mill in Manhattan, KS. A new batch of each treatment diet was manufactured for each farrowing group and packaged in 22 kg bags. During bagging, feed samples were collected from the bags 5, 10, 15, 20, 25, 30, and 35, and these samples were pooled and used for AA and nutrient analysis.

### *Chemical Analysis*

Four samples (1 per batch) per dietary treatment from the pooled samples were sent to a commercial laboratory (Ward Laboratories, Kearney, NE) for CP (AOAC 900.03; AOAC, 2006), Ca (AOAC 965.14/985.01; AOAC, 2006), and P analysis (AOAC 965.17/985.01; AOAC, 2006). In addition, 4 samples (1 per batch) per dietary treatment were sent to another commercial laboratory (Ajinomoto Heartland Inc., Eddyville, IA) for complete diet amino acid analysis (AOAC 994.12; AOAC, 2006; Table 2.

### *Data Analysis*

Data were analyzed using generalized linear mixed models where dietary treatment was a fixed effect, with random effects of group and block. Statistical models were fitted using the GLIMMIX procedure of SAS (Version 9.3, SAS Inst. Inc., Cary, NC).

Sow ADFI, BW, BW change, backfat change, litter weight, litter gain, lactation length, and SID Lys consumed were fitted assuming a normal distribution of the response variable. Litter weight and litter count on d 2 were used as covariates for d 10 litter weight, weaning litter weight and litter weight gain. In these cases, residual assumptions were checked using studentized residuals and were found to be reasonably met.

Wean-to-estrus interval, litter size, and subsequent total born were fitted assuming negative binomial distribution. Females bred until d 7 after weaning, d 30 conception rate and farrowing rate were fitted using a binary distribution. Subsequent litter performance variables, born alive, percentage stillborns and mummies, were all fitted using a binomial distribution. All results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

**Table 2.** Chemical analysis of diets (as-fed basis), Exp.1[1]

| | Standardized ileal digestible Lys, % | | | |
|---|---|---|---|---|
| Item, % | 0.80 | 0.95 | 1.10 | 1.25 |
| DM | 88.32 | 88.14 | 88.29 | 88.37 |
| CP | 17.99 | 18.68 | 20.01 | 21.40 |
| Ca | 1.03 | 1.05 | 1.08 | 1.09 |
| P | 0.77 | 0.75 | 0.79 | 0.79 |
| Total AA, % | | | | |
| Lys | 1.01 | 1.12 | 1.26 | 1.43 |
| Ile | 0.72 | 0.74 | 0.78 | 0.85 |
| Leu | 1.55 | 1.48 | 1.64 | 1.74 |
| Met | 0.30 | 0.31 | 0.37 | 0.44 |
| Met & Cys | 0.63 | 0.64 | 0.71 | 0.81 |
| Thr | 0.70 | 0.77 | 0.86 | 0.97 |
| Trp | 0.22 | 0.22 | 0.24 | 0.27 |
| Val | 0.85 | 0.92 | 1.06 | 1.21 |
| His | 0.48 | 0.49 | 0.50 | 0.54 |
| Phe | 0.84 | 0.93 | 0.97 | 1.03 |

[1]Diet samples were collected from each batch of feed at manufacturing from every 5fth bag. Crude protein and total AA analyses were conducted in duplicate on composite samples by Ajinomoto Heartland Inc. (Chicago, IL). Dry matter, Ca, and P analyses were conducted on composite samples by Ward Laboratories (Kearney, NE).

### *Experiment 2*

The experiment was conducted on a commercial sow farm in central Nebraska from mid-June until mid-August, 2016. Females were individually housed from d 0 to d 113 of gestation and were fed a common diet with 0.70% SID Lys according to body condition (thin, ideal, and fat females were offered 2.5, 1.8 and 1.3 kg, respectively). All females had ad libitum access to water.

A total of 710 primiparous and multiparous females (Line 241, DNA Genetics) were used. At d 112 of gestation, females were weighed, and on a subsample of females ($n$ = 369), back fat and longissimus muscle depth were collected via ultrasound (Aloka SSD 500V, Hitachi Aloka Medical Ltd., Wallingford, CT; between the 10th and 11th ribs, 10 cm from the midline). Females were blocked by BW within expected farrowing date and parity (1 to 7) and were then randomly assigned to 1 of 4 dietary treatments within blocks. Dietary treatments were corn-soybean meal-based and consisted of increasing SID Lys (0.75, 0.90, 1.05 and 1.20%). Treatments were formulated like in Exp. 1 by increasing both crystalline Lys and soybean meal to maintain a similar soybean meal to crystalline Lys ratio. Other feed-grade AA were added as needed to maintain a similar minimum ratio to Lys across treatments. All other nutrients met or exceeded the NRC (2012) requirement estimates. Energy (ME, kcal/kg) was the same across all dietary treatments (Table 3).

On d 113 of gestation, females were moved to the farrowing house and fed treatment diets. Sows received 2.5 kg/d of feed until farrowing. Cross fostering occurred irrespective of dietary treatment until 48 h postpartum in an attempt to equalize litter size (minimum of 10 pigs per litter). Litters were weighed on d 2 (after equalization) and d 17 post-farrowing.

At weaning (average of 21.3 d post farrowing and range of 19 to 24) sows were returned to the gestation barn where sow body weight was determined and back fat and longissimus muscle depth were again measured via ultrasound. Each sow was housed individually and checked daily for signs of estrus using a boar. The WEI was determined as the number of days between weaning and when sows were first observed to show a positive response to the back-pressure test. Conception rate was determined based on pregnancy confirmation using ultrasound at approximately d 30 after first insemination.

Due to the magnitude of this study and the commercial setting, sow BW 24 h after farrowing was not able to be measured. A post-farrowing weight was calculated for each sow by subtracting the weight of conceptus from each sow's d 112 body weight. Final weight of conceptus was calculated using the original equation listed in NRC (2012) generated from Dourmad et al. (1998), and corrected by Thomas (2017) using the variables of parity, length of gestation, and total born.

No dietary treatments were applied after weaning and all females were fed a blend of 1.8 kg of a 0.70% SID Lys gestation diet and 1.3 kg of a 1.05% SID Lys lactation diet until breeding. After breeding, each sow was fed the gestation diet according to their body condition for the remainder of gestation (thin, ideal, and fat females were fed 2.5, 1.8, and 1.3 kg respectively). Subsequent performance (total born, number born alive, mummies, and stillborn) were collected from sows remaining in the herd on their subsequent parity.

Experimental diets were manufactured at the Pillen Family Farms Feed Mill (Albion, NE). Feed was continuously delivered in bulk throughout the study period, and feed delivery amounts by treatment were recorded to determine total feed consumed in lactation. Average daily feed intake by treatment was calculated by total feed delivered during the trial period divided by number of sows on each treatment diet for each day of the trial period.

**Table 3.** Diet composition (as-fed basis), Exp. 2[1]

| | Standardized ileal digestible Lys, % | | | |
|---|---|---|---|---|
| Ingredient | 0.75 | 0.90 | 1.05 | 1.20 |
| Corn | 73.40 | 68.36 | 63.28 | 58.51 |
| Soybean meal, 46.5% CP | 19.28 | 24.23 | 29.18 | 33.96 |
| Corn oil | 3.00 | 3.00 | 3.00 | 3.00 |
| Limestone | 1.41 | 1.39 | 1.36 | 1.34 |
| Monocalcium P, 21% | 1.33 | 1.30 | 1.27 | 1.24 |
| Salt | 0.50 | 0.50 | 0.50 | 0.50 |
| L-Lys-HCL | 0.15 | 0.19 | 0.23 | 0.28 |
| L-Thr | 0.04 | 0.07 | 0.11 | 0.15 |
| L-Trp | 0.01 | 0.01 | 0.02 | 0.02 |
| DL-Met | --- | 0.003 | 0.05 | 0.09 |
| L-Val | 0.06 | 0.12 | 0.18 | 0.24 |
| Sal Curb[2] | 0.33 | 0.33 | 0.33 | 0.33 |
| Sow vitamin/mineral premix[3] | 0.20 | 0.20 | 0.20 | 0.20 |
| Choline chloride | 0.13 | 0.13 | 0.13 | 0.13 |
| AxtraPhy 2500[4] | 0.02 | 0.02 | 0.02 | 0.02 |
| Dye[5] | 0.16 | 0.16 | 0.16 | --- |
| Total | 100 | 100 | 100 | 100 |
| Calculated analysis | | | | |
| Standardized ileal digestible (SID) AA, % | | | | |
| Lys | 0.75 | 0.90 | 1.05 | 1.20 |
| IIe:Lys | 71 | 68 | 66 | 64 |
| Met: Lys | 30 | 30 | 30 | 31 |
| Met & Cys: Lys | 61 | 56 | 56 | 56 |
| Thr:Lys | 67 | 67 | 67 | 67 |
| Trp:Lys | 20 | 20 | 20 | 20 |
| Val:Lys | 90 | 90 | 90 | 90 |
| Total Lys, % | 0.87 | 1.04 | 1.20 | 1.37 |
| ME, kcal/kg | 3,479 | 3,479 | 3,479 | 3,479 |
| CP, % | 15.5 | 17.5 | 19.6 | 21.6 |
| Ca, % | 0.85 | 0.85 | 0.85 | 0.85 |
| P, % | 0.62 | 0.63 | 0.65 | 0.66 |
| Available P, % | 0.45 | 0.45 | 0.45 | 0.45 |

[1]Diets were fed from d 114 of gestation to weaning.

[2]Kemin Industries (Des Moines, IA).

[3]Provided per kg of premix: 18 mg Cu; 0.8 mg I; 100 mg Fe; 40 mg Mn; 0.15 mg Se; 125 mg Zn; 11,000 IU vitamin A, 1,980 IU vitamin D; 99 IU vitamin E; 4 mg vitamin K; 0.04 mg vitamin B12; 44.2 mg niacin; 27.5 mg pantothenic acid; 8.6 mg riboflavin; 3.1 mg folic acid; 0.44 mg biotin; 5.1 mg vitamin B6; 2.2 mg thiamin; 0.44 mg chromium.

[4]Dupont (St. Louis, MO).

[5]Different colored dyes were added to distinguish among diets at the farm.

### *Chemical Analysis*

Samples of the diet were taken at the feeder, 3 times per week. Samples were pooled by week to make a composite sample. Six samples per dietary treatment were sent to a commercial laboratory (Ward Laboratories, Kearney, NE) for CP (AOAC 900.03; AOAC, 2006), Ca (AOAC 965.14/985.01; AOAC, 2006), and P (AOAC 965.17/985.01; AOAC, 2006). Additionally, 6 samples (1 per week) per dietary treatment were sent to another commercial laboratory (University of Missouri Experimental Station Chemical Laboratories, Columbia, MO) for complete diet amino acid analysis (AOAC 975.44 and 982.30; AOAC, 2006; Table 4).

**Table 4.** Chemical analysis of the diets (as-fed basis), Exp. 2[1]

| | Standardized ileal digestible Lys, % | | | |
|---|---|---|---|---|
| Item, % | 0.75 | 0.90 | 1.05 | 1.20 |
| DM | 88.02 | 88.24 | 88.54 | 88.88 |
| CP | 14.78 | 16.87 | 18.25 | 20.08 |
| Ca | 0.97 | 0.94 | 1.04 | 0.99 |
| P | 0.62 | 0.66 | 0.62 | 0.63 |
| Total AA, % | | | | |
| Lys | 0.89 | 1.03 | 1.19 | 1.31 |
| Ile | 0.64 | 0.71 | 0.82 | 0.88 |
| Leu | 1.36 | 1.48 | 1.61 | 1.69 |
| Met | 0.22 | 0.24 | 0.32 | 0.38 |
| Met & Cys | 0.46 | 0.50 | 0.62 | 0.68 |
| Thr | 0.58 | 0.68 | 0.79 | 0.89 |
| Trp | 0.12 | 0.15 | 0.16 | 0.18 |
| Val | 0.82 | 0.94 | 1.12 | 1.25 |
| His | 0.38 | 0.42 | 0.48 | 0.51 |
| Phe | 0.75 | 0.84 | 0.94 | 1.00 |
| Free lys | 0.12 | 0.14 | 0.18 | 0.21 |

[1]Diets were collected twice per week and pooled to make a composite sample. Six composite samples per dietary treatment were sent for analysis. Total AA analyses were conducted on composite samples by University of Missouri Experimental Station Chemical Laboratories (Columbia, MO). Dry matter, Crude protein, Ca and P analyses were conducted by Ward Laboratories (Kearney, NE).

### *Data Analysis*

Data were analyzed using generalized linear mixed models where dietary treatment and parity category (P1, P2, and P3+) and dietary treatment within parity category were evaluated as fixed effects, with random effect of block. The response variables of sow BW (d112, post farrow, and weaning), BW loss, backfat change, longissimus muscle depth change, litter weight (d 2 and d 17), litter gain and lactation length were fitted assuming a normal distribution. Total born was used as a covariate for post farrow sow BW. Longissimus muscle depth on d 112 was used as a covariate for its depth at weaning and change over lactation. Litter weight on d 2 was used as a covariate to improve the fit of the model for d 17 litter weight, and litter gain response variables. Litter weight on d 2 and lactation length were used as covariates for sow weaning BW, sow BW change from d 112 to weaning, and sow BW change from post farrow to weaning.

Day 2 litter size, d 17 litter size and subsequent total born were fitted using a negative binomial distribution. Females bred by d 7, d 30 conception rate and farrowing rate were fitted using a binary distribution. Subsequent born alive, stillborn, and mummies were modeled using a binomial distribution.

Results were considered significant at $P \leq 0.05$. Use of covariates were included in the model if they improved the Bayesian information criterion by greater than 2 units. For normally distributed data the residual assumptions were found to be reasonably met using evaluation of the studentized residuals. Statistical models were fit using PROC GLIMMIX of SAS (Version 9.4, SAS Inst. Inc., Cary, NC).

## RESULTS AND DISCUSSION

### *Chemical Analysis*

In Exp. 1, chemical analysis of DM, CP, Ca, P, and AA were similar to the formulated values (Table 2). The analyzed total Lys concentration in the 0.80% SID Lys diet was slightly higher than formulated. In Exp. 2, chemical analysis of DM, CP, Ca, P, and AA were similar to the formulated values (Table 4).

### *Sow BW, Backfat, and Loin Eye Depth Change in Lactation*

There were no differences among treatments in initial BW or backfat depth in Exp. 1 (Table 5) and Exp. 2 (Table 6) which validated treatment randomization. In Exp. 2, increasing SID Lys to 1.20% reduced BW loss within parity 2 (linear, $P = 0.028$) and parity 3 + (quadratic, $P < 0.007$) sow categories (Fig. 1). Sow BW loss in lactation is inevitable due to higher nutrient demands than voluntary feed intake can support. Previous studies (Dourmad et al.,1998; Xue et al., 2012; Huang et al., 2013) found a decrease in BW loss as Lys increased in the diet. The results of multiparous sows do not agree with the results of primiparous sows where no differences in BW loss regardless of dietary Lys concentration in Exp. 1 ($P = 0.235$) and Exp. 2 ($P = 0.361$) were found. In support of these findings, Yang et al. (2000) and Xue et al. (2012) did not observe any differences in BW loss as Lys increased in first parity sows. However, Shi et al. (2015) observed that primiparous sow BW loss decreased with increasing SID Lys and estimated the optimal dietary SID Lys for minimal BW loss at 0.85%. The summary of research and present data would suggest that BW loss can be reduced when increasing SID Lys in multiparous sows, with minor or no benefit in primiparous sows.

Previous literature observed no differences in backfat loss during lactation regardless of dietary SID Lys concentration (Touchette et al., 1998; Yang et al., 2000; Shi et al., 2015). In Exp. 1 increasing dietary SID Lys decreased (linear, $P = 0.046$) backfat loss in first parity sows. Conversely, in Exp. 2 backfat loss increased (linear, $P = 0.028$) with increasing SID Lys. One explanation for this may be that the increase in litter growth rate as SID Lys increased would require more energy and if feed intake did not differ, mobili-

**Table 5.** Effects of increasing standardized ileal digestible (SID) lysine in lactation diets on sow performance, Exp. 1[1]

| | Standardized ileal digestible Lys, % | | | | | Probability, *P* < | |
|---|---|---|---|---|---|---|---|
| Item | 0.80 | 0.95 | 1.10 | 1.25 | SEM | Linear | Quadratic |
| BW, kg | | | | | | | |
| d 110 | 194.9 | 196.0 | 195.2 | 195.7 | 2.97 | 0.929 | 0.894 |
| d 0 | 184.3 | 184.0 | 183.7 | 185.2 | 2.50 | 0.835 | 0.667 |
| d 10 | 182.3 | 181.8 | 182.8 | 183.9 | 2.43 | 0.530 | 0.716 |
| Wean | 179.2 | 178.2 | 180.6 | 181.8 | 2.49 | 0.335 | 0.738 |
| BW loss, kg | | | | | | | |
| d 0 to 10 | –2.03 | –2.23 | –1.43 | –1.31 | 0.958 | 0.439 | 0.860 |
| d 10 to wean | –3.08 | –2.83 | –2.28 | –2.08 | 0.878 | 0.318 | 0.971 |
| d 0 to wean | –5.12 | –5.06 | –3.76 | –3.38 | 1.377 | 0.235 | 0.899 |
| ADFI, kg | | | | | | | |
| d 0 to 10 | 4.66 | 4.44 | 4.50 | 4.64 | 0.127 | 0.952 | 0.130 |
| d 10 to wean | 6.36 | 6.27 | 6.21 | 6.31 | 0.173 | 0.743 | 0.573 |
| d 0 to wean | 4.99 | 4.74 | 4.90 | 4.97 | 0.136 | 0.821 | 0.226 |
| Total Lys intake[2], g/d | 50.4 | 53.5 | 61.0 | 71.2 | 1.61 | 0.001 | 0.016 |
| SID Lys intake[3], g/d | 39.9 | 45.0 | 53.9 | 62.1 | 1.35 | 0.001 | 0.243 |
| BF loss, mm | | | | | | | |
| d 0 to 10 | –0.99 | –1.62 | –0.95 | –1.09 | 0.249 | 0.549 | 0.306 |
| d 10 to wean | –1.48 | –0.94 | –1.23 | –0.60 | 0.265 | 0.087 | 0.874 |
| d 0 to wean | –2.51 | –2.53 | –2.18 | –1.65 | 0.329 | 0.046 | 0.410 |
| Lactation length, d | 18.7 | 18.8 | 18.6 | 18.4 | 0.34 | 0.946 | 0.534 |
| Wean-to-estrus interval, d | 5.00 | 4.91 | 4.97 | 4.61 | 0.45 | 0.691 | 0.800 |
| Females bred by 7 d after weaning, % | 89.9 | 89.9 | 94.2 | 100.0 | 6.05 | 0.975 | 0.977 |
| d 30 conception rate[4], % | 87.5 | 96.0 | 96.3 | 78.8 | 8.00 | 0.537 | 0.051 |
| Farrowing rate[5], % | 79.2 | 88.0 | 96.0 | 74.8 | 8.03 | 0.789 | 0.290 |

[1]A total of 111 primiparous sows (DNA 241, DNA Genetics, Columbus, NE) across 4 farrowing groups were used in a 21-d trial with 27 to 29 sows per dietary treatment.

[2]Calculated using analyzed Lys values and ADFI.

[3]Calculated using formulated SID Lys values and ADFI.

[4]Number of sows confirmed pregnant on d 30 post mating divided by number of sows bred.

[5]Number of sows farrowed divided by number of sows bred by d 21 after weaning.

zation of lipid stores to satisfy milk production would be required (Dourmad et al., 2008). However, sows fed 1.20% SID Lys had decreased litter growth, which may have been due to a reduction in ADFI and thus energy intake. The decrease in energy intake could have contributed to additional back fat loss on the 1.20% SID Lys treatment.

In Exp. 2, as SID Lys increased in the diet we observed a reduction in loin eye depth loss during lactation (linear, $P = 0.002$) from –1.9 to 0.5 mm, which resulted in an increase (linear, $P = 0.002$) in actual loin eye depth at weaning. In support of these findings, Shi et al. (2015) observed a quadratic decrease in loin eye area loss during lactation with increasing SID Lys, with the greatest reduction occurring at 1.02% SID Lys (54 g/d total Lys) in primiparous sows. In addition, Touchette et al. (1998) determined that minimum loin eye area loss occurred at 48 g/d SID Lys, and Dourmad et al. (1998) observed losses in lean tissue were greater in sows fed 0.67% total Lys compared to 0.77 to 0.87% total Lys. It is likely that body protein mobilization occurs when the sow is deficient in AA intake, but is not necessarily independent from an energy deficiency (Dourmad et al., 2008). When energy intake is insufficient, a sow may mobilize body protein to support the energy deficiency (Pomar et al., 1991). When evaluating restricted total dietary Lys intake, Clowes et al. (2003) looked at the amount of protein loss that could be sustained by a lactating sow without impacting performance. Their study demonstrated that there were no differences in body protein loss up to d 20 of lactation; however, from d 20 to weaning on d 23, there was significant body weight loss, which followed an increase in body protein loss. This suggests that until d 20 of lactation, a minimal amount of body reserves have been mobilized even when severely deficient in total dietary Lys, but after d 20 as milking pressure and litter growth increases, larger amounts of body protein mobilization occur, and dietary Lys is needed to reduce negative impacts from excessive protein mobilization.

### *Sow ADFI*

In Exp. 1, no difference ($P = 0.821$) was observed in ADFI as dietary SID Lys increased from 0.80 to 1.25%. Multiple studies (Huang et al., 2013; Huber et al., 2015; Shi et al., 2015) have shown no differences in ADFI with

**Table 6.** Effects of increasing lysine on sow performance in lactation of high-performing gilts and sows under commercial conditions, Exp. 2[1]

| | Standardized ileal digestible Lys, % | | | | | Probability, $P <$ | |
|---|---|---|---|---|---|---|---|
| Item | 0.75 | 0.90 | 1.05 | 1.20 | SEM | Linear | Quadratic |
| Count, n | 187 | 185 | 194 | 144 | – | – | – |
| Parity | 3.1 | 3.2 | 3.2 | 3.2 | 0.15 | 0.576 | 0.928 |
| Sow BW, kg | | | | | | | |
| d 112[2] | 209 | 209 | 209 | 208 | 1.8 | 0.478 | 0.932 |
| Post-farrow [2,3] | 195 | 194 | 194 | 193 | 1.8 | 0.487 | 0.958 |
| Wean[2] | 173 | 176 | 180 | 177 | 2.0 | 0.017 | 0.046 |
| Sow BW change, kg | | | | | | | |
| Post-farrow[3] to wean[2] | –21.3 | –18.2 | –14.6 | –16.9 | 1.45 | 0.001 | 0.018 |
| d 112 to wean[2] | –35.7 | –31.9 | –28.5 | –31.6 | 1.50 | 0.003 | 0.004 |
| Sow back fat[4], mm | | | | | | | |
| d 112[2] | 20.0 | 21.2 | 20.3 | 20.1 | 0.65 | 0.676 | 0.184 |
| Wean[2] | 18.6 | 18.4 | 17.6 | 18.0 | 0.45 | 0.121 | 0.395 |
| Change (d 112 to wean)[2] | –1.4 | –2.6 | –2.8 | –2.6 | 0.44 | 0.028 | 0.061 |
| Loin eye depth, mm | | | | | | | |
| d 112[2] | 52.9 | 52.4 | 52.3 | 52.6 | 0.77 | 0.722 | 0.575 |
| Wean[2] | 50.2 | 51.2 | 52.0 | 52.6 | 0.64 | 0.002 | 0.784 |
| Change (d 112 to wean)[2] | –1.9 | –1.0 | –0.1 | 0.5 | 0.61 | 0.002 | 0.784 |
| Lactation length, d | 21.3 | 21.4 | 21.4 | 21.4 | 0.11 | 0.485 | 0.435 |
| Females bred by d 7 after weaning[2], % | 88.9 | 92.6 | 94.8 | 92.4 | 2.60 | 0.227 | 0.199 |
| d 30 conception rate[5], % | 94.7 | 89.7 | 95.8 | 90.8 | 2.86 | 0.928 | 0.700 |
| Farrowing rate[6], % | 92.3 | 85.6 | 93.8 | 88.6 | 3.39 | 0.957 | 0.951 |
| ADFI from feed delivery records[7], kg | 6.45 | 6.36 | 6.68 | 5.90 | – | – | – |
| SID Lys intake[8], g/d | 48.4 | 57.2 | 70.2 | 70.6 | – | – | – |

[1]A total of 710 sows (DNA 241, DNA Genetics, Columbus, NE) and litters were used in a lactation study from d 112 of gestation until weaning.

[2]Significant differences of treatment within parity category observed.

[3]Post-farrow weight was calculated using d 112 BW and subtracting weight of conceptus (calculated using modified equation by Thomas, 2017).

[4]A subsample of sows (n = 369) were ultrasounded on d 112 for backfat and loin eye depth and subsequently used in the backfat and loin eye depth change calculation. All 710 sows were measured at weaning for backfat and loin eye depth.

[5]Number of sows confirmed pregnant on d 30 post mating divided by number of sows bred.

[6]Number of sows farrowed divided by number of sows bred by d 21 after weaning.

[7]Calculated using total feed deliveries by treatment and dividing by total number of sows on feedline.

[8]Calculated using ADFI multiplied by SID Lys in the experimental diet.

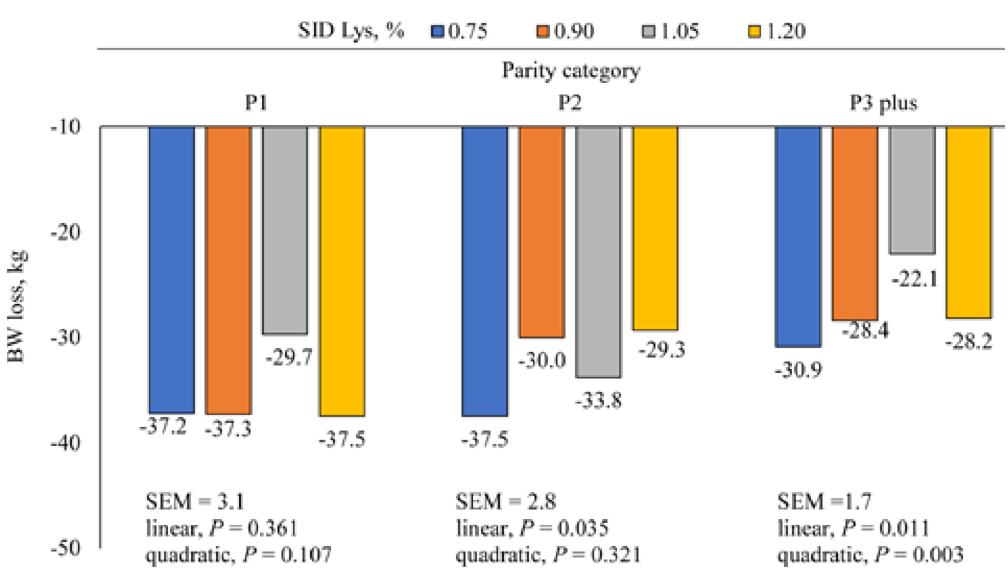


**Figure 1.** Estimated mean sow BW loss from d 112 of gestation until weaning within parity category for sows fed increasing SID Lys in lactation, Exp. 2.

increasing SID Lys from 0.76 to 1.14%. One study observed a decrease in ADFI as total Lys increased from 0.60 to 1.60% (Yang et al., 2000), and hypothesized the decrease in intake was due to elevated serum urea nitrogen levels and varying branch chain AA ratios across their experimental diets. Because our SID Lys range falls within the range of Yang et al. (2000), it is not clear whether SID Lys levels above 1.25% deter feed intake. In Exp. 2, we were unable to capture individual sow ADFI and cannot make a conclusion on the effect of dietary SID Lys on individual sow intake in that study. However, ADFI for each treatment was calculated using the total amount of feed delivered for each treatment divided by total sows consuming each diet. Average daily feed intake increased as SID Lys increased from 0.75 to 1.05%, but ADFI decreased on the 1.20% SID Lys treatment.

### *Litter Performance*

There were no differences in lactation length, litter size on d 2 or litter size at weaning in Exp. 1 and Exp. 2. In addition, in Exp. 1 regardless of treatment, there were no differences in litter weight at d 2 (Table 7). However, in Exp. 2 litter weight at d 2 increased from 21.2 to 22.2 kg (quadratic, $P = 0.016$) as SID Lys level increased up to 1.05% SID Lys, this was unexpected due to cross fostering to equalize litter size (Table 8).

An early study by Johnston et al. (1993) suggests a linear correlation exists between Lys intake in lactation and litter weight gain. More recently, Xue et al. (2012) observed a linear increase in litter weight gain as SID Lys increased from 45.0 to 68.5 g/d in mixed parity sows. Yang et al. (2000) observed a quadratic response in litter gain with optimal litter growth rates occurring at 44, 55, and 56 g/d total Lys for parities 1, 2, and 3, respectively. These 2 studies are in agreement with Exp. 2 where litter gain increased (quadratic, $P = 0.001$) with increasing SID Lys and was maximized at 1.05% SID Lys for mixed parity sows. There was a decrease observed for litter growth in sows fed 1.20% SID Lys, however there was also a decrease in ADFI on this treatment. Tokach et al. (1992) observed that energy had to be increased along with Lys to obtain benefits in milk output, which would suggest why we saw a decrease in litter growth on the highest Lys treatment with reduced feed intake.

In contrast, no differences in litter growth were observed by Dourmad et al. (1998), Shi et al. (2015) and Huber et al. (2015) when fed increasing dietary levels of 0.66 to 0.87%, 0.76 to 1.14%, or 0.73 to 0.94% SID Lys, respectively. In Exp. 1, no improvement ($P = 0.209$) in litter gain was observed as SID Lys increased from 39 to 63 g/d for primiparous sows. However, the lowest SID Lys fed in Exp. 1 would be near the SID Lys of 44 g/d for optimal litter growth rate observed by Yang et al. (2000) in parity 1 sows, which could be why no difference was observed in our study. When calculating the estimated SID Lys (g/d) per kg of litter gain in Exp. 1, the 0.80 and 0.95% SID Lys treatments were supplying 39.9 and 45.0 g/d of SID Lys, respectively. This is less than the predicted requirement of 47.4 to 48.7 g/d SID Lys that the

**Table 7.** Effects of increasing standardized ileal digestible (SID) lysine in lactation diets on litter and subsequent performance, Exp. 1[1]

| | SID Lysine, % | | | | | Probability, $P$ < | |
|---|---|---|---|---|---|---|---|
| Item | 0.80 | 0.95 | 1.10 | 1.25 | SEM | Linear | Quadratic |
| Litter size, n | | | | | | | |
| d 2 | 13.1 | 13.3 | 13.0 | 12.3 | 0.70 | 0.983 | 0.953 |
| d 10 | 13.1 | 13.3 | 13.0 | 12.3 | 0.70 | 0.983 | 0.953 |
| Wean | 12.9 | 13.1 | 12.9 | 12.3 | 0.70 | 0.916 | 0.988 |
| Litter weight, kg | | | | | | | |
| d 2 | 19.2 | 19.4 | 18.5 | 18.7 | 0.49 | 0.263 | 0.965 |
| d 10 | 42.0 | 41.6 | 41.4 | 41.5 | 0.53 | 0.451 | 0.528 |
| Wean | 69.5 | 69.0 | 67.4 | 67.7 | 1.31 | 0.120 | 0.728 |
| Litter gain, kg | | | | | | | |
| d 2 to 10 | 22.8 | 22.5 | 21.9 | 22.1 | 0.57 | 0.267 | 0.617 |
| d 10 to wean | 27.6 | 27.7 | 25.7 | 26.1 | 1.22 | 0.194 | 0.899 |
| d 2 to wean | 50.2 | 49.9 | 48.0 | 48.4 | 1.36 | 0.209 | 0.766 |
| Litter ADG d 2 to wean, g | 2,984 | 2,959 | 2,896 | 2,938 | 57.3 | 0.374 | 0.545 |
| Subsequent performance[2] | | | | | | | |
| Total piglets born per sow farrowed, n | 14.3 | 16.4 | 15.2 | 15.7 | 0.95 | 0.603 | 0.394 |
| Born alive, % | 94.2 | 89.8 | 91.0 | 93.7 | 2.05 | 0.955 | 0.054 |
| Stillborn, % | 5.0 | 7.2 | 7.0 | 5.0 | 1.73 | 0.998 | 0.193 |
| Mummy, % | 0.6 | 3.0 | 1.5 | 1.0 | 1.03 | 0.960 | 0.090 |

[1]A total of 111 primiparous sows (DNA 241, DNA Genetics, Columbus, NE) across 4 farrowing groups were used in a 21-d trial with 27 to 29 sows per dietary treatment.

[2]Number of sows included for subsequent performance were 19, 22, 26, and 20 for dietary treatments of 0.80, 0.95, 1.10, and 1.25% SID Lys, respectively.

**Table 8.** Effects of increasing lysine in lactation on litter performance of high-performing gilts and sows under commercial conditions, Exp. 2[1]

| | Standardized ileal digestible Lys, % | | | | | Probability, $P$ < | |
|---|---|---|---|---|---|---|---|
| Item | 0.75 | 0.90 | 1.05 | 1.20 | SEM | Linear | Quadratic |
| Total born | 15.9 | 15.4 | 15.4 | 16.4 | 0.38 | 0.497 | 0.255 |
| Litter size[2], n | | | | | | | |
| d 2 | 13.6 | 13.7 | 13.7 | 13.7 | 0.07 | 0.950 | 0.965 |
| d 17 | 12.6 | 12.7 | 12.7 | 12.7 | 0.11 | 0.896 | 0.945 |
| Litter weight, kg | | | | | | | |
| d 2 | 21.5 | 21.8 | 22.2 | 21.2 | 0.34 | 0.835 | 0.016 |
| d 17 | 61.3 | 61.5 | 64.1 | 60.2 | 0.64 | 0.807 | 0.001 |
| Litter gain d 2 to 17, kg | 39.7 | 39.8 | 42.5 | 38.6 | 0.64 | 0.807 | 0.001 |
| Litter ADG d 2 to 17, g | 2,695 | 2,704 | 2,887 | 2,619 | 43.4 | 0.807 | 0.001 |
| Subsequent performance[3] | | | | | | | |
| Total born per sow farrowed, n | 15.9 | 16.0 | 16.3 | 15.1 | 0.41 | 0.482 | 0.310 |
| Born alive, % | 92.0 | 93.0 | 92.0 | 92.4 | 0.78 | 0.863 | 0.666 |
| Stillborns, % | 4.3 | 3.3 | 4.2 | 5.1 | 0.63 | 0.150 | 0.065 |
| Mummies, % | 3.5 | 3.6 | 3.7 | 2.4 | 0.51 | 0.158 | 0.110 |

[1]A total of 710 sows (DNA 241, DNA Genetics, Columbus, NE) and litters were used in a lactation study from d 112 of gestation until weaning.

[2]Litters were cross-fostered to equalize litter size up to 48-h post-farrowing.

[3]Number of sows included in subsequent performance are 161, 149, 140, 108 for dietary treatments of 0.75, 0.90, 1.05 and 1.20% SID Lys, respectively.

NRC (2012) model would estimate for the observed litter growth for all treatments. However, no differences in litter growth were observed. This coupled with greater backfat loss on the low SID Lys treatments in Exp. 1 demonstrates that sows will continue to mobilize body reserves to meet the demands of milk production and litter growth when diets are low in SID Lys. When estimating the g/d SID Lys recommended per kg of litter growth observed in Exp. 2 (NRC, 2012), our sows should require 43 to 47 g SID Lys. However, our estimated consumption based on ADFI was 48 to 70 g/d of SID Lys. This would mean our sows in Exp. 2 were consuming more SID Lys than what was needed for litter growth and may have been depositing excess SID Lys and AA's as body protein, which is supported by increased loin eye depth at weaning with increasing SID Lys. Our study would be in agreement with previous literature (Touchette et al., 1998) that suggests the Lys requirement for litter growth is less than that for reducing loin eye depth loss. Our study would also demonstrate that 39.9 g/d of SID Lys was sufficient to meet litter demands in primiparous sows. It is important to note that the NRC (2012) model for SID Lys requirement per kg of litter growth does not incorporate studies with litter growth greater than 2.7 kg/d. Thus, with the use of more recent genetic lines in the current study, we observed litter growth rates that were above those used to create the model, which may be why the calculated SID Lys requirements for litter growth observed in our study were over predicted.

Unlike multiparous sows who show an increase in milk yield when made anabolic during lactation, primiparous sows seem to partition extra energy into body growth rather than milk production (Pluske et al., 1998). This could explain why only multiparous sows showed an increase (quadratic, $P = 0.001$) in litter growth when supplied with additional SID Lys in lactation. Clowes et al. (2003) suggests that there is no impact in litter growth up to d 20 of lactation when total dietary Lys consumption ranged from 24 to 50 g/d, however from d 20 to weaning at d 23, there was significant decrease in litter growth and milk protein concentration due to large amounts ( > 12%) of sow body protein being mobilized on the low total Lys treatment. This indicates that until d 20 of lactation, a minimal amount of body reserves has been mobilized but as the milking pressure and litter growth increases after that point, increasing dietary SID Lys and other AA's may be needed to maintain productivity.

### *Reproductive Performance*

In Exp. 1, there was no difference ($P = 0.975$) in percentage of females bred by d 7 after weaning. This is in agreement with Yang et al. (2000) and Shi et al. (2015) where no differences were found in WEI or percentage mated post weaning in primiparous sows. However, in the commercial setting of Exp. 2, there was a difference in percentage of females bred by 7 d in parity 1 sows, where increasing SID Lys from 0.75 to 1.20% increased (linear, $P = 0.047$) the percentage of females mated (Fig. 2). Similarly, Xue et al. (2012) observed a decrease in WEI as SID Lys increased. These conflicting results could be due to the research setting (commercial vs. university) and make it difficult to determine the optimal SID Lys level in first

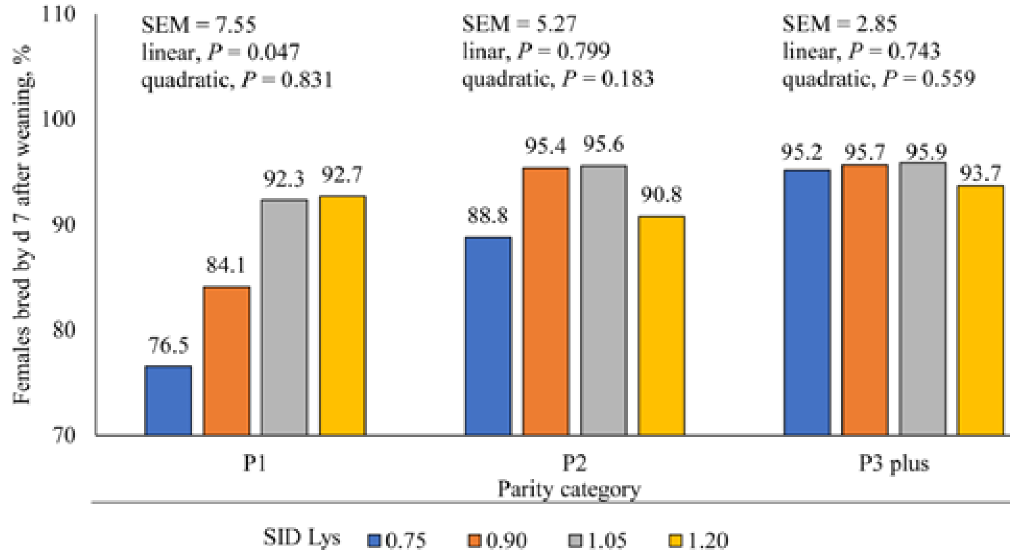


**Figure 2.** Estimated percentage females bred by d 7 after weaning within parity category for sows fed increasing SID Lys in lactation, Exp. 2.

parity sows needed to minimize WEI and improve the percentage of females bred by d 7 after weaning.

In Exp. 2, no difference was observed in percentage of parity 2 or parity 3+ sows bred by d 7 after weaning which is in agreement with results of Yang et al. (2000). However, as SID Lys increased in parity 1 sows, protein loss was reduced and there was an increase in percentage bred by d 7 after weaning. This would suggest that increased body protein mobilization in parity 1 sows decreases signs of estrus by d 7 after weaning. Similarly, King (1987) observed a shorter wean to estrus interval when body protein loss was minimized in parity 1 sows. Furthermore, because expression of estrus by d 7 increased in parity 1 sows as SID Lys increased to 1.20%, and litter growth was maximized at 1.05% SID Lys, it can be hypothesized that the SID Lys requirement for reproduction is greater than that for litter growth.

There were no differences observed in d 30 conception rate in Exp. 1 or Exp. 2. Few studies report a value for conception rate; however, Shi et al. (2015) observed no differences in conception rate as SID Lys increased from 0.76 to 1.14%. No difference in farrowing rate was observed in either of our studies, which is in agreement with the current body of literature (Touchette et al., 1998; Yang et al., 2000).

### *Subsequent Litter Characteristics*

A study conducted by Yang et al. (2000) observed a decrease in total born and born alive and increased stillborns for the subsequent litter as SID Lys level in the previous lactation increased. However, they explained that litter size (total born and born alive) did not differ in sows fed 0.60 to 1.10% SID Lys and was only reduced in sows fed 1.35 and 1.60%. They hypothesized this decrease at the highest SID Lys concentrations was due to elevated serum urea nitrogen levels or low lactation feed intake. Touchette et al. (1998) also saw decreased total born and born alive with increasing dietary SID Lys in lactation, but only when ratios of other amino acids to SID Lys were held constant, thus increasing as SID Lys increased. They suggest that litter size may be affected by different amino acid ratios in the diet. Clowes et al. (2003) demonstrated that protein restriction during lactation can negatively affect follicle size and, consequently, ovulation rate, which may reduce subsequent total born.

In contrast, both of our studies demonstrated that there were no differences in subsequent total born, born alive, stillborn or mummies as SID Lys level increased in the previous lactation. More recently, Shi et al. (2015) observed no difference in subsequent total born, born alive, or stillborn when SID Lys was increased from 0.76 to 1.14%. Schenkel et al. (2010) conclude that subsequent litter size is affected by absolute body reserves at weaning and the amount of tissue mobilization during lactation. Their study does not mention any data on percentage of piglets born alive, stillborn or mummies. In addition, tissue mobilization in the current studies did not occur at the same level as described by Schenkel et al. (2010), and may suggest that we minimized any reduction in subsequent total born with the levels of SID Lys fed.

In conclusion, our results demonstrate that the sow will mobilize body fat reserves to satisfy litter growth requirements if nutrients are not met by dietary intake. However, increasing the levels of AA's can support the reduction of protein loss in lactation. While the optimal level of dietary SID Lys required by the sow may vary based on response criteria and parity, it is evident that reducing protein mobilization is beneficial to reproductive performance.

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