The effects of parity and stage of gestation on whole body and maternal growth and feed efficiency of gestating sows

by

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Abstract

A study was conducted on a commercial sow farm to determine the effects of parity and stage of gestation on growth and feed efficiency of gestating sows. These data were also used to model changes in composition of maternal weight gain and products of conceptus throughout gestation. Feed intake and BW were measured daily from d 5 to 112 of gestation for 712 females. From d 5 to 39 of gestation, ADFI was lowest for parity 3+ sows compared to the other periods of gestation. Parity 2 sows, although provided the same feed allowance, had greater ADFI during the first period than parity 3+ sows. Average daily gain was lowest and G:F was the poorest from d 5 to 39 for each parity group compared with d 40 to 109 of gestation. Parity 1 and 2 sow ADG increased following d 39 of gestation but decreased from d 75 to 109. Parity 3+ sow ADG increased in each subsequent period of gestation. Parity 1 sows had the greatest ADG and G:F in comparison to parity 2 and 3+ sows in each period of gestation. Energy available for maternal growth was estimated after accounting for the energy needed to meet the sow's maintenance requirement and the energy required for the growth of the conceptus. Following d 39 of gestation, energy available for maternal growth decreased at the expense of maintenance and conceptus requirements in each subsequent period of gestation for each parity group. After accounting for the weight of the conceptus, maternal ADG decreased from d 39 to 74, and increased d 74 to 109 of gestation, regardless of parity. Maternal G:F was greatest for parity 1 sows in most gestation periods. In conclusion, parity and stage of gestation impact sow feed efficiency and maternal growth with parity 1 sows having the greatest weight gain and best feed efficiency.

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Chapter 1 - Effects of space allocation on finishing pig growth performance and carcass characteristics

ABSTRACT: A total of 405 pigs (PIC 327 × 1050) were used in 2 experiments (Exp. 1, initially 66.1 ± 1.8 kg BW, Exp. 2 initially 60.8 ± 2.5 kg BW) to examine the effects of space allocation on finishing pig growth performance and carcass characteristics. Pigs were randomly allotted to pens upon entry into the finishing facility. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 3 treatments with either 7 or 8 replications per treatment (Exp.1 and 2, respectively). There were 9 pigs per pen and gates were adjusted to provide 0.84, 0.74, or 0.65 m^2 per pig. Each pen was equipped with a dry single-sided feeder with two 35.6 cm × 11.4 cm (length × width) feeder spaces and a cup waterer.

In both experiments, as space allocation decreased, overall ADG and ADFI decreased (linear, $P < 0.019$) with no evidence for differences in G:F. In Exp. 2, there was marginal evidence for a linear improvement ($P = 0.061$) in G:F as space allocation decreased from d 42 to 56. Final BW was 3.8 and 5.3 kg greater (linear, $P \leq 0.005$) in Exp. 1 and 2, respectively, when comparing the 0.65 to the 0.84 m^2 per pig space allocation treatments. Using a predicted *k*-value of 0.0336, ADFI and, subsequently, ADG should have begun to decrease when pigs reached 121.2, 101.7 and 83.3 kg at 0.84, 0.74, or 0.65 m^2 per pig, respectively. In Exp. 1, we found marginal evidence for a reduction in ADFI as space allocation decreased starting at a mean BW of 80.3 kg (d 14; linear, $P = 0.072$). In Exp. 2, ADFI and consequently ADG decreased linearly ($P < 0.029$) starting at a mean BW of 74 kg, as space allocation decreased, before pigs reached the *k*- value that should have influenced performance. It is unknown if growth performance was impacted for the 0.84 m^2 treatment group as this was the greatest space allocation treatment.

Overall, these studies indicate that decreasing space allocation resulted in poorer ADG driven by a reduction in ADFI. The data suggests that the accepted *k*-value of 0.0336 might underestimate the impact of space restriction on finishing pig ADG and ADFI.

Key words: finishing pigs, growth, *k*- value, space allocation

Introduction

Pork producers are faced with a trade-off between allowing sufficient space to maximize performance yet minimize facility cost per pig. Previous research has demonstrated when grow-finish pigs are housed with decreasing amounts of space per pig, feed intake decreases, resulting in a reduction in ADG, with variable effects on feed efficiency (Brumm and Miller, 1996; Gonyou and Stricklin, 1998). Flohr et al. (2016) evaluated the impact of initial floor space allowance and removing pigs from pens as they were approached market weight. The authors observed that removing pigs from the pen and providing additional floor space can be useful in recapturing ADG and ADFI back to rates similar to those pigs maintained with adequate floor space. However, the specific source of the improvements in ADG and ADFI could not only be attributed to floor space but to other additional resources that become available after removals, such as feeder space and water availability.

Petherick and Baxter (1981) first expressed space allowance as an allometric relationship between BW and body dimensions by which the three-dimensional term of BW was converted to a two-dimensional measure of area in the expression of floor space: $A = k \times BW^{0.67}$, where A represents floor space allowance in m^2, *k* represents an empirical coefficient, and $BW^{0.67}$ in kg represents the geometric conversion of weight to area. Prediction equations from Gonyou et al.

(2006) used non-linear statistical modeling to capture a broken line allometric based space requirement for ADFI and ADG.

In commercial swine production, average final market weights have increased steadily for the past twenty years. From 1994 to 2014, the average market weight increased from 116 to 129 kg, approximately a 0.65 kg increase in market weight per year (USDA, 2015). Yet, many of the pig space allowances have remained constant for the past 20 years. Therefore, the objective of this experiment was to evaluate the effects of space allocation on growth performance and carcass characteristics of finishing pigs marketed at approximately 130 kg BW.

Materials and Methods

General

These experiments were conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS and were approved by and conducted in accordance with the guidelines of the Kansas State University Institutional Animal Care and Use Committee. The facility was totally enclosed, and environmentally regulated containing 36 pens. The experiments were designed with 3 treatments providing 0.84, 0.74 or 0.65 m^2 per pig and 9 pigs per pen (5 barrows and 4 gilts). The pens were equipped with adjustable gating to provide the different space allowances. In case of a pig removal due to illness or death, pen gates were adjusted to maintain the desired floor space allowance. Each pen was equipped with a dry single-sided feeder (Farmweld, Teutopolis, IL) with two 35.6 cm × 11.4 cm (length × width) feeder spaces and a cup waterer. All pens contained 9 pigs yielding 7.9 linear cm of trough space per pig. Pens were located over a completely slatted concrete floor with a 1.2 m pit underneath for manure storage. A robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) was used to deliver and record daily feed additions to each individual pen.

Animals and Diets

A total of 405 pigs (PIC 327 × 1050) from 2 consecutive finishing groups (Exp. 1 initially 66.1 ± 1.8 kg BW, Exp. 2 initially 60.8 ± 2.5 kg BW) were used. Pigs were allotted randomly to pens upon entry into the finisher and the experiments lasted 66 and 77 d for Exp. 1 and 2, respectively. Pens of pigs were balanced by initial BW and randomly allotted to 1 of the 3 treatments with 7 and 8 replications per treatment for Exp. 1 and 2, respectively. Pigs were given ad libitum access to feed and water throughout the study. Feed was manufactured at the K-State O.H. Kruse Feed Technology Innovation Center. Pigs were fed a common 3 phase corn-soybean meal-based diet in meal form (Table 1.1). Diets were formulated to meet or exceed NRC (2012) requirement estimates for of finishing pigs. The diets were formulated to contain 0.85, 0.72, and 0.65% standardized ileal digestible Lys in phases 1 through 3, respectively.

Sample Collection

Samples of the complete feed were taken from the feeder at the beginning and end of each phase. Samples were then subsampled and submitted (Ward Laboratories, Inc, Kearney, NE) for analysis of DM (method 935.29; AOAC Int., 2012), CP (AOAC 900.03, 2006), CF (method 978.10; AOAC Int., 2012 for preparation and Ankom 2000 Fiber Analyzer, Ankom Technology, Fairport, NY), starch (AOAC 996.11, 2006), ADF and NDF (Van Soest, 1963), ash (method 942.05; AOAC Int., 2012), Ca, and P (method 968.08 b; AOAC Int., 2012 for preparation using ICAP 6500, ThermoElectron Corp., Waltham, MA) (Table 1.2).

Pigs and feeders were weighed approximately every 2 wk to calculate ADG, ADFI, and G:F. Prior to marketing, all pigs were individually weighed and tattooed for carcass data collection and transported approximately 213 km to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO) for processing and carcass data collection. Carcass measurements taken at the plant included HCW, backfat, 10^{th} rib loin depth, percentage lean, and iodine value. Carcass yield was calculated by dividing the HCW at the plant by the pig's live weight at the farm before transport to the plant. Percentage lean was determined using the NPPC equation incorporating HCW as one of the variables. Fat depth and loin depth were measured with an optical probe inserted between the third and fourth last rib (counting from the ham end of the carcass) at a distance approximately 7 cm from the dorsal midline. Jowl fat samples were also collected and analyzed by near infrared spectroscopy (Bruker MPA, Breman, Germany) for fat IV using the equation of Cocciardi et al. (2009).

Statistical Analysis

The experimental data were analyzed as a randomized complete block design using the MIXED procedure of SAS (Version 9.4, SAS Institute Inc., Cary, NC) with pen as the experimental unit and initial BW as a blocking factor. Backfat, loin depth, lean percentage, and iodine value were adjusted to a common carcass weight. The final models used for inference were fitted using restricted maximum likelihood estimation. Degrees of freedom were estimated using the Kenward-Rogers approach. Estimated means and corresponding standard errors (SEM) are reported for all cell means. Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results

In Exp. 1, we found marginal evidence for a decrease (linear, $P < 0.081$) in ADFI as space allocation decreased up to a mean BW of 94.7 kg (Table 1.3). Space allocation had no effect on ADG, or G:F up to a mean BW of 108 kg. Thereafter, from d 42 to 55, decreasing space allocation decreased ADFI (linear, *P* = 0.017) leading to marginal evidence for a decrease (linear; *P* = 0.064) in ADG. From d 55 to 66, decreasing space allocation decreased (linear, *P* = 0.001) ADFI and subsequently ADG (linear, *P* = 0.035). Space allocation did not affect G:F. Overall, (d 0 to 66) as space allocation decreased, ADG and ADFI decreased (linear; *P* < 0.019) and G:F was not affected (linear; *P* = 0.738). Final BW decreased (linear; *P* = 0.005) as space allocation decreased, which resulted in a 3.8 kg difference in pig BW between the 0.65 and 0.84 m^2 per pig treatments.

In Exp. 2, space allocation had no effect on ADG, ADFI, or G:F up to a mean BW of 74 kg. In all subsequent periods, ADFI decreased (linear, *P* < 0.028; Table 1.4) as space allocation decreased, which led to a decrease (linear; *P* < 0.029) in ADG in all periods except d 27 to 42 which showed only marginal evidence for a decrease (linear; *P* < 0.062) in ADG. There was marginal evidence that as space allocation decreased (linear, *P* = 0.061) G:F improved from d 42 to 56; however, G:F was not affected in any other periods. Overall, as space allocation decreased, ADG and ADFI decreased (linear; *P* < 0.003) and G:F was not affected (linear; *P* = 0.414). Final BW decreased (*P* = 0.004) as space allocation decreased, which resulted in a 5.3 kg difference in pig BW between the 0.65 and 0.84 m^2 per pig treatments.

For carcass characteristics, in Exp. 1, there was marginal evidence for a quadratic response to percentage carcass yield as space allocation decreased (quadratic; *P* = 0.060). However, in Exp. 2, HCW decreased (linear; *P* < 0.001) and percentage-lean increased (linear; *P* = 0.034) as space allocation decreased (Table 1.4).

Discussion

Floor space allowances for finishing pigs has been previously researched to predict optimum floor space based on BW. The use of allometry can be used to convert the three-dimensional term of weight to a two-dimensional measure of area, generating an expression in the form of $A = k \times BW^{0.67}$, where A represents floor space allowance in m^2, k represents a space allowance coefficient, and $BW^{0.67}$ in kg represents the geometric conversion of weight to area (Whittemore, 1998). Gonyou et al. (2006) developed floor space prediction equations for ADG and ADFI based on the same allometric principle ($A = k \times BW^{0.67}$) and reported a critical k-value of 0.0336 m^2 per $BW^{0.67}$ below which ADFI was reduced for finisher pigs on fully slated flooring with equal group sizes. Thus, the critical k-value of 0.0336 m^2 per $BW^{0.67}$ acts as a threshold below which feed intake and growth performance is expected to be reduced due to inadequate space allowance.

Body weight corresponding to a k-value of 0.0336 was calculated (Table 1.5, Table 1.6), using the formula reported by Whittemore (1998), for each of the three space allocation treatments used in the present study. Based on this critical k-value, the negative effects on feed intake should have been observed as pigs reached the projected average BW of 121.2, 101.7 and 83.3 kg for 0.84, 0.74, or 0.65 m^2 per pig, respectively. We found marginal evidence for negative effects of decreased space allocation on ADFI starting at an average BW of 80.3 kg (d 14) which suggests that the commonly accepted k-value threshold of 0.0336 might be underestimating the impact of decreased space allocation on ADFI. In Exp. 2, feed consumption and consequently ADG decreased linearly starting at an average BW of 74 kg (d 14) as space allocation decreased, before pigs reached the k value that should have influenced performance. It is unknown if performance of the 0.84 m^2 treatment group was impacted by space allowance during this study or if performance was impacted before reaching the threshold of 0.0336. This treatment group offered the greatest space allocation and therefore, we are unable to know if growth performance was impacted by space allowance simply due to the lack of comparison to a greater space allocation treatment group.

The present study is in agreement with previous research where ADFI and ADG decreased, and G:F was unchanged (Brumm and Miller, 1996; Gonyou and Stricklin 1998; Jensen et al., 2012). However, there is literature to support changes in G:F as space allocation decreases (Brumm and NRC-89 Committee on Management of Swine, 1996; Street and Gonyou, 2008, Flohr et al., 2016). After compiling data from 17 studies during a meta-analysis, Flohr (2015) observed small but significant relationships between G:F.

Flohr (2015) recently developed equations to predict the influence of floor space on finishing pig growth performance and found an increase in the precision of estimates compared to those of Gonyou et al. (2006). Flohr (2015) used improvements in modeling techniques to account of known random errors and included a larger data base to develop the equations. The authors also concluded upon different critical *k* thresholds based on the BW range of finishing pigs. Thus, the regression equations proposed by Flohr (2015) provide good alternative estimates of predict finishing pig growth performance when provided different floor space allowances.

One concern expressed in published reviews evaluating space allocation is the maintaining of adequate feeder space per pig when space allocation is decreased. Previous research indicates that the 7.9 cm per pig of feeder space provided in our study is considered unrestrictive and should not have negatively affected performance (Wolter et al., 2003; Myers et al., 2012). Furthermore, our ability to manipulate space allocation by utilizing adjustable gates allowed us to change the space allocation without impacting the feeder space per pig, which is typically observed when additional pigs are added to pens to decrease space allowance.

Consequently, our trial was successful in determining the effects of space allocation on pig performance without affecting the results by restricting feeder space per pig. The differences in trial performance compared with expected outcomes from published reviews may have been attributable to group size, behavior, or other physiological variables. It is unknown whether these variables contributed to the negative effects on performance as space allocation decreased.

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Table 1.1 Composition of experimental diets (as-fed basis)

	Phase[1]		
Item	1	2	3
Ingredient, %			
Corn	78.45	82.85	85.25
Soybean meal, 46.5% CP	19.20	14.95	12.70
Monocalcium P, 21% P	0.33	0.30	0.30
Limestone	1.10	1.08	1.00
Salt	0.35	0.35	0.35
L-Lys HCl	0.25	0.22	0.20
DL- Met	0.02	-	-
L-Thr	0.05	0.05	0.05
Vitamin and trace mineral premix[2]	0.26	0.20	0.15
Phytase[3]	0.015	0.015	0.015
Total	100.0	100.0	100.0
Calculated analysis			
Standard ileal digestible (SID) amino acids, %			
Lys	0.85	0.72	0.65
Ile:lys	64	66	67
Leu:lys	149	162	172
Met:lys	29	30	31
Thr:lys	61	64	67
Trp:lys	18	18	18
Val:lys	73	76	79
SID lys NE, g/Mcal	2.57	2.17	1.96
ME, kcal/kg	3,309	3,316	3,322
NE, kcal/kg	2,474	2,502	2,520
Total Lys, %	0.96	0.82	0.75
CP, %	15.9	14.2	13.3
Ca, %	0.53	0.50	0.47
P, %	0.41	0.39	0.38
Available P, %	0.27	0.26	0.26

[1]Phase 1, 2, and 3 diets were fed from d 0 to 28, d 28 to 56, and d 56 to slaughter, respectively.
[2]Provided per kg of diet = 4,409,200 IU vitamin A, 551,150 IU vitamin D, 17,637 IU vitamin E, 1,764 mg vitamin K, 15 mg vitamin B12, 19,841 mg niacin, 11,023 mg pantothenic acid, 3307 mg riboflavin, 1,100 mg Zn, 1,100 mg Fe, 300 mg Mn, 110 mg Cu, 2 mg I, and 2 mg Se.
[3]HiPhos (DSM Inc, Parsippany, NJ) provided phytase units 102,853 FYT/ kg of product and released 0.10% P available P.

Table 1.2 Chemical analysis of diets (as-fed basis)

	Phase[1]		
Item, %[2]	1	2	3
DM	91.57	91.15	91.05
CP	17.1	14.8	14.1
ADF	3.6	3.2	4.5
NDF	6.9	5.2	10.7
Crude fiber	2.9	1.9	3.1
Ca	0.41	0.46	0.50
P	0.40	0.38	0.39
Ash	3.29	2.83	3.28
Starch	45.2	52.0	47.0

[1]Phase 1, 2, and 3 diets were fed from d 0 to 28, d 28 to 56, and d 56 to slaughter, respectively.
[2]Values represent the mean of one composite sample of each diet.

Table 1.3 Effects of space allocation on finishing pig performance (Exp. 1)[1]

	Space allocation per pig, sq m[2]			Probability, P<	
Item	0.84	0.74	0.65	Linear	Quadratic
No. of pens	7	7	6	---	---
d 0 to 14					
d 0 weight, kg	66.1 ± 0.723	66.1 ± 0.723	66.1 ± 0.728	0.953	0.944
ADG, kg	1.05 ± 0.028	1.00 ± 0.028	1.00 ± 0.031	0.238	0.538
ADFI, kg	2.67 ± 0.042	2.63 ± 0.042	2.57 ± 0.044	0.081	0.780
G:F	0.392 ± 0.008	0.381 ± 0.008	0.388 ± 0.009	0.656	0.300
d 14 to 28					
d 14 weight, kg	80.8 ± 0.715	80.1 ± 0.715	80.1 ± 0.743	0.318	0.543
ADG, kg	1.07 ± 0.027	0.98 ± 0.027	1.02 ± 0.029	0.180	0.057
ADFI, kg	2.87 ± 0.050	2.78 ± 0.050	2.75 ± 0.053	0.072	0.533
G:F	0.375 ± 0.009	0.353 ± 0.009	0.371 ± 0.010	0.790	0.096
d 28 to 42					
d 28 weight, kg	95.9 ± 0.828	93.8 ± 0.828	94.4 ± 0.864	0.078	0.071
ADG, kg	0.92 ± 0.037	0.97 ± 0.037	0.91 ± 0.041	0.875	0.293
ADFI, kg	2.85 ± 0.066	2.80 ± 0.066	2.81 ± 0.070	0.598	0.578
G:F	0.323 ± 0.009	0.345 ± 0.009	0.325 ± 0.010	0.850	0.102
d 42 to 55					
d 42 weight, kg	108.8 ± 1.059	107.3 ± 1.059	107.2 ± 1.111	0.164	0.486
ADG, kg	0.96 ± 0.021	0.91 ± 0.021	0.91 ± 0.023	0.064	0.415
ADFI, kg	3.05 ± 0.069	2.99 ± 0.069	2.80 ± 0.074	0.017	0.454
G:F	0.316 ± 0.008	0.308 ± 0.008	0.324 ± 0.009	0.467	0.235
d 55 to 66					
d 55 weight, kg	121.3 ± 1.186	119.2 ± 1.186	119.0 ± 1.237	0.064	0.347
ADG, kg	1.06 ± 0.030	1.03 ± 0.030	0.96 ± 0.032	0.035	0.633
ADFI, kg	3.16 ± 0.043	3.11 ± 0.043	2.96 ± 0.046	0.001	0.216
G:F	0.336 ± 0.009	0.331 ± 0.009	0.326 ± 0.010	0.452	0.980
d 0 to 66					
d 66 weight, kg	133.4 ± 1.109	130.6 ± 1.109	129.6 ± 1.168	0.005	0.323
ADG, kg	1.01 ± 0.015	0.98 ± 0.015	0.96 ± 0.016	0.019	0.568
ADFI, kg	2.90 ± 0.042	2.84 ± 0.042	2.77 ± 0.045	0.009	0.805
G:F	0.348 ± 0.003	0.343 ± 0.003	0.347 ± 0.003	0.738	0.282
Carcass traits					
HCW, kg	98.6±1.546	94.2 ± 1.504	95.3 ± 1.746	0.116	0.111
Yield, %	73.4±0.234	73.1 ± 0.227	73.8 ± 0.267	0.228	0.060
BF, mm	18.4±0.558	17.8 ± 0.535	17.0 ± 0.646	0.101	0.821
Loin depth, cm	6.3±0.140	6.5 ± 0.136	6.4 ± 0.158	0.641	0.471
Lean, %	53.6±0.329	54.1 ± 0.316	54.3 ± 0.385	0.188	0.718
Iodine value, mg/100g	69.1±0.311	68.9 ± 0.299	69.7 ± 0.350	0.204	0.246

[1]A total of 189 finishing pigs (PIC 327 × 1050, initially 66 kg BW) were used in a 66-d study.

[2]Each pen contained 9 pigs and space allocation was manipulated by utilizing adjustable gates.

Table 1.4 Effects of space allocation on finishing pig performance (Exp. 2)[1]

	Space allocation per pig, sq m[2]			Probability, P<	
Item	0.84	0.74	0.65	Linear	Quadratic
Pens, no.	8	8	8	---	---
d 0 to 14					
d 0 weight, kg	60.8 ± 0.939	60.8 ± 0.939	60.7 ± 0.939	0.956	0.899
ADG, kg	0.97 ± 0.026	0.95 ± 0.026	0.93 ± 0.026	0.322	0.817
ADFI, kg	2.30 ± 0.032	2.26 ± 0.032	2.28 ± 0.032	0.621	0.412
G:F	0.422 ± 0.011	0.419 ± 0.011	0.410 ± 0.011	0.401	0.806
d 14 to 27					
d 14 weight, kg	74.3 ± 0.927	74.0 ± 0.927	73.8 ± 0.927	0.513	0.941
ADG, kg	1.02 ± 0.027	0.95 ± 0.027	0.94 ± 0.027	0.029	0.428
ADFI, kg	2.90 ± 0.052	2.79 ± 0.052	2.73 ± 0.052	0.028	0.694
G:F	0.352 ± 0.006	0.341 ± 0.006	0.343 ± 0.006	0.175	0.300
d 27 to 42					
d 27 weight, kg	87.6 ± 1.035	86.4 ± 1.035	86.0 ± 1.035	0.142	0.638
ADG, kg	1.03 ± 0.018	0.99 ± 0.018	0.98 ± 0.018	0.062	0.612
ADFI, kg	2.93 ± 0.038	2.80 ± 0.038	2.75 ± 0.038	0.003	0.421
G:F	0.351 ± 0.006	0.354 ± 0.006	0.356 ± 0.006	0.557	0.928
d 42 to 56					
d 42 weight, kg	103.6 ± 0.974	101.8 ± 0.974	100.7 ± 0.974	0.015	0.707
ADG, kg	0.97 ± 0.013	0.95 ± 0.013	0.91 ± 0.013	0.002	0.797
ADFI, kg	3.10 ± 0.039	2.92 ± 0.039	2.80 ± 0.039	<0.001	0.626
G:F	0.314 ± 0.005	0.324 ± 0.005	0.326 ± 0.005	0.061	0.460
d 56 to 77					
d 56 weight, kg	117.4 ± 0.992	115.0 ± 0.992	113.5 ± 0.992	0.005	0.688
ADG, kg	0.98 ± 0.015	0.97 ± 0.015	0.90 ± 0.015	0.001	0.098
ADFI, kg	3.20 ± 0.046	3.09 ± 0.046	2.86 ± 0.046	<0.001	0.312
G:F	0.306 ± 0.005	0.314 ± 0.005	0.315 ± 0.005	0.203	0.565
d 0 to 77					
d 77 weight, kg	138.0 ± 1.160	135.5 ± 1.160	132.7 ± 1.160	0.004	0.902
ADG, kg	0.99 ± 0.013	0.96 ± 0.013	0.93 ± 0.013	0.003	0.949
ADFI, kg	2.91 ± 0.032	2.80 ± 0.032	2.70 ± 0.032	<0.001	0.899
G:F	0.341 ± 0.003	0.344 ± 0.003	0.345 ± 0.003	0.414	0.833
Carcass traits					
HCW, kg	103.0 ± 1.057	100.0±1.047	96.7 ± 1.111	<0.001	0.878
Yield, %	77.6 ± 1.152	77.9±1.150	77.3 ± 1.155	0.631	0.475
BF, mm	20.1 ± 0.601	19.8±0.586	18.6 ± 0.643	0.127	0.557
Loin depth, cm	6.41 ± 0.129	6.42±0.126	6.62 ± 0.137	0.292	0.571
Lean, %	52.9 ± 0.268	53.0±0.262	53.7 ± 0.288	0.034	0.296
Iodine value, mg/100g	68.8 ± 0.304	69.3±0.294	69.0 ± 0.319	0.764	0.282

[1]A total of 215 finishing pigs (PIC 327 × 1050, initially 61 kg BW) were used in a 77-d study.

[2]Each pen contained 9 pigs and space allocation was manipulated by utilizing adjustable gates.

Table 1.5 Determination of *k*-values for different space allocations and pig weights (Exp. 1)[1]

	Space allocation per pig, m^2			*k*- value[3,4]		
Item	0.84	0.74	0.65	0.84 sq m	0.74 sq m	0.65 sq m
BW when k = 0.0336, kg[5]	121.2	101.7	83.3	---	---	---
Weight, kg						
d 0	66.1	66.1	66.1	0.0504	0.0448	0.0392
d 14	80.8	80.1	80.1	0.0441	0.0394	0.0345
d 28	95.9	93.8	94.4	0.0393	0.0354	**0.0309**
d 42	108.8	107.3	107.2	0.0361	**0.0324**	**0.0284**
d 55	121.3	119.2	119.0	0.0336	**0.0302**	**0.0265**
d 66	133.4	130.6	129.6	**0.0315**	**0.0284**	**0.0250**

[1]Average pig weight reported for each space allocation and weigh day.

[2]Each pen contained 9 pigs and space allocation was manipulated by utilizing adjustable gates.

[3]*k*- values calculated using a formula reported by Whittemore (1998): Space per pig (m^2) =k*BW (kg) $^{0.67}$ or Space per pig (m^2) = k*BW (kg) $^{0.67}$.

[4]Bold type with shaded background indicate *k*-values below 0.0336, the critical *k*-value for adequate feed intake as defined by Gonyou et al. (2006).

[5]Calculated body weight for each space allocation when k = 0.0336, the critical *k*-value for adequate feed intake for grow-finish, fully slatted flooring and equal group sizes (Gonyou et al., 2006).

Table 1.6 Determination of *k*-values for different space allocations and pig weights (Exp. 2)[1]

	Space allocation per pig, m^2			*k*- value[3,4]		
Item	0.84	0.74	0.65	0.84 sq m	0.74 sq m	0.65 sq m
BW when k = 0.0336, kg[5]	121.2	101.7	83.3	---	---	---
Weight, kg						
d 0	60.8	60.8	60.7	0.0534	0.0474	0.0415
d 14	74.3	74.0	73.8	0.0466	0.0416	0.0364
d 27	87.6	86.4	86.0	0.0418	0.0375	**0.0329**
d 42	103.6	101.8	100.7	0.0373	0.0336	**0.0296**
d 56	117.4	115.0	113.5	0.0343	**0.0309**	**0.0273**
d 77	138.0	135.5	132.7	**0.0308**	**0.0277**	**0.0246**

[1]Average pig weight reported for each space allocation and weigh day.
[2]Each pen contained 9 pigs and space allocation was manipulated by utilizing adjustable gates.
[3]*k*- values calculated using a formula reported by Whittemore (1998): Space per pig (m^2) =k*BW (kg) $^{0.67}$ or Space per pig (m^2) = k*BW (kg) $^{0.67}$.
[4]Bold type with shaded background indicate *k*-values below 0.0336, the critical *k*-value for adequate feed intake as described by Gonyou et al. (2006).
[5]Calculated body weight for each space allocation when k = 0.0336, the critical *k*-value for adequate feed intake for grow-finish, fully slatted flooring and equal group sizes (Gonyou et al., 2006).

Chapter 2 - Lessons learned from managing electronic sow feeders and collecting weight gain of gestating sows housed on a large commercial farm

ABSTRACT: A study was conducted on a commercial 5,600 sow farm to determine sow gestation feed efficiency by daily collection of feed intake and sow body weight data. Feed intake and sow weights were obtained daily via electronic sow feeders (ESF) and a scale capable of capturing sow body weight every time the female exited the feeding station. The objective of this review is to discuss the challenges that emerged when collecting this data and possible solutions that will be useful for further research conducted under similar gestation feeding systems. A total of 861 females were enrolled in the study, of which 712 completed. Removals were due to 1) death or culling decisions by the farm, 2) removal from the gestation pen for greater than 3 days in which feed intake was not recorded, or 3) unknown female identification. In this specific system, feed intake data had to be downloaded prior to system reset each day or the data would be deleted. Improvements in ESF system software to allow for long term storage of feed intake data would be advantageous. A single, total feed intake value is reported for females, regardless of how many times they may have walked through the feeding station. It would be valuable to obtain records for the individual feeding events to determine how many times females in the ESF system walk through the feeding stations and how many are feeding vs. non-feeding events. In this system, there was wide variation in the daily weight of sows because they walked through the feeding system several times a day. Discrepancies in individual female body weight were found to be attributed to 1) the speed in which a sow moved across the scale,

especially during times of high activity in the pen, 2) inappropriate scale length, and 3) interference with scale RFID antenna. Possible solutions to consider include adding panels before and after the scale to keep sows from moving too quickly across the scale, reducing scale length, and careful placement of RFID antenna and testing to be certain readings are accurate to the sow on the scale. When collecting sow body weight data with this system, it was necessary to manually weigh all females at the beginning and end of gestation to eliminate outliers in the data set. Nevertheless, combining the feeding of gestating sows via ESF with daily weight collection has the potential to generate valuable data sets; however, taking the steps to ensure the data collected is meaningful and valid is imperative for success.

Key words: body weight, data collection, electronic sow feeders, sow

Introduction

In many U.S. production systems, a standard practice is to house sows in individual stalls during gestation. Gestation stalls allow numerous benefits, including individual animal care and feed allowance based on body weight and condition. However, the EU announced in 2001 their ban of gestation stalls by 2013 because of welfare concerns regarding space allowance and social behavior (Spoolder et al., 2009). The U.S. has followed with nine states enforcing bans on the use of gestation stalls. Furthermore, pressure from pork retailers, the restaurant industry, and welfare activists has resulted in many production systems considering moving to group housing for gestating sows. As many production systems are transitioning from individual gestation stalls to different styles of group housing there are new opportunities for data collection in gestation facilities (Levis and Connor, 2013).

Electronic sow feeding systems (ESF) are computerized feeding stations that serve as a non-competitive feeding system for group housed sows (Casey, 2003). Electronic sow feeders typically have single enclosed feeding stations that can feed up to 60 group-housed sows per station each day. The stations are equipped with computers that track and dispense a specified amount of feed for each sow. The sows have an ear tag that contains a radio frequency identification (RFID) transponder for individual identification. This type of system is appealing to producers as it allows them to manage and monitor individual feed intake and provide opportunities to adjust feeding program strategies to better satisfy changes in gestation nutrient requirements. Electronic sow feeders are also appealing from a research standpoint because some systems allow for recorded individual feed intake and more than one feed line can supply each station to provide different diets to be fed (Buis, 2016). It is also possible to use a scale in conjunction with the ESF which is capable of capturing sow body weight every time the sow exits the feeding system.

The information presented in this paper was from a study to determine sow gestation weight gain and feed efficiency by collecting daily ESF intake and sow body weight data. The objective of this paper is to discuss the challenges that emerged when collecting this data and some solutions that will be useful for future research conducted in similar gestation feeding systems.

General

The study was conducted at a 5,600-sow farm in central Nebraska. The gestation barn contained 16 pens, housing 260 females (Camborough®, PIC, Hendersonville, TN) per pen. Gilts (parity 1) and sows (parity 2+) were penned separately to allow for additional attention to gilts who were still adjusting to the ESF system. Pens for sows provided 2.0 m^2 per sow and those for gilts provided 1.95 m^2 per gilt. Each pen was equipped with 6 electronic feeding stations (Nedap Velos, Gronelo, Netherlands) allowing for up to 45 females per station (Figure 2.1 and Figure 2.2). Each feeding station was 2.0 m long × 0.56 m wide. Feed was dispensed at a rate of 150 g/min with the addition of 100 ml of water. Each feeding station was calibrated weekly. The calibration process consisted of collecting 5 consecutive rotations (approximately 90 g of feed dispensed per rotation, for a total collection of approximately 450 g) of feed from the screw dispenser from each feeding station. The samples were weighed to determine how much feed was dispensed per rotation which was subsequently entered into the Nedap Velos system to complete the calibration. For the study, 3 of the pens were equipped with a scale (2.13 m long × 0.51 m wide, New Standard US Inc., Sioux Falls, SD) located in the alleyway the sows walked across when they exited the feeding stations (Figure 2.3).

Females were group-housed from d 4 to 112 of gestation in dynamic groups, meaning recently bred sows (approximately d 4 of gestation) were entering the pen as sows due to farrow were exiting (approximately d 112 of gestation). This occurred over a 3 to 4-week period, thereafter the pen remained static (no movement of newly bred sows into the pen) until the first of the sows reached d 112 of gestation and the process repeated.

The study was conducted over a 149-day period, from late May to mid-October. A total of 861 females were enrolled in the study, of which 712 completed. Of the initial 861 females, 40 were removed from the data set due to death or culling decisions made by the farm. Ninety-seven females were deleted from the data set because they were removed from their pen for greater than 3 consecutive days due to illness or lameness. Because of consecutive missing feed intake data, these females were removed from study. The remaining 12 females were removed due to unknown RFID.

Data Collection

Feed Intake

Feed intake data had to be manually extracted daily through the Nedap Velos software because long term data storage was not available during the time of the study. Feed intake data provided RFID, farm ID, day of gestation, total feed offered, total feed consumed, location (pen), date, feeding strategy (indicating amount of feed offered), feed line (the system had two feed lines but only 1 was used during the study), and parity. Because the system reset at 14:00 each day, feed intake data was downloaded at approximately 13:00 to ensure all females had eaten their daily allocation. Due to the lack of long term storage intake was downloaded daily from 13:00 to 14:00, prior to system reset. There was initial concern about possible download errors attributed to system software malfunctions, but the number of missing intake values was small. However, it would be advantageous to improve system software and allow for the intake data to be stored long term.

Females were assigned to a feed allowance based on parity and body condition score. Females could consume the set amount of feed in one visit or over several visits to the feeding station. However, the system only generates 1 total intake value per day of gestation. Hence, if a sow consumed her entire feed allowance in two separate feedings, only one intake value was reported and represented the sum of both feeding events. It would be valuable to be able to obtain records of the individual feeding events to determine how many times females walk through the feeding stations and how many of these are non-feeding vs. feeding events. It is also important to note that within this or most other ESF systems, it is assumed that the feed which is dispensed is consumed by the sow before leaving the feeding station and therefore, every time a sow enters the feeding station the feeder bowl is assumed to be empty.

Within the first week of data collection, we observed missing feed intake values (no value reported) and zeroes reported as feed intake values. It was unclear what the difference was between these two values. We observed that there is a 5 sec delay between when the sow's RFID is read and when the feeding station dispenses feed. If the sow leaves the station within these 5 seconds, feed will not be dispensed and is recorded as an intake value of 0. A sow who does not enter the feeding station on a specific day will have a missing intake value for that day. The importance of understanding the difference between the two values was being certain the values being generated were accurate. Previous research has indicated that errors can occur during the collection of feed intake data from ESF and the importance of feeder management to minimize these errors (Casey et al., 2005). Initially, it was believed that it was impossible to walk through the feeding station without feed being dispensed. Therefore, differences in values reported were thought to be attributed to a system error. After investigation, it was determined that sows could walk through the ESF system and be recorded without feed being dispensed.

Body Weight

Sow weights were automatically recorded as the sow entered the scale using an RFID sensor, like that used in the ESF system. This provided the date, time, RFID, and body weight. Weights were stored on secure digital (SD) memory cards that could be removed from the scale head and loaded onto a computer. The barn environment is not conducive to handling memory cards and caution should be taken to minimize human error when removing and replacing (losing or dropping into the pit). Scales were calibrated weekly during the time of feeder calibration.

Two individuals were required for scale calibration. One individual would obtain their weight using a kitchen scale and this weight was then entered into the scale system as the calibration weight. Then the scale system would be zeroed and the individual who was weighed would step onto the scale while the other individual observed the scale head. Weights were obtained standing at the beginning, middle and end of the scale to check for accuracy. Occasionally, manure would have to be removed from under the scale to improve readings.

Sows had to walk across the scale as they moved from the feeding station back into the pen. Through observation, we found that when workers were in the pen, sow activity through the feeding stations was high. Similar to Buis (2016), this increase in activity caused sows to move too quickly across the scale for an accurate weight. A proposed solution was to provide panels at the beginning and end of the scale to slow the rate of passage across the scale. This was considered during the study but was not implemented due to concern that this may cause the females to move too slowly and cause the sows to pile before the scale causing an unhealthy environment for the animals. Specifically, the concern pertained to the gilts who were still adjusting to the ESF environment. We also observed multiple sows on the scale at one time. The sow in front had her front legs off the scale while the sow behind only had her front legs on the scale. Although not a possible option during our study, reducing the scale length may be a possible solution for future research.

We also observed that as a sow moved across the scale, the antenna reads the RFID and continues to record weights until the next responder tag is detected. Some females would stand on the back of the scale but not far enough forward for the antenna to read the RFID. Thus, these weights were recorded appearing to be those from the previous sow. To resolve this, the antenna was adjusted toward middle of the scale. After making this adjustment, the females RFID was recognized as she stepped on the scale. This is another situation where a shorter scale may be beneficial.

Another problem observed was that the antenna on the scale could read through the panels of the scale and if a sow was laying in the pen against the outside of the scale, her RFID could be read. However; once a sow was on the scale, that sow's RFID was read and recorded properly. In addition, if a sow in the pen was laying against the panel adjacent to the scale, this pressure against the plastic panels of the scale impacted the accuracy of weights. The effect was greatest when multiple animals were nesting in this area. To prevent these interferences from occurring, sternum bars can be added to the pen adjacent to the scale to prevent sows from laying or nesting in this area.

Each of these uncertainties contributed to the variability in daily weight collection and reinforced the need to weigh each sow individually at least twice during the study. These weights were collected on all females near the beginning and end of gestation. Each female was stopped on the scale using sort boards to obtain a specific weight. With approximately 260 females in dynamic pens, there was a range in the day of gestation in which the individual weights were captured. On average, the first weight was obtained on d 26 of gestation and the second weight was obtained on d 87 of gestation (± 10 d). These reference weights were then used to eliminate outliers in the data set based on the ADG generated from the two weights and predicted body weights based on the initial known weight and day of gestation.

Data Management

In addition to feed intake and body weight data collection, backfat measurements were obtained following breeding and d 112 of gestation, respectively, before farrowing. Sow reproductive performance was recorded using the PigCHAMP Knowledge Software (Ames, IA). The following reproductive traits were obtained: total number of piglets born, total number of piglets born alive, number of stillborns, number of mummified fetuses, number of weaned piglets, parity, and gestation length. Due to the size of these data files (daily feed intake, daily BW, backfat measurement, and reproductive performance), each data file was managed individually then merged or combined using statistical software (SAS Version 9.4, SAS Institute Inc., Cary, NC).

Backfat measurement and reproductive performance data files did not require additional manipulation prior to analysis. Each file contained the relevant information identified by the individual sow. Body weight and feed intake data files required additional steps before analysis. First, it was necessary to eliminate outlier weights from the BW data set. For this process, the reference weights were utilized and the following steps were applied:

- Average daily gain (ADG) was calculated from the two reference weights for each sow.

  ADG = (Weight2-Weight1)/(Date2-Date1);
- Using ADG, a predicted weight was calculated based on the initial known weight and day of gestation.

  Predicted weight = (Weight1 + (ADG*d)); where (d) is calculated as the difference in days between the measured weight and the reference weight.
- The ratio of predicted weight to the measured weight was determined and if the measured weight was 5% above or below the predicted weight, the weight was deleted. Body weights greater or less than 5% of the predicted weight were considered to be outliers and will be discussed later in this review.

  Ratio = Predicted weight / Actual weight;

Following these steps, the number of observations in the weight data set was decreased dramatically. Figure 2.4 and figure 2.5 show body weights for an individual sow, before and after applying the above steps. It is important to note that, we made the assumption ADG in gestation is fixed. This assumption could be improved by obtaining additional reference weights throughout gestation and creating a curvilinear ADG prediction throughout gestation. Following these steps, the BW data set was merged with the remaining data.

The second data set prepared for analysis was feed intake. Females that did not walk through the feeding system and thereby did not consume any feed had blank feed intake values that were replaced with zeroes. As previously mentioned, errors occurred during the download of feed intake a total of 13 d over the course of the trial (149 d). The specific dates of errors were known and because it is not logical to assume feed intake values of zero for these days, the daily allotment of feed for the sow was assumed to be the amount of feed consumed on that day.

Because a single BW was needed for each day for subsequent analysis, sows with no BW values for a day or sows with multiple BW on a day had to be addressed. Sows without a BW measurement may have had a weight on a given day of gestation but it may have been deemed an outlier following the procedures described above, and recorded as a missing value in the data set. Conversely, it was also possible for sows to have multiple accurate weights per day. Using the PROC MEANS statement in SAS, we were able generate an average BW per day for each sow if multiple accurate BW were available. One approach for replacing missing BW values is with the predicted weight, of which was used to eliminate outliers in the data set. Recall, the predicted weight was calculated using each sows ADG value and the sows first recorded BW obtained by the scale system. Agreement was measured using a paired t test to evaluate the difference between measured weights, from the scale system, and predicted weights. The predicted weight was 0.05 kg less than the measured with 95% confidence interval 0.014 to 0.077 kg. This method allows for us to have confidence in the method used to eliminate outliers from the data set. An alternative approach to generating missing body weights, which was used in this study, is with the product generated from the most recent surrounding measured weight and the ADG.

After removing outlier weights from the data set and reporting a feed intake and BW value for each day of gestation, these data sets were then merged with backfat and reproductive performance data. Two additional errors were identified following the merge that are believed to be specific to this farm. First, discrepancies were found in the parity reported between feed intake and reproductive performance data. Recall, feed intake and reproductive performance data files each report parity for a given sow. It is unknown if this is a recording error in the feeding system or farm recording system. To resolve this problem, parity was used from the reproductive performance data only. Second, when comparing gestation lengths from the reproductive performance data and the gestation lengths that were manually determined based on when the females left the pen and the date females farrowed, we found that the days of gestation were off by one day (d 4 of gestation in reproductive performance data is d 5 of gestation in the feed intake data). This error was attributed to the feeding system reset time of 14:00 versus the reproductive data being reset at midnight.

Implications

As the swine industry transitions from individual gestation stalls to group housing, ESF combined with scales offer unique data collection possibilities for improved sow management as well as research opportunities. Feed intake and weight change data can be used to develop models for nutrient requirements and partitioning of nutrients among maternal and fetal growth.

There are unlimited possibilities for research of the effects of gestation feeding and sow lifetime reproductive performance. Daily intake and BW collection of gestating sows can be successful, but it is imperative that the data collection process is well understood and managed appropriately. Observing the females in the feeding system is helpful in providing insight to any discrepancies that may be occurring in the data set. Furthermore, understating why and how any abnormalities in the data set occur is critical in assuring accurate data. Nevertheless, daily feed intake and BW collection of pregnant sows throughout the course of gestation can be successful and with these recommendations for collecting further research in commercial settings, we will obtain valuable information regarding the females of today's production systems.

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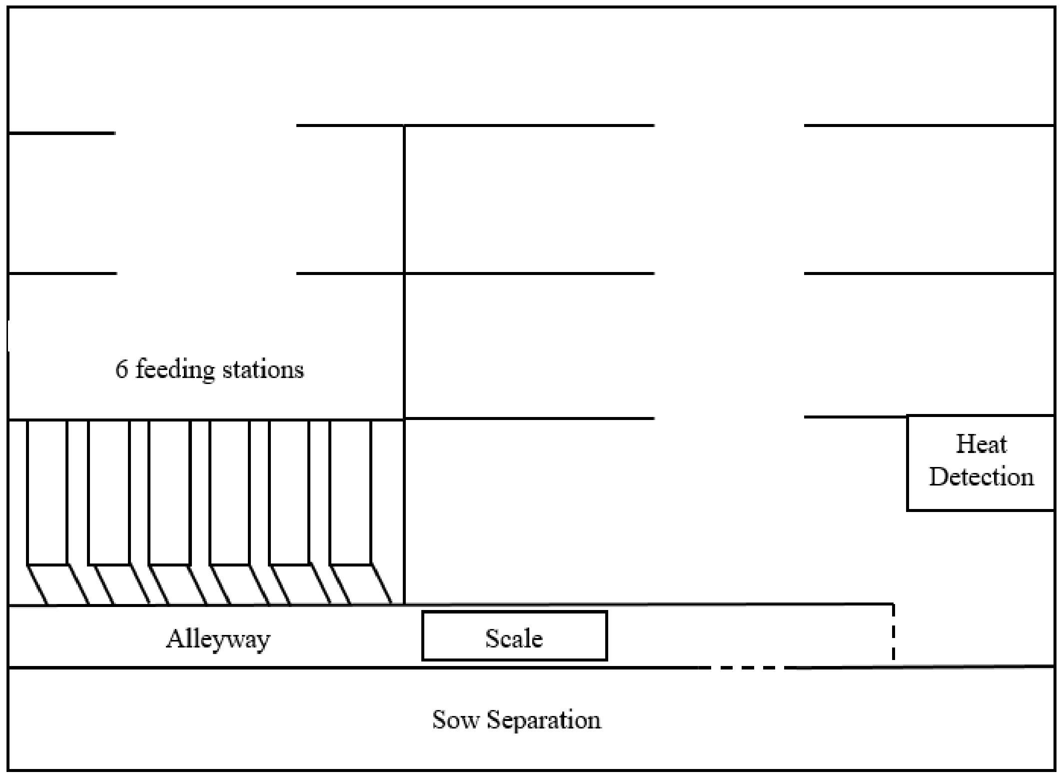

Figure 2.1 Group housing design where research study was conducted.

Figure 2.2 One individual pen showing 6 electronic sow feeding stations.

Figure 2.3 One sow has left the feeding station and is walking over the scale as she exits the system. The sows seen to the left are sows in the pen and the area to the right is the sow holding area. The transponder reader can be seen on the right side of the sow near the front of the scale.

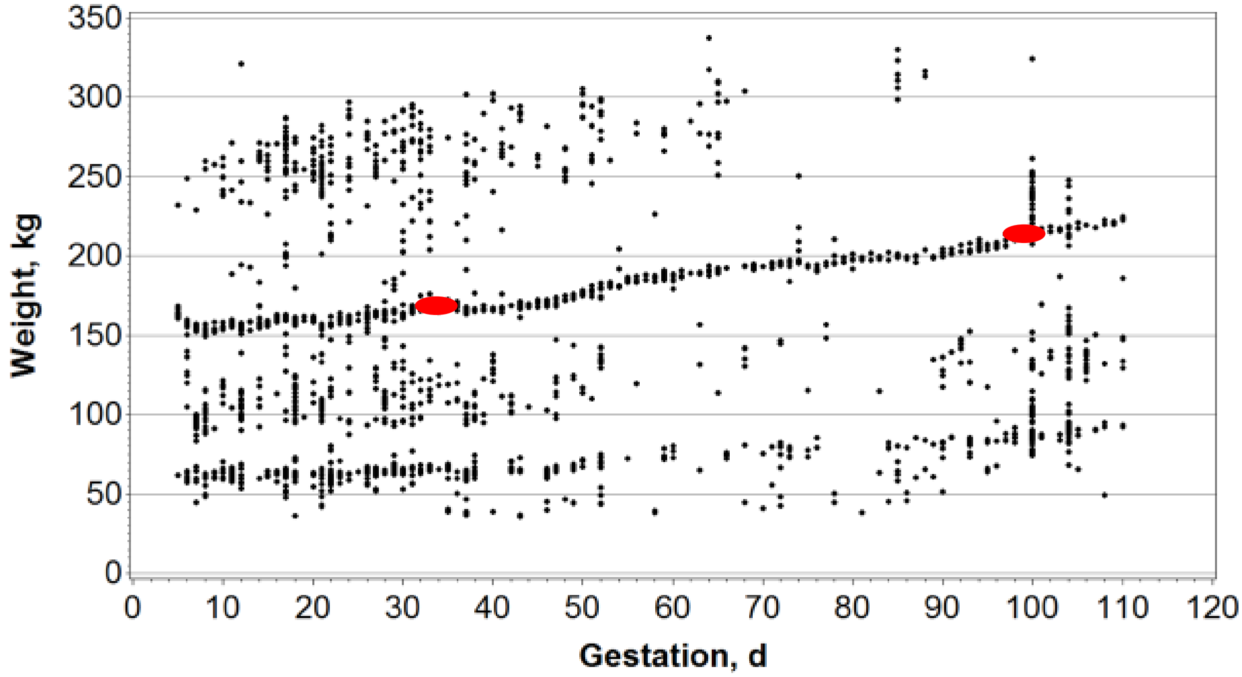

Figure 2.4 An example of the individual sow's BW throughout the course of gestation. Each black dot indicates a weight obtained throughout the study (1,862 total weights). The red dots are the two reference weights where sows were individually weighed.

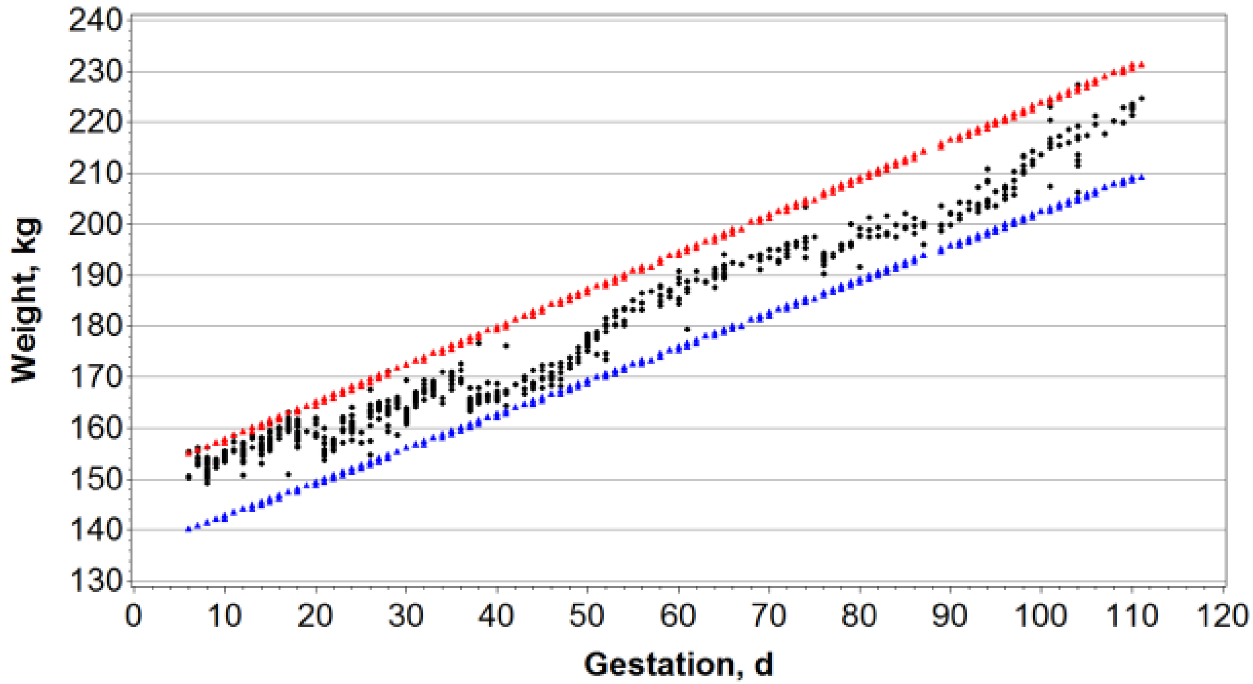

Figure 2.5 Individual sow BW throughout the course of gestation. The block dots indicate weights obtained throughout the study (671 accurate weights). The red and blue lines were calculated based on the reference weights manually collected and used to determine ADG that could then be used to predict sow BW. Weights obtained 5% above (red line) or below (blue line) the predicted weight were deleted and deemed inaccurate.

Chapter 3 - Effect of parity and stage of gestation on growth and feed efficiency of gestating sows

ABSTRACT: The effects of parity and stage of gestation on female growth criteria, and reproductive performance were evaluated on a commercial sow farm. A total of 712 females (Camborough®, PIC, Hendersonville, TN) were group-housed and individually fed with electronic sow feeders. Gilts (parity 1) and sows were offered 2.0 and 2.26 kg of feed per day (4.7 and 5.3 Mcal NE per d), respectively. Females were moved from the breeding stall to pens on d 5 of gestation. A scale was located in the alleyway after sows left individual feeding stations. Feed intake and BW were recorded daily throughout gestation generating values for ADFI, ADG, and G:F for each sow. Data was divided into 3 parity groups: 1, 2, and 3+ and gestation was divided into 3 periods: d 5 to 39, 40 to 74, and 75 to 109.

From d 5 to 39, ADFI was decreased ($P < 0.05$) for parity 3+ sows compared to the other periods of gestation. Parity 2 sows, although provided the same feed allowance, had greater ($P < 0.05$) ADFI during the first period of gestation than parity 3+ sows. Parity 1 and 2 sow ADG increased ($P < 0.05$) from d 39 to 74 of gestation, then decreased ($P < 0.05$) from d 74 to 109 of gestation. Parity 3+ sow ADG increased ($P < 0.05$) in each subsequent period of gestation. Parity 1 sows had the greatest ($P < 0.05$) ADG in comparison to parity 2 and 3+ sows in each period of gestation. Regardless of parity group, G:F was poorest ($P < 0.05$) from d 5 to 39 of gestation compared with sequential periods of gestation. Parity 1 sow G:F was greater ($P < 0.05$) than parity 2 and 3+ sows for all periods of gestation. Backfat gain indicated that parity 1 sows maintained backfat (approximately 18 mm) while parity 2 and 3+ sows gained ($P < 0.05$) approximately 1 mm backfat throughout gestation. Total born was greatest ($P < 0.05$) for parity

3+ sows with parity 1 sows marginally greater ($P < 0.10$) than parity 2 sows. Although there was statistical evidence ($P < 0.001$) for a positive correlation between BW gain and total born in parities 1 (r = 0.23; P = < 0.001), 2 (r = 0.15; $P = 0.035$), and 3+ (r = 0.29; $P < 0.001$), these correlations are very weak. Overall, this study indicates that parity 1 sows have the greatest G:F in gestation and that there is a lack of evidence for strong correlations between feed intake, growth, and reproductive performance.

Key words: electronic sow feeder, feed efficiency, gestation, sows

Introduction

Our knowledge regarding the dietary energy requirements of the gestating sow currently enables us to manage feed supply during gestation on the basis of three main criteria: the sow's body condition (or BW), parity, and stage of gestation (Kim et al., 2013; Quiniou, 2014). The impact of these factors on gestating sow nutrient requirements has been heavily researched through the years (Noblet and Etienne, 1987b; Dourmad et al., 2008; NRC, 2012). Several studies have observed feed intake and BW of rearing gilts (Rozeboom, 2015) and gestating sows housed in small University farms (Dourmad, 1991; Young et al., 2005; Kruse et al., 2010); however, research is limited in commercial production systems, specifically pertaining to the growth and feed efficiency of prolific (> 14.5 pigs born alive) gestating sows.

With the transition from individual- to group-housed pregnant females, some systems are allowing for the collection of daily intake and BW data. Monitoring the daily intake and BW of pregnant females throughout gestation allows for a better understanding of sow intake patterns and growth performance, each of which are important when determining gestating sow nutrient requirements.

Therefore, the objectives of this study were to document feed intake patterns in group-housed gestating sows fed via electronic sow feeders (ESF) from a commercial sow farm and determine the effect of parity and stage of gestation on growth and feed efficiency. In addition, backfat gain and reproductive performance measurements were obtained to determine if potential correlations existed between feed intake, growth, and reproductive performance.

Materials and Methods

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The experiment was conducted at a commercial sow farm in central Nebraska. Females were individually housed in stalls (gilts 0.56 × 2.1 m and sows 0.61 × 2.3) from d 0 to 5 of gestation, then were group-housed from d 5 to 112 of gestation. Pens for sows provided 2.04 m^2 per sow and those for gilts provided 1.95 m^2 per gilt. Each pen was equipped with 6 electronic feeding stations (Nedap Velos, Gronelo, Netherlands) allowing for up to 45 females per station and 28 nipple waterers to provide ad libitum access to water. Each feeding station was 2.0 m long × 0.56 m wide. Females were group-housed in dynamic groups (260 females per pen), meaning serviced sows were entering the group (approximately d 5 of gestation) as sows due to farrow were exiting (approximately d 112 of gestation). This occurred over a 3 to 4-wk period, thereafter, the pen remained static (no movement of newly bred sows into the pen) until the sows reached d 112 of gestation and the process repeated. Each pen was equipped with a scale (2.13 m long × 0.51 m wide, New Standard US Inc., Sioux Falls, SD) located in the alleyway following the feeding stations and prior to returning to the pen for individual sow weight collection every time the sow exited the feeding station.

Animals and Diets

From d 5 to 112 of gestation, females were fed a diet (Table 3.1) containing 0.63% standardized ileal digestible (**SID**) Lys according to parity and body condition (gilts and ideal sows, and skinny sows were offered 2.0, 2.3, and 3.0 kg/d, respectively), following standard practice at this commercial farm. This would have provided daily NE intakes of 4.7, 5.3, and 7.0 Mcal assuming a sow consumed all her daily feed allowance. A total of 861 females (Camborough®, PIC, Hendersonville, TN; 296 gilts and 565 sows) were enrolled in the study on d 5 of gestation. At d 112 of gestation, at 14:00, females were moved to the farrowing house and provided ad libitum access to a lactation diet containing 1.2% SID Lys. Both gestation and lactation diets were corn-soybean meal-based and presented in meal form.

Thomas et al., (2016) report the procedures for feed intake and BW data collection and management of this study. Feed intake data was manually extracted daily through Nedap Velos software at approximately 13:00 to ensure all females had eaten their daily allocation before system reset at 14:00. The Nedap Velos system reported 1 total intake value per day of gestation and it is assumed that the feed which was dispensed was consumed by the sow before leaving the feeding station. Sows had to walk across a scale as they moved from the feeding station back into the pen and as a result, sow BW was automatically recorded. Sows were also manually weighed at least twice during the course of the study. These weights were collected on all females near the beginning and end of gestation. These weights were then used to eliminate outlier weights in the data set based on the ADG generated from the two weights and predicted body weights based on the initial known weight and day of gestation.

The study was conducted over a 149-day period, from late May to mid-October. A total of 861 females were enrolled in the study, of which 712 completed. Of the initial 861 females, 40 were removed due to death or culling decisions made by the farm. Ninety-seven females were deleted from the study because they were removed from their pen for greater than 3 consecutive days due to illness or lameness. The remaining 12 females were removed due to unknown RFID.

Daily intake and weight values were recorded for each sow from d 5 to 112 of gestation. As a result, ADFI, BW, ADG and G:F were generated daily for each sow. This data was then divided into 3 parity groups (1, 2, and 3+) and gestation was divided into 3-5-wk intervals (d 5 to 39, 40 to 74, and 75 to 109). Days 110, 111, and 112 of gestation were not included in the analysis. When determining ADFI, BW, and ADG, for each period, the average per period is reported and the median is reported for G:F. Scatter plots were created to visualize feed intake and BW data over the course of gestation and identify any variability that may exist.

Total gestation feed intake was determined by calculating the sum of all intake values for each individual sow. Body weight gain for each sow was determined by calculating the difference between initial and final BW. Body weight includes the weight of the conceptus. The number of ESF feeding visits was defined as any visits that were greater than 5 minutes apart. Feed intake software only generated a single feed intake value per day for each female, thus because sows entered the ESFs multiple times per day, we were unable to determine if each of these visits were feeding events.

Backfat depth was measured at entry into pen gestation and on entering the farrowing house (approximately d 5 and 112 of gestation). Backfat depth was measured at the P2 position (last rib, 7 cm from the center line of the back) using a Lean-Meater (RENCO, Minneapolis, MN). Backfat gain during gestation was estimated by calculating the difference between values taken at d 5 and d 112 of gestation.

Reproductive performance criteria of sows were recorded using the PigCHAMP Knowledge Software (Ames, IA) and were extracted at the end of the trial. The following reproductive traits were collected in parity 1 to 5 sows: the total number of pigs born, total number of pigs born alive, number of stillborn pigs, number of mummified fetuses, number of weaned pigs, and gestation length.

Diet Sampling and Analysis

Diet samples were taken from each electronic feeding station every wk during feeder calibration. Weekly samples of corn, soybean-meal, and dried distillers grains with solubles for gestation feed were obtained from the feed mill prior to mixing. Samples were submitted (Ward Laboratories, Inc., Kearney, NE) for analysis of DM (method 935.29; AOAC Int., 2012), CP (AOAC 900.03, 2012), crude fiber (method 978.10; AOAC Int., 2012 for preparation and Ankom 2000 Fiber Analyzer [Ankom Technology, Fairport, NY]), ash (method 942.05; AOAC Int., 2012), ether extract (method 920.39 a; AOAC Int., 2012 for preparation and ANKOM XT20 Fat Analyzer [Ankom Technology, Fairport, NY]), Ca, and P (method 968.08 b; AOAC Int., 2012 for preparation using ICAP 6500 [ThermoElectron Corp., Waltham, MA]).

Statistical Analysis

Prior to data analysis, descriptive statistics in the form of means, histograms and scatterplots were generated using the PROC MEANS, PROC GPLOT, and PROC SGPLOT statements in SAS (Version 9.4, SAS Institute Inc., Cary, NC). Correlations between selected variables were performed using the PROC CORR statement in SAS. Extreme observations were found for female ADG, using descriptive statistics, generated from the variability between daily

BW collection. Observations were deemed as outliers based on a calculated critical t-score using a Bonferroni adjustment (0.05 / number of observations). This indicated that observations ± 4.97 standard deviations from the mean were considered outliers and were removed from the data set.

Female ADFI, BW, ADG, and G:F were analyzed using generalized linear mixed models whereby the linear predictor included parity group, period of gestation and all interactions as fixed effects, as well as the random effects of period nested within individual sow. So specified, models recognized the individual female as the experimental unit for this study. Female ADFI, BW, ADG, and G:F were fitted assuming a normal distribution of the response variable. Backfat and reproductive performance were analyzed similarly whereby the linear predictor included parity group as the fixed effect and individual sow as the random effect. The final models used for inference were fitted using restricted maximum likelihood estimation. Degrees of freedom were estimated using the Kenward-Rogers approach.

Estimated means and corresponding standard errors (SEM) are reported for all cell means. Pairwise comparisons were conducted on such means using either Tukey or Bonferroni adjustment to prevent inflation of Type I error due to multiple comparisons. Statistical models were fitted using the GLIMMIX procedure of SAS. Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results and Discussion

General

Chemical analysis of DM, CP, crude fiber, ether extract, Ca, P, and ash for each of the major feed ingredients and for the complete feed are presented in Table 3.2. The values reported for the complete feed reasonably met formulated values and the individual feed ingredients aligned similarly with values reported in the NRC (2012). Gilts, ideal sows, and skinny sows should have consumed 4.7, 5.3, and 7.0 Mcal NE per day based on their feed allowances which are similar to estimates from the NRC (2012) for parity 1, 2 and 3+ sows consuming a diet containing 2,518 kcal NE per kg with intakes ranging from 2.13 to 2.61 kg per day.

Descriptive statistics for selected data are presented in Table 3.3. Average initial backfat depth was 16.1 mm ± 3.69 (mean ± SE) with a range of 8 to 26 mm. Average final backfat depth was 16.6 mm ± 3.18 with a range of 7 to 28 mm. Average BW gain was 56.8 kg ± 14.35. As changes in lean tissue growth rates in dam-line females has changed over the years, backfat and BW research have received considerable attention. Research has emphasized the importance of gestation feeding strategies that are based on female backfat and BW at breeding as opposed to previously evaluating body condition score in effort to obtain ideal body condition at farrowing (Young et al., 2004; Foxcroft et al., 2005). Although there is some disagreement on whether the ideal backfat depth at farrowing should be between 16 to 18 mm or 18 to 21 mm, most would agree that backfat depth under 15 mm and over 24 mm are problematic (Young et al., 1991; Hughes, 1993; Tantasuparuk et al., 2001). The average total born was 14.9 ± 3.13 and ranged from 1 to 25. In comparison, the average total born reported for 2015 in the industry productivity analysis (Staldler, 2015) was 13.5 ± 1.0 and the average total born reported for farms in the top 25% was 13.9 ± 0.8. The average number of pigs weaned was 13.3 ± 2.19 with a range of 0 to 17. The average number of pigs weaned reported for 2015 in the industry productivity analysis was 10.0 ± 1.2 and the average number of pigs weaned for farms in the top 25% was 11.0 ± 0.7.

Feed Intake

From d 5 to 39 of gestation, ADFI was decreased ($P < 0.05$) for parity 3+ sows compared to the other periods of gestation (Table 3.4). There was no evidence for differences ($P > 0.05$) in

ADFI following d 39 of gestation for parity 3+ sows. There was no evidence for differences (P > 0.05) in ADFI for parity 1 or 2 sows from d 5 to 109 of gestation; however, numerically, ADFI was decreased from d 5 to 39 of gestation compared with later gestation. There is an obvious reduction in ADFI within the first 10 d in the pen in parity 1 sows (Figure 3.1). Parity 2 and 3+ sows show a similar reduction but return to the assigned feed allowance much faster than parity 1 sows (Figures 3.2 and 3.3). Parity 1 sow ADFI appears more variable throughout the course of gestation, with some sows consuming less than the provided 2.0 kg per d feed allowance (Figure 3.1). Parity 2 and 3+ sows show improvements in ADFI with most sows consuming the 2.3 or 3.0 kg per d feed allowance throughout the course of gestation (Figures 3.2 and 3.3). Parity 2 sows, although provided the same feed allowance, had greater ADFI during the first period (P < 0.05) than parity 3+ sows. Regardless of period, ADFI for parity 1 sows was lower (P < 0.05) compared to parity 2 and 3+ sows, which is attributed to the assigned feeding strategies.

Most producers would attribute this variation in ADFI by period, especially in parity 1 sows group housed and fed via ESF, to the gilt training program of the farm. A gilt training program is designed to allow gilts to become familiar with the ESF system prior to breeding. In this production system, gilts receive two weeks of training prior to breeding and being placed in gestation group housing (Vier et al., 2016). The data indicates that even with extensive training, parity 1 sows were reluctant to consume the full feed allowance and remain at full feed for the course of gestation. Parity 2 and 3+ sows show better feed intake, but they appear to have similar struggles when they initially return to the ESF after weaning. On average, females visited the feeding stations 3 times per day.

There are many factors that may have attributed to the reduction in feed intake during the first 10 d of gestation and the occurrences of reduced feed intake seen throughout gestation.

Recall, sows within this system entered into dynamic groups on d 5 of their respective gestation (260 females per pen, respectively) forming a pen over a 3 to 4-week period. This group management strategy exposed the sows to continuous stresses of re-mixing (social harassment by pen mates). However, previous research indicates that managing sows in large groups, such as these, allows for pigs to alter their strategy of negotiations with social encounters as they fail to recognize all individuals in these large group sizes (Spoolder et al., 2009). As group size increases, pen size increases, thus space per female is greater. Females on this farm were provided 1.95 and 2.04 m^2 for gilts and sows, respectively. The minimum space requirements for group-housed sows remains undefined; however, Hemsworth et al. (2013) concluded that 1.4 m^2 per sow was not enough space and detrimental to animal welfare. However, it was not possible to give guidance on actual space allowance beyond this restriction. Based on previous research, housing management and space allowance in our study do not appear to be restricting but it is unknown what the impact of these, in addition to other group housing factors, may have on intake or subsequent performance.

Growth and Feed Efficiency

Regardless of parity, BW increased ($P < 0.05$) during each period of gestation (Table 3.4). Parity 3+ sows had the greatest BW ($P < 0.05$) compared to parity 1 or 2 sows, regardless of period. By the final period of gestation, parity 1 sows were 4 kg heavier ($P < 0.05$) than parity 2 sows. Body weight gain from d 5 to 112 of gestation, was 68.6, 49.3, and 51.3 kg for parity 1 (Figure 3.4), 2 (Figure 3.5), and 3+ (Figure 3.6) sows, respectively,) with parity 1 BW gain greater ($P < 0.05$) than parity 2 and 3+ sows, (Table 3.5). Body weight gain in young females is expected to be greater than multiparous sows because they will not reach a mature weight until the 4^{th} or 5^{th} parity. Literature indicates average BW gain in gilts should approximate 55 kg

(NRC, 1998; Ji et al., 2005) and 40 to 45 kg in sows (Verstegen et al., 1987; Noblet et al., 1990). Parity 1 sows from this herd gained 19.3 and 17.3 kg more than parity 2 and 3+ sows, exceeding previous recommendations.

Parity 1 and 2 sow ADG increased ($P < 0.05$) from d 39 to 74 of gestation then decreased ($P < 0.05$) from d 74 to 109 of gestation (Table 3.4). Parity 3+ sow ADG increased ($P < 0.05$) during each period of gestation. Parity 1 and 3+ sow G:F increased ($P < 0.05$) following d 39 of gestation with no evidence for differences ($P > 0.05$) following d 74 of gestation. Parity 2 sow G:F increased ($P < 0.05$) from d 39 to 74 of gestation and decreased ($P < 0.05$) from d 74 to 109 of gestation. Fetus development is slow during the first third of pregnancy, and about 2/3 of fetal growth or energy deposition in the uterus occurs during the last 1/3 of pregnancy (Dourmad et al., 2008). Therefore, we would expect to see an increase in ADG and improvement in G:F attributed to the increase in fetal growth in the later stages of gestation. Parity 1 sows do not appear to show this increase in ADG or G:F. Parity 2 sows do not show an increase in ADG but G:F improves following d 74 of gestation. Parity 3+ sows show an increase in ADG but no changes in G:F following d 39 of gestation.

Parity 1 sow ADG and G:F was greater ($P < 0.05$) than parity 2 and 3+ in all periods of gestation(Table 3.4). Parity 2 sow ADG was greater ($P < 0.05$) than parity 3+ from d 5 to 39 of gestation; however, parity 3+ sow ADG was greater ($P < 0.05$) from d 75 to 109. Regardless of stage of gestation, there was no evidence for differences ($P > 0.05$) in G:F between parity 2 and 3+ sows. The differences in ADG and G:F among parities may be attributed to the differences in the composition (lean and fat) of gain. Dourmad et al. (1999) suggested that for a given energy supply, higher protein retention is generally measured in parity 1 sows than in older sows. This is partly explained by parity 1 sows having a lower energy requirement for maintenance because of their body weight.

Backfat

Initial backfat depth was greatest ($P < 0.05$) for parity 1 sows, followed by parity 3+ and 2 sows (Table 3.5). There was no evidence for a difference in final backfat depth between parity 2 and 3+ sows; however, backfat depth of parity 1 sows were nearly 3 mm greater ($P < 0.05$). Backfat gain indicates that parity 1 sows maintained backfat while parity 2 and 3+ sows gained ($P < 0.05$) backfat.

Backfat thickness as an indicator of body condition, in addition to other criteria, have been used to support feeding recommendations in gestating sows (Quiniou, 2014). Backfat thickness guidelines indicate thin, ideal, and fat body condition for sows with less than 17, 19, and greater than 21 mm, respectively (Young et al., 2005; Houde et al., 2010; Quiniou, 2014). Differences in initial and final backfat between parity groups in this study (Table 3.5) may indicate that parity 1 sows were over conditioned. Based on the observations from this farm, parity 1 sows lose 4 mm of backfat during lactation. During the following gestation, the sows (now parity 2) gain 1.4 mm of backfat during gestation. During the next lactation period, the sows maintain backfat into the following gestation period (now parity 3 sow). These differences in backfat lead us to believe parity 1 sows from this herd were over conditioned.

Reproductive performance

Total born was greatest ($P <0.05$) for parity 3+ sows with parity 1 sows marginally greater ($P < 0.01$) than parity 2 sows (Table 3.5). Number of pigs born alive was greatest ($P < 0.05$) for parity 3+ sows, but there was no evidence for differences between parity 1 and 2 sows. There was no evidence for differences in stillborn pigs among the parity groups. The number of mummified fetuses were greater (*P* < 0.10) in parity 1 sows in comparison to parity 2 and 3+ sows. There was no evidence for differences in the number of pigs weaned among the parity groups.

Previous research is equivocal regarding the relationships that exist between female backfat thickness and subsequent reproductive performance (McKay 1993; Manes et al., 2004; Tummaruk et al., 2007). We observed no evidence for an association between: 1) backfat depth at the end of gestation and number of stillborn pigs, 2) backfat gain and number of weaned pigs, or 3) initial backfat and total number of pigs born. There was evidence for a negative correlation (r = -0.15; *P* = 0.020) between total feed intake and stillbirths in parity 1 sows (Table 3.6) and backfat gain was positively correlated (r = 0.14; *P* = 0.026) to the number of mummified fetuses. There was evidence for a negative correlation (r = -0.17; *P* = 0.018) between backfat gain and stillborn pigs in parity 2 sows. In parity 3+ sows, there was evidence for a negative correlation between backfat gain and total number of pigs born (r = -0.26; *P* < 0.001, Figure 3.7) indicating as females gained more backfat, total number of pigs born decreased. There was a positive correlation (r = 0.13; *P* = 0.037) between BW gain and the number of mummified fetuses in parity 3+ sows. There was evidence for a positive correlation in parity 1 (r = 0.23; *P* < 0.001), 2 (r = 0.15; *P* = 0.035), and 3+ (r = 0.29; *P* < 0.001) sows between BW gain and total born (Figure 3.8). This is expected, as total number of pigs born increases, the weight associated with products of conceptus increases leading to increased BW gain. It is important to note that although these correlations are significant, they are also very weak. Significant correlations were detected due to the large number of observations in this study.

When comparing total intake consumed throughout the course of gestation to backfat gain and BW gain, we observed a large range in backfat gain and BW gain among females fed the same amount of feed. We expect that as females consume more feed, backfat will increase as well as BW. There was evidence for a positive correlation (r = 0.24; $P < 0.001$) between backfat gain and total intake in parity 3+ sows. Recall, 12 sows form this study were deemed as skinny and received 3.0 kg per day and of these 12 sows, 9 were party 3+ sows. This is likely influencing the observed correlation between backfat gain and total intake in parity 3+ sows. There was also evidence for a positive correlation between BW gain and total intake in parity 1 (r = 0.37; $P < 0.001$) and parity 3+ (r = 0.15; $P = 0.015$) sows (Figure 3.9). Again, these correlations are significant but are very weak.

Conclusion

From the existing data, is it apparent that even with a vigorous gilt training program, feed intake is decreased during the initial 10 days following the introduction of females to an ESF system, regardless of parity. Feed intake is also variable throughout the course of gestation, regardless of parity, with females not necessarily consuming their full feed allowance. Although there were some significant correlations observed between feed intake, BW gain, and backfat depth with litter size, these correlations were very weak and likely of little practical significance. Overall, this study improves our knowledge on feeding the pregnant sow and how to properly meet her nutrient requirements in gestation based on differences in parity and period of gestation.

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Table 3.1 Diet composition (as fed basis)[1]

Ingredient	%
Corn	54.75
Soybean meal	11.85
DDGS, 8.5% oil[2]	30.00
Monocalcium phosphate	0.65
Limestone	1.65
Salt	0.50
Liquid lysine, 50%	0.15
Choline chloride, 60%	0.11
Vitamin and trace mineral premix[3]	0.38
TOTAL	100
Calculated analysis	
Standardized ileal digestible (SID) AA, %	
Lys	0.63
Ile:Lys	93
Leu:Lys	258
Met:Lys	46
Met & Cys:Lys	88
Thr:Lys	82
Trp:Lys	23
Val:Lys	112
ME, kcal/kg	3,225
NE, kcal/kg	2,341
CP, %	18.5
Ca, %	0.83
P, %	0.59
Available P, %	0.47
Standardized Total Tract Dig. (STTD) P, %	0.35
Ca:P	1.42

[1]Diet was fed from d 5 to 112 of gestation.

[2]Distillers dried grains with solubles.

[3]Provided per kg of diet: 22,000 mg vitamin E, 1,650 mg folic acid, 2,200 mg pyridoxine, 198 mg chromium, 49,500 mg carnitine, 1,700 mg Ca from calcium carbonate, 110 mg Cu from copper sulfate, 198 mg I, 734 mg Fe from ferrous sulfate, 220 mg Mn from manganous oxide, 198 mg Se from sodium selenite, and 734 mg Zn from zinc sulfate.

Table 3.2 Chemical analysis of major feed ingredients and complete feed (as-fed-basis)[1]

	Corn	SBM	DDGS	Complete feed
Proximate analysis, %				
DM	87.93	89.40	90.53	89.33
CP	7.60	47.58	28.76	19.36
Crude fiber	1.88	3.27	8.24	3.81
Ca	0.03	0.45	0.03	0.90
P	0.27	0.68	0.87	0.63
Ether extract	3.28	0.91	8.59	4.35
Ash	1.21	6.31	5.42	5.18

[1]Diet samples (21 total samples) were taken from each electronic feeding station weekly and ingredients samples (16 total samples) were obtained from the feedmill as ingredients were added to the mixer.

Table 3.3 Descriptive statistics for data included in the study[1]

Item	Mean	SD	Minimum	Maximum
Initial backfat, mm	16.1	3.69	8	26
Final backfat, mm	16.6	3.18	7	28
Backfat gain, mm[2]	0.57	3.29	-9	11
Total intake, kg[3]	228.5	17.61	181	310
Initial BW, kg	165.0	22.99	107	234
Final BW, kg	221.8	21.01	163	294
BW gain, kg[4]	56.8	14.35	8	116
Parity	2.3	1.31	1	5
Total born	14.9	3.13	1	25
Born alive	14.2	3.06	1	23
Stillbirths	0.37	0.68	0	9
Mummies	0.30	0.59	0	4
Pigs weaned	13.3	2.19	0	17
Gestation length, d	115.3	0.99	112	117

[1]Values from a total of 712 females (Camborough®, PIC, Hendersonville, TN) were used.
[2]Backfat gain = Final backfat – Initial backfat
[3]Total intake = Sum of daily intake values throughout the course of gestation for each individual sow
[4]BW gain = Final BW – Initial BW

Table 3.4 Growth and feed efficiency of gestating sows housed under commercial conditions as influenced by parity and gestation period[1,2]

	Day of gestation			
	5 to 39	40 to 74	75 to 109	Probability, *P* <
ADFI[3], kg				
Parity 1	$1.95^{x} \pm 0.006$	$1.96^{x} \pm 0.006$	$1.97^{x} \pm 0.006$	<0.001
Parity 2	$2.24^{z} \pm 0.006$	$2.25^{y} \pm 0.006$	$2.25^{y} \pm 0.006$	<0.001
Parity 3+	$2.22^{ay} \pm 0.005$	$2.27^{by} \pm 0.005$	$2.27^{by} \pm 0.005$	<0.001
BW[4], kg				
Parity 1	$155.2^{ax} \pm 0.95$	$177.7^{bx} \pm 0.95$	$202.4^{cx} \pm 0.95$	<0.001
Parity 2	$165.9^{ay} \pm 1.09$	$181.3^{by} \pm 1.09$	$198.7^{cy} \pm 1.09$	<0.001
Parity 3+	$190.4^{az} \pm 0.90$	$205.4^{bz} \pm 0.90$	$223.6^{cz} \pm 0.90$	<0.001
ADG[5], kg				
Parity 1	$0.53^{ay} \pm 0.011$	$0.75^{bx} \pm 0.011$	$0.65^{cx} \pm 0.011$	<0.001
Parity 2	$0.39^{ax} \pm 0.013$	$0.56^{by} \pm 0.013$	$0.40^{ay} \pm 0.013$	<0.001
Parity 3+	$0.30^{az} \pm 0.010$	$0.53^{by} \pm 0.010$	$0.61^{cx} \pm 0.010$	<0.001
G:F[6]				
Parity 1	$0.29^{ay} \pm 0.005$	$0.33^{bz} \pm 0.005$	$0.34^{by} \pm 0.005$	<0.001
Parity 2	$0.19^{ax} \pm 0.006$	$0.22^{bx} \pm 0.006$	$0.20^{ax} \pm 0.006$	<0.001
Parity 3+	$0.20^{ax} \pm 0.005$	$0.22^{bx} \pm 0.005$	$0.22^{bx} \pm 0.005$	<0.001

[1]A total of 712 females (PIC 1050) were used in a 108-d trial with 249, 188, and 275 females in parity groups 1, 2, and 3+.
[2]Values within response criteria with different superscripts within a row[abcde] or column[xyz] differ, *P*<0.05.
[3]Average daily feed intake is reported as the mean for each period.
[4]Female BW is reported as the mean for each period and includes the weight of the sow and products of conceptus.
[5]Female ADG is reported as the mean for each period.
[6]G:F is reported as the median for each period.

Table 3.5 Influence of parity group on backfat depth, weight, and reproductive performance[1,2]

	Parity group			
	1	2	3+	Probability, *P* <
Sow backfat, mm				
Initial	18.2[a] ± 0.21	14.2[c] ± 0.24	15.4[b] ± 0.20	<0.001
Final	18.1[a] ± 0.19	15.6[b] ± 0.22	15.9[b] ± 0.18	<0.001
Gain	-0.03[b] ± 0.236	1.42[ax] ± 0.213	0.53[aby] ± 0.391	<0.001
Sow weight, kg				
Initial	146.4[c] ± 0.983	159.8[b] ± 1.132	185.3[a] ± 0.936	<0.001
Final	215.1[b] ± 1.096	209.2[c] ± 1.261	236.7[a] ± 1.043	<0.001
Weight gain	68.6[a] ± 0.725	49.3[b] ± 0.835	51.3[b] ± 0.690	<0.001
Total born	14.8[bx] ± 0.196	14.2[by] ± 0.226	15.5[a] ± 0.187	<0.001
Born alive	14.0[b] ± 0.192	13.6[b] ± 0.220	14.9[a] ± 0.182	<0.001
Stillbirths	0.4 ± 0.044	0.3 ± 0.051	0.4 ± 0.042	0.451
Mummies	0.4[y] ± 0.037	0.3[x] ± 0.042	0.3[x] ± 0.035	0.047
Pigs weaned	13.4 ± 0.139	13.4 ± 0.160	13.2 ± 0.132	0.582

[1]A total of 712 females (PIC 1050) were used in a 108-d trial with 249, 188, and 275 females in parity groups 1, 2, and 3+, respectively.

[2]Values with different superscripts within a row[abc] *P*< 0.05 and values with different superscripts within a row[xyz] *P* < 0.10.

Table 3.6 Association between reproductive performance and total feed intake, backfat gain and BW gain, grouped by parity[1]

Parity 1		Total born	Born alive	Stillbirths	Mummies	Pigs weaned
Total intake, kg[2]	R	0.04	0.04	-0.15	0.02	0.11
	Probability, *P* <	0.815	0.484	0.020	0.808	0.081
Backfat gain, mm[3]	R	-0.03	-0.07	0.02	0.14	0.01
	Probability, *P* <	0.640	0.291	0.709	0.026	0.917
BW gain, kg[4]	R	0.23	0.21	0.09	0.01	0.03
	Probability, *P* <	<0.001	0.001	0.151	0.830	0.621
Parity 2						
Total intake, kg[2]	R	-0.03	-0.03	0.00	0.03	0.07
	Probability, *P* <	0.700	0.650	0.980	0.679	0.351
Backfat gain, mm[3]	R	0.02	0.06	-0.17	-0.09	-0.04
	Probability, *P* <	0.830	0.400	0.018	0.2070	0.5558
BW gain, kg[4]	R	0.15	0.15	0.01	-0.01	0.06
	Probability, *P* <	0.035	0.038	0.900	0.874	0.438
Parity 3+						
Total intake, kg[2]	R	-0.11	-0.10	-0.04	-0.06	0.06
	Probability, *P* <	0.062	0.098	0.467	0.343	0.354
Backfat gain, mm[3]	R	-0.26	-0.25	-0.05	-0.05	0.03
	Probability, *P* <	<0.001	<0.001	0.419	0.397	0.599
BW gain, kg[4]	R	0.29	0.29	-0.03	0.13	-0.04
	Probability, *P* <	<0.001	<0.001	0.604	0.037	0.528

[1]A total of 712 females (PIC 1050) were used in a 108-d trial with 249, 188, and 275 females in parity groups 1, 2, and 3+, respectively.
[2]Total intake = Sum of daily intake values throughout the course of gestation for each individual sow
[3]Backfat gain = Final backfat – Initial backfat
[4]BW gain = Final BW – Initial BW

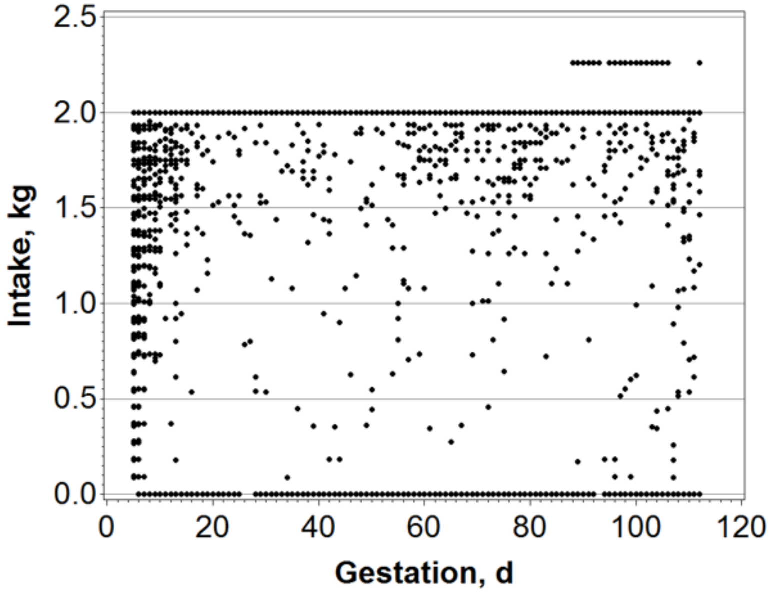

Figure 3.1 Daily feed intake from d 5 to 112 of gestation for parity 1 sows. Each dot represents an individual sow but dots may overlap. All gilts were offered 2.0 kg/day of feed with the exception of 7 gilts who were offered 2.3 kg/d at d 112 of gestation and 1 gilt who was offered 2.3 kg/d from d 88 to 106 of gestation.

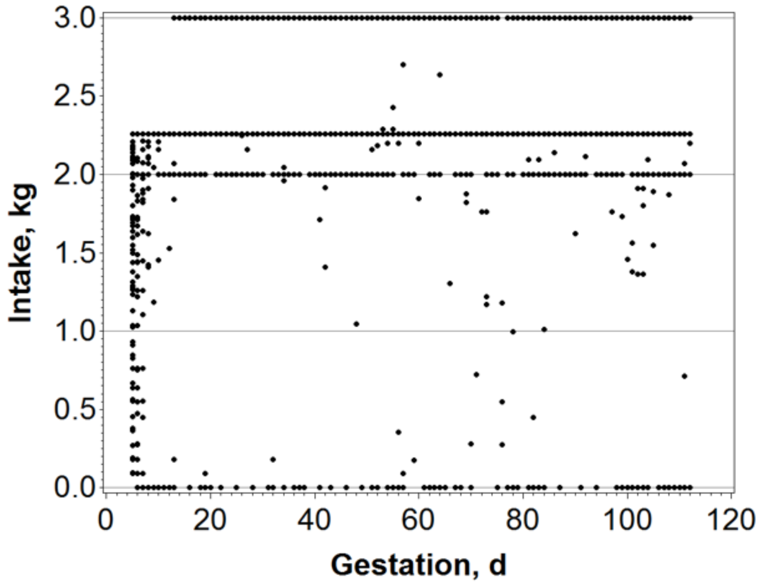

Figure 3.2 Daily feed intake from d 5 to 112 of gestation for parity 2 sows. Each dot represents an individual sow but dots may overlap. Parity 2 sows of ideal body condition were offered 2.3 kg/day of feed and those deemed skinny (3 sows) were offered 3.0 kg/d of feed. One sow was offered 2.0 kg/d of feed.

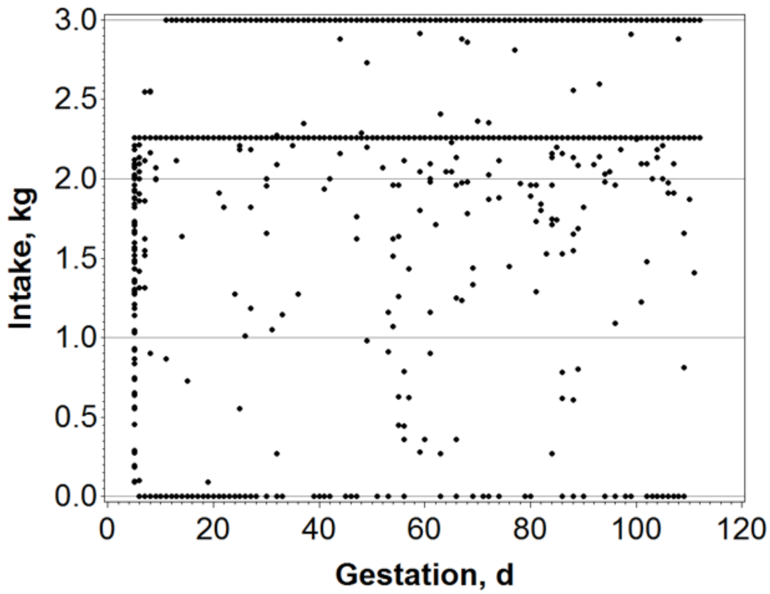

Figure 3.3 Daily feed intake from d 5 to 112 of gestation for parity 3+ sows. Each dot represents an individual sow but dots may overlap. Parity 3+ sows were offered 2.3 kg/d of feed and those deemed skinny (9 sows) were offered 3.0 kg/d of feed.

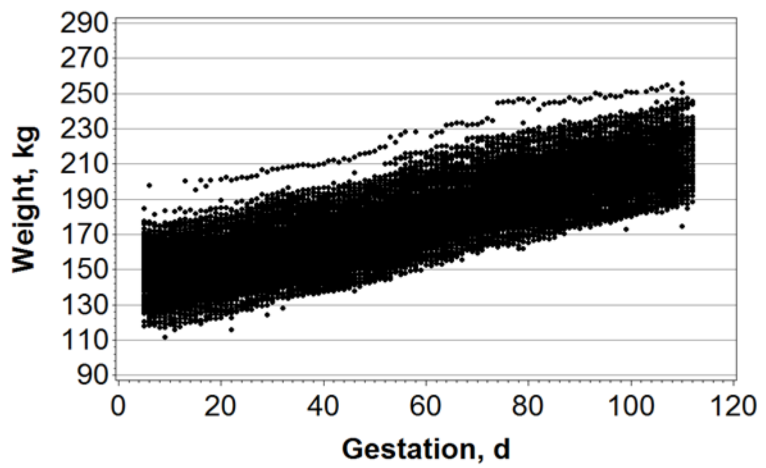

Figure 3.4 Daily BW from d 5 to 112 of gestation for parity 1 sows. Each dot represents an individual sow but dots may overlap.

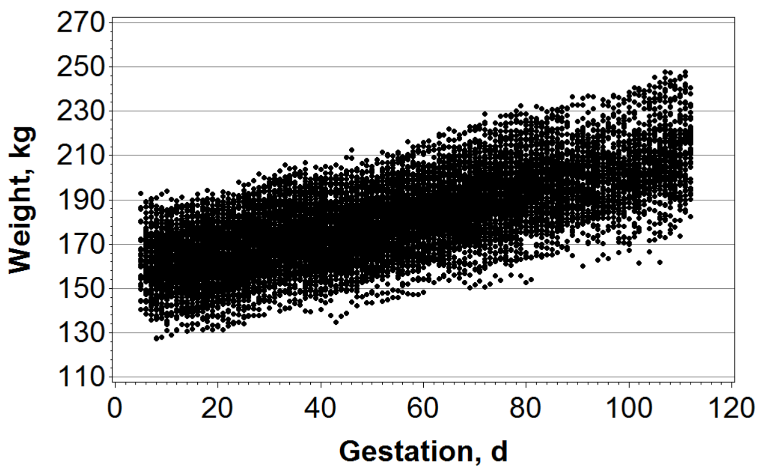

Figure 3.5 Daily BW from d 5 to 112 of gestation for parity 2 sows. Each dot represents an individual sow but dots may overlap.

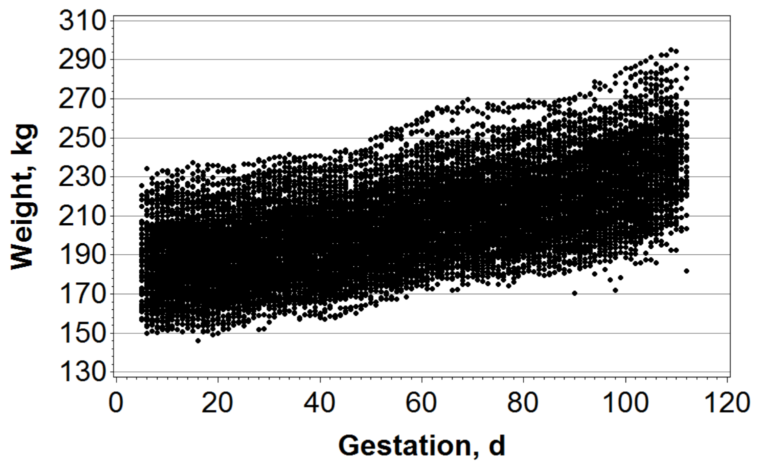

Figure 3.6 Daily BW from d 5 to 112 of gestation for parity 3+ sows. Each dot represents an individual sow but dots may overlap.

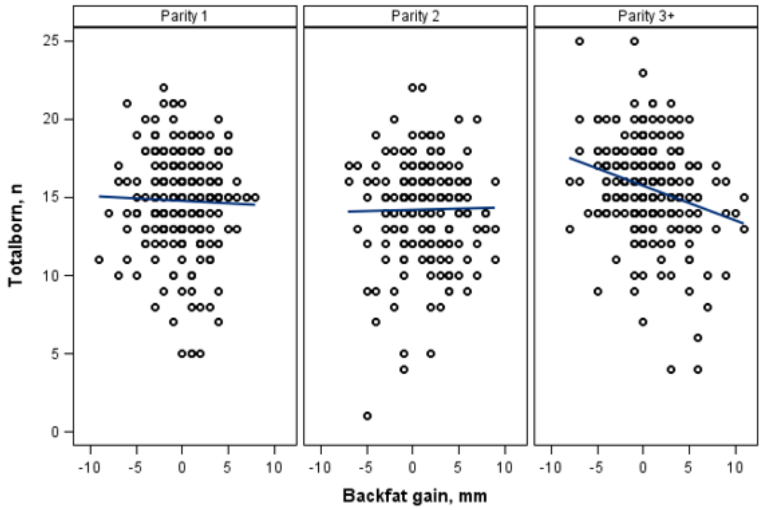

Figure 3.7 Comparison of total born and backfat gain by parity group. Backfat measurements were obtained upon entry into pen gestation (d 5) and again when loaded into the farrowing house (d 112 of gestation).

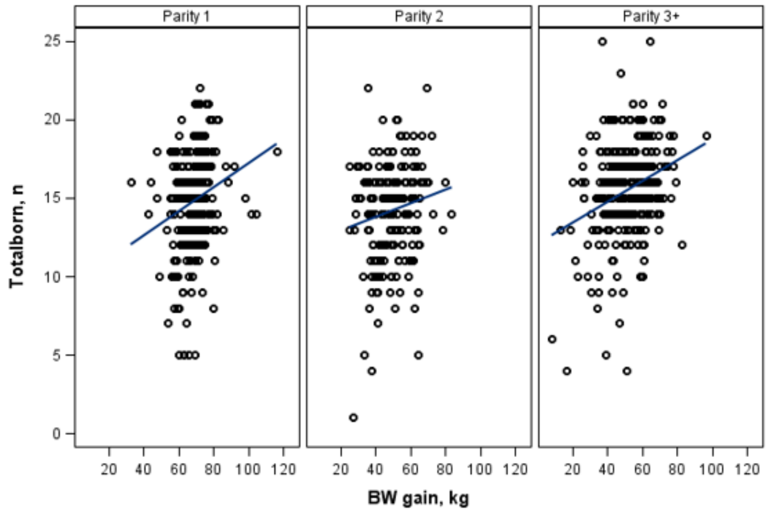

Figure 3.8 Comparison of total born and BW gain by parity group. Initial and final BW obtained upon entry into pen gestation (d 5) and when loaded into the farrowing house (d 112 of gestation), respectively, were used to calculated BW gain.

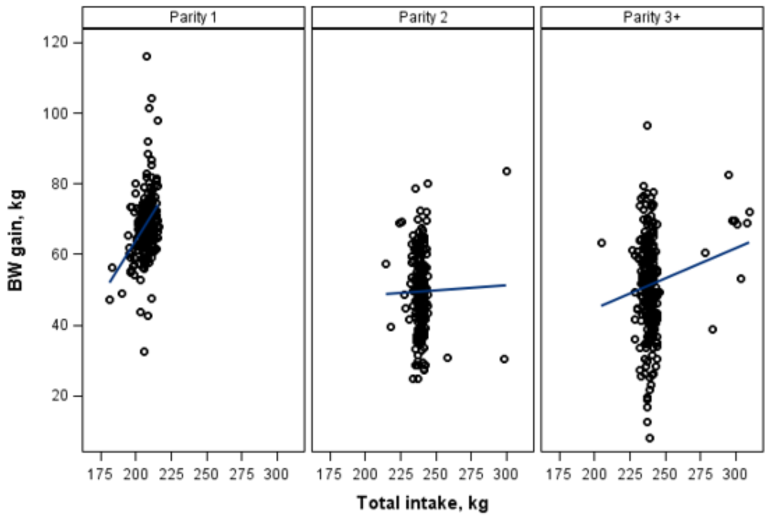

Figure 3.9 Comparison of BW gain and total intake by parity group. Initial and final BW obtained upon entry into pen gestation (d 5) and when loaded into the farrowing house (d 112 of gestation), respectively, were used to calculated BW gain.

Chapter 4 - Effect of parity and stage of gestation on maternal growth and feed efficiency of gestating sows

ABSTRACT: The objective of this study was to evaluate the effect of parity and stage of gestation on maternal weight gain and efficiency of feed use in group-housed gestating sows from a commercial sow farm. A total of 712 females (Camborough®, PIC, Hendersonville, TN) were group-housed from d 5 to 112 of gestation and individually fed with electronic sow feeders (ESF). Feed intake and BW were recorded daily throughout gestation via the ESF and a scale located in an alleyway just after sows exited the feeding station. Gilts (parity 1) and sows received 6.5 and 7.3 Mcal ME per d, respectively, while 12 thin females received 9.8 Mcal ME per d. Maternal weight gain, not including products of conceptus, and feed efficiency was predicted using a series of equations to model nutrient utilization in gestation. Data was divided into 3 parity groups: 1, 2, and 3+ and gestation was divided into 3 periods: d 5 to 39, 40 to 74, and 75 to 109.

After dividing energy requirements into tissue pools for maintenance, growth (maternal protein and fat deposition) and products of conceptus, the greatest portion of the energy requirement was for maintenance and maternal growth. The predicted energy used for maternal protein and fat deposition decreased ($P < 0.05$) in each period of gestation, regardless of parity group. Parity 2 sows had the greatest ($P < 0.05$) energy use for maternal protein and fat deposition in all stages of gestation while parity 1 sows had a negative energy balance during the final stage of gestation. Parity 1 sow maternal BW increased ($P < 0.05$) in each period of gestation; however, parity 2 and 3+ sow maternal BW remained static after d 74 of gestation. Parity 3+ sows had the greatest ($P < 0.05$) maternal BW throughout the course of gestation in comparison to other parity groups. Regardless of parity, maternal ADG decreased ($P < 0.05$)

from d 39 to 74 before increasing ($P < 0.05$) during the final stage of gestation. Parity 1 sows had the greatest ($P < 0.05$) ADG in all gestation periods. Parity 1 sow G:F decreased ($P < 0.05$) in each sequential period of gestation. Parity 2 and 3+ sow G:F decreased ($P < 0.05$) from d 39 to 74 but improved ($P < 0.05$) during the final period of gestation. Parity 1 sow G:F was greater than parity 2 and 3+ sows in most gestation periods. Overall, this study and subsequent prediction models show how stage of gestation and parity affect growth of different tissue pools, sow maternal BW, and feed usage throughout the course of gestation.

Key words: maternal growth, gestation, sows

Introduction

Previous research in regards to gestating sow nutrient requirements (Close et al., 1985; Noblet et al., 1990; Dourmad et al., 1999) has been used to develop models based on the sow's body condition, parity and stage of gestation (Noblet and Etienne, 1987b; Dourmad et al., 2008; NRC 2012). The models predict energy requirements and utilization for individual sows where priority is given to satisfy energy requirements for body maintenance functions, growth of conceptus and maternal body protein deposition with nutrients above these requirements available for maternal lipid deposition (Dourmad et al., 2008; NRC, 2012). In cases when energy is insufficient, maternal body lipid is mobilized and used as an energy source. Dourmad et al. (1996) indicated that the initial stage of gestation seems to be the sole period during which body reserves can be reestablished.

Previous literature has reported changes in nutrient utilization by different stages of gestation and parity through comparative slaughter techniques (Dourmad et al., 1996;

McPherson et al., 2004; Ji et al., 2005). However, data is limited pertaining to the application of these models in today's commercial sow herds to determine maternal growth and efficiency of feed usage of modern sows. This information will allow for a better understanding of how females use energy provided during gestation and their metabolic state upon entry into the farrowing house. Therefore, the objective of this study was to investigate the effect of parity and stage of gestation on modeled maternal weight gain and efficiency of feed utilization in group-housed gestating sows from a commercial sow farm.

Materials and Methods

Data and Measurements

The data used to model maternal weight gain and efficiency of feed use in this analysis were from a study by Thomas et al. (2016) that was conducted on a commercial sow farm to examine the effects of parity and stage of gestation on whole body growth and feed efficiency of gestating sows. A total of 712 females (Camborough®, PIC, Hendersonville, TN) were group-housed and individually fed with electronic sow feeders (Nedap Velos, Gronelo, Netherlands) with ad libitum access to water. Females were moved from the breeding stall to pens on d 5 of gestation to d 112 and fed a diet with 0.63% standardized ileal digestible (SID) Lys. Feed allowance was based on parity and body condition with gilts (parity 1), ideal sows, and skinny sows fed 6.5, 7.3, and 9.8 Mcal ME per d, respectively following standard practice at this commercial farm. The diet was formulated to contain 3,225 kcal per kg ME and all females had ad libitum access to water. A scale (2.13 m long × 0.51 m wide, New Standard US Inc., Sioux Falls, SD) was located in the alleyway after the feeding stations and leading to the pen. Daily feed intake and BW were recorded throughout gestation to determine ADFI, ADG, and feed efficiency for each sow. Body weight (kg) was reported as the sum of maternal BW and the weight of the conceptus.

Reproductive performance criteria of sows were recorded using the PigCHAMP Knowledge Software (Ames, IA) and were extracted at the end of the trial. The total number of pig born, total number of pig born alive, number of stillborn pigs, number of mummified fetuses, number of weaned pig, and gestation length were recorded.

Definitions and Calculations

Maternal body predictions do not include the products of conceptus, of which is defined as the fetus, placenta and fluids. Maternal weight gain and feed efficiency were predicted for each female using a series of equations to model nutrient utilization by determining daily conceptus weight, daily maintenance requirement, daily energy retention of conceptus, and daily energy use for maternal protein and lipid deposition. Models presented by the NRC (2012) and Dourmad et al. (2008) were used to predict the response of the sow to a given nutrient supply. Both models follow that in pregnant sows, energy is partitioned between that for maintenance, for growth of conceptus, and for maternal protein and lipid deposition as outlined by Dourmad et al. (1999). Priority is given to maintenance requirements and the demands of the growing conceptus (Dourmad et al., 1999). If nutrient allowances exceed these requirements, excess nutrients can contribute to the sow’s body reserves. Conversely, body reserves will be mobilized when energy intake is below that for maintenance and products of conceptus. The NRC (2012) prediction equation for energy-dependent maternal protein deposition requires an adjustment factor to account for unexplained changes in protein deposition that is not clearly defined. Consequently, the model proposed by Dourmad et al. (2008) was used to predict maternal protein and lipid deposition. Variables were calculated on an ME basis, as presented in the sow gestation models (Dourmad et al., 2008; NRC, 2012).

The NRC (2012) predicts the weight of conceptus and energy content of conceptus using natural logarithmic values and as a function of time and litter size at farrowing:

Weight of conceptus (kg/d) = (exp (8.621 - 21.02 × exp (-0.053 × gestation, d) + 0.114 × total born, n))/1000;

Energy content of conceptus (kJ/d) = (exp (11.72 – 8.62 × exp (-0.0138 × gestation, d) + 0.0932 × total born, n)).

The equations are from Dourmad et al. (1999) where the authors combined a set of regression equations, developed by Noblet et al. (1985), generating one equation for both weight and energy content of conceptus (fetus, placenta, and fluids). The equations allow for estimations of conceptus weight and energy content at any given day of gestation; however, these equations should be used with caution as they were developed over 30 years ago from a population of 26 gilts (Large White breed) with a range in litter size of 9 to 14. Total born has increased significantly since those studies, now averaging over 14 pigs in some of the most prolific sow herds (Thomas et al., 2016). When applying these equations to sows with over 14 pig born alive, the predictions are unrealistically high. The NRC (2012) accounts for these changes in litter size by correcting for mean piglet birth weight, using the following ratio:

Ratio = (total born, n × average piglet birth weight, kg) / (1.12 × exp {[9.095 – 17.69 exp (-0.0305 × gestation length, d) + 0.0878 × total born, n]}/1000).

The numerator portion of the ratio is the actual litter birth weight and the denominator portion of the ratio, are derived from Dourmad et al. (1999) (except for the value 1.12), as the anticipated litter birth weight (fetus only, not including the weight of the placenta or fluids) based on anticipated gestation length (114 d) and litter size. It is unknown what the value 1.12 represents and details are not reported in the NRC (2012) nor are they found in the previous literature discussing the use of these equations (Noblet et al., 1985; Noblet et al., 1990; Dourmad et al., 1999). In the calculations generated in our study, weight of conceptus and energy content of conceptus on d 114 of gestation are corrected for mean piglet birth weight based on the above ratio, excluding the value 1.12:

$$\text{Ratio} = (\text{total born, n} \times \text{average piglet birth weight, kg}) / (\exp\{[9.095 - 17.69 \exp(-0.0305 \times 114) + 0.0878 \times \text{total born, n}]\}/1000).$$

In our study, it was not possible to collect pig birth weight. As a result, pig birth weight was estimated from an experiment by Goncalves et al. (2016). Goncalves et al. (2016) determined the effects of amino acid and energy intake during late gestation on pig birth weight of high performing (14.5 total born) females (Camborough®, PIC, Hendersonville, TN) housed under commercial conditions. Individual pig birth weights from a total of 1,102 females were used to develop a prediction equation with total born and parity group (1 or 2+) as predictor variables. The optimum equation to predict pig birth weight is described as:

$$\text{Pig birth weight (kg)} = b - 0.035 \times \text{total born, n}.$$

Where the intercept (b) for parities 1 and 2+ were 1.78 and 1.90, respectively.

The ratio can then be applied to the predicted weight of conceptus and the predicted energy content of conceptus on d 114 of gestation, providing a final conceptus weight and final conceptus energy content, correcting for litter birth weight, yielding more realistic predictions. Recall, daily predictions are required for modeling purposes for each of these variables and the ratio can only be used to determine weight and energy content of conceptus on d 114 of gestation because we only have known pig BW at farrowing. In an effort to determine weight and energy content of conceptus for each d of gestation, we reviewed the data from Noblet et al. (1985) where the NRC (2012) equation originated, and we determined the regression equation calculated for a litter size of 12. Next, we determined conceptus weight and energy content of conceptus from d 4 through 114 of gestation for a litter size of 12. We were then able to calculate the percent of final conceptus weight and percent of final energy content of conceptus for each d of gestation. Multiplying these percentages by final conceptus weight and final energy content of conceptus at d 114 of gestation generated a value for each d of gestation. Thus, the optimum equations used to predict weight and energy content of conceptus at each d of gestation are:

Weight of conceptus (kg/d) = Final conceptus weight at d 114 (kg) × % of final conceptus weight;

Energy content of conceptus on each day (kJ/d) = Final energy content of conceptus at d 14 (kJ) × % of final energy content of conceptus.

Where final conceptus weight and final energy content of conceptus are calculated using the NRC (2012) equations, correcting for mean piglet birth weight, on d 114 of gestation.
Energy retention of the conceptus (ERc, kJ) was determined by calculating the difference in energy content of conceptus between each day of gestation.

Following the gestation sow model proposed by Dourmad et al. (2008), ME for maintenance (MEm) under thermoneutral conditions and with moderate physical activity ranges from 400 to 460 kJ per kg BW0.75 (Noblet and Etienne, 1987b; Everts, 1994). Our estimations assume that temperature conditions were thermoneutral throughout the duration of this study and that females spent no more than 4 hours per day standing; however, neither temperature measurements nor female physical activity were not recorded during this study and therefore it is unknown if these factors impact our estimations for female maintenance requirement. The optimum equation used to predict female maintenance requirement per d of gestation is:

$$\text{MEm (kJ/d)} = 440 \times \text{BW}^{0.75}.$$

Nitrogen retention in the pregnant sow was estimated to determine maternal protein deposition. Nitrogen retention was calculated considering N retained in the conceptus (NRc) and N retained in maternal tissues which depends on parity, stage of gestation and the supple of ME above the maintenance requirement. Protein content of the conceptus was predicted using the following equation (Noblet et al., 1990, Dourmad et al., 2008) which can then be divided by 6.25, yielding N content of conceptus:

$$\text{Protein content of conceptus (g/d)} = (\exp (8.090 - 8.71 \times \exp (-0.0149 \times \text{gestation, d}) + 0.0872 \times \text{total born, n});$$

$$\text{Nitrogen content of conceptus (g/d)} = \text{Protein content of conceptus (g)} / 6.25.$$

Nitrogen retained in the conceptus (NRc) was determined by calculating the difference in daily N content of conceptus. Whole body N retention was calculated using the following equation (Dourmad et al., 1999; Dourmad et al., 2008), assuming protein and amino acid intake was not limiting:

$$\text{NR (g/d)} = 0.85 \times (\text{NRc} - 0.04 + 45.9 \times (\text{gestation, d}/100) - 105.3 \times (\text{gestation, d}/100)2 + 64.4 \times (\text{gestation, d}/100)3 + a \times (\text{ME} - \text{MEmm}) / 1000).$$

Where NRc = N retention in conceptus (g/joules), a = 0.571 in the first pregnancy and a = 0.366 for other parities, ME= kJ per day ME intake, and MEmm = maintenance requirement at d 5 of gestation.

The amount of energy available to be deposited as protein in maternal tissues (ERmp) was calculated from N retention (Dourmad et al., 2008):

$$\text{ERmp (kJ/d)} = 23.8 \times 6.25 \times (\text{NR} - \text{NRc}).$$

In this model, priority is given to satisfy energy requirements for body maintenance functions, growth of conceptus, and maternal body protein deposition, with the remaining nutrients available for lipid deposition (ERmf). If energy intake is insufficient to support maintenance requirements, growth of conceptus, and maternal body protein deposition, maternal body lipid is mobilized and used as a source of energy (Dourmad et al., 2008):

$$\text{ERmf (kJ/d)} = (\text{Intake, kJ/d} - (\text{MEm} + \text{ERc} / \text{kc} + \text{ERmp} / \text{kp})) \times \text{kf}.$$

Where kc, kp, and kf are the efficiencies of ME for uterine growth, protein deposition and fat deposition. Efficiencies of 0.50, 0.60, and 0.80 were used for kc, kp, and kf in this study as reported by Dourmad et al. (2008). The efficiency of utilization of ME has been evaluated in previous research with estimates for maternal gain between 70 to 85% (Close et al., 1985; Noblet and Etienne, 1987b; Everts and Dekker, 1994). In the case of energy mobilization from body reserves (lipid mobilization) to provide energy, the efficiency is the same as fat, 0.80 (kr; Noblet et al., 1990).

The energy available for maternal tissue deposition was determined by combining the energy available for protein and lipid deposition. This was then converted from kJ to kcal to kg, assuming the kcal per kg ME provided in the diet was 3,225 kcal per kg, and later used to determine maternal feed efficiency:

$$\text{Energy available for maternal deposition (kg/d)} = ((\text{ERmp} + \text{ERmf}) / 4.184) / (\text{kcal/kg ME}).$$

If the female did not eat or did not consume enough and energy intake was insufficient to support maintenance requirements, growth of the conceptus, and maternal protein deposition, the energy available for maternal deposition will be negative. This indicates that the female is in a negative energy balance and is mobilizing maternal lipids to meet maintenance requirements, energy required by the conceptus, and maternal protein deposition.

Finally, protein and lipid deposition were determined in terms of female BW (Dourmad et al., 2008):

Maternal protein deposition (g/d) = (ERmp / 23.8);

Maternal lipid deposition (g/d) = (ERmf / 39.7).

Total maternal protein and maternal lipid deposition were predicted by calculating the sum of each, for each individual sow.

Maternal BW gain per d of gestation was determined by subtracting the weight of conceptus (fetus, placenta, and fluids), correcting for mean piglet birth weight, from the average weight recorded per d of gestation. Maternal BW gain from d 5 to 112 of gestation, respectively, was determined using the following equation:

Maternal BW gain, kg = (final BW, kg – initial BW, kg) – final weight of conceptus, kg.

When calculating maternal BW gain, the d of gestation for the final BW and weight of conceptus were the same. Meaning, if a female was moved to farrowing on d 111 of gestation, the final BW would be from d 111 of gestation and the corresponding weight of conceptus would also be from d 111 of gestation.

Maternal ADG was defined as the difference in daily maternal BW. Maternal feed efficiency is reported as G:F and was determined using the following equation:

G:F = Maternal ADG, kg / energy available for maternal deposition, kg.

Data from this study was divided into 3 parity groups (1, 2, and 3+) and gestation was divided into 3 periods (indicating the average d within each period): d 5 to 39 (22), 40 to 74 (56), and 75 to 109 (92). Averages for each period were reported for all predictions with the exception of G:F, where the median for each period was reported.

Statistical Analysis

Prior to data analysis, descriptive statistics in the form of means, histograms and scatterplots were generated using the PROC MEANS, PROC GPLOT, and PROC SGPLOT statements in SAS (Version 9.4, SAS Institute Inc., Cary, NC). Extreme observations were found for female ADG, using descriptive statistics, generated from the variability between daily BW collection. Observations were deemed as outliers based on a calculated critical t-score using a Bonferroni adjustment (0.05 / number of observations). This indicated that observations ± 4.97 standard deviations from the mean were considered outliers and were removed from the data set.

PROC MIXED in SAS was used to develop the pig birth weight. The statistical significance for inclusion of terms in the model was determined at $P < 0.05$. Further evaluation of models with significant terms was then conducted based on the Bayesian Information Criterion (BIC). A model comparison with a reduction in BIC of more than 2 was considered improved. The fixed effects evaluated were total born and parity group (1 and 2+) and the random effect evaluated was wk. There was no total born by parity group interaction or quadratic response of total born, thus these terms were removed from the model. The final model for the piglet birth weight prediction equation contained parity and total born as input variables.

Weight of conceptus, female maintenance requirement, energy retention of conceptus, energy available for maternal protein deposition, protein deposition, energy available for maternal lipid deposition, lipid deposition, energy available for maternal deposition, maternal BW, ADG, and G:F were analyzed using generalized linear mixed models whereby the linear predictor included parity group, period of gestation and all interactions as fixed effects, as well as the random effects of period nested within individual sow. So, specified- models recognized the individual female as the experimental unit for this study. Response variables were fitted assuming a normal distribution. The final models used for inference were fitted using restricted maximum likelihood estimation. Degrees of freedom were estimated using the Kenward-Rogers approach.

Estimated means and corresponding standard errors (SEM) are reported for all cell means. Pairwise comparisons were conducted on such means using either Tukey or Bonferroni adjustment to prevent inflation of Type I error due to multiple comparisons. Statistical models were fitted using the GLIMMIX procedure of SAS. Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results and Discussion

Descriptive Statistics

Descriptive statistics for predicted data is presented in Table 4.1. The average predicted pig birth weight was 1.3 kg ± 0.13 (mean ± SD) with a range of 1.0 to 1.9 kg. Our calculations are similar to Quiniou (2014) whom reported an average pig birth weight of 1.38 kg for sows farrowing an average of 13.8 pigs per litter. Average final conceptus weight was predicted to be 29.9 kg ± 6.49 with a range from 2.0 to 50.5 kg. Previous research estimates the weight of conceptus calculated for 110 d of pregnancy and a litter size of 12 to be approximately 20 kg (Verstegen et al., 1987; Noblet et al. 1990). We expect our predictions of conceptus weight to be greater than 20 kg because the average total born from this herd is greater than 12 and the d of gestation in which weight of conceptus is reported is greater than d 110 of gestation. Thus, as litter size and gestation length increase, we expect conceptus weight to increase.

Average maternal BW gain was predicted to be 27.2 kg ± 15.51 with a range from -14.2 to 83.1 kg. Previous research suggests maternal weight gain is highly dependent on gestation feeding level and on the composition and the amount of previous lactation weight loss (Dourmad et al., 1999). Maternal weight gain is recommended to be between 20 to 25 kg of which 15 kg may be for development to mature BW, which is not achieved until the 4th or 5th parity (Verstegen et al., 1987; Noblet et al. 1990). Dourmad et al. (1996) investigated the effects of energy intake in gestation on changes in BW of multiparous sows reporting maternal weight gains of 25.6, 46.8 and 59.2 kg for low-, medium-, and high-energy diets. Diets fed in this study are comparable to the low and medium energy diets and therefore we expect maternal weight gains between 25.6 and 46.8 kg.

Predicted total lipid deposition averaged 7.3 kg ± 4.46 and ranged from -3.6 to 31.1 kg. This indicates in some females, feeding level exceeded body maintenance requirements, the demands of the conceptus, and protein deposition in the maternal body with the remaining energy deposited as lipid. In some cases, the opposite occurred and energy intake was insufficient to support all requirements and as a result, maternal body lipid was mobilized and used as a source of energy. Total protein deposition averaged 4.0 kg ± 0.58 and ranged from 2.6 to 5.9 kg.

Predicted Weight of Conceptus

Regardless of parity, conceptus weight increased ($P < 0.05$) in each subsequent period of gestation (Table 4.2). Differences between conceptus weight among parities started between d 40 to 74 of gestation and continued into the final period of gestation with parity 3+ sows having the greatest ($P < 0.05$) conceptus weight and parity 1 sows having the lowest.

Recall, weight of conceptus is represented as a function of litter size, mean pig birth weight, and d of gestation. Fetal development is very low in early gestation, with nearly 60% of fetal growth occurring during the last 45 d of gestation (Noblet et al., 1990; Dourmad et al., 1999; Trottier and Johnston, 2001; Figure 4.1). Conceptus weight is comprised of the fetus, placenta, and fluids. The differences between parities for conceptus weights is likely attributed to differences in litter size and consequently, litter weight. Average total born for parity 1, 2 and 3+ sows in this study as 14.8, 14.2, and 15.5 (Thomas et al., 2016). The average corresponding litter weights predicted in this study for parity 1, 2 and 3+ sows were 18.1 kg ± 2.50, 19.6 kg ± 3.24, and 20.74 kg ± 2.71. Research from Smit et al. (2014) indicated conceptus weight will increase as litter size increases not only due to fetal weight but due to an increase in placenta weight. Parity 3+ sows have the greatest total born and litter weight, thus it is logical that conceptus weight is also greatest in comparison to other parity groups. Thomas et al. (2016) reported no evidence for differences between total born in parity groups 1 and 2; however, predicted litter birth weight is greater in parity 2 sows compared to parity 1 sows. Recall, the prediction equation used to estimate litter birth weight included two intercepts, one for parity 1 sows and another for parity 2+ sows, which is likely attributing to this discrepancy in litter birth weight and total born. In addition, difference in fetal and placenta weights may be causing these differences.

Predicted Maintenance Requirement

Regardless of parity, maintenance requirements increased ($P < 0.05$) in each sequential period of gestation (Table 4.2). Regardless of period of gestation, parity 3+ sows had the greatest ($P < 0.05$) maintenance requirement compared to parity 2 and 1 sows. The maintenance requirement for parity 2 sows was greater ($P < 0.05$) than parity 1 sows from d 5 to 74; however, from d 74 to 109 of gestation, parity 1 sows had a greater ($P < 0.05$) maintenance requirement.

Female maintenance requirement represents the amount of dietary energy and essential nutrients required to maintain BW and composition (de Lange et al., 2000). In this study, nutrient requirements for maintenance were determined based on sow BW. Older, heavier sows have increased nutrient needs and require more feed to maintain their body than younger, lighter sows. Thomas et al. (2016) reported parity 1 sows used in this study had greater BW following d 74 of gestation compared to parity 2 sows. This is reflective in sow maintenance requirements following d 74 of gestation when parity 1 sow requirements were greater than parity 2 sows (Figure 4.2).

Predicted Energy Retention of the Conceptus

Regardless of parity, energy retention of the conceptus increased ($P < 0.05$) in each sequential period of gestation (Table 4.2). There was no evidence for differences among parity groups until d 40 of gestation at which time parity 3+ sows had the greatest ($P < 0.05$) energy retention of the conceptus. From d 74 to 109 of gestation, energy retention of the conceptus was greatest ($P < 0.05$) for parity 3+ sows, followed by parity 2 and 1 sows (Figure 4.3).

Similar to weight of conceptus, energy retention of the conceptus is determined as a function of litter size, mean birth weight, and d of gestation. Sows from this study were offered energy intakes ranging from 6.5 to 9.8 Mcal ME daily which is within the range proposed by Noblet et al. (1990) for adequate energy intake to meet the demands of the conceptus. Previous research indicates that the growth of the products of conceptus and the associated nutrients needed for that growth are fairly resistant to nutritional manipulations with changes in fetal weight being very small if any (Noblet et al., 1985; Noblet et al.,1990; Dourmad et al., 1996). Only in cases of extreme reductions in nutrient intake in which 12% of backfat loss occurs will the performance of the offspring be affected.

Predicted Energy Used for Maternal Protein Deposition

Regardless of parity group, the predicted energy used for maternal protein deposition decreased ($P < 0.05$) in each subsequent period of gestation (Table 4.2). Regardless of period of gestation, parity 1 sows had the greatest ($P < 0.05$) energy use for maternal protein deposition followed by parity 2 and 3+ sows. Due to the method of calculation, conclusions for predictions for maternal protein deposition into maternal tissue are the same as those reported for energy used for protein deposition (Table 4.2).

As previously elucidated, the distribution of nutrients is not constant throughout gestation (Ji et al., 2005; Moehn and Ball, 2013). Nitrogen retention in early gestation is mainly of maternal origin because retention in the products of conceptus amounts to only a very small amount, but in mid to late gestation, the metabolic focus shifts to fetal growth which advances at a very rapid rate (Dourmad et al., 1996; McPherson et al., 2004; Dourmad et al., 2008). This explains the reduction in energy available for maternal protein deposition (Figure 4.4), and subsequently maternal protein deposition (Figure 4.5) through gestation and the increase observed in the energy retention of the conceptus.

Previous literature indicates that for a given energy supply, higher protein retention is generally greater in gilts than in multiparous sows which may be partly explained by the low energy requirement for maintenances in relation with their lower BW (Dourmad et al., 1999). In our study, parity 1 sows (gilts) had increased maternal protein deposition throughout gestation in comparison to multiparous sows despite being fed less than multiparous sows. Thomas et al. (2016) observed that from d 5 to 60 of gestation, parity 1 sows used in this study were lighter in comparison to parity 2 and 3+ sows, but thereafter, parity 1 sow BW was greater than parity 2+ sows. This difference may be attributed to the method used to predict whole body N retention where coefficients were different for parity 1 and 2+ sows (0.571 vs. 0.366) as a result of parity 1 sows being more efficient at protein deposition in comparison to older parity sows.

Predicted Energy Used for Maternal Lipid Deposition

Regardless of parity, the amount of energy used for maternal lipid deposition decreased ($P < 0.05$) in each subsequent period of gestation (Table 4.2). Parity 2 sows had the greatest ($P < 0.05$) energy available for maternal lipid deposition in each period of gestation, followed by parity 3+ and 1 sows. Due to the method of calculation, conclusions for predictions for maternal lipid deposition into maternal tissue are the same as those reported for energy used for lipid deposition (Table 4.2).

The decrease in energy available for maternal lipid deposition (Figure 4.6), and the subsequent amount of maternal lipid deposition (Figure 4.7), as pregnancy increases may be attributed to the reduction in ME per unit metabolic body weight as females from this production system were offered the same allowance of feed throughout the course of gestation. In parity 1 sows during late pregnancy (d 75 to 109 of gestation), feed intake was insufficient to prevent mobilization of body fat and maternal lipid reserves was reduced by 26 g/d.

After dividing energy requirements into tissue pools for maintenance, growth (maternal protein and fat deposition), and products of conceptus (fetal, placenta, and fluids), it is clear that the greatest portion of the energy requirement is for maintenance and maternal growth (Figures 8, 9, and 10). Each tissue pool is affected by differences throughout gestation and parity group as described above.

Predicted Maternal Growth and Feed Efficiency

Regardless of parity group, the energy used for maternal protein and lipid deposition decreased ($P < 0.05$) in each subsequent period of gestation (Table 4.3). This reduction in energy used for maternal protein and lipid deposition as the female progresses through gestation can be attributed to increasing maintenance requirements and demands of the conceptus. Parity 2 sows had the greatest ($P < 0.05$) energy available for maternal protein and lipid deposition, regardless of period, followed by parity 3+ and 1 sows which can be attributed to feed intake levels.

Maternal BW increased ($P < 0.05$) in each sequential period of gestation for parity 1 sows (Table 4.3). In parity 2 and 3+ sows, maternal BW increased ($P < 0.05$) from d 39 to 74 of gestation; however, there was no evidence ($P > 0.05$) for differences in maternal BW from d 75 to 109 of gestation. Maternal BW was greatest ($P < 0.05$) for parity 3+ sows. From d 5 to 39 of gestation, parity 2 sow maternal BW was greater ($P < 0.05$) than parity 1 sows with no evidence for differences between the two parity groups from d 40 to 74 of gestation. From d 75 to 109 of gestation, parity 1 sow maternal BW was greater ($P < 0.05$) compared to parity 2 sows.

Regardless of parity group, maternal ADG decreased ($P < 0.05$) in the period from d 39 to 74 of gestation and increased ($P < 0.05$) from d 74 to 109 of gestation (Table 4.3). Maternal ADG was greater ($P < 0.05$) for parity 1 sows compared with parity 2 or 3+ sows in all gestation periods. Parity 2 sow maternal ADG was greater ($P < 0.05$) than parity 3+ sows from d 5 to 74 of gestation.

In early to mid-gestation, nutrients are used primarily to support maternal growth. Following d 70 of gestation the metabolic focus shifts to the growing demands of the conceptus (McPherson et al., 2004, Ji et al., 2006). Our findings are similar but maternal ADG starts to decrease before d 70 of gestation. For parity 1 sows, maternal ADG was highest in early gestation and decreased following d 39 of gestation. Regardless of parity, maternal ADG increases in late gestation, when we would expect the rates of maternal deposition to be the lowest as fetal growth is greatest during this time. We hypothesize that mammary gland development may have resulted in this increase in maternal ADG from d 74 to 109 of gestation. Maternal ADG in parity 1 sows was greater than parity 2 and 3+ sows in all phases of gestation, but ADG of parity 2 sows was only greater than parity 3+ sows from d 5 to 74 of gestation.

In parity 1 sows, maternal G:F is reduced ($P < 0.05$) in each subsequent period of gestation, resulting in a negative value from d 75 to 109 of gestation (Table 4.3). Parity 1 sow maternal G:F is greater ($P < 0.05$) than parity 2 and 3+ sows from d 5 to 74 of gestation but lowest ($P < 0.05$) from d 75 to 109 of gestation. Parity 2 and 3+ sows' maternal G:F is reduced ($P < 0.05$) from d 39 to 74 of gestation but improves ($P < 0.05$) from d 74 to 109 . Parity 2 sow maternal G:F is greater ($P < 0.05$) than parity 3+ sows from d 75 to 109 of gestation. To our knowledge, G:F in sows in gestation has not been previously reported.

Conclusion

From the existing data, it is apparent that sow gestation nutrient requirements are affected largely by requirements of the sow for maintenance and maternal protein and lipid deposition, each of which is heavily influenced by parity and stage of gestation. Through the partitioning of each of these tissue pools, predictions indicate that even though parity 1 sows are in a negative energy balance late in pregnancy, maternal ADG and G:F are greater in most gestation periods compared with parity 2 and 3+ sows. Further research is needed to investigate these differences and if there is an impact on subsequent performance.

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Table 4.1 Descriptive statistics for predicted data[1]

Item	Mean	SD	Minimum	Maximum
Piglet birth weight, kg[2]	1.3	0.13	1.0	1.9
Litter birth weight, kg[3]	19.5	3.00	1.9	25.6
Final weight of conceptus, kg[4]	29.9	6.49	2.0	50.5
Maternal weight gain, kg[5]	27.2	15.51	-14.2	83.1
Total lipid deposition, kg[6]	7.3	4.46	-3.6	31.1
Total protein deposition, kg[7]	4.0	0.58	2.6	5.9

[1]Values from a total of 712 females (Camborough®, PIC, Hendersonville, TN) were used to predict the above variables with the exception prediction method 2, where a total of 692 females were used.

[2]Piglet birth weight (kg) = b – 0.035 × total born, n, where b for parities 1 and 2+ were 1.78 and 1.90.

[3]Litter birth weight (kg) = piglet birth weight kg × total born, n.

[4]Final weight of conceptus (d 114), kg = (((exp (8.621 - 21.02 × exp (-0.053 × gestation, d) + 0.114 × total born, n))/1,000) × (total born, n × average piglet birth weight, kg) / (exp {[9.095 – 17.69 exp (-0.0305 × 114) + 0.0878 × total born, n]}/1000)).

[5]Maternal weight gain, kg = (final gestation BW, kg – initial gestation BW, kg) – final weight of conceptus, kg.

[6]Total lipid deposition, kg = Sum of lipid deposition for each sow given by, (ERmf/ 39.7)/1000.

[7]Total protein deposition, kg = Sum of protein deposition for each sow given by, (ERmp/23.8)/1000.

Table 4.2 Predicted model parameters based on parity and stage of gestation[1,2,3]

	Day of gestation, d			
	5 to 39	40 to 74	75 to 109	Probability, *P* <
Weight of conceptus, kg[4]				
Parity 1	0.359[a] ± 0.217	10.546[bx] ± 0.217	24.327[cx] ± 0.217	<0.001
Parity 2	0.387[a] ± 0.250	11.244[bx] ± 0.250	25.899[cy] ± 0.250	<0.001
Parity 3+	0.420[a] ± 0.206	12.263[by] ± 0.206	28.305[cz] ± 0.206	<0.001
Maintenance requirement, kcal[5]				
Parity 1	4,620[ax] ± 20.0	5,114[bx] ± 20.0	5,640[cx] ± 20.0	<0.001
Parity 2	4,859[ay] ± 23.0	5,194[by] ± 23.0	5,563[cy] ± 23.0	<0.001
Parity 3+	5,387[az] ± 19.0	5,702[bz] ± 19.0	6,076[cz] ± 19.0	<0.001
Energy retention of conceptus, kcal[6]				
Parity 1	20.54[a] ± 2.157	122.90[bx]± 2.157	328.34[cx] ±2.157	<0.001
Parity 2	22.36[a] ± 2.482	132.40[by] ± 2.482	352.94[cy] ± 2.482	<0.001
Parity 3+	23.67[a] ± 2.052	140.99[bz] ± 2.052	376.80[cz] ± 2.052	<0.001
Energy used for maternal protein deposition, kcal[7]				
Parity 1	275[ax] ± 1.64	229[bx] ± 1.64	210[cx] ±1.64	<0.001
Parity 2	258[ay] ± 1.89	211[by] ± 1.89	190[cy] ± 1.89	<0.001
Parity 3+	228[az] ± 1.56	186[bz] ± 1.56	163[cz] ± 1.56	<0.001
Maternal protein deposition, g[8]				
Parity 1	48[ax] ± 0.29	40[bx] ± 0.29	37[cx] ± 0.29	<0.001
Parity 2	45[ay] ± 0.33	37[by] ± 0.33	33[cy] ± 0.33	<0.001
Parity 3+	40[az] ± 0.27	33[bz] ± 0.27	29[cz] ± 0.27	<0.001
Energy used for maternal lipid deposition, kcal[9]				
Parity 1	928[ax] ± 20.17	463[bx] ± 20.17	-244[cx] ± 20.17	<0.001
Parity 2	1,510[ay] ± 23.22	1,170[by] ± 23.22	531[cy] ± 23.22	<0.001
Parity 3+	1,070[az] ± 19.19	830[bz] ± 19.19	171[cz] ± 19.19	<0.001
Maternal lipid deposition, g[10]				
Parity 1	98[ay] ± 2.13	49[bx] ± 2.13	-26[cx] ± 2.13	<0.001
Parity 2	159[ax] ± 2.45	123[by] ± 2.45	56[ay] ± 2.45	<0.001
Parity 3+	113[az] ± 2.02	87[by] ± 2.02	18[cx] ± 2.02	<0.001

[1]A total of 712 females (Camborough®, PIC, Hendersonville, TN) were used in a 108-d trial with 249, 188, and 275 females in parity groups 1, 2, and 3+.
[2]Values with different superscripts within a row[abcde] or column[xyz] differ, *P*<0.05.
[3]The mean, per period of gestation, for each variable is reported.

Table 4.3 Maternal growth and feed efficiency of gestating sows as influenced by parity and stage of gestation[1,2]

	Day of gestation, d			
	5 to 39	40 to 74	75 to 109	Probability, *P* <
Energy available for maternal protein and lipid deposition, kcal[3]				
Parity 1	$1{,}203^{ax} \pm 21.7$	$692^{bx} \pm 21.7$	$-35^{cx} \pm 21.7$	<0.001
Parity 2	$1{,}767^{ay} \pm 24.9$	$1{,}380^{by} \pm 24.9$	$721^{cy} \pm 24.9$	<0.001
Parity 3+	$1{,}298^{az} \pm 20.6$	$1{,}016^{bz} \pm 20.6$	$334^{cz} \pm 20.6$	<0.001
BW, kg[3]				
Parity 1	$154.8^{ax} \pm 0.94$	$167.1^{bx} \pm 0.94$	$178.1^{cx} \pm 0.94$	<0.001
Parity 2	$165.5^{ay} \pm 1.09$	$170.1^{bx} \pm 1.09$	$172.8^{by} \pm 1.09$	<0.001
Parity 3+	$190.0^{az} \pm 0.90$	$193.2^{bz} \pm 0.90$	$195.3^{bz} \pm 0.90$	<0.001
ADG, kg[3]				
Parity 1	$0.47^{ax} \pm 0.011$	$0.27^{bx} \pm 0.011$	$0.41^{cx} \pm 0.011$	<0.001
Parity 2	$0.32^{ay} \pm 0.013$	$0.04^{by} \pm 0.013$	$0.15^{cy} \pm 0.013$	<0.001
Parity 3+	$0.23^{az} \pm 0.011$	$-0.04^{bz} \pm 0.011$	$0.34^{cz} \pm 0.011$	<0.001
G:F[4]				
Parity 1	$1.29^{ax} \pm 0.110$	$0.67^{bx} \pm 0.110$	$-1.24^{cx} \pm 0.110$	<0.001
Parity 2	$0.67^{ay} \pm 0.127$	$-0.04^{by} \pm 0.127$	$1.13^{cy} \pm 0.127$	<0.001
Parity 3+	$0.88^{ay} \pm 0.105$	$-0.34^{by} \pm 0.105$	$0.17^{cz} \pm 0.105$	<0.001

[1]A total of 712 females (Camborough®, PIC, Hendersonville, TN) were used in a 108-d trial with 249, 188, and 275 females in parity groups 1, 2, and 3+.
[2]Values with different superscripts within a row^{abcde} or column^{xyz} differ, $P<0.05$.
[3]Values represent the mean, per period of gestation.
[4]Values represent the median per period of gestation.

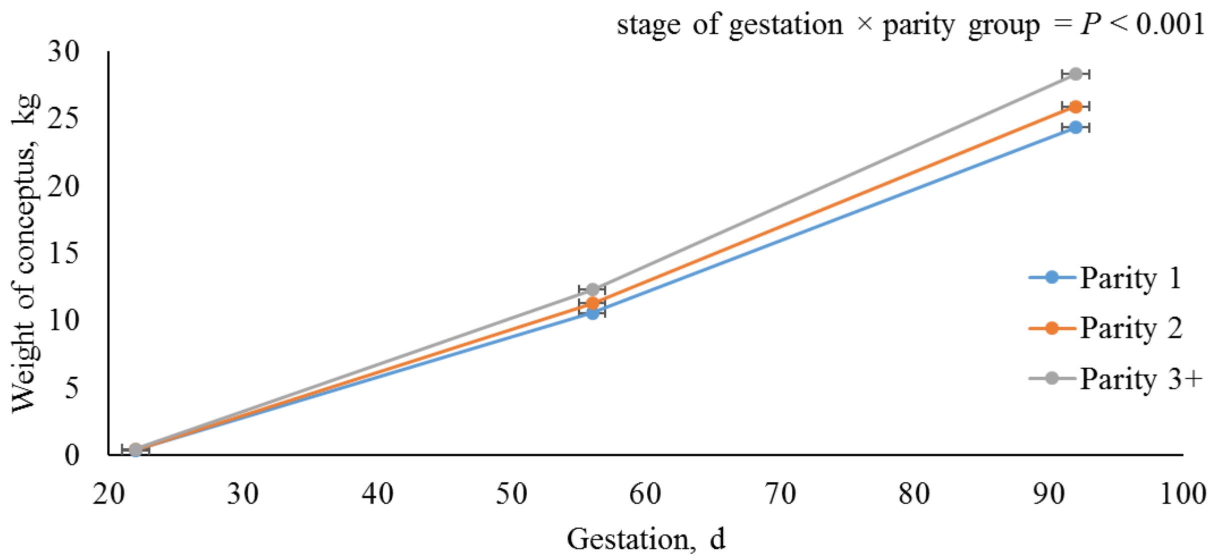

Figure 4.1 Predicted weight of conceptus from d 5 to 112 of gestation for parity 1, 2 and 3+ sows.

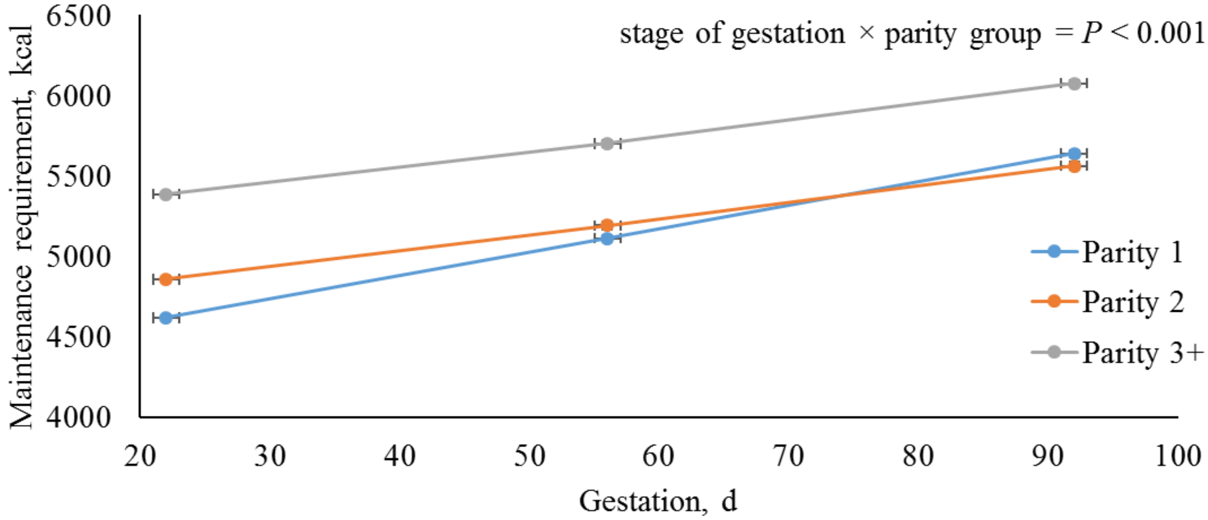

Figure 4.2 Predicted maintenance requirement from d 5 to 112 of gestation for parity 1, 2 and 3+ sows.

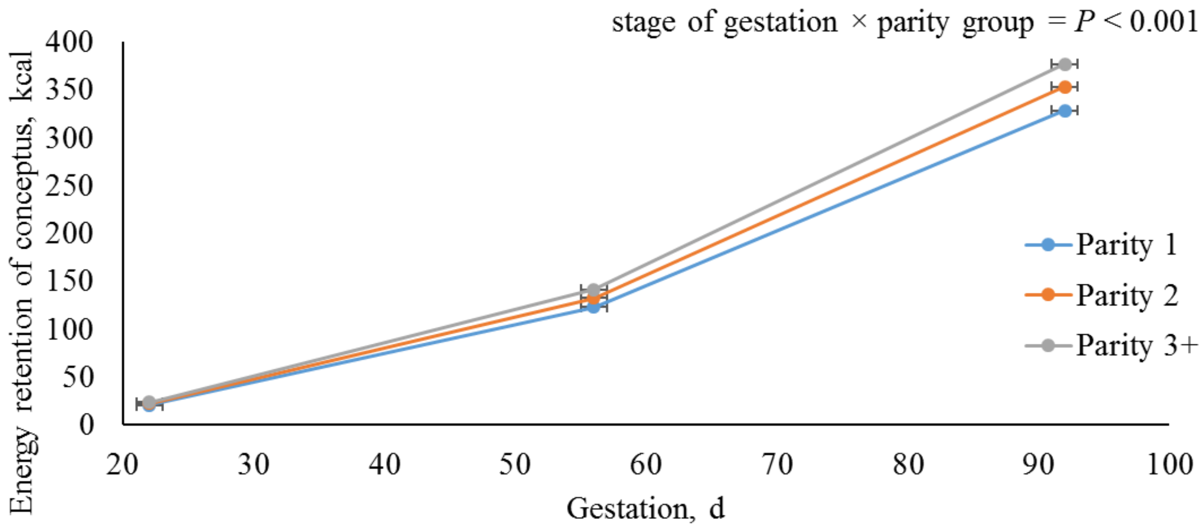

Figure 4.3 Predicted energy retention of conceptus from d 5 to 112 of gestation for parity 1, 2 and 3+ sows.

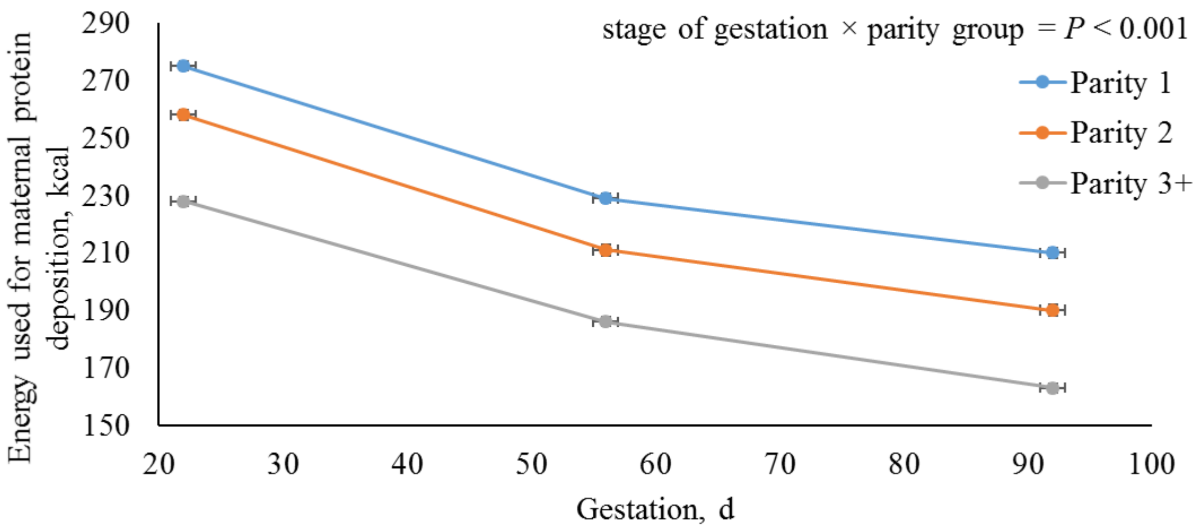

Figure 4.4 Predicted energy used for maternal protein deposition from d 5 to 112 of gestation for parity 1, 2 and 3+ sows.

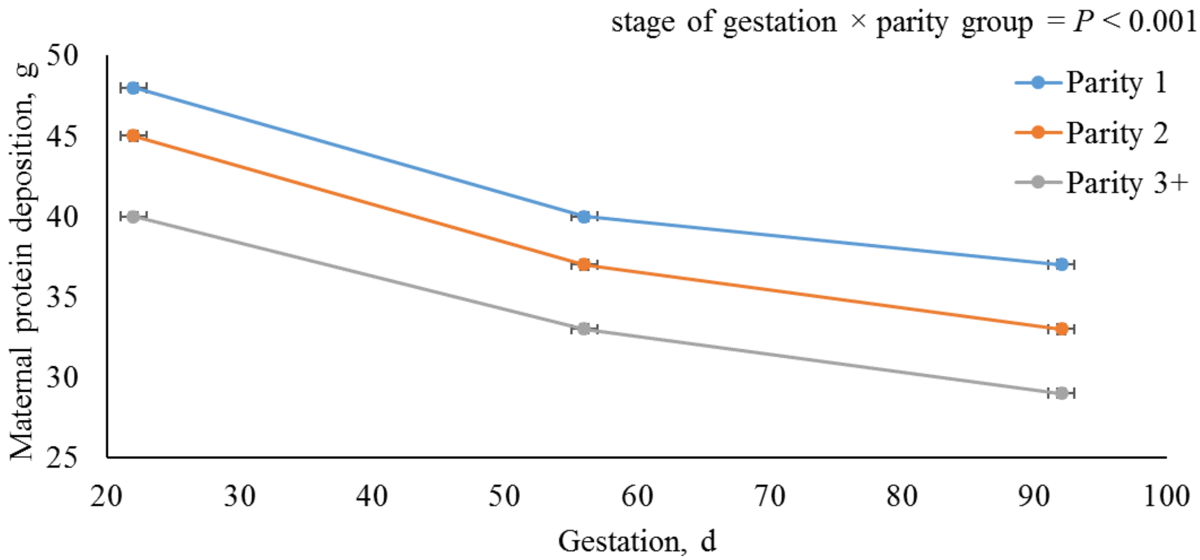

Figure 4.5 Predicted maternal protein deposition from d 5 to 112 of gestation for parity 1, 2 and 3+ sows.

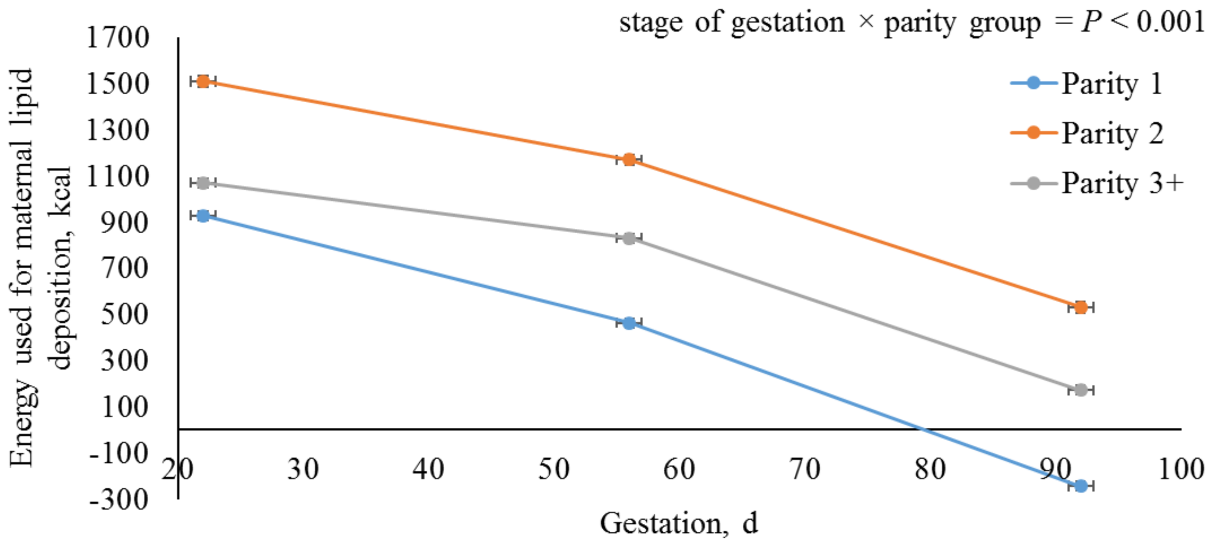

Figure 4.6 Predicted energy used for maternal lipid deposition from d 5 to 112 of gestation for parity 1, 2 and 3+ sows.

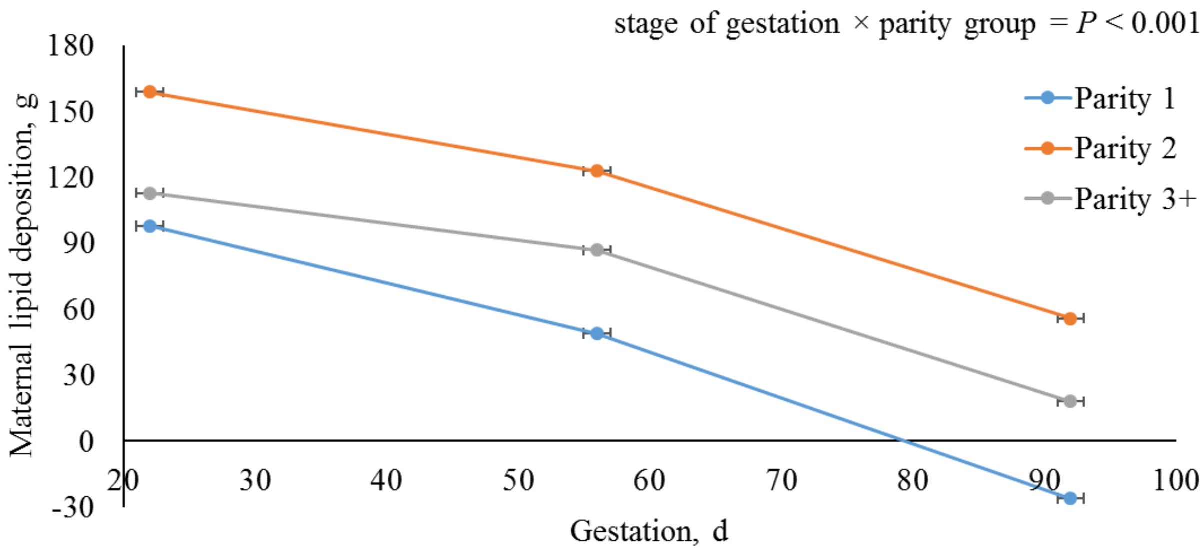

Figure 4.7 Predicted maternal lipid deposition from d 5 to 112 of gestation for parity 1, 2 and 3+ sows.

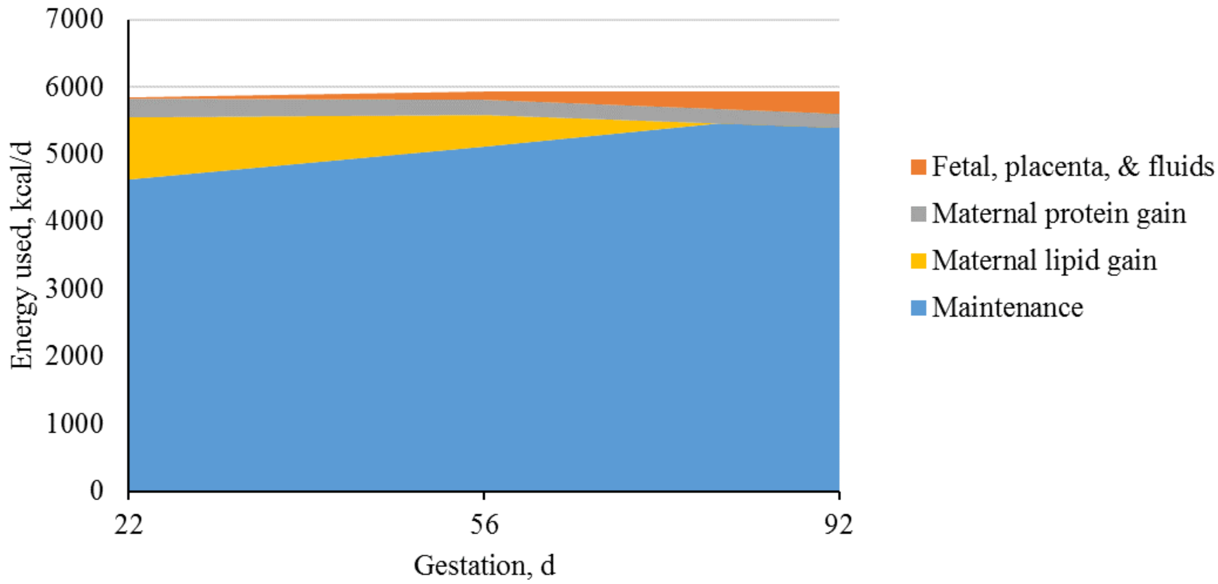

Figure 4.8 Predicted energy needs of parity 1 sows (kcal/d) during gestation based on different body tissues.

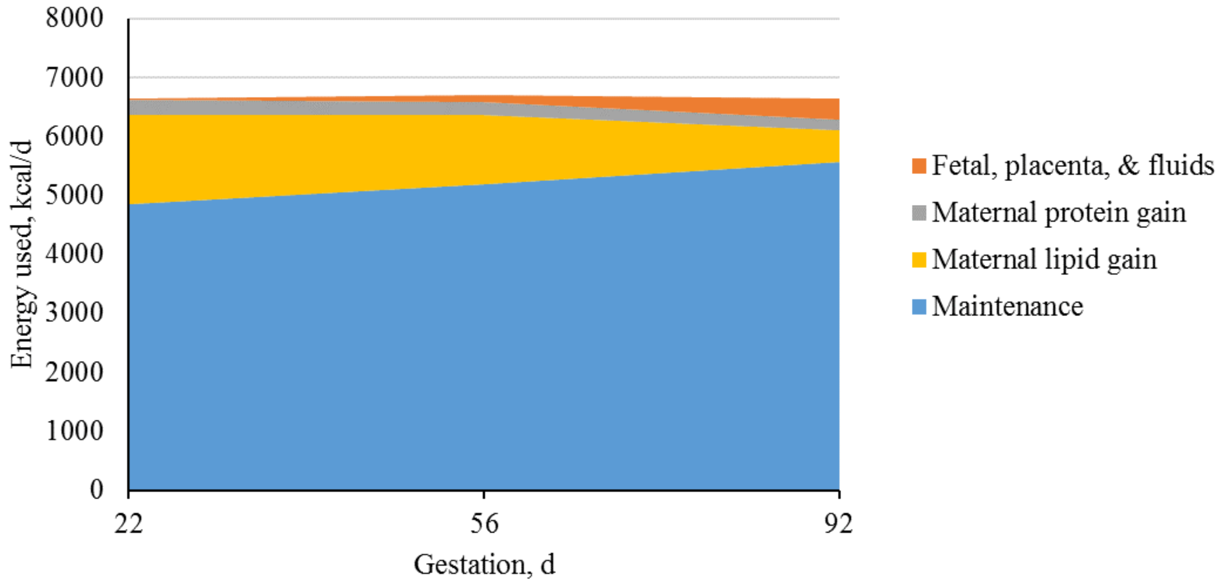

Figure 4.9 Predicted energy needs of parity 2 sows (kcal/d) during gestation based on different body tissues.

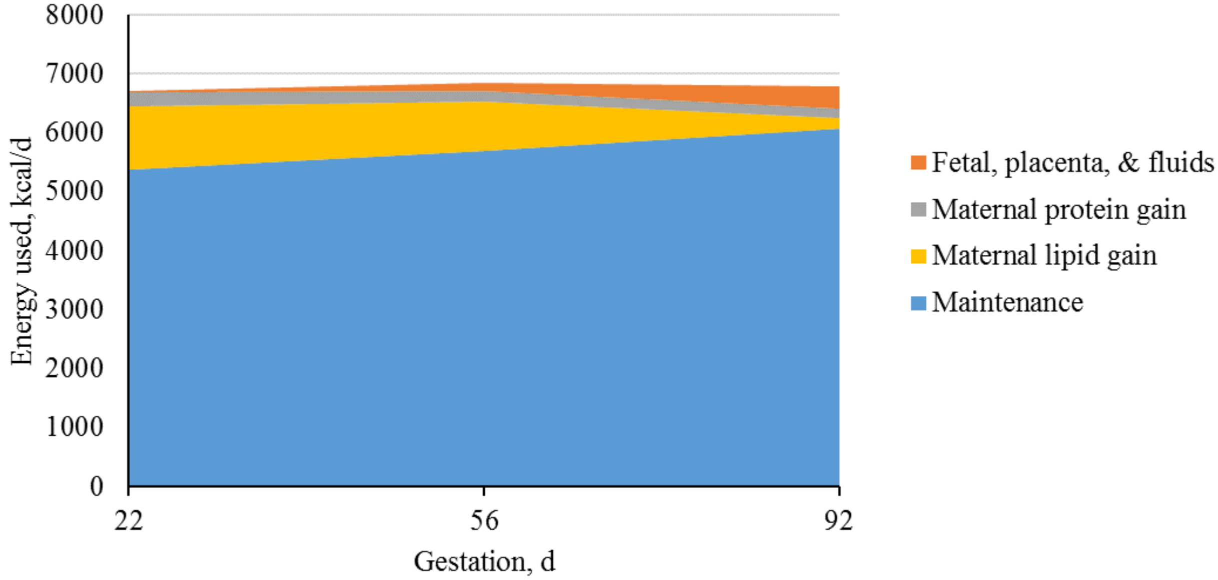

Figure 4.10 Predicted energy needs of parity 3+ sows (kcal/d) during gestation based on different body tissues.