Regression Analysis to Predict Growth Performance from Dietary Net Energy in Growing-Finishing Pigs

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Summary

Energy concentration in livestock feed is often altered to optimize pig growth performance and feed cost; therefore, an accurate prediction of growth performance as affected by feeding different energy levels is crucial. Data from 41 trials from 17 journal articles, 10 technical memos, and a thesis were used to develop a regression equation to predict ADG or gain to feed (G:F) as influenced by BW and NE content. Linear and quadratic terms of NE, average BW, CP, standardized ileal digestible [SID] lysine, crude fiber, NDF, ADF, fat, and ash, including their interaction terms, were the variables in the regression analysis. Our regression analysis showed that improvements in growth rate and feed efficiency could be obtained by increasing dietary NE across a wide variety of trials with different dietary ingredients and under different environmental conditions, but the magnitude of improvement in growth performances by dietary NE can be minimized if the amino acids are limiting. Regression equations from this paper can be used to predict the influence of dietary NE on ADG and G:F; however, these equations still need validation from growth studies not included in their development.

Key words: growth performance, finishing pig, net energy, regression

Introduction

Dietary energy components represent the greatest portion of the feed cost and over half the total cost in swine production. Increased energy levels in diets have been shown to improve growth performance but simultaneously increase feed costs. Given the increased price of traditional dietary energy sources, the swine industry has shifted to using more high-fiber, low-energy diets to reduce feed costs, but feeding lower energy diets decreases growth performance. Therefore, the prediction of growth performance is essential to quantify the effect of dietary energy.

Digestible (DE) and metabolizable energy (ME) are the most commonly used energy systems in swine industry, but these energy values do not account for the varying metabolic utilization and production of heat increments between nutrients. The energy value of feed with a high content of fiber or protein is overestimated, whereas the energy of fat or starch is underestimated (Noblet, 2007[2]). For this reason, NE should be the most accurate system to evaluate the effect of dietary energy on growth performance, but NE is difficult to measure, and few estimates of NE are available for many by-product ingredients. Therefore, the purpose of this study was to obtain a regression equation

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[2] Noblet, J. 2007. Recent developments in net energy research for swine. Advances in Pork Production 18:149.

to predict growth rate and feed efficiency of growing-finishing pigs based on dietary NE content using meta-analysis.

Procedures

A literature search was conducted via Kansas State University Libraries using the internet and the CABI search engine including data from theses, technical memos, and university publications using the key words "energy and growth and pig" or "fiber and growth and pig." The search was restricted to dates from 1991 through November 2012. All publications were initially screened by determining that the research was conducted on growing-finishing pigs (>20 kg BW) and provided growth performance responses. Screening left 36 publications providing 50 trials.

Selection for inclusion and exclusion criteria

For inclusion, treatment diets in the trials had to vary in dietary DE, ME, or NE. Other criteria included: pigs used in the trial had to have ad libitum access to feed and water, treatments had to be replicated (>4 replications /treatment), and the experimental design had to include randomization (completely randomized design, CRD, or randomized complete block design, RCBD). The number of pigs per pen was also investigated, and the trial that used only 1 pig per pen was excluded. The ingredients and inclusion rates used in each dietary treatment had to be clearly stated such that diets could be re-created. All diets were then reformulated using the NRC ingredient library (chapter 17, NRC 2012[3]) as a reference for nutrients. The trial had to have ingredients that were listed in NRC (2012) ingredient library. Trials using ractopamine HCl were not considered. After excluding trials using these criteria, 41 trials were extracted from 17 journal articles, 10 technical memos, and a thesis.

Data from each trial were then recorded in a template; the template included the mean ADG and G:F for each treatment in each feeding period. If the report did not provide responses in each period, the overall mean was recorded. Average BW of each treatment was also extracted by averaging the initial and final BW of each period. Days on feed of each period were included in the template and used to calculate final BW of pigs fed each treatment from ADG and initial BW when the report omitted the periodic BW range. Other information included during the data extraction process was number of pigs per pen, replications, gender, genetic background, type of study (CRD or RCBD), dietary treatment, basic diet information (corn, soybean meal, wheat, barley, oats, wheat middlings, wheat bran), and type of report (journal article, technical memo, thesis).

Diet composition calculations

Dietary treatment of each trial was reformulated using a spreadsheet-based software program (Kansas State University Diet Formulation Program V.7.1) to obtain dietary nutrient content. Dietary nutrient content was derived from accumulating the nutrient of each ingredient according to its proportion in the diet. The NRC ingredient library (chapter 17, NRC, 2012) was used as a reference for nutrient ingredients in diet reformulation. The dietary NE (kcal/kg), CP (%), SID lysine (%), crude fiber (CF, %), NDF (%), ADF (%), fat (%), and ash (%) on an as-fed basis were obtained and recorded in the template for each dietary treatment.

[3] NRC. 2012. Nutrient Requirements of Swine. Natl. Acad. Press, Washington, DC.

Preparation of database

All of the selected trials reported overall growth performance, and some also reported growth performance by period. For trials that reported growth performance by period, growth performance and nutrient profile by period were recorded in the database as different experiments. In trials that reported overall performance but listed the feed formulation by period, the average dietary NE and nutrient content across periods was used to correspond with the overall growth performance.

To avoid the effects of factors other than energy, trials that had a factorial design were divided into experiments by factors that were crossed with the energy factor. Factors divided into separate experiments were CP, fat source, lysine:calorie ratio, with or without wheat middlings, and yellow dent vs. NutriDense corn. For the trials (n = 3) with a lysine:calorie ratio treatment factor, only data from the optimal lysine:calorie ratio as indicated in the literature was used in the analysis.

Overall, data from 100 experiments in 41 trials were used as a database for the statistical analysis (Table 1). The database included diets with a range of 1,980 to 2,815 kcal/kg NE, 8.9 to 22.9 % CP, 0.51 to 1.15% SID lysine, 1.9 to 12.5% CF, 6.7 to 29.5% NDF, 2.5 to 14.9% ADF, 3.1 to 6.7% ash, and 1.8 to 10% fat. Pigs used in the database could be described as modern genetic lines with BW from 21 to 138 kg BW, with the trial average BW ranging from 33.2 to 127.8 kg. Most of the trials (20) applied treatments to barrows and gilts in a single-sex pen; however, due to the lack of interaction with gender, these trials reported the main effect averaged across gender. Some trials were conducted using mixed-sex pens (5), and some used only barrows (4) or gilts (12); thus, data used in the analysis were derived from both single-sex and mixed-sex pens. No trials that used intact males were in the database.

The MIXED procedure of SAS (SAS institute, Inc., Cary, NC) was used to develop a regression equation to predict ADG or G:F depending on BW and NE content. The dietary NE applied within each experiment (285 observations) was the experimental unit for the modeling of the equation, and experiment within trial was included as a random effect. Linear and quadratic terms of NE, average BW, CP, CF, NDF, ADF, fat, and ash, including their interaction term, were the variables in the regression analysis. The statistical significance for inclusion of terms in the models was determined at $P < 0.10$. Further evaluation of models with significant terms was then conducted based on the Akaike Information Criteria (AIC), where models that minimized AIC were preferred candidate models. Minimizing AIC has been shown to result in regression models that have better precision (Littell et al., 2002[4]). The adequacies of candidate models were also examined using residual analysis. Briefly, this consisted of evaluating a histogram of residuals for evidence of normality and plotting studentized residuals against the corresponding fitted values.

Results and Discussion

Prediction equations for ADG

The equation predicting ADG using dietary NE as a single predictor (AIC = 3018.7) was improved when including the average BW in the model (AIC = 3,017.6). Because

[4] Littell, R.C., W.W. Stroup, and R.J. Freund. 2002. SAS for Linear Models, 4th edition. SAS Institute Inc., Cary, NC.

of the improvement in the precision of the model and because growing-finishing swine feed is generally formulated according to BW range, average BW was included in the model. The regression analysis showed that the model with dietary NE, average BW, CP, and the interaction between dietary NE and CP (NE × CP) demonstrated the smallest AIC (AIC = 3,002.0) compared with other significant models. Because diets were formulated to achieve a certain dietary lysine level by adjusting the amount of intact protein and crystalline lysine, the lysine level and CP in diet were highly correlated; therefore, CP in the equation was replaced with SID lysine to investigate whether the model could be improved. Having SID lysine with dietary NE and average BW improved the AIC value (3004.5). Having the interaction between NE and SID lysine (NE × SID lysine) in the model with dietary NE, average BW, and SID lysine also resulted in a better AIC (3002.5), but adding SID lysine as another variable in the model with NE, average BW, CP, and NE × CP presented the best AIC (3,000.8; Table 2). The interaction between NE and CP or lysine indicated that the magnitude of improvement in ADG by dietary NE was maximized when CP or lysine level increased (Figure 1). Generally, feed intake is adjusted according to energy density in the diet to achieve a suitable amount of energy intake on a daily basis; thus, feeding a high-energy diet results in a reduction in feed intake, which in turn can compromise the amount of amino acids consumed per day. On the contrary, when formulating a diet at low energy density, feed intake increases and amino acids can be consumed to meet the requirement. Therefore, when feeding a high-energy diets, the increase in amino acid content in the diet would improve the growth rate to a greater extent than feeding at low energy density, where proper amino acids intake can be achieved with higher feed consumption. The interaction between dietary NE and CP or lysine seems to suggest that amino acid levels were limiting growth rate across many of the trials included in the analysis; therefore, the equations adapted from Main et al. (2008[5]) that determine lysine:calorie requirements for barrows and gilts were used to calculate the lysine requirement at different dietary energy levels [Gilts SID Lys:NE ratio : -0.000000153*((Initial BW + Final BW)/2)^3 + 0.000104928*((Initial BW + Final BW)/2)^2 - 0.030414451*((Initial BW + Final BW)/2) + 6.043540689; Barrow SID Lys:NE ratio : 0.0000454*((Initial BW + Final BW)/2)^2 - 0.0249885*((Initial BW + Final BW)/2) + 5.8980083]. The trials that fed SID lysine below the requirement were then removed from the database, resulting in 104 observations from 17 trials for re-analysis. Neither SID lysine nor CP was a significant predictor in the re-analysis. Instead, the model with dietary NE, average BW, and the quadratic term of average BW demonstrated the smallest AIC (1071.2) compared with other significant models (Table 3). The model indicated that increasing dietary NE resulted in a linear improvement in ADG across all BW. Also, ADG increases with heavier average BW, but decreases when average BW is above 87 kg (Figure 2).

Prediction equations for G:F

The AIC values of all significant equations to predict G:F were negative, and the same principal can be applied to compare the precision of equations (Burnham and Anderson, 1998[6]). Thus, the equation that minimized the AIC value was preferred, which in

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[5] Main, R.G., S.S. Dritz, M.D. Tokach, R.D. Goodband, and J.L. Nelssen. 2008. Determining an optimum lysine:calorie ratio for barrows and gilts in a commercial finishing facility. J. Anim. Sci. 86: 2190–2207.

[6] Burnham, K.P., and D.R. Anderson. 1998. Model selection and inference: a practical information–theoric approach. Springer–Verlag, New York.

this case was the equation with the most negative AIC value. The equation to predict G:F using dietary NE as a single predictor presented the AIC value of -1,320.3. When including average BW, CP, and the interaction between dietary NE and CP in the model, the AIC value was largely improved to -1,449.7, which is the smallest of the AIC value compared with other significant models.

The CP term in the equation was then replaced with SID lysine. Having SID lysine with dietary NE and average BW improved the AIC value (-1,466.6), but having NE × SID lysine in the model with dietary NE, average BW, and SID lysine presented the best AIC (-1,470.1). Therefore, the equation to predict G:F from dietary NE obtained from this regression method was a function of dietary NE, average BW, SID lysine, and NE × SID lysine (Table 2). The equation showed that feed efficiency improved with the increase in dietary NE. Similar to the ADG model, however, the magnitude of improvement in feed efficiency by dietary NE was maximized when lysine level increased which suggested that lysine levels were limiting growth across many of the trials in database.

When the trials that fed SID lysine below the requirement were removed from the database, the equation that presented the best AIC (-600.8) was a function of dietary NE, average BW, and fat, which showed that G:F improved with increasing dietary NE, fat, and lower BW (Table 3). The improvement of G:F with fat in the model may suggest that the NE value of fat is underestimated.

Application of prediction equations

Discrepancies in health status, genetics, and environment among farms could make a difference between the predicted value and the actual growth rate or feed efficiency. The predicting equations can be adjusted accordingly to accommodate differences. One method is to adjust the intercept of the equation. With this method, a set of data on NE, CP, and SID lysine of diet that was fed to a certain BW on the farm can be used to calculate the ADG and G:F from the predicting equation. The difference between predicted and actual value of growth performance is then used to adjust the intercept of the equation; for instance, the 90- to 110-kg pigs in farm A demonstrated a growth rate and feed efficiency of 898.9 g/d and 0.317 when feeding a corn-soybean meal diet that contained 2,511 kcal/kg NE, 15.7% CP, and 0.67 % SID lysine. Based on these feed characteristics and BW range, the predicting equation would calculate the growth rate of 885.7 g/d (ADG = (0.1809×2511) + (1.6119×100) + (34.2735×15.7) + (0.01476×2511×15.7) + (129.63×0.67) + 1047.92) and G:F of 0.303 (G:F = (0.000004365×2511) - (0.00162×100) - (0.08023×0.67) + (0.000094*2511*0.67)+0.3496). As a result, the actual ADG was 13.2 g/d greater than the predicted value; thus, the intercept of the ADG prediction equation can be adjusted to 1,061.12 (1,047.92+13.2). Likewise, the 0.014 G:F difference between predicted and actual value was used to adjust the intercept of G:F prediction equation to 0.3636 (0.3496 + 0.014).

The NRC (2012) ingredient library was the source of ingredient nutrients and the nutrients of the diets that were used in the regression analysis to obtain these equations. Therefore, it is important that the nutrient values of every ingredient be obtained from NRC (2012) when using these predicting equations. These equations also should be used to predict growth performance within the range of nutrients in the database

(1,980 to 2,815 kcal/kg NE, 8.9 to 22.9 % CP, 0.51 to 1.15% SID lysine, 1.8 to 10% fat).

In conclusion, dietary NE is an important predictor of the growth performance of growing-finishing pigs. Our regression analysis showed that improvements in growth rate and feed efficiency could be obtained by increasing dietary NE across a wide variety of trials with different dietary ingredients and under different environmental conditions. However, the magnitude of improvement in growth performances by dietary NE can be minimized if the amino acids are limiting. These prediction equations still need to be validated with the growth studies that feed amino acids above the requirement.

Table 1. Summary of papers used in the regression analysis to predict growth performance from dietary net energy in growing-finishing pigs

First author, year	Source type: J = journal T = thesis M = technical memo	Trials	Gender[1]	Range of dietary NE, (kcal/kg)	Range of CP, (%)	Initial BW, (kg)	Final BW, (kg)	Diet
Friesen et al., 1991[2]	J	1	both	2,560–2,784	16.8–17.2	57.9	89.9	Sorghum–soybean meal (SBM)
Myer and Comb, 1991	J	1	both	2,204–2,619	14.3–14.9	27.0	102.0	Corn–SBM–oat
Lopez-Bote et al., 1997	J	1	both	2,257–2,409	17.5–17.7	30.4–30.5	89.1–90.1	Barley–SBM–sunflower meal
Smith et al., 1997	M	1	gilt	2,515–2,626	10.7–17.6	47.7	106.9–115.5	Corn–SBM
Knowles et al., 1998	J	3	gilt, barrow	2,499–2,733	8.9–15.6	63.0–83.0	101.0–119.2	Corn–SBM–wheat middlings–rice bran
Smith et al., 1999[3]	J	2	gilt	2,402–2,726	16.4–21.9	29.2–44.5	104.3–107	Corn–SBM
De la Llata et al., 2001[4]	J	1	both	2,396–2,786	13.9–22.9	36.0	118.0–121.6	Corn–SBM
Engel et al., 2001	J	1	gilt	2,523–2,775	13.7–14.4	59.2–61.0	109.8–111.7	Corn–SBM
Baudon et al., 2003	M	1	both	2,469–2,809	14.0–17.3	57.7	127.3	Corn–SBM
Kerr et al., 2003[5]	J	1	gilt	2,393–2,534	11.3–21.4	25.3	109.7	Corn–SBM–wheat middlings
Shriver et al., 2003[5]	J	1	both	2,529–2,688	12.2–15.7	28.4–28.8	114–117.5	Corn–SBM–soybean hull
Young et al., 2003	M	1	both	2,500–2,746	16.3–17.2	71.8	105.5	Corn–SBM
Hastad et al., 2005[5]	J	1	gilt	2,434–2,815	14.9–20.9	50.1	113.9–117.0	Corn–SBM
Hastad et al., 2005	M	2	gilt	2,442–2,735	16.9–20.7	30.6–35.3	117.5–120.0	Corn–SBM
Beaulieu et al., 2007	J	2	both	2,187–2,572	14.7–20.4	31.06–37.4	115.0–119.0	Wheat–barley–SBM–canola meal
Benz et al., 2007	M	1	both	2,500–2,785	15.5–17.0	54.5	133.9	Corn–sorghum–SBM
De la Llata et al., 2007[3]	J	2	gilt, barrow	2,405–2,749	15.1–22.6	24.0–34.0	120.0	Corn–SBM
Duttlinger et al., 2008	M	1	both	2,534–2,788	14.2–14.7	77.9	102.6	Corn–SBM
Apple et al., 2009	J	1	mixed	2,484–2,797	11.5–17.0	28.1	113.6	Corn–SBM
Ball et al., 2010	J	1	both	2,215–2,304	20.9–21.3	39.7–39.8	90.9–93.4	Wheat–Barley–SBM

continued

Table 1. Summary of papers used in the regression analysis to predict growth performance from dietary net energy in growing-finishing pigs

First author, year	Source type: J = journal T = thesis M = technical memo	Trials	Gender[1]	Range of dietary NE, (kcal/kg)	Range of CP, (%)	Initial BW, (kg)	Final BW, (kg)	Diet
Asmus et al., 2011[6]	M	1	both	2,343–2,546	13.4–20.9	40.9–41.0	120.5–122.6	Corn–SBM–DDGS–wheat middlings
Barns et al., 2011	T	1	both	2,408–2,491	16.8–17.3	46.6	129.8–134.9	Corn–SBM–DDGS–wheat middlings
Barns et al., 2011	T	1	both	2,423–2,710	16.0–17.0	42.3	128.2–136.9	Corn–SBM–DDGS
Wheat middlings								
Barns et al., 2011[7]	T	1	both	2,409–2,619	15.1–18.6	48.1	121.0–124.8	Corn–SBM–DDGS
Wheat middlings								
Benz et al., 2011	J	1	both	2,495–2,732	15.5–16.1	44.1	123.0	Corn–SBM
Chen et al., 2011	J	2	barrow	2,329–2,701	12.2–16.5	62.0–69.0	95.0–98.0	Corn–SBM–wheat bran
Chu et al., 2012	J	3	mixed	2,260–2,650	13.6–20.9	20.8–78.6	55.9–105.8	Corn–SBM–wheat bran
Graham et al., 2012[8]	M	1	mixed	2,359–2,537	13.9–20.0	53.0	121.9	Corn–SBM–DDGS–Wheat middlings
Jungst et al., 2012	M	3	both	2,368–2,709	15.4–20.3	28.6–30.4	135.2–138.2	Corn–SBM–DDGS–Wheat middlings
Jungst et al., 2012	M	1	gilt	1,980–2,480	12.3–19.5	33.9–34.3	118.9–121.2	Corn–SBM–soyhulls–Wheat middlings

[1] "Both" in gender category refers to applying treatments to barrows and gilts in a single–sex pen; "mixed" refers to trials that applied treatments in mixed-sex pen.
[2] Only data for diets supplemented with 0.2% lysine were used in the analysis.
[3] Only data for diets with lysine:calorie ratio at the requirement as indicated in the literature were used in the analysis.
[4] Two experiments were reported in the literature, but only data from experiment 1 were used in the analysis.
[5] Two experiments were reported in the literature, but only data from experiment 2 were used in the analysis.
[6] Data from treatments that fed low-NDF and high-NDF diets throughout the experiment without withdrawal periods were used in the analysis.
[7] Only data from feeding diets without xylanase were used.
[8] Data of treatments that fed corn–SBM without ractopamine and diets with 30% DDGS and 19% midds without ractopamine throughout the experiment without withdrawal periods were used in the analysis.

Table 2. Regression equations to predict ADG and G:F from dietary NE using ingredient NE values from NRC (2012)[1]

Growth performance	Model	AIC[2]
ADG (g/day)	= –0.1809*NE (kcal/kg) + 1.6119*Average BW (kg) – 34.2735*CP (%) + 0.01476*NE (kcal/kg)*CP (%) + 129.63*SID lysine (%) + 1047.92	3,000.8
G:F	= 0.000004365*NE (kcal/kg) – 0.00162*Average BW (kg) – 0.08023*SID lysine (%) + 0.000094* NE (kcal/kg)*SID lysine (%) + 0.3496	–1,470.1

[1] Data from 41 trials divided into 100 experiments were used as a database for the statistical analysis.
[2]Akaike Information Criteria (AIC) were used to compare the precision of the model where the model with smaller AIC value was preferred. The AIC values of all significant equations to predict G:F were negative; however, the same principal can be applied to compare the precision of equations. Thus, the equation that minimized AIC value was preferred; in this case, it was the equation with the most negative AIC value.

Table 3. Regression equation to predict ADG and G:F from dietary NE using ingredient NE values from NRC (2012)[1]

Growth performance	Model	AIC[2]
ADG (g/day)	= 0.1135*NE (kcal/kg) + 8.8142*Average BW (kg) – 0.05068* Average BW (kg) *Average BW (kg) + 275.99	1,071.2
G:F	= 0.000096*NE (kcal/kg) – 0.0025*Average BW(kg) + 0.003071*Fat(%) + 0.3257	–600.8

[1] Trials that fed standardized ileal digestible (SID) lysine below the requirement were removed from the database, resulting in 104 observations from 17 trials for regression analysis.
[2]Akaike Information Criteria (AIC) were used to compare the precision of the model where the model with smaller AIC value was preferred. The AIC values of all significant equations to predict G:F were negative; however, the same principal can be applied to compare the precision of equations. Thus, the equation that minimized AIC value; in this case, the equation with the most negative AIC value was preferred.

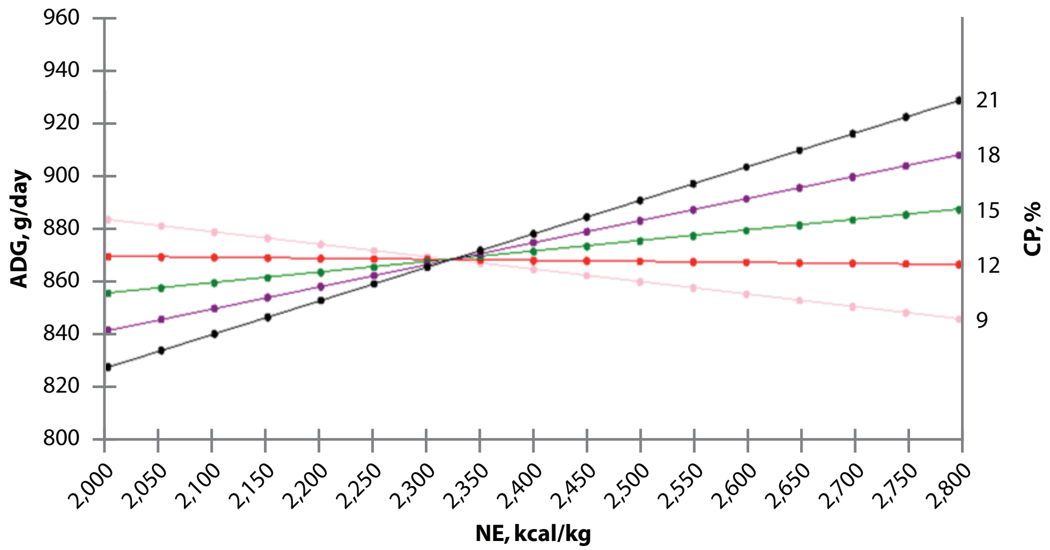

Figure 1. Predicted ADG of 100-kg pig fed increasing dietary NE (kcal/kg) at varying levels of CP (%) from regression analysis using the model [ADG (g/d) = –0.1809*NE (kcal/kg) + 1.6119*average BW (kg) – 34.2735*CP(%) + 0.01476*NE(kcal/kg)*CP(%) + 129.63*SID lysine(%) + 1047.92] (SID = standardized ileal digestible). Increasing dietary NE resulted in a linear improvement in ADG; however, the rate of improvement (slope) was different due to the level of CP. The magnitude of improvement in ADG by dietary NE was maximized when CP level increased.

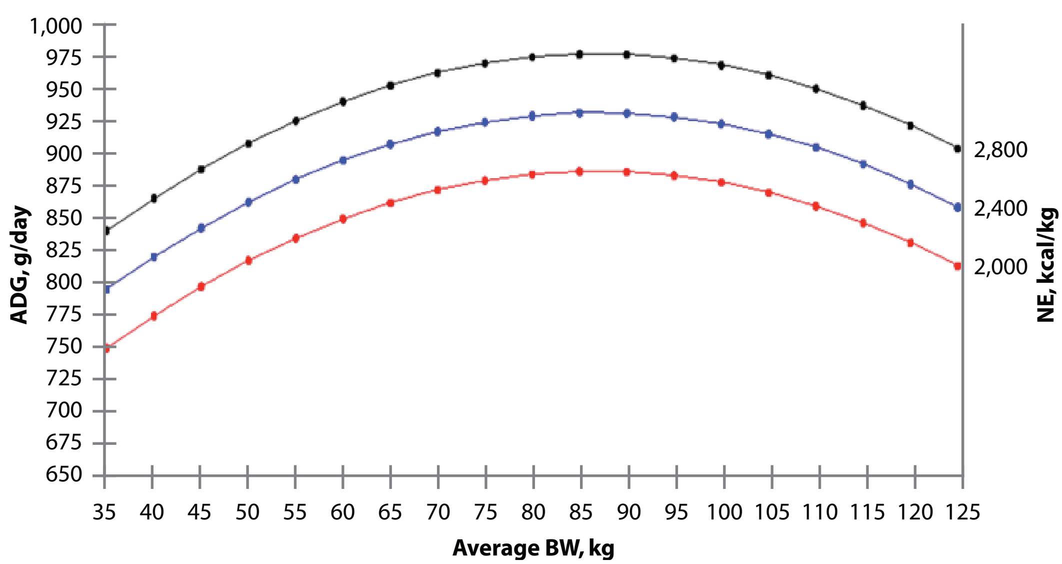

Figure 2. Predicted ADG of pigs fed varying levels of dietary NE at heavier average BW from regression analysis using the model [ADG (g/d) = 0.1135*NE (kcal/kg) + 8.8142*average BW (kg) – 0.05068*average BW (kg)*average BW (kg) + 275.99]. Growth rate increases with heavier average BW, but decreases when average BW is above 87 kg.