

# Influence of dietary net energy content on performance of growing pigs fed low crude protein diets supplemented with crystalline amino acids

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## Summary

**Objective:** To investigate the effects of dietary net energy (NE) content on the performance of growing pigs fed low-protein diets supplemented with crystalline amino acids.

**Materials and methods:** A total of 144 barrows ( $22.96 \pm 2.72$  kg, Experiment One) or 360 barrows ( $27.80 \pm 3.48$  kg, Experiment Two) were assigned to six treatments. Diets in both experiments were based on corn and soybean meal, including an unsupplemented high-crude-protein (CP) diet (19.0% CP, 2.50 Mcal NE per kg) and five low-CP diets (4% lower CP) supple-

mented with lysine, methionine, threonine, and tryptophan. For Experiment One, five levels of NE (2.64, 2.58, 2.50, 2.42, and 2.36 Mcal per kg) were formulated in the low-protein diets. In Experiment Two, the low-protein diets contained 2.45, 2.40, 2.35, 2.30, and 2.25 Mcal NE per kg.

**Results:** In Experiment One, for pigs on low-CP diets with different NE levels, ADG ( $P < .05$ ) and gain:NE intake (kg per Mcal NE) increased linearly with decreasing NE levels ( $P < .01$ ). In Experiment Two, for pigs on low-CP diets with different NE levels, there was a significant quadratic increase in ADG, gain:feed, and gain:NE intake as net

energy levels increased from 2.25 to 2.35 Mcal NE per kg ( $P < .05$ ).

**Implications:** Feeding a low-CP, amino-acid-supplemented, corn-soybean-meal-based diet with a proper NE level maximizes the performance of growing pigs. Optimum performance will be obtained if the diet provides approximately 2.40 Mcal NE per kg.

**Key words:** swine, net energy, performance, low-protein diet

**Received:** September 13, 2009

**Accepted:** April 22, 2010

## Resumen - Influencia del contenido neto de energía dietética en el desempeño de cerdos de crecimiento alimentados con dietas bajas en proteína cruda y suplementados con aminoácidos cristalinos

**Objetivo:** Investigar los efectos del contenido neto de energía (NE) dietético en el desempeño de cerdos de crecimiento alimentados con dietas bajas en proteína suplementadas con aminoácidos cristalinos.

**Materiales y métodos:** Un total de 144 cerdos castrados ( $22.96 \pm 2.72$  kg, Experimento Uno) ó 360 cerdos castrados ( $27.80 \pm 3.48$  kg, Experimento Dos) se asignaron a seis tratamientos. Las dietas en ambos experimentos se basaron en maíz y harina de soya, incluyendo una dieta alta en proteína cruda (CP) no suplementada (19.0% CP,

2.50 Mcal NE por kg) y cinco dietas bajas en CP (CP 4% más baja) suplementadas con lisina, metionina, treonina, y triptófano. Para el Experimento Uno, se formularon cinco niveles de NE (2.64, 2.58, 2.50, 2.42, y 2.36 Mcal por kg) para las dietas bajas en proteína. En el Experimento Dos, las dietas bajas en proteína contenían 2.45, 2.40, 2.35, 2.30, y 2.25 Mcal NE por kg.

**Resultados:** En el Experimento Uno, para los cerdos alimentados con dietas baja en CP con diferentes niveles de NE, la ganancia diaria de peso (ADG por sus siglas en inglés) ( $P < .05$ ) y la ganancia:consumo de NE (kg por Mcal NE) aumentaron linealmente en relación a los niveles decrecientes de NE ( $P < .01$ ). En el Experimento Dos, para los cerdos alimentados con las dietas bajas en CP con diferentes

niveles de NE, hubo un aumento cuadrático significativo en la ADG, ganancia:alimento, y ganancia:consumo de NE al aumentar los niveles netos de energía de 2.25 a 2.35 Mcal NE por kg ( $P < .05$ ).

**Implicaciones:** Alimentar con una dieta baja en CP, suplementada con aminoácidos, basada en harina de frijol de soya y maíz con un nivel apropiado de NE maximiza el desempeño del crecimiento de cerdos de crecimiento. El desempeño óptimo se obtendrá si la dieta provee aproximadamente 2.40 Mcal NE por kg.

## Résumé - Influence du contenu alimentaire net en énergie sur les performances de porcs nourris avec des rations faibles en protéines brutes supplémentées avec des acides aminés cristallisés

**Objectif:** Étudier les effets du contenu alimentaire net en énergie (NE) sur les performances de porcs en croissance nourris avec des rations faibles en protéines supplémentées avec des acides aminés cristallisés.

**Matériels et méthodes:** Un total de 144 castrats ( $22.96 \pm 2.72$  kg, Expérience 1) ou 360 castrats ( $27.80 \pm 3.48$  kg, Expérience 2) ont été répartis dans six groupes de traitement. Les diètes dans les deux expériences étaient à base de farine de maïs

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This article is available online at <http://www.aasv.org/shap.html>.

Yi XW, Zhang SR, Yang Q, et al. Influence of dietary net energy content on performance of growing pigs fed low crude protein diets supplemented with crystalline amino acids. *J Swine Health Prod.* 2010;18(6):294-300.

et de soya, incluant une ration non-supplémentée à haute teneur en protéine brute (CP) (19.0% CP, 2.50 Mcal NE par kg) et cinq rations à faible teneur en CP (CP inférieur de 4%) supplémentées avec de la lysine, de la méthionine, de la thréonine, et du tryptophane. Pour l'Expérience 1, cinq valeurs de NE (2.64, 2.58, 2.50, 2.42, et 2.36 Mcal par kg) ont été préparées dans les ratios à faible teneur en protéine. Lors de l'Expérience 2, les rations à faible teneur en protéine contenaient 2.45, 2.40, 2.35, 2.30, et 2.25 Mcal de NE par kg.

**Résultats:** Au cours de l'Expérience 1, pour les porcs recevant les rations à faibles teneurs en CP avec différents niveaux de NE, le gain moyen journalier (ADG) ( $P < .05$ ) et le gain:apport de NE (kg par

Mcal de NE) augmentait de façon linéaire avec la réduction des niveaux de NE ( $P < .01$ ). Lors de l'Expérience 2, pour les porcs recevant des rations faibles en CP avec différents niveaux de NE, il y avait une augmentation quadratique significative du ADG, du gain:aliment, et du gain:apport de NE à mesure que les niveaux d'énergie augmentaient de 2.25 à 2.35 Mcal de NE par kg ( $P < .05$ ).

**Implications:** Une diète faible en CP, supplémentée avec des acides aminés, à base de farine de maïs et de soya, avec un niveau approprié de NE peut maximiser les performances de porcs en croissance. Les performances optimales seront obtenues si la diète fournit approximativement 2.40 Mcal de NE par kg.

Recent advances in determination of amino-acid requirements for growing pigs and inclusion of crystalline amino acids (CAA) may allow the crude protein (CP) content of swine diets to be reduced by two or three percentage units with no negative effects on animal performance or nitrogen retention.<sup>1-3</sup> However, lower average daily gain (ADG) or lower gain:feed or both often occur when dietary CP is reduced by four or more percentage units below National Research Council (NRC)<sup>4</sup> recommendations.<sup>5-7</sup> Two explanations are usually given to account for the poorer performance arising from feeding low-protein diets. Either these diets do not provide sufficient nitrogen to allow for synthesis of non-essential amino acids,<sup>2,3</sup> or the supply of essential amino acids is inadequate. The latter situation may involve incorrect initial assumptions about the amino-acid requirements of pigs, poor amino-acid digestibility, or a change in amino-acid balance (ideal protein) as the protein level changes. Many of these concepts have been studied, yet producers are still faced with suboptimal growth of pigs fed diets with lower dietary CP, regardless of amino-acid content.<sup>5,6</sup>

The reason for poor performance (lower ADG or lower gain:feed or both) in pigs fed diets with CP concentrations lower than NRC recommendations by four or more percentage units is unknown. It may be partially due to more dietary energy being available for fat synthesis as a result of lowered energy expenditure needed for catabolism of excess dietary protein.<sup>8,9</sup> Furthermore, as the CP level of a corn-soybean meal diet is reduced, less soybean meal

(with high protein content) and more corn and other energy ingredients (with high starch content) will necessarily be used. However, this increases the net energy (NE) content of diet, as variations in NE content arise when efficiencies of metabolism energy utilization differ between nutrients, with the highest values for starch (82%) and the lowest (60%) for crude protein.<sup>10,11</sup> Because of these differences, the heat increment associated with metabolic utilization of energy is higher for CP than for starch.<sup>11</sup> In order to take into account the changes in metabolic utilization of energy that occur with changes in dietary CP, it is necessary to evaluate feeds on an NE basis. Therefore, the NE system should be used to predict performance and energy gain in pigs fed low-protein diets.<sup>1,9,10</sup>

Le Bellego et al<sup>1</sup> suggested that formulation of low-protein diets using the NE system would reduce feed costs and improve performance. Knowles et al<sup>12</sup> reported that decreasing the NE content in a low CP diet (11.7% CP, 2.58 Mcal NE per kg) to the same level as that of a high CP diet (15.5% CP, 2.58 Mcal NE per kg) did not affect finisher pig performance. However, less information is available on the effect of dietary NE level on performance of growing pigs fed low-protein diets.<sup>3</sup> The objective of this research was to determine the level of net energy that optimizes performance of growing pigs fed low-CP diets.

## Materials and methods

All experimental procedures were approved by the University of China Agricultural Committee on Laboratory Animal Care.

## Study design

Two experiments were conducted at China Agricultural University Swine Center to determine the effects of dietary NE on the performance of growing pigs fed low-CP diets supplemented with CAA. Crossbred barrows (Yorkshire × Landrace × Duroc) obtained from the China Agricultural University Agricultural Center Swine Unit (Beijing, China) were used in both experiments. The barrows were housed in a curtain-sided building in 4.5 × 2.8-m pens with concrete slats running the entire length of each pen. Feed and water were provided on an ad libitum basis.

In Experiment One, 144 barrows (22.96 ± 2.72 kg) were assigned to six treatments, with six pens per treatment and four pigs per pen. Diets were fed for 38 days. In Experiment Two, 360 barrows (27.80 ± 3.48 kg) were assigned to six treatments, with six pens per treatment and ten pigs per pen. Diets were fed for 34 days. In both experiments, pigs were allotted to treatments so that weight and pig ancestry were equalized across treatments. Pig weight and feed disappearance were measured for each pen weekly and used to calculate ADG, average daily feed intake (ADFI), gain:feed, and gain:NE intake.

## Dietary treatments

Experimental diets were based on corn and soybean meal (Table 1) and consisted of an unsupplemented high-CP diet that contained 19.0% CP and 2.50 Mcal NE per kg, and five low-CP diets supplemented with crystalline lysine, methionine, threonine, and tryptophan to meet NRC requirements.<sup>4</sup> For Experiment One, five levels of NE (2.64, 2.58, 2.50, 2.42, and 2.36 Mcal NE per kg) were formulated, while in Experiment Two, the low-protein diets contained 2.45, 2.40, 2.35, 2.30, and 2.25 Mcal NE per kg (Tables 2 and 3).

All diets were formulated to meet or exceed the NRC recommendations<sup>4</sup> for minerals and vitamins. The amino-acid content of the diets was based on actual amino-acid analyses of corn, soybean meal, and wheat bran. Dietary NE contents of the diets were calculated according to the NE calculations of Noblet et al<sup>10</sup> and were based on chemical analyses of feed ingredients for ether extract (EE), crude fiber (CF), and CP, as well as starch (ST), which was determined using the method of Thivend et al,<sup>13</sup> and digestible energy (DE), which was obtained from the China Feed Bank.<sup>14</sup> The NE contents of the crystalline lysine, methionine,

**Table 1:** Chemical analysis (dry matter basis) of ingredients used in Experiment One and Two diets for grower pigs (barrows) housed in a research facility

	Corn	Soybean meal	Wheat bran
Crude protein (g/kg)	78	456	173
Crude fiber (g/kg)	31	52	78
Ether extract (g/kg)	32	10	15
Starch (g/kg)	641	22	148
DE (Mcal/kg)*	3.39	3.47	2.23
NE (Mcal/kg)†	2.63	1.97	1.42

\* Digestible energy (DE) values obtained from the China Feed Bank.<sup>14</sup>

† Net energy (NE) values based on Noblet et al,<sup>10</sup> where NE = (0.703 × kcal/kg DE) + (1.58 × g/kg ether extract) + (0.47 × g/kg starch) – (0.97 × g/kg crude protein) – (0.98 × g/kg crude fiber).

**Table 2:** Ingredient composition of diets (as-fed basis) for grower pigs\* housed in a research facility (Experiments One and Two)

Dietary CP level	Experiment One						Experiment Two					
	High CP	Low CP			High CP			Low CP				
Dietary NE level (Mcal/kg)	2.50	2.36	2.42	2.50	2.58	2.64	2.50	2.25	2.30	2.35	2.40	2.45
Ingredients												
Corn (%)	65.30	74.10	78.22	78.61	76.66	75.00	65.30	64.50	67.70	71.70	71.00	70.00
Soybean meal (%)	28.40	14.00	15.00	16.50	16.70	17.00	28.40	14.00	15.40	17.00	17.10	17.50
Wheat bran (%)	0.00	8.14	3.00	0.00	0.00	0.00	0.00	17.73	13.18	7.65	7.25	6.86
Soybean oil (%)	3.28	0.00	0.00	1.15	2.87	4.27	3.28	0.00	0.00	0.00	1.00	2.00
Limestone (%)	0.62	0.60	0.50	0.50	0.53	0.51	0.62	0.80	0.80	0.80	0.80	0.80
Dicalcium phosphate (%)	1.00	1.03	1.15	1.20	1.20	1.20	1.00	0.80	0.80	0.80	0.80	0.80
NaCl (%)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix (%)†	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L-lysine HCl (%)‡	0.00	0.45	0.45	0.40	0.40	0.40	0.00	0.47	0.44	0.41	0.41	0.40
DL-methionine (%)‡	0.00	0.12	0.12	0.10	0.10	0.10	0.00	0.13	0.12	0.11	0.11	0.11
L-threonine (%)‡	0.00	0.12	0.12	0.10	0.10	0.10	0.00	0.14	0.13	0.11	0.11	0.11
L-tryptophan (%)‡	0.00	0.04	0.04	0.04	0.04	0.04	0.00	0.03	0.03	0.03	0.03	0.02

\* Experiment One, 144 barrows (22.96 ± 2.72 kg) at the beginning of the 38-day study; Experiment Two, 360 barrows (27.80 ± 3.48 kg) at the beginning of the 34-day study. High and low CP diets contained 19% and 15% CP, respectively.

† Premix provided the following per kg of complete diet: vitamin A, 5512 IU; vitamin D3, 2200 IU; vitamin E, 64 IU; vitamin K3, 2.2 mg; vitamin B12, 27.6 µg; riboflavin, 5.5 mg; pantothenic acid, 13.8 mg; niacin, 30.3 mg; choline chloride, 551 mg; Mn, 10 mg; Fe, 100 mg; Zn, 100 mg; Cu, 20 mg; I, 0.3 mg; Se, 0.3 mg.

‡ Supplemental crystalline amino acids.  
CP = crude protein; NE = net energy.

**Table 3:** Chemical analysis and calculated nutritional value of diets fed to grower pigs\* housed in a research facility (Experiments One and Two)

Dietary CP levels	Experiment One						Experiment Two					
	High CP	Low CP			High CP	Low CP						
Dietary NE levels (Mcal/kg)	2.50	2.36	2.42	2.50	2.58	2.64	2.50	2.25	2.30	2.35	2.40	2.45
<b>Chemical analysis</b>												
Crude protein (%)	19.0	14.4	14.1	14.1	14.2	14.1	19.0	14.5	14.3	14.6	14.5	14.6
Calcium (%)	0.68	0.66	0.67	0.68	0.68	0.68	0.68	0.66	0.65	0.64	0.63	0.64
Total phosphorus (%)	0.55	0.56	0.55	0.55	0.55	0.55	0.55	0.56	0.55	0.55	0.55	0.55
Lysine (%)	1.01	0.97	0.96	0.96	0.97	0.98	1.01	0.97	0.96	0.96	0.97	0.96
Methionine + cystine (%)	0.69	0.59	0.60	0.61	0.61	0.61	0.69	0.69	0.69	0.67	0.67	0.68
Threonine (%)	0.74	0.67	0.70	0.65	0.69	0.71	0.74	0.67	0.71	0.65	0.68	0.70
Tryptophan (%)	0.18	0.16	0.19	0.16	0.18	0.18	0.18	0.17	0.18	0.16	0.17	0.18
<b>Calculated nutritional value</b>												
DE (Mcal/kg) †	3.43	3.20	3.26	3.35	3.43	3.50	3.43	3.09	3.15	3.21	3.27	3.43
NE (Mcal/kg) ‡	2.50	2.36	2.42	2.50	2.58	2.64	2.50	2.25	2.30	2.35	2.45	2.40
<b>True ileal digestible amino acids§</b>												
Lysine (%)	0.87	0.83	0.83	0.84	0.84	0.84	0.87	0.89	0.89	0.88	0.88	0.89
Methionine + cystine (%)	0.53	0.50	0.49	0.50	0.47	0.49	0.53	0.50	0.49	0.50	0.49	0.50
Threonine (%)	0.60	0.52	0.53	0.54	0.54	0.54	0.60	0.55	0.56	0.54	0.54	0.56
Tryptophan (%)	0.17	0.16	0.16	0.16	0.16	0.16	0.17	0.16	0.16	0.16	0.16	0.16

\* Barrows described in Table 2. High and low CP diets contained 19% and 15% CP, respectively.

† DE calculated using values for ingredients obtained from China Feed Bank.<sup>14</sup>

‡ NE values based on Noblet et al<sup>10</sup> (Table 1), where NE = (0.703 × kcal/kg DE) + (1.58 × g/kg ether extract) + (0.47 × g/kg starch) – (0.97 × g/kg CP) – (0.98 × g/kg crude fiber). The NE contents of the crystalline lysine, methionine, threonine, and tryptophan were 3.37, 4.13, 2.94, and 4.78 Mcal NE/kg DM and were obtained from Institut National de la Recherche Agronomique- Association Française de Zootechnie.<sup>15</sup> The NE content of the soybean oil was 6.91 Mcal NE/kg DM. This value was calculated by using China Feed Bank<sup>14</sup> DE value in equation 3 of Noblet et al,<sup>10</sup> ie, (NE = [0.843 × DE] - 463).

§ Values estimated using true ileal digestible coefficients provided by NRC<sup>4</sup> for amino acids.

CP = crude protein; DE = digestible energy; NE = net energy.

threonine, and tryptophan used in both experiments (3.37, 4.14, 2.94, and 4.78 Mcal NE per kg dry matter (DM), respectively) were obtained from Institut National de la Recherche Agronomique-Association Française de Zootechnie.<sup>15</sup> The equation used for the calculation of NE was NE = (0.703 × kcal per kg DE) + (1.58 × g per kg EE) + (0.47 × g per kg ST) - (0.97 × g per kg CP) - (0.98 × g per kg CF).

### Chemical analysis

Samples of the ingredients and diets were analyzed according to the methods of the Association of Official Analytical Chemists (AOAC; 1995).<sup>16</sup> Analyses were conducted for calcium (AOAC method 935.13), phosphorus (AOAC method 965.17), DM (AOAC method 934.01), CP (AOAC

method 988.05), EE (AOAC method 954.02), and CF (AOAC method 962.09). Ingredients and diets were hydrolyzed in 6N HCl at 110°C for 24 hours, whereas content of sulfur-containing amino acids was measured after performic acid oxidation, and tryptophan content was determined after alkaline hydrolysis (AOAC method 994.12).<sup>16</sup> Amino-acid analyses were performed by high performance liquid chromatography (Hitachi L-8800 Amino Acid Analyzer; Tokyo, Japan).

### Statistical analysis

Data for each response variable were analyzed by ANOVA using the GLM procedure of SAS version 8e (SAS Institute Inc, Cary, North Carolina), with all six dietary treatments included in the model. The

LSMEANS procedure of SAS was used to calculate mean values, and the PDIF option was used to separate means and to test the data for potential outliers. The high-protein treatment was then removed from the data set and the linear and quadratic effects of altering dietary NE levels in the low-CP diets were evaluated using orthogonal polynomial contrasts. Pen was the experimental unit for all analyses. Differences were considered significant at  $P < .05$ .

## Results

### Experiment One

When the performance of barrows fed low-protein diets with 2.50 Mcal NE per kg was compared to performance of barrows fed the high-protein diet, there was

**Table 4:** Effects of dietary NE levels on growth performance of grower pigs housed in a research facility (Experiment One)\*

Dietary CP levels	High CP	Low CP + CAA					SEM	P			
	Dietary NE levels (Mcal/kg)	2.50	2.36	2.42	2.50	2.58		2.64	ANOVA	Linear†	Quadratic†
Body weight Day 0 (kg)	22.96	22.96	22.91	22.99	22.96	22.98	1.23	.99	.98	.99	NA
Body weight Day 38 (kg)	52.45	53.00	51.86	49.63	50.13	50.91	1.80	.73	.30	.33	NA
ADG (kg/day)	0.78 <sup>ab</sup>	0.79 <sup>a</sup>	0.76 <sup>abc</sup>	0.70 <sup>c</sup>	0.72 <sup>bc</sup>	0.74 <sup>abc</sup>	0.02	.02	.02	< .01	.10
ADFI (kg/day)	1.59	1.60	1.55	1.49	1.52	1.54	0.05	.68	.29	.28	.44
NE intake (Mcal/day)	3.96	3.78	3.76	3.74	3.93	4.06	0.13	.38	.06	.08	.43
Gain:feed	0.49	0.49	0.49	0.47	0.47	0.48	0.01	.32	.05	.09	.36
Gain:NE intake (kg/Mcal NE)	0.20 <sup>ab</sup>	0.21 <sup>a</sup>	0.20 <sup>ab</sup>	0.19 <sup>bc</sup>	0.18 <sup>c</sup>	0.18 <sup>c</sup>	0.004	< .01	< .01	< .01	.38

\* Barrows described in Table 2 were housed in 36 pens in a growing environment for a 38-day study, with four pigs/pen and six pens/treatment. High and low CP diets contained 19% and 15% CP, respectively.

† Linear and quadratic contrasts for low CP diets.

‡ High-protein (H) versus low-protein (L) diet.

<sup>abcd</sup> Means in the same row with no common superscript differ ( $P < .05$ ; ANOVA).

CP = crude protein; NE = net energy; CAA = crystalline amino acids; ADG = average daily gain; ADFI = average daily feed intake; NA = not applicable.

**Table 5:** Effects of dietary NE levels on growth performance of grower pigs housed in a research facility (Experiment Two)\*

Dietary CP levels	High CP	Low CP + CAA					SEM	P			
	Dietary NE levels (Mcal/kg)	2.50	2.25	2.30	2.35	2.40		2.45	ANOVA	Linear†	Quadratic†
Body weight Day 0 (kg)	27.82	27.69	27.85	27.84	27.93	27.64	1.54	.99	.99	.98	NA
Body weight Day 34 (kg)	51.85	50.46	50.94	52.2	52.04	50.69	1.83	.97	.76	.68	NA
ADG (kg/day)	0.71 <sup>abc</sup>	0.67 <sup>c</sup>	0.68 <sup>bc</sup>	0.72 <sup>a</sup>	0.71 <sup>ab</sup>	0.68 <sup>bc</sup>	0.01	.04	.22	< .01	.22
ADFI (kg/day)	1.47	1.47	1.44	1.47	1.46	1.43	0.03	.86	.40	.60	.67
NE intake (Mcal/day)	3.56	3.30	3.31	3.46	3.50	3.50	0.07	.06	< .01	< .01	< .01
Gain:feed	0.48 <sup>a</sup>	0.46 <sup>b</sup>	0.47 <sup>a</sup>	0.49 <sup>a</sup>	0.49 <sup>a</sup>	0.47 <sup>a</sup>	0.005	< .01	.01	< .01	.22
Gain:NE intake (kg/Mcal NE)	0.19 <sup>a</sup>	0.20 <sup>b</sup>	0.21 <sup>b</sup>	0.21 <sup>b</sup>	0.20 <sup>b</sup>	0.19 <sup>a</sup>	0.002	< .01	.01	< .01	< .01

\* Barrows described in Table 2 were housed in 36 pens in a research growing environment for a 34-day study, with 10 pigs/pen and six pens/treatment. High and low CP diets contained 19% and 15% CP, respectively.

† Linear and quadratic contrasts for low CP diets.

‡ High-protein (H) versus low-protein (L) diets.

<sup>abc</sup> Means in the same row with no common superscript differ ( $P < .05$ ; ANOVA).

CP = crude protein; NE = net energy; CAA = crystalline amino acids; ADG = average daily gain; ADFI = average daily feed intake; NA = not applicable.

no difference in ADG, ADFI, NE intake, or gain:feed ( $P > .05$ ) (Table 4). In barrows fed the low-protein, CAA-supplemented diet containing 2.36 Mcal NE per kg, ADG and gain:NE intake were greater than in barrows fed the low-protein diet with 2.50 and 2.58 Mcal NE per kg (Table 4). However, ADG, gain:NE intake, and gain:feed did not differ between barrows fed the low-protein diet with 2.36 Mcal NE per kg and those fed the high CP diet ( $P > .05$ ).

Among the groups fed the low-protein diets with different NE levels, ADG ( $P < .05$ ) and gain:NE intake ( $P < .01$ ) increased with decreasing NE level, but NE intake decreased linearly ( $P < .05$ ). A significant quadratic effect ( $P < .01$ ) was also observed for ADG and gain:NE intake.

## Experiment Two

Performance data are presented in Table 5. There was no difference in ADFI and NE intake between the barrows fed the high-CP diet and those fed any of the low-CP diets ( $P > .05$ ). However, ADG and gain:feed were greater in barrows fed the 2.35 Mcal NE per kg diet than in barrows fed the 2.45, 2.30, and 2.25 Mcal NE per kg diets ( $P < .05$ ). There was no difference in ADG, gain:NE intake, and gain:feed between barrows fed the 2.35 Mcal NE per kg diet and those fed the high-CP diet ( $P > .05$ ).

In barrows fed the low-CP dietary treatments with different NE levels, there was a significant quadratic increase in ADG, gain:feed, and gain:NE intake as NE levels increased from 2.25 to 2.35 Mcal NE per kg ( $P < .05$ ).

## Broken-line analyses

Broken-line analyses<sup>17</sup> estimated that the NE level which optimized the ratios of gain to NE intake were 2.50 and 2.31 Mcal NE per kg for Experiments One and Two, respectively. The average of these values yielded an estimate of 2.40 Mcal NE per kg.

## Discussion

Low-protein diets have been associated with lower energy losses for metabolizing excess dietary protein.<sup>8</sup> It is well known that low-protein diets decrease the energy needed for deamination of excess amino acids and excretion of nitrogen in urine. Moreover, lowering the CP level of a corn-soybean meal diet can reduce body-protein turnover and heat production of animals.<sup>8</sup> Therefore, reducing CP increases the energy available

for tissue deposition. This agrees with the NE system, in which energy requirements and diet energy values are expressed on the same basis, which should theoretically be independent of feed characteristics.<sup>10</sup> The NE system represents the best estimate of the “true” energy value of a feed. The energy value of protein or fibrous feeds is overestimated when expressed on a DE (or ME) basis. On the other hand, the energy values of fat or starch sources are underestimated in a DE system.<sup>11</sup> Therefore, understanding how energy is utilized by the pig and how the pig responds to changes in dietary NE levels is essential in determining the optimal concentration of dietary energy in low-protein diets. However, despite a large number of low-protein diet studies reported in the literature, the relationships between dietary NE concentration and animal growth when low-protein diets are fed are not well understood.

Studies using corn and soybean-meal basal diets have evaluated the impact of NE content by varying wheat bran and soybean oil concentrations in low-protein diets; in those experiments, results have been inconsistent.<sup>2,3,12</sup> Knowles et al<sup>12</sup> reported that altering dietary fiber or fat did not affect swine growth performance, but Kerr et al<sup>3</sup> found that adding fiber to low-protein diets did affect growth performance. The results of the current experiment indicate that the NE content of the diet may affect the performance of pigs fed low-CP diets supplemented with CAA. In Experiment One, there was a significant linear increase in weight gain as the NE content of the low-protein diet decreased, with the weight gain of pigs fed diets containing 2.64 and 2.58 Mcal NE per kg being less than that of pigs fed the high CP diet containing 2.50 Mcal NE per kg. Moreover, in this study, in pigs fed CAA-supplemented diets in which the CP content was reduced by four percentage units and with 2.36 (Experiment One) or 2.35 (Experiment Two) Mcal NE per kg, performance was better than that of pigs fed the low-CP diet and did not differ from that of pigs fed the high-protein diet. This finding can be explained, at least partially, by the inverse relationship between the NE content of the diet and performance.

The lack of improvement in growth with increasing dietary energy concentration may suggest that requirements for NE content are different for optimal performance when low-CP diets rather than high-CP diets

are fed, which is in agreement with the findings of Knowles et al<sup>12</sup> and Kerr et al.<sup>3</sup> These results also suggest that formulation of growing-pig diets with a proper NE level improves energy utilization of low-CP diets, which may also improve pig performance. This observation is in agreement with the data reported by Noblet and Le Goff.<sup>18</sup>

Dietary NE had no effect on overall daily feed intake in either experiment. Although it is well known that changes in dietary energy may have large impacts on feed intake,<sup>19</sup> most studies have dealt with relatively large differences in dietary energy levels. These have been discussed in a recent review.<sup>20</sup> It has generally been assumed that over a wide range of dietary energy concentrations, growing pigs will adjust feed intake to maintain a constant or nearly constant daily energy intake.<sup>21</sup> Each current experiment is a case in point, and the effect agrees with results of Knowles et al<sup>12</sup> and Kerr et al,<sup>3</sup> who respectively reported identical consumption of feeds of different net energy content when low-CP diets were supplemented with amino acids.

It has long been suggested that grower pigs are less likely to be able to maintain growth performance when dietary energy is reduced. In this study, this effect was observed in the second experiment, but not in the first. Although it is consistent with the literature to suggest that physical gut capacity may have been a limiting factor for growth performance, it could also have been driven by the innate growth curve of the pig and the consequent need or demand for nutrients such as amino acids.<sup>20</sup> In the current studies (Experiment One), when diets contained 2.64 and 2.58 Mcal NE per kg, there may have been insufficient intake of amino acids, especially limited amino acids, to support lean tissue growth. In order to avoid providing energy for deamination of excess amino acids in many studies involving low-protein diets, energy levels are varied, but amino-acid levels are not.<sup>2,3,12</sup> Our current studies agree with the literature in that when lower levels of NE were fed (ie, 2.42 and 2.36 Mcal NE per kg in Experiment One or 2.40 and 2.35 Mcal NE per kg in Experiment Two), the total intake of amino acids was sufficient to support greater daily gain. In addition, the daily intake of NE was lower for pigs fed these diets (ie, 3.76 and 3.78 Mcal NE per day in Experiment One), which would also result in less energy being available for daily gain.

In the current studies, amino-acid contents of diets were formulated to meet NRC recommendations, and broken-line analyses using the data from the two experiments estimated that the NE level which optimized the ratios of gain to NE intake was 2.40 Mcal NE per kg. Kerr et al<sup>3</sup> reported greater ADG and gain:feed of growing pigs fed low-protein diets as dietary NE increased from 2.412 to 2.536 Mcal NE per kg when the true ileal digestible lysine level was 0.96% of the low-protein diets. However, at true ileal digestible lysine levels of 0.84% (Experiment One) or 0.89% (Experiment Two), the ileal digestible lysine:NE ratios of the diets are 3.50 and 3.71 g per Mcal NE, respectively, which are comparable to results of the studies of Kerr et al,<sup>3</sup> in which the ileal digestible lysine:NE ratio of the diets was 3.78 g per Mcal NE.

## Implications

- Under the conditions of these studies, the optimum NE level in low-protein diets supplemented with CAA is approximately 2.40 Mcal NE per kg.
- Under the conditions of these studies, performance of growing pigs is not negatively affected when diets containing CP 4% lower than recommended are supplemented with CAA and have the appropriate NE content.
- Further experiments are needed to determine whether changes in amino-acid levels can improve performance of pigs fed low-protein diets.

## Acknowledgements

This study was supported by the National Natural Science Foundation of P.R. China (NSFC30525029). The authors wish to thank Dr Lee Chiba for the critical review of the manuscript.

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