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## Effect of Fiber Source and Crude Protein Level on Nursery Pig Performance

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## Effect of Fiber Source and Crude Protein Level on Nursery Pig Performance

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### Summary

A total of 360 pigs (200 × 400; DNA, Columbus, NE; initially = 11.0 lb) were used in a 45-d growth trial to evaluate the effects of fiber source and crude protein level on growth performance and fecal dry matter of nursery pigs. Upon arrival to the nursery research facility, pigs were randomly assigned to pens with 5 pigs per pen and 9 replicate pens per treatment. Dietary treatments were arranged in a 2 × 4 completely randomized factorial with main effects of crude protein (21 or 18% CP) and fiber source (none, coarse wheat bran, oat hulls, or cellulose; Arbocel, J. Rettenmaier USA, Schoolcraft, MI). Treatment diets were formulated in two dietary phases from d 0 to 10 and 10 to 24, with a common post-treatment diet fed from d 24 to 45. The 21% CP diets contained 1.40% standardized ileal digestible lysine (SID) in phase 1 and 1.35% SID Lys in phase 2. Treatment diets were formulated to a maximum SID Lys:digestible CP level of 6.35%, thus SID Lys decreased in the 18% CP (1.25% SID Lys) diets to maintain the ratio. Diets containing a fiber source were formulated to the level of insoluble fiber provided by 4% coarse wheat bran, resulting in the addition of 1.85% oat hulls and 1.55% cellulose to the respective diets. No fiber source × CP level interactions ( $P > 0.05$ ) were observed throughout the study. During the experimental period, decreasing dietary CP (and subsequently SID Lys) decreased ( $P = 0.05$ ) ADG, and d 24 body weight (BW) and worsened feed efficiency (F/G). Average daily gain and d 45 BW decreased ( $P < 0.05$ ) for pigs fed 18% CP diets compared to pigs fed 21% CP diets overall from 0 to 45. Fecal dry matter on d 17 was increased ( $P < 0.001$ ) for pigs fed 18% CP diets compared to pigs fed 21% CP diets. No main effects of fiber source were observed for growth performance throughout the study. However, fecal dry matter percentage increased ( $P < 0.05$ ) for pigs fed added cellulose compared to pigs fed no fiber or coarse wheat bran on d 10 and 24 of the trial. Similarly, pigs fed cellulose had increased ( $P = 0.028$ ) fecal dry matter compared to pigs fed no fiber, with pigs fed coarse wheat bran and oat hulls intermediate. In conclusion, reducing dietary crude protein resulted in decreased growth performance while minimal improvements in fecal dry matter were observed during the experimental period. The source or inclusion of insoluble fiber in nursery diets had no impact on performance. The inclusion of cellulose improved fecal dry matter compared to feeding no dietary fiber or coarse wheat bran.

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## Introduction

Newly weaned pigs often experience post-weaning diarrhea (PWD), which is characterized by recurrent discharge of loose, watery feces in the first weeks after weaning. To mitigate the severity of PWD, pharmacological levels of Zn (3,000 to 2,000 ppm of Zn) can be fed to young pigs, as high levels of Zn have been observed to possess antimicrobial effects and to decrease intestinal inflammation, along with promoting growth performance. However, increasing regulations on pharmacological levels of Zn have increased the need for an alternative dietary strategy that minimizes the harmful effects of PWD while maintaining pig performance.

Due to an immature gastrointestinal system, pigs often struggle to digest high protein diets. Undigested protein passes through the digestive tract, ultimately serving as a substrate for microbial fermentation in the large intestine. Protein fermentation has been determined as a significant contributing factor to PWD from the production of harmful fermentation by-products. Reducing the dietary crude protein (CP) level of the diet while supplementing crystalline amino acids has been identified as an effective method to improve the fecal consistency and intestinal health of weanling piglets. However, mixed implications on growth performance have been observed when dietary CP is reduced.

Another possible method to improve post-weaning performance could be to promote colonization of commensal microbiota with the inclusion of fiber ingredients. Insoluble dietary fiber increases digesta passage rate, blocking the attachment of pathogenic bacteria. Therefore, the objective of this study was to determine the effect of dietary crude protein with and without the inclusion of a fiber source on nursery pig performance and fecal dry matter.

## Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan, KS. The facility has two identical barns that are completely enclosed, environmentally controlled, and mechanically ventilated. Each pen contained a 4-hole, dry self-feeder and a cup waterer to provide *ad libitum* access to feed and water. Pens (4 × 4 ft) had metal tri-bar floors and allowed approximately 2.7 ft<sup>2</sup>/pig.

Following arrival to the research facility, 360 pigs (200 × 400; DNA, Columbus, NE; initially 11.0 lb) were used in a 45-d study with 5 pigs per pen and 9 replicate pens per treatment. Pigs were weaned at approximately 21 d of age and upon arrival, pigs were randomly assigned to pens and then pens were allotted to 1 of 8 dietary treatments in a completely randomized design. Treatments were equally represented in each of the 2 barns, with 4 replications and 5 replications in barn 1 and 2, respectively.

Treatment diets were arranged in a 2 × 4 factorial with main effects of CP level (21 or 18% CP) and fiber source (none, 4% coarse wheat bran, 1.85% oat hulls, or 1.55% cellulose; Arbocel, J. Rettenmaier USA, Schoolcraft, MI). Prior to the study, the fiber ingredients were analyzed (University of Illinois, Urbana-Champaign, IL) for acid

detergent fiber (ADF), neutral detergent fiber (NDF), insoluble, soluble, and total dietary fiber (Table 1). These values were used in diet formulation to provide a similar amount of insoluble fiber in all diets that contained the fiber sources using the inclusion of 4% coarse wheat bran as the target insoluble fiber content. The diets with 21% CP contained 1.40% standardized ileal digestible (SID) Lys in phase 1 and 1.35% SID Lys in phase 2, while the 18% CP diets contained 1.25% SID Lys in both phases (Table 2 and 3). Diets were formulated to a maximum SID Lys:digestible CP level of 6.35%, thus SID Lys decreased in the 18% CP diets. All diets were formulated to obtain a similar ratio of essential SID amino acids to SID Lys by using feed grade amino acids. Ingredient nutrient values as well as their SID coefficients used in diet formulation were derived from NRC.<sup>2</sup> Treatment diets were offered in two dietary phases (phase 1 fed from d 0 to 10 and phase 2 from d 10 to 24 post-weaning). A post-treatment period with a common diet (1.35% SID Lys) was fed from d 24 to 45 (Table 4).

The first phase was fed in pellet form, the feed was manufactured at the Kansas State University Bioprocessing and Industrial Value-Added Products Innovation Center, Manhattan, KS. The second phase of experimental diets was fed as meal, which was manufactured at the Tom Avery Poultry Research farm in Manhattan, KS. The average particle size of the coarse wheat bran, oat hulls, and cellulose included in the experimental diets were determined to be 1,041, 1,168, and 101 microns, respectively. Particle size analysis was done using the ANSI/ASAE S319.2 method with a Ro-tap 13-sieve shaker using flow agent and sieve agitators. Pig weight and feed disappearance were measured on d 0, 10, 17, 24, and 45 of the trial to determine ADG, ADFI, and F/G.

Fecal samples were collected from the same three pigs per pen on d 10, 17, 24, and 45 of the study. Fecal samples were collected into clean, single use zipper storage bags and were then stored at -4°F until fecal dry matter analysis. Fecal samples were pooled by pen for each day of collection and dried at 131°F for 48 h in a forced air oven. Fecal dry matter was determined as follows: (dried sample weight at 48 h - pan weight) / (initial wet sample weight - pan weight) × 100.

### *Statistical Analysis*

Statistical analysis was performed using the lmer function from the lme4 package in R (version 3.6.1 (2019-07-05), R Foundation for Statistical Computing, Vienna, Austria). Growth performance data were analyzed as a 2 × 4 factorial in a completely randomized design with pen as the experimental unit. Barn was included in the model as a random effect. The main effects of CP level and fiber source, as well as their interactions, were tested. A repeated measures statement, with the random effect of barn, was used for analyzing fecal dry matter. Differences between treatments were considered significant at  $P \leq 0.05$  and marginally significant at  $0.05 < P \leq 0.10$ .

## **Results and Discussion**

For growth measurements, no CP × fiber source interactions were observed throughout the 45-d study (Tables 5 and 6). From d 0 to 10, pigs fed 21% CP had increased ( $P < 0.05$ ) ADG, d 10 BW, and improved feed efficiency compared to pigs fed diets with 18% CP (Table 7). Similar responses to dietary CP level were observed from d 10

<sup>2</sup> NRC. 2012. Nutrient Requirements of Swine. 11<sup>th</sup> ed. Natl. Acad. Press, Washington, D.C.

to 24, as pigs fed 18% CP diets had decreased ( $P = 0.020$ ) ADG and poorer ( $P = 0.025$ ) F/G compared to pigs fed 21% CP diets. No evidence for differences for growth performance were observed among any of the fiber sources in phase 1 and 2.

For the overall experimental phase (d 0 to 24), pigs fed 18% CP had decreased ( $P = 0.003$ ) ADG and poorer ( $P < 0.001$ ) F/G compared to pigs fed 21% CP diets. The decrease in performance for pigs fed 18% CP resulted in lighter ( $P = 0.002$ ) BW on d 24 compared to pigs fed 21% CP diets. A post-treatment period with a common diet was fed from d 24 to 45, and no evidence for differences in any growth criteria for previously fed CP level or fiber source was observed. Overall (d 0 to 45), pigs fed 18% CP had decreased ( $P < 0.05$ ) ADG and final BW at the end of the study compared to pigs fed 21% CP diets. Fiber source had no effect on nursery pig growth performance.

Reducing the dietary CP level and subsequently reducing SID Lys initiated decreased growth performance in the current study for pigs fed 18% CP (1.25% SID Lys). Diets were formulated to a maximum SID Lys:digestible CP of 6.35%, therefore SID Lys was reduced to maintain this ratio in the 18% CP diets. Reducing dietary CP has been observed to result in mixed growth performance responses, which could be attributed to comparing studies with differences in weaning age, initial BW, the dietary CP content classified as low or high, and if SID Lys was balanced across treatment diets.

Fecal dry matter percentage was used to evaluate treatment effects on the incidence of scours. No CP level  $\times$  fiber source interactions were observed for fecal dry matter (DM) percentage (Tables 7 and 8). However, fecal DM was increased on d 10 and 24 for pigs fed diets with added cellulose, compared to those pigs fed diets with no added fiber or pigs fed diets containing coarse wheat bran, and pigs fed oat hulls intermediate. Pigs fed added cellulose had increased fecal DM compared to pigs fed no fiber on d 17 of the trial. On d 17, fecal DM was also increased for pigs fed 18% CP compared to pigs fed 21% CP diets. No evidence for differences in fecal DM percentage on d 45 were observed between pigs previously fed 21% or 18% CP or between pigs fed diets with or without a fiber source from d 0 to 24.

In summary, reducing dietary crude protein resulted in decreased growth performance while minimal improvements in fecal dry matter were observed during the experimental period. The source or inclusion of insoluble fiber in nursery diets had no impact on performance. The inclusion of cellulose improved fecal dry matter compared to feeding no dietary fiber or coarse wheat bran.

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**Table 1. Analyzed chemical fiber composition of ingredients<sup>1</sup>**

| Analyzed composition, %      | Fiber source |           |                        |
|------------------------------|--------------|-----------|------------------------|
|                              | Wheat bran   | Oat hulls | Cellulose <sup>2</sup> |
| ADF                          | 12.8         | 45.2      | 65.9                   |
| NDF                          | 42.4         | 81.0      | 78.0                   |
| Total dietary fiber          | 44.7         | 85.3      | 96.0                   |
| Insoluble fiber <sup>3</sup> | 41.6         | 83.6      | 93.9                   |
| Soluble fiber                | 3.1          | 1.7       | 2.1                    |

<sup>1</sup>Analyzed by University of Illinois (Urbana – Champaign, IL).

<sup>2</sup>Arbocel (J. Rettenmaier USA, Schoolcraft, MI).

<sup>3</sup>Treatment diets were formulated to balance for analyzed insoluble fiber content.

**Table 2. Phase 1 diet composition (as-fed basis)<sup>1</sup>**

| Ingredient, %                                   | Fiber source and crude protein: |       |            |       |           |       |           |       |
|-------------------------------------------------|---------------------------------|-------|------------|-------|-----------|-------|-----------|-------|
|                                                 | No fiber                        |       | Wheat bran |       | Oat hulls |       | Cellulose |       |
|                                                 | 21%                             | 18%   | 21%        | 18%   | 21%       | 18%   | 21%       | 18%   |
| Corn                                            | 44.85                           | 52.30 | 41.50      | 49.00 | 42.95     | 50.40 | 43.00     | 50.45 |
| Soybean meal, 46.5% CP                          | 18.10                           | 10.40 | 17.45      | 9.75  | 18.20     | 10.50 | 18.35     | 10.65 |
| Coarse wheat bran                               | ---                             | ---   | 4.00       | 4.00  | ---       | ---   | ---       | ---   |
| Oat hulls                                       | ---                             | ---   | ---        | ---   | 1.85      | 1.85  | ---       | ---   |
| Cellulose <sup>2</sup>                          | ---                             | ---   | ---        | ---   | ---       | ---   | 1.55      | 1.55  |
| Fish meal                                       | 4.50                            | 4.50  | 4.50       | 4.50  | 4.50      | 4.50  | 4.50      | 4.50  |
| Dried whey                                      | 25.00                           | 25.00 | 25.00      | 25.00 | 25.00     | 25.00 | 25.00     | 25.00 |
| Enzymatically treated soybean meal <sup>3</sup> | 3.75                            | 3.75  | 3.75       | 3.75  | 3.75      | 3.75  | 3.75      | 3.75  |
| Soybean oil                                     | 1.50                            | 1.50  | 1.50       | 1.50  | 1.50      | 1.50  | 1.50      | 1.50  |
| Calcium carbonate                               | 0.30                            | 0.35  | 0.35       | 0.40  | 0.23      | 0.25  | 0.30      | 0.35  |
| Monocalcium phosphate, 21%                      | 0.20                            | 0.30  | 0.10       | 0.20  | 0.20      | 0.30  | 0.20      | 0.30  |
| Salt                                            | 0.30                            | 0.33  | 0.30       | 0.33  | 0.30      | 0.33  | 0.30      | 0.33  |
| L-Lysine                                        | 0.43                            | 0.48  | 0.44       | 0.49  | 0.43      | 0.48  | 0.42      | 0.47  |
| DL-Methionine                                   | 0.22                            | 0.20  | 0.22       | 0.20  | 0.22      | 0.20  | 0.22      | 0.20  |
| L-Threonine                                     | 0.20                            | 0.21  | 0.20       | 0.21  | 0.20      | 0.21  | 0.20      | 0.21  |
| L-Tryptophan                                    | 0.07                            | 0.08  | 0.07       | 0.08  | 0.07      | 0.08  | 0.07      | 0.08  |
| L-Valine                                        | 0.14                            | 0.17  | 0.14       | 0.17  | 0.14      | 0.17  | 0.14      | 0.17  |
| Trace mineral premix                            | 0.15                            | 0.15  | 0.15       | 0.15  | 0.15      | 0.15  | 0.15      | 0.15  |
| Vitamin premix                                  | 0.25                            | 0.25  | 0.25       | 0.25  | 0.25      | 0.25  | 0.25      | 0.25  |
| Phytase <sup>4</sup>                            | 0.08                            | 0.08  | 0.08       | 0.08  | 0.08      | 0.08  | 0.08      | 0.08  |
| Total                                           | 100                             | 100   | 100        | 100   | 100       | 100   | 100       | 100   |

*continued*

**Table 2. Phase 1 diet composition (as-fed basis)<sup>1</sup>**

| Ingredient, %                                | Fiber source and crude protein: |       |            |       |           |       |           |       |
|----------------------------------------------|---------------------------------|-------|------------|-------|-----------|-------|-----------|-------|
|                                              | No fiber                        |       | Wheat bran |       | Oat hulls |       | Cellulose |       |
|                                              | 21%                             | 18%   | 21%        | 18%   | 21%       | 18%   | 21%       | 18%   |
| Calculated analysis                          |                                 |       |            |       |           |       |           |       |
| Standardized digestible (SID) amino acids, % |                                 |       |            |       |           |       |           |       |
| Lysine                                       | 1.40                            | 1.25  | 1.40       | 1.25  | 1.40      | 1.25  | 1.40      | 1.25  |
| Isoleucine:lysine                            | 56                              | 53    | 56         | 52    | 56        | 52    | 56        | 53    |
| Leucine:lysine                               | 110                             | 108   | 108        | 106   | 109       | 107   | 109       | 108   |
| Methionine:lysine                            | 37                              | 38    | 37         | 38    | 37        | 38    | 37        | 38    |
| Methionine and cysteine:lysine               | 57                              | 57    | 58         | 58    | 57        | 57    | 57        | 57    |
| Threonine:lysine                             | 64                              | 64    | 64         | 64    | 64        | 64    | 64        | 64    |
| Tryptophan:lysine                            | 21.0                            | 20.9  | 21.1       | 21.0  | 21.0      | 20.9  | 21.1      | 21.0  |
| Valine:lysine                                | 70                              | 70    | 70         | 70    | 70        | 70    | 70        | 70    |
| Total lysine, %                              | 1.54                            | 1.37  | 1.54       | 1.37  | 1.58      | 1.41  | 1.54      | 1.37  |
| Metabolizable energy, kcal/lb                | 1,562                           | 1,563 | 1,543      | 1,545 | 1,546     | 1,548 | 1,538     | 1,539 |
| Net energy, kcal/lb                          | 1,177                           | 1,196 | 1,161      | 1,180 | 1,163     | 1,182 | 1,158     | 1,176 |
| SID lysine:NE, g/Mcal                        | 5.40                            | 4.74  | 5.47       | 4.81  | 5.46      | 4.80  | 5.49      | 4.82  |
| Crude protein, %                             | 21.0                            | 18.0  | 21.0       | 18.0  | 21.0      | 18.0  | 21.0      | 18.0  |
| Calcium, %                                   | 0.65                            | 0.66  | 0.65       | 0.66  | 0.65      | 0.66  | 0.65      | 0.66  |
| Phosphorus, %                                | 0.62                            | 0.61  | 0.63       | 0.61  | 0.65      | 0.64  | 0.62      | 0.61  |
| STTD <sup>5</sup> P, %                       | 0.54                            | 0.54  | 0.54       | 0.54  | 0.54      | 0.54  | 0.54      | 0.54  |
| Insoluble fiber, %                           | 5.0                             | 4.4   | 6.4        | 5.8   | 6.4       | 5.8   | 6.4       | 5.8   |
| Insoluble:soluble fiber                      | 4.5                             | 5.1   | 5.4        | 6.2   | 5.7       | 6.6   | 5.6       | 6.5   |

<sup>1</sup>Phase 1 diets were fed from approximately 11.0 to 12.4 lb.

<sup>2</sup>Arbocel (J. Rettenmaier USA, Schoolcraft, MI).

<sup>3</sup>HP 300 (Hamlet Protein, Findlay, OH).

<sup>4</sup>Ronozyme HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) provided an estimated release of 0.10% STTD P.

<sup>5</sup>Standardized total tract digestible phosphorus.

**Table 3. Phase 2 diet composition (as-fed basis)<sup>1</sup>**

| Ingredient, %              | Fiber source and crude protein: |       |            |       |           |       |           |       |
|----------------------------|---------------------------------|-------|------------|-------|-----------|-------|-----------|-------|
|                            | No fiber                        |       | Wheat bran |       | Oat hulls |       | Cellulose |       |
|                            | 21%                             | 18%   | 21%        | 18%   | 21%       | 18%   | 21%       | 18%   |
| Corn                       | 56.10                           | 63.80 | 52.80      | 60.45 | 54.20     | 61.90 | 54.15     | 61.95 |
| Soybean meal, 46.5% CP     | 30.00                           | 22.00 | 29.35      | 21.30 | 30.15     | 22.05 | 30.45     | 22.20 |
| Coarse wheat bran          | ---                             | ---   | 4.00       | 4.00  | ---       | ---   | ---       | ---   |
| Oat hulls                  | ---                             | ---   | ---        | ---   | 1.85      | 1.85  | ---       | ---   |
| Cellulose <sup>2</sup>     | ---                             | ---   | ---        | ---   | ---       | ---   | 1.55      | 1.55  |
| Dried whey                 | 10.00                           | 10.00 | 10.00      | 10.00 | 10.00     | 10.00 | 10.00     | 10.00 |
| Calcium carbonate          | 0.98                            | 0.98  | 1.03       | 1.03  | 0.90      | 0.88  | 0.98      | 0.98  |
| Monocalcium phosphate, 21% | 0.80                            | 0.90  | 0.70       | 0.80  | 0.80      | 0.90  | 0.80      | 0.90  |
| Salt                       | 0.55                            | 0.58  | 0.55       | 0.58  | 0.55      | 0.58  | 0.55      | 0.58  |
| L-Lysine                   | 0.47                            | 0.60  | 0.48       | 0.61  | 0.47      | 0.60  | 0.46      | 0.59  |
| DL-Methionine              | 0.21                            | 0.23  | 0.21       | 0.23  | 0.21      | 0.23  | 0.21      | 0.23  |
| L-Threonine                | 0.21                            | 0.26  | 0.21       | 0.26  | 0.21      | 0.26  | 0.21      | 0.26  |
| L-Tryptophan               | 0.06                            | 0.08  | 0.06       | 0.08  | 0.06      | 0.08  | 0.06      | 0.08  |
| L-Valine                   | 0.13                            | 0.20  | 0.13       | 0.20  | 0.13      | 0.20  | 0.13      | 0.20  |
| L-Isoleucine               | ---                             | 0.03  | ---        | 0.03  | ---       | 0.03  | ---       | 0.03  |
| Trace mineral premix       | 0.15                            | 0.15  | 0.15       | 0.15  | 0.15      | 0.15  | 0.15      | 0.15  |
| Vitamin premix             | 0.25                            | 0.25  | 0.25       | 0.25  | 0.25      | 0.25  | 0.25      | 0.25  |
| Phytase <sup>3</sup>       | 0.08                            | 0.08  | 0.08       | 0.08  | 0.08      | 0.08  | 0.08      | 0.08  |
| Total                      | 100                             | 100   | 100        | 100   | 100       | 100   | 100       | 100   |

*continued*

**Table 3. Phase 2 diet composition (as-fed basis)<sup>1</sup>**

| Ingredient, %                                | Fiber source and crude protein: |       |            |       |           |       |           |       |
|----------------------------------------------|---------------------------------|-------|------------|-------|-----------|-------|-----------|-------|
|                                              | No fiber                        |       | Wheat bran |       | Oat hulls |       | Cellulose |       |
|                                              | 21%                             | 18%   | 21%        | 18%   | 21%       | 18%   | 21%       | 18%   |
| Calculated analysis                          |                                 |       |            |       |           |       |           |       |
| Standardized digestible (SID) amino acids, % |                                 |       |            |       |           |       |           |       |
| Lysine                                       | 1.35                            | 1.25  | 1.35       | 1.25  | 1.35      | 1.25  | 1.35      | 1.25  |
| Isoleucine:lysine                            | 56                              | 52    | 56         | 52    | 56        | 52    | 57        | 52    |
| Leucine:lysine                               | 114                             | 107   | 112        | 105   | 113       | 106   | 113       | 107   |
| Methionine:lysine                            | 36                              | 37    | 36         | 37    | 36        | 37    | 36        | 37    |
| Methionine and cysteine:lysine               | 57                              | 57    | 58         | 58    | 57        | 57    | 57        | 57    |
| Threonine:lysine                             | 64                              | 64    | 64         | 64    | 64        | 64    | 64        | 64    |
| Tryptophan:lysine                            | 20.8                            | 20.9  | 20.9       | 21.0  | 20.8      | 20.9  | 20.9      | 20.9  |
| Valine:lysine                                | 70                              | 70    | 70         | 70    | 70        | 70    | 70        | 70    |
| Total lysine, %                              | 1.49                            | 1.37  | 1.49       | 1.37  | 1.53      | 1.41  | 1.49      | 1.37  |
| Metabolizable energy, kcal/lb                | 1,490                           | 1,494 | 1,472      | 1,476 | 1,475     | 1,479 | 1,466     | 1,470 |
| Net energy, kcal/lb                          | 1,105                           | 1,126 | 1,088      | 1,110 | 1,090     | 1,112 | 1,085     | 1,106 |
| SID lysine:NE, g/Mcal                        | 5.54                            | 5.04  | 5.63       | 5.11  | 5.62      | 5.10  | 5.65      | 5.12  |
| Crude protein, %                             | 21.0                            | 18.0  | 21.0       | 18.0  | 21.0      | 18.0  | 21.0      | 18.0  |
| Calcium, %                                   | 0.76                            | 0.75  | 0.76       | 0.75  | 0.76      | 0.75  | 0.76      | 0.75  |
| Phosphorus, %                                | 0.60                            | 0.58  | 0.61       | 0.59  | 0.63      | 0.61  | 0.60      | 0.58  |
| STTD <sup>4</sup> P, %                       | 0.49                            | 0.49  | 0.49       | 0.49  | 0.49      | 0.49  | 0.49      | 0.49  |
| Insoluble fiber, %                           | 7.1                             | 6.6   | 8.5        | 8.0   | 8.6       | 8.0   | 8.5       | 8.0   |
| Insoluble:soluble fiber                      | 4.3                             | 4.6   | 4.9        | 5.3   | 5.1       | 5.5   | 5.0       | 5.5   |

<sup>1</sup>Phase 2 diets were fed from approximately 12.4 to 22.0 lb.

<sup>2</sup>Arbocel (J. Rettenmaier USA, Schoolcraft, MI).

<sup>3</sup>HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) provided an estimated release of 0.10% STTD P.

<sup>4</sup>Standardized total tract digestible phosphorus.

**Table 4. Phase 3 common diet composition, (as-fed basis)<sup>1</sup>**

| Ingredient, %                            | Common diet |
|------------------------------------------|-------------|
| Corn                                     | 65.47       |
| Soybean meal, 46.5% CP                   | 28.30       |
| Choice white grease                      | 2.00        |
| Calcium carbonate                        | 0.75        |
| Monocalcium phosphate, 21% P             | 1.10        |
| Sodium chloride                          | 0.60        |
| L-Lysine-HCl                             | 0.55        |
| DL-Methionine                            | 0.25        |
| L-Threonine                              | 0.23        |
| L-Tryptophan                             | 0.05        |
| L-Valine                                 | 0.16        |
| Trace mineral premix                     | 0.15        |
| Vitamin premix with phytase <sup>2</sup> | 0.25        |
| Pellet stabilizer <sup>3</sup>           | 0.15        |
| Total                                    | 100.00      |
| SID amino acids, %                       |             |
| Lysine                                   | 1.30        |
| Isoleucine:lysine                        | 53          |
| Leucine:lysine                           | 111         |
| Methionine:lysine                        | 39          |
| Met and cysteine:lysine                  | 60          |
| Threonine:lysine                         | 63          |
| Tryptophan:lysine                        | 19.3        |
| Valine:lysine                            | 70          |
| Histidine:lysine                         | 35          |
| Net energy, kcal/lb                      | 1,152       |
| Crude protein, %                         | 19.9        |
| Calcium, %                               | 0.65        |
| STTD <sup>4</sup> P, %                   | 0.48        |
| Insoluble fiber, %                       | 7.5         |
| Insoluble fiber:soluble fiber            | 4.4         |

<sup>1</sup>Phase 3 common diets were fed from d 24 to 45.

<sup>2</sup>Ronozyme HiPhos GT 2700 (DSM Nutritional Products, Parsippany, NJ) provided an expected P release of 0.15%.

<sup>3</sup>Alltech All-Bind HD (Alltech, Nicholasville, KY).

<sup>4</sup>STTD P = standardized total tract digestible phosphorus.

**Table 5. Interactive effects of fiber source and crude protein (CP) on nursery pig performance<sup>1</sup>**

|                                 | Fiber source and crude protein <sup>2</sup> : |      |            |      |           |      |                        |      |       |                       |
|---------------------------------|-----------------------------------------------|------|------------|------|-----------|------|------------------------|------|-------|-----------------------|
|                                 | None                                          |      | Wheat bran |      | Oat hulls |      | Cellulose <sup>3</sup> |      |       | Probability, <i>P</i> |
| Item                            | 21%                                           | 18%  | 21%        | 18%  | 21%       | 18%  | 21%                    | 18%  | SEM   | Fiber × CP            |
| BW, lb                          |                                               |      |            |      |           |      |                        |      |       |                       |
| d 0                             | 11.0                                          | 11.0 | 11.0       | 11.0 | 11.0      | 10.9 | 11.0                   | 10.9 | 0.11  | 0.376                 |
| d 10                            | 12.7                                          | 12.2 | 12.6       | 12.4 | 12.5      | 12.0 | 12.7                   | 12.1 | 0.17  | 0.752                 |
| d 24                            | 22.4                                          | 21.7 | 22.4       | 21.4 | 22.6      | 21.0 | 22.8                   | 21.4 | 0.62  | 0.881                 |
| d 45                            | 48.2                                          | 47.7 | 48.2       | 47.0 | 47.2      | 45.6 | 49.1                   | 46.3 | 1.22  | 0.783                 |
| d 0 to 10                       |                                               |      |            |      |           |      |                        |      |       |                       |
| ADG, lb                         | 0.17                                          | 0.11 | 0.16       | 0.14 | 0.15      | 0.11 | 0.16                   | 0.12 | 0.020 | 0.701                 |
| ADFI, lb                        | 0.24                                          | 0.22 | 0.23       | 0.24 | 0.23      | 0.21 | 0.24                   | 0.23 | 0.025 | 0.414                 |
| F/G                             | 1.48                                          | 2.30 | 1.44       | 1.98 | 1.69      | 2.01 | 1.48                   | 1.93 | 0.210 | 0.666                 |
| d 10 to 24                      |                                               |      |            |      |           |      |                        |      |       |                       |
| ADG, lb                         | 0.70                                          | 0.68 | 0.70       | 0.64 | 0.71      | 0.65 | 0.72                   | 0.67 | 0.038 | 0.849                 |
| ADFI, lb                        | 0.88                                          | 0.88 | 0.93       | 0.86 | 0.92      | 0.85 | 0.90                   | 0.88 | 0.051 | 0.604                 |
| F/G                             | 1.26                                          | 1.31 | 1.32       | 1.34 | 1.29      | 1.32 | 1.25                   | 1.33 | 0.027 | 0.688                 |
| d 0 to 24 (Experimental period) |                                               |      |            |      |           |      |                        |      |       |                       |
| ADG, lb                         | 0.48                                          | 0.44 | 0.48       | 0.43 | 0.48      | 0.42 | 0.49                   | 0.44 | 0.028 | 0.989                 |
| ADFI, lb                        | 0.61                                          | 0.60 | 0.64       | 0.60 | 0.63      | 0.58 | 0.62                   | 0.61 | 0.039 | 0.853                 |
| F/G                             | 1.28                                          | 1.38 | 1.33       | 1.39 | 1.33      | 1.38 | 1.28                   | 1.39 | 0.026 | 0.567                 |
| d 24 to 45 (Common diet)        |                                               |      |            |      |           |      |                        |      |       |                       |
| ADG, lb                         | 1.24                                          | 1.24 | 1.23       | 1.22 | 1.17      | 1.17 | 1.26                   | 1.18 | 0.034 | 0.639                 |
| ADFI, lb                        | 1.68                                          | 1.69 | 1.72       | 1.66 | 1.64      | 1.61 | 1.74                   | 1.65 | 0.065 | 0.702                 |
| F/G                             | 1.36                                          | 1.37 | 1.41       | 1.37 | 1.40      | 1.38 | 1.39                   | 1.40 | 0.030 | 0.444                 |
| d 0 to 45                       |                                               |      |            |      |           |      |                        |      |       |                       |
| ADG, lb                         | 0.83                                          | 0.81 | 0.82       | 0.80 | 0.80      | 0.77 | 0.85                   | 0.79 | 0.029 | 0.840                 |
| ADFI, lb                        | 1.11                                          | 1.11 | 1.14       | 1.10 | 1.10      | 1.06 | 1.15                   | 1.10 | 0.051 | 0.896                 |
| F/G                             | 1.34                                          | 1.37 | 1.38       | 1.37 | 1.38      | 1.38 | 1.35                   | 1.39 | 0.024 | 0.239                 |

<sup>1</sup>A total of 360 pigs (initial BW of 10.9 ± 0.1 lb) were used in a 45-d growth study with 5 pigs per pen and 9 pens per treatment.

<sup>2</sup>Diets containing a fiber source were formulated on the insoluble fiber content of the respective ingredient.

<sup>3</sup>Arbocel (J. Rettenmaier USA, Schoolcraft, MI).

**Table 6. Main effects of fiber source and crude protein (CP) on nursery pig performance<sup>1</sup>**

| Item                            | CP   |      | SEM   | P-value | Fiber source <sup>2</sup> |            |           |                        | SEM   | P-value |
|---------------------------------|------|------|-------|---------|---------------------------|------------|-----------|------------------------|-------|---------|
|                                 | 21%  | 18%  |       |         | None                      | Wheat bran | Oat hulls | Cellulose <sup>3</sup> |       |         |
| BW, lb                          |      |      |       |         |                           |            |           |                        |       |         |
| d 0                             | 11.0 | 10.9 | 0.10  | 0.193   | 11.0                      | 11.0       | 10.9      | 10.9                   | 0.11  | 0.816   |
| d 10                            | 12.6 | 12.2 | 0.09  | 0.001   | 12.4                      | 12.5       | 12.2      | 12.4                   | 0.12  | 0.485   |
| d 24                            | 22.5 | 21.4 | 0.44  | 0.002   | 22.1                      | 21.9       | 21.8      | 22.1                   | 0.50  | 0.934   |
| d 45                            | 48.2 | 46.6 | 0.81  | 0.038   | 48.0                      | 47.6       | 46.4      | 47.7                   | 1.00  | 0.438   |
| d 0 to 10                       |      |      |       |         |                           |            |           |                        |       |         |
| ADG, lb                         | 0.16 | 0.12 | 0.015 | 0.001   | 0.14                      | 0.15       | 0.13      | 0.14                   | 0.017 | 0.580   |
| ADFI, lb                        | 0.23 | 0.22 | 0.023 | 0.218   | 0.23                      | 0.23       | 0.22      | 0.24                   | 0.024 | 0.405   |
| F/G                             | 1.52 | 2.06 | 0.106 | 0.001   | 1.89                      | 1.71       | 1.85      | 1.70                   | 0.149 | 0.731   |
| d 10 to 24                      |      |      |       |         |                           |            |           |                        |       |         |
| ADG, lb                         | 0.71 | 0.66 | 0.028 | 0.020   | 0.69                      | 0.67       | 0.68      | 0.69                   | 0.032 | 0.919   |
| ADFI, lb                        | 0.91 | 0.87 | 0.041 | 0.128   | 0.88                      | 0.89       | 0.89      | 0.89                   | 0.044 | 0.985   |
| F/G                             | 1.28 | 1.32 | 0.013 | 0.025   | 1.29                      | 1.33       | 1.31      | 1.29                   | 0.019 | 0.434   |
| d 0 to 24 (Experimental period) |      |      |       |         |                           |            |           |                        |       |         |
| ADG, lb                         | 0.48 | 0.43 | 0.022 | 0.003   | 0.46                      | 0.46       | 0.45      | 0.46                   | 0.024 | 0.903   |
| ADFI, lb                        | 0.63 | 0.60 | 0.033 | 0.111   | 0.61                      | 0.62       | 0.61      | 0.62                   | 0.035 | 0.926   |
| F/G                             | 1.31 | 1.38 | 0.013 | < 0.001 | 1.33                      | 1.36       | 1.35      | 1.34                   | 0.018 | 0.619   |
| d 24 to 45 (Common diet)        |      |      |       |         |                           |            |           |                        |       |         |
| ADG, lb                         | 1.22 | 1.20 | 0.019 | 0.416   | 1.24                      | 1.22       | 1.17      | 1.22                   | 0.025 | 0.226   |
| ADFI, lb                        | 1.70 | 1.66 | 0.054 | 0.160   | 1.69                      | 1.69       | 1.63      | 1.70                   | 0.058 | 0.283   |
| F/G                             | 1.39 | 1.38 | 0.026 | 0.334   | 1.36                      | 1.39       | 1.39      | 1.39                   | 0.028 | 0.455   |
| d 0 to 45                       |      |      |       |         |                           |            |           |                        |       |         |
| ADG, lb                         | 0.83 | 0.79 | 0.021 | 0.048   | 0.82                      | 0.81       | 0.78      | 0.82                   | 0.024 | 0.366   |
| ADFI, lb                        | 1.12 | 1.10 | 0.044 | 0.121   | 1.11                      | 1.12       | 1.08      | 1.12                   | 0.046 | 0.464   |
| F/G                             | 1.36 | 1.38 | 0.021 | 0.108   | 1.35                      | 1.38       | 1.38      | 1.37                   | 0.022 | 0.299   |

<sup>1</sup>A total of 360 pigs (initial BW of 10.9 ± 0.1 lb) were used in a 45-d growth study.

<sup>2</sup>Diets containing a fiber source were formulated on the insoluble fiber content of the respective ingredient.

<sup>3</sup>Arbocel (J. Rettenmaier USA, Schoolcraft, MI).

**Table 7. Interactive effects of fiber source and crude protein (CP) in nursery pig diets on fecal dry matter, %<sup>1</sup>**

| Day of collection | Fiber source and crude protein: <sup>2</sup> |      |            |      |           |      |                        |      | Probability, <i>P</i> |            |
|-------------------|----------------------------------------------|------|------------|------|-----------|------|------------------------|------|-----------------------|------------|
|                   | None                                         |      | Wheat bran |      | Oat hulls |      | Cellulose <sup>3</sup> |      |                       |            |
|                   | 21%                                          | 18%  | 21%        | 18%  | 21%       | 18%  | 21%                    | 18%  | SEM                   | Fiber × CP |
| d 10              | 23.8                                         | 26.2 | 25.6       | 25.6 | 27.0      | 28.1 | 29.3                   | 28.7 | 1.13                  | 0.409      |
| d 17              | 19.3                                         | 22.4 | 22.0       | 23.2 | 22.5      | 23.9 | 20.8                   | 26.1 | 0.93                  | 0.128      |
| d 24 <sup>4</sup> | 22.0                                         | 22.2 | 20.6       | 22.6 | 22.2      | 23.2 | 24.3                   | 25.1 | 0.80                  | 0.819      |
| d 45              | 27.0                                         | 27.0 | 27.7       | 25.8 | 25.3      | 26.8 | 25.4                   | 25.3 | 0.92                  | 0.376      |

<sup>1</sup>Values represent the mean of 3 pigs per pen and 9 pens per treatment. Three pigs per pen were randomly selected and sampled. Fecal samples were then pooled by pen respective of day of collection and dried at 130°F for 48 h in a forced air oven.

<sup>2</sup>Diets containing a fiber source were formulated on the insoluble fiber content of the respective ingredient.

<sup>3</sup>Arbocel (J. Rettenmaier USA, Schoolcraft, MI).

<sup>4</sup>Experimental diets were fed from d 0 to 24 and a common diet was fed from d 24 to 45.