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Effects of Increasing Levels of Copper from Either CuSO4 or Combinations of CuSO4 and a Cu-Amino Acid Complex on Growth Performance, Carcass Characteristics, and Economics of Finishing Pigs

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Effects of Increasing Levels of Copper from Either CuSO4 or Combinations of CuSO4 and a Cu-Amino Acid Complex on Growth Performance, Carcass Characteristics, and Economics of Finishing Pigs

Abstract

A total of 1,089 pigs (PIC 280 ×1050; initially 82.2 lb) were used in a 105-d experiment to determine the effects of increasing added Cu from either $CuSO_4$ alone or a 50/50 blend of $CuSO_4$ and Cu-AA (Availa®-Cu, Zinpro Corporation, Eden Prairie, MN) on growth performance, carcass characteristics, and economics of finishing pigs. All 6 dietary treatments contained 17 ppm Cu from $CuSO_4$ from the trace mineral premix. Additional treatment diets contained added $CuSO_4$ to provide 70 and 130 ppm total Cu or a 50/50 blend of added Cu from $CuSO_4$ and Cu-AA to provide 70, 100, and 130 ppm total Cu. There were 25 or 26 pigs per pen and 7 replicate pens per treatment.

Overall, added Cu above 17 ppm did not influence ADG; however, pigs fed 70 and 130 ppm added Cu from the 50/50 blend of $CuSO_4$ and Cu-AA had decreased ($P = 0.045$) ADFI and improved feed efficiency ($P = 0.048$) compared with those fed 70 and 130 ppm of added Cu from $CuSO_4$ only. Similar to the F/G response, pigs fed diets that contained $CuSO_4$ alone had poorer ($P = 0.030$) carcass F/G than those fed added Cu from the 50/50 blend of $CuSO_4$ and Cu-AA. Neither Cu source nor level influenced economics. In conclusion, these data suggest pigs fed diets that contained added Cu from $CuSO_4$ alone consume more feed but have poorer feed efficiency which translates into poorer carcass F/G compared to those fed a 50/50 blend of $CuSO_4$ and Cu-AA. Copper level did not impact growth performance. Based on our study, it appears that the 50/50 blend of $CuSO_4$/Cu-AA optimized feed efficiency and carcass feed efficiency of pigs marketed on a constant time basis.

Keywords

carcass characteristics, copper, finishing pig, growth, level, source

Cover Page Footnote

Appreciation is expressed to New Horizon Farms, Pipestone, MN, for use of feed mill and research facilities and Heath Houselog for management assistance. The authors would also like to express appreciation to Zinpro Corporation for partial funding.

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Effects of Increasing Levels of Copper from Either $CuSO_4$ or Combinations of $CuSO_4$ and a Cu-Amino Acid Complex on Growth Performance, Carcass Characteristics, and Economics of Finishing Pigs[1]

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Summary

A total of 1,089 pigs (PIC 280 ×1050; initially 82.2 lb) were used in a 105-d experiment to determine the effects of increasing added Cu from either $CuSO_4$ alone or a 50/50 blend of $CuSO_4$ and Cu-AA (Availa®-Cu, Zinpro Corporation, Eden Prairie, MN) on growth performance, carcass characteristics, and economics of finishing pigs. All 6 dietary treatments contained 17 ppm Cu from $CuSO_4$ from the trace mineral premix. Additional treatment diets contained added $CuSO_4$ to provide 70 and 130 ppm total Cu or a 50/50 blend of added Cu from $CuSO_4$ and Cu-AA to provide 70, 100, and 130 ppm total Cu. There were 25 or 26 pigs per pen and 7 replicate pens per treatment.

Overall, added Cu above 17 ppm did not influence ADG; however, pigs fed 70 and 130 ppm added Cu from the 50/50 blend of $CuSO_4$ and Cu-AA had decreased ($P = 0.045$) ADFI and improved feed efficiency ($P = 0.048$) compared with those fed 70 and 130 ppm of added Cu from $CuSO_4$ only. Similar to the F/G response, pigs fed diets that contained $CuSO_4$ alone had poorer ($P = 0.030$) carcass F/G than those fed added Cu from the 50/50 blend of $CuSO_4$ and Cu-AA. Neither Cu source nor level influenced economics.

In conclusion, these data suggest pigs fed diets that contained added Cu from $CuSO_4$ alone consume more feed but have poorer feed efficiency which translates into poorer carcass F/G compared to those fed a 50/50 blend of $CuSO_4$ and Cu-AA. Copper level did not impact growth performance. Based on our study, it appears that the 50/50

[1] Appreciation is expressed to New Horizon Farms, Pipestone, MN, for use of feed mill and research facilities and Heath Houselog for management assistance. The authors would also like to express appreciation to Zinpro Corporation for partial funding.
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blend of $CuSO_4$/Cu-AA optimized feed efficiency and carcass feed efficiency of pigs marketed on a constant time basis.

Key words: carcass characteristics, copper, finishing pig, growth, level, source

Introduction

Feeding high concentrations of Cu from $CuSO_4$ has been associated with improved growth performance of growing pigs. However, the responses observed in different trials are variable and may depend on feeding period or concentration. Coble et al. (2015)[4] reported ADG tended to increase when pigs were fed added Cu from tri-basic copper chloride during the early finishing period. However, Feldpausch et al. (2015)[5] reported no growth promoting benefit of 150 ppm added Cu from $CuSO_4$ during either the early or late finishing periods. Further investigation is warranted to better understand how high levels of Cu will impact growing and finishing pig performance. Furthermore, it is not well understood if the specific source of Cu will lead to differences in pig performance. Therefore, the objective of this study was to determine the effects of increasing Cu provided from either $CuSO_4$ alone or a 50/50 blend of $CuSO_4$ and Cu-AA on growth performance, carcass characteristics, and economics of finishing pigs housed in a commercial environment.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The experiment was conducted in a commercial research facility in southwestern Minnesota. The facility was double-curtain-sided with completely slatted concrete flooring. The barn contained 42 pens with 25 or 26 pigs (mixed gender) in each, equipped with a 4-hole conventional dry self-feeder (Thorp Equipment, Thorp, WI) and 1 cup-waterer, providing ad libitum access to feed and water. A computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) delivered and recorded daily feed additions of each diet to the respective pen.

A total of 1,089 pigs (PIC 280 ×1050; initially 82.2 lb) were used in a 105-d experiment to determine the effects of increasing Cu provided from either $CuSO_4$ alone or a 50/50 blend of $CuSO_4$ and Cu-AA (Availa-Cu®, Zinpro Corporation, Eden Prairie, MN) on growth performance, carcass characteristics, and economics of finishing pigs. On d 0, pens of pigs were weighed, blocked by average pig BW, and randomly allotted to 1 of 6 dietary treatments. There were 7 replicate pens per treatment. The 6 dietary treatments consisted of a control diet which contained 17 ppm Cu from $CuSO_4$ from the trace mineral premix, or the control diet with either added $CuSO_4$ to provide 70

[4] Coble, K. F.; Burnett, D. D.; Goodband, R. D.; Gonzales, J. M.; Usry, J.; Tokach, M. D.; Pluske, J. R.; DeRouchey, J. M.; Woodworth, J. C.; Dritz, S. S.; Flohr, J. R.; and Vaughn, M. A. (2015) "Effect of Diet Type and Added Copper on Growth Performance, Carcass Characteristics, Energy Digestibility, Gut Morphology, and Mucosal mRNA Expression of Finishing Pigs," Kansas Agricultural Experiment Station Research Reports: Vol. 1: Iss. 7.

[5] Feldpausch, J. A.; Amachawadi, R. G.; Scott, H. M.; Tokach, M. D.; Dritz, S. S.; Woodworth, J. C.; Nagaraja, T. G.; Goodband, R. D.; and DeRouchey, J. M. (2015) "Effects of Added Copper and Zinc on Growth Performance and Carcass Characteristics of Finishing Pigs Fed Diets with or without Ractopamine HCl," Kansas Agricultural Experiment Station Research Reports: Vol. 1: Iss. 7.

and 130 ppm total Cu, or a 50/50 blend of Cu from $CuSO_4$ and Cu-AA to provide 70, 100, and 130 ppm total Cu.

Experimental diets were fed in 5 phases (approximately 80 to 100, 100 to 135, 135 to 170, 170 to 230, and 230 to 280 lb). For diets that contained added Cu above that provided from the trace mineral premix, Cu was added at the expense of corn. Nutrient values for the ingredients were based on the NRC (2012)[6]. Diets were fed in meal form and were manufactured at the New Horizon Feed Mill (Pipestone, MN).

Complete diet samples were collected from a minimum of 6 feeders per phase and combined to make 1 composite sample per treatment within phase. Each sample was then split, ground and then sent to Minnesota Valley Testing Laboratories (New Ulm, MN) for analysis of DM, CP, ash, Ca, P, and Cu concentrations (Table 2, 3 and 4).

Pigs were weighed and feed disappearance was measured approximately every 2 weeks to calculate ADG, ADFI, and F/G. On d 79 of the trial, pens were weighed and the 3 heaviest pigs from each pen were removed and transported 59 miles to JBS USA (Worthington, MN) for harvest. These pigs were used in calculation of pen growth performance, but not carcass characteristics.

On d 105, final pen weights were recorded and feed disappearance was measured. The remaining pigs in the barn were individually tattooed with a pen identification number to allow individual carcass measurements to be recorded, and transported to the same aforementioned harvest facility for carcass data collection. Carcass yield was calculated using HCW at the plant divided by average individual live weight at the farm. Standard carcass measurements of backfat (BF), loin depth (LD), and percentage lean (Lean, %) were measured, with pen as experimental unit and carcass as the observational unit. Fat depth and loin depth were measured with an optical probe [Fat-O-Meter (SFK, Herlev, Denmark)] inserted between the third and fourth last rib (counting from the ham end of the carcass) at a distance approximately 2.76 in. from the dorsal midline.

Economic comparisons were made based on both a constant ending weight and a constant day basis. Total feed cost per pig, cost per pound of gain, carcass ADG, F/G, carcass gain value, and income over feed cost (IOFC) were calculated. An assumed carcass yield of 75% was used to calculate initial HCW at the beginning of the experiment. Hot carcass weight ADG was calculated by subtracting initial HCW from the final HCW obtained at the plant, then divided by 105 d on test. Hot carcass weight F/G was calculated by dividing the pen total feed intake by pen total carcass weight gain. Feed cost was calculated by multiplying total feed intake per pig by a weighted mean diet cost on a per pen basis. Prices used for corn, soybean-meal, and DDGS at the time of the experiment were $0.06, 0.14, and 0.05/lb, respectively. Prices used for the Cu-AA and $CuSO_4$ were $2.14 and $1.00/lb, respectively. Carcass price at time of slaughter was calculated at $0.74 per pound. Cost per pound of gain was calculated by dividing the total feed cost per pig by the total carcass pounds gained overall. The value of the carcass weight gained during the experiment (gain value) was calculated by multiplying the carcass value by the pen final carcass weight. Income over feed cost was calculated by subtracting total feed cost from gain value. The income over feed and facilities cost

[6] NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, D.C.

(IOFFC) was calculated for the constant market weight evaluation because pigs with faster growth rates will reach a 210 lb carcass sooner, therefore decreasing housing costs. Facility cost was calculated by multiplying the number of overall days the pigs need to reach a 210 lb carcass based on their respective growth rate by $0.11 per head per day facility cost.

Data were analyzed as a randomized complete block design using PROC GLIMMIX (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Hot carcass weight was used as a covariate for carcass characteristics including percentage lean, loin depth, and backfat. Effects of Cu source and linear and quadratic effects of Cu level were analyzed with significance defined as $P \leq 0.05$ and marginally significant as $P > 0.05$ and ≤ 0.10.

Results and Discussion

The chemical analyses of the complete diets were similar to the intended formulation (Tables 1, 2, 3, and 4). Total Ca and P levels were similar among diets across each dietary phase. The total analyzed Cu concentrations for diets formulated to 17, 70, and 130 ppm total Cu from $CuSO_4$ ranged from 27 to 58, 62 to 94, and 46 to 133 ppm, respectively. Total analyzed Cu concentrations for diets formulated to 70, 100, and 130 ppm total Cu from $CuSO_4$/Cu-AA ranged from 69 to 130, 80 to 119, and 98 to 142 ppm, respectively.

Of the 30 experimental diets, 6 diets were outside the analytical variation limits for Cu (25%, AAFCO, 2014)[7]. In Phase 1, the diet formulated to contain 70 ppm Cu from $CuSO_4$ was slightly lower and the diet formulated to contain 130 ppm Cu from the 50/50 blend was lower in analyzed Cu concentration than expected. In Phase 2, the control diet was slightly higher in analyzed Cu than expected. In Phase 3, the control diet and the diet formulated to contain 70 ppm Cu from the 50/50 blend were higher in analyzed Cu than expected and the diet formulated to contain 130 ppm Cu from $CuSO_4$ alone was much lower in analyzed Cu than expected.

All other total Cu values for each diet were within the acceptable analytical limits described by the AAFCO (2014) given that 17 ppm of Cu from $CuSO_4$ was provided by the trace mineral premix and accounting for the Cu provided by ingredients used in formulation. Corn, soybean meal, and corn DDGS can contain on average 15, 50, and 52 ppm Cu, respectively (NRC, 2012). Based on these Cu concentrations, corn, soybean meal and corn DDGS may have contributed up to 14 ppm Cu to the complete diet in our study. Thus, some of the variation observed in the Cu analysis may partially be explained by the Cu concentrations provided by major ingredients used in formulation.

From d 0 to 43, neither Cu source nor level influenced growth performance (Table 5).

From d 43 to 105, ADFI was lower ($P = 0.037$) for pigs fed the 50/50 blend of added Cu from $CuSO_4$ and Cu-AA compared to those fed added Cu from $CuSO_4$ alone. Feed efficiency tended to be improved (linear, $P = 0.057$) as level of Cu increased.

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[7] Association of American Feed Control Officials (AAFCO). 2014. Official Publication. Assoc. Am. Feed Cont. Off., Champaign, IL.

Overall, d 0 to 105, neither Cu level nor source influenced ADG. Pigs fed 70 and 130 ppm added Cu from the 50/50 blend of $CuSO_4$ and Cu-AA had lower ($P = 0.045$) ADFI and improved feed efficiency ($P = 0.048$) compared with those fed the same amount of added Cu from only $CuSO_4$. Due to the decreased ADFI and improved F/G of pigs fed the 50/50 blend of added Cu from $CuSO_4$ and Cu-AA, carcass F/G also improved ($P = 0.030$; Table 6) compared with those fed added Cu from $CuSO_4$ alone.

Regarding economics, neither Cu source nor level influenced economics when reported on a constant time or constant weight basis (Table 7).

Although there are limited data available describing the effects of Cu blends, a variety of experiments have demonstrated conflicting results on the growth-promoting benefits of added Cu above that provided by the trace mineral premix. Hastad et al. (2001)[8] reported there were no growth benefits above 135 lb of BW for pigs fed diets that contained 50, 100, or 200 ppm added Cu from $CuSO_4$. However, much of our data agree with similar experiments that have compared the effects of inorganic and organic sources of Cu. Previously, Coble et al. (2014)[9] used $CuSO_4$ and an organic Cu chelate (Mintrex Cu) and reported no differences in ADG. In their study, pigs fed diets that contained either 50 or 125 ppm of added Cu from $CuSO_4$ throughout the entire experiment had greater ADFI but poorer feed efficiency than the control. This resulted in poorer F/G for pigs fed $CuSO_4$ throughout the experiment. These results were similar to our study in that although pigs fed added $CuSO_4$ consumed more feed, they had poorer F/G due to the lack of a gain response. In addition, Coble et al. (2014) also reported pigs fed diets that contained $CuSO_4$ had poorer carcass F/G which supports the current study's findings. Although the study herein and Coble et al. (2014) demonstrated intake was higher for pigs fed Cu from $CuSO_4$, Feldpausch et al. (2015)[10] added 125 ppm of Cu from $CuSO_4$ and did not observe any differences in growth or carcass characteristics.

In summary, our study suggests differences exist between feeding added Cu as either a blend or single source on growth performance, carcass characteristics or economics. These data suggest pigs fed diets that contain added Cu from $CuSO_4$ had greater ADFI but are less efficient. Furthermore, carcass F/G worsened when diets contained $CuSO_4$ compared to those fed a 50/50 blend of $CuSO_4$ and Cu-AA, which is likely explained by the poorer F/G of pigs fed $CuSO_4$ alone. Our data suggest a 50/50 blend of $CuSO_4$ and Cu-AA has the potential to improve F/G as a result of reduced feed intake but no difference in overall gain or ending BW. Based on our study, it appears a 50/50 blend of $CuSO_4$ and Cu-AA optimizes feed efficiency and carcass feed efficiency for pigs marketed on a constant time basis.

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[8] Hastad et al., Swine Day 2001. Report of Progress 880, pp. 111–117. Kansas Agricultural Experiment Station. Manhattan, KS.

[9] Coble et al., Swine Day 2014. Report of Progress 1110, pp. 155-163. Kansas Agricultural Experiment Station. Manhattan, KS.

[10] Feldpausch, J. A.; Amachawadi, R. G.; Scott, H. M.; Tokach, M. D.; Dritz, S. S.; Woodworth, J. C.; Nagaraja, T. G.; Goodband, R. D. and DeRouchey, J. M. (2015) "Effects of Added Copper and Zinc on Growth Performance and Carcass Characteristics of Finishing Pigs Fed Diets with or without Ractopamine HCl," Kansas Agricultural Experiment Station Research Reports: Vol. 1: Iss. 7.

Table 1. Diet composition (as-fed basis)

	Phase[1,2]				
Item	1	2	3	4	5
Ingredient, %					
Corn	56.04	61.33	65.87	69.32	79.48
Soybean meal (46.0 % CP)	21.61	16.52	11.97	8.52	8.39
DDGS	20.00	20.00	20.00	20.00	10.00
Calcium carbonate	1.25	1.20	1.18	1.15	1.13
Monocalcium P (21.5% P)	0.15	---	---	---	0.09
Salt	0.35	0.35	0.35	0.35	0.35
L-Lys-HCl	0.36	0.37	0.39	0.39	0.32
DL-Met	0.01	---	---	---	---
L-Thr	0.05	0.04	0.05	0.06	0.07
L-Trp	---	0.01	0.02	0.02	0.02
Optiphos 2000[3]	0.01	0.01	0.01	0.01	0.01
Trace mineral premix[4]	0.10	0.10	0.10	0.10	0.10
Vitamin premix[4]	0.08	0.08	0.08	0.08	0.05
Cu Source[5]	---	---	---	---	---
Total	100.00	100.00	100.00	100.00	100.00

continued

Table 1. Diet composition (as-fed basis)

	Phase[1,2]				
Item	1	2	3	4	5
Calculated analysis					
Standardized ileal digestible (SID) AA, %					
Lys	1.02	0.91	0.82	0.74	0.65
Ile:Lys	63	62	60	59	59
Leu:Lys	152	159	164	171	166
Met:Lys	29	29	30	31	30
Met + Cys:Lys	55	56	57	59	59
Thr:Lys	61	61	61	63	65
Trp:Lys	18.4	18.5	18.5	18.5	18.5
Val:Lys	70	70	70	70	70
Total Lys, %	1.18	1.06	0.96	0.87	0.76
ME, kcal/lb	1,502	1,508	1,510	1,512	1,511
NE, kcal/lb	1,103	1,119	1,131	1,141	1,155
SID Lys:ME, g/Mcal	5.28	4.62	4.10	3.66	2.84
CP, %	20.02	18.08	16.36	15.05	12.94
Ca, %	0.61	0.55	0.52	0.50	0.50
P, %	0.45	0.40	0.38	0.36	0.34
Available P, %	0.29	0.26	0.25	0.25	0.22

[1]Phases 1, 2, 3, 4, and 5 were fed from d 0 to 9, 9 to 28, 28 to 43, 43 to 72, and 72 to 105, respectively.
[2]The basal diet contained 17 ppm Cu from $CuSO_4$.
[3]Optiphos 2000 (Huvepharma, Peach Tree, GA) provided 568 phytase units (FTU)/lb with a release of 0.10% available P.
[4]The vitamin premix supplied vitamin A 3,200,000 I.U, vitamin D3 500,000 I.U., vitamin E 16,000 I.U., vitamin (B12) 12 mg, riboflavin (B2) 2,800 mg, niacin 18,000 mg, d-pantothenic acid 10,000 mg, menadione 1600 mg. The trace mineral premix supplied Zn 110 ppm, Fe 110 ppm, Mn 33 ppm, Cu 17 ppm, I 0.33 ppm, and Se 0.30 ppm. Vitamin concentrations are expressed on a per lb of product basis whereas minerals are expressed on a ppm basis.
[5]Copper sulfate ($CuSO_4$; Prince Agri. Products Inc., Quincy, IL) or Availa® Cu (Cu-AA; Zinpro Corporation, Eden Prairie, MN). All experimental diets contained the basal diet and added Cu from either $CuSO_4$ only or a 50/50 blend of $CuSO_4$ and Cu-AA. For diets containing $CuSO_4$ only, either 0, 53 or 113 ppm of additional Cu from $CuSO_4$ was added at the expense of corn. For diets containing a 50/50 blend of $CuSO_4$ and Cu-AA, each diet was formed by adding additional Cu at either 18 and 35, 33 and 50, or 48 and 65 ppm from $CuSO_4$ and Cu-AA, respectively, at the expense of corn.

Table 2. Chemical analysis of diets (as-fed basis)

	Phase 1						Phase 2					
	Added Cu, ppm						Added Cu, ppm					
	Control[2]	$CuSO_4$[3], ppm		$CuSO_4$/Cu-AA[4], ppm[5]			Control[2]	$CuSO_4$[3], ppm		$CuSO_4$/Cu-AA[4], ppm[5]		
Item	0	70	130	70	100	130	0	70	130	70	100	130
DM, %	86.35	86.29	85.27	86.31	86.32	86.29	86.34	85.88	86.00	86.23	85.94	85.80
CP, %	20.70	20.50	20.50	20.10	20.20	20.30	19.40	19.20	17.60	19.90	18.20	18.30
Ash, %	4.38	4.50	4.44	5.06	3.78	4.22	4.20	3.88	3.93	3.78	3.96	3.77
Ca, %	0.61	0.58	0.42	0.85	0.62	0.57	0.59	0.46	0.56	0.45	0.62	0.51
P, %	0.51	0.50	0.55	0.50	0.51	0.51	0.46	0.48	0.45	0.46	0.45	0.45
Cu, ppm[6]	27	62	131	100	99	98	40	78	117	69	88	120

[1]Multiple samples of each diet were collected, blended and sub-sampled before being analyzed at Minnesota Valley Testing Laboratory (New Ulm, MN).
[2]The trace mineral premix was formulated to contribute 17 ppm of Cu from $CuSO_4$ to the complete basal diet.
[3]Copper sulfate ($CuSO_4$; Prince Agri. Products, Quincy, IL).
[4]Availa® Cu (Zinpro Corporation, Eden Prairie, MN).
[5]Copper concentration was achieved by a 50/50 inclusion of each copper source.
[6]Copper values represent means from 2 individual samples analyzed 1 or 2 times at Minnesota Valley Testing Laboratories (New Ulm, MN).

Table 3. Chemical analysis of diets (as-fed basis)[1]

	Phase 3						Phase 4					
	Added Cu, ppm						Added Cu, ppm					
	Control[2]	$CuSO_4$[3], ppm		$CuSO_4$/Cu-AA[4], ppm[5]			Control[2]	$CuSO_4$[3], ppm		$CuSO_4$/Cu-AA[4], ppm[5]		
Item	0	70	130	70	100	130	0	70	130	70	100	130
DM, %	85.74	86.06	86.21	86.21	85.89	86.12	85.97	86.13	86.03	86.18	85.90	85.81
CP, %	16.50	15.90	15.20	16.70	16.10	16.20	13.30	13.50	13.70	14.50	15.30	15.80
Ash, %	3.52	3.61	3.61	3.48	3.47	3.57	3.34	3.38	3.35	3.46	3.44	3.62
Ca, %	0.45	0.61	0.63	0.49	0.47	0.55	0.55	0.60	0.58	0.54	0.48	0.55
P, %	0.41	0.39	0.37	0.40	0.41	0.40	0.36	0.36	0.36	0.36	0.40	0.41
Cu, ppm[6]	58	73	46	130	80	109	31	80	133	89	119	137

[1]Multiple samples of each diet were collected, blended and sub-sampled before being analyzed at Minnesota Valley Testing Laboratory (New Ulm, MN).
[2]The trace mineral premix was formulated to contribute 17 ppm of Cu from $CuSO_4$ to the complete basal diet.
[3]Copper sulfate ($CuSO_4$; Prince Agri. Products, Quincy, IL).
[4]Availa® Cu (Zinpro Corporation, Eden Prairie, MN).
[5]Copper concentration was achieved by a 50/50 inclusion of each copper source.
[6]Copper values represent means from 2 individual samples analyzed 1 or 2 times at Minnesota Valley Testing Laboratories (New Ulm, MN).

Table 4. Chemical analysis of diets (as-fed basis)[1]

	Phase 5					
	Added Cu, ppm					
	Control[2]	$CuSO_4$[3], ppm		$CuSO_4$/Cu-AA[4], ppm[5]		
Item	0	70	130	70	100	130
DM, %	85.93	85.86	85.98	86.09	86.17	85.72
CP, %	13.70	13.50	14.00	13.50	13.30	13.80
Ash, %	3.40	3.43	3.29	3.41	3.11	3.15
Ca, %	0.63	0.62	0.55	0.66	0.51	0.51
P, %	0.35	0.38	0.37	0.37	0.36	0.39
Cu, ppm[6]	31	94	110	89	115	142

[1]Multiple samples of each diet were collected, blended and sub-sampled before being analyzed at Minnesota Valley Testing Laboratory (New Ulm, MN).
[2]The trace mineral premix was formulated to contribute 17 ppm of Cu from $CuSO_4$ to the complete basal diet.
[3]Copper sulfate ($CuSO_4$; Prince Agri. Products, Quincy, IL).
[4]Availa® Cu (Zinpro Corporation, Eden Prairie, MN).
[5]Copper concentration was achieved by a 50/50 inclusion of each copper source.
[6]Copper values represent means from 2 individual samples analyzed 1 or 2 times at Minnesota Valley Testing Laboratories (New Ulm, MN).

Table 5. Effects of increasing Cu from either $CuSO_4$ or combinations of $CuSO_4$ and Cu-AA on finishing pig growth performance[1]

	Control[2]	$CuSO_4$[3], ppm		$CuSO_4$/Cu-AA[4], ppm				Probability, $P <$		
									Cu level	
Item	17	70	130	70	100	130	SEM	Cu Source[5]	Linear	Quadratic
BW, lb										
d 0	82.0	82.0	82.3	82.0	82.6	82.0	2.48	0.848	0.748	0.867
d 43	169.4	170.1	171.7	171.0	172.2	170.4	3.75	0.880	0.292	0.559
d 105	281.6	285.3	285.9	284.3	287.7	282.9	4.01	0.467	0.247	0.235
d 0 to 43										
ADG, lb	2.03	2.05	2.07	2.07	2.08	2.05	0.035	0.936	0.264	0.408
ADFI, lb	4.71	4.77	4.83	4.78	4.87	4.71	0.086	0.321	0.186	0.142
F/G	2.32	2.33	2.33	2.31	2.34	2.29	0.022	0.169	0.945	0.505
d 43 to 105										
ADG, lb	1.83	1.87	1.88	1.86	1.87	1.83	0.028	0.400	0.455	0.334
ADFI, lb	5.82	5.90	5.89	5.82	5.83	5.65	0.075	0.037	0.603	0.349
F/G	3.18	3.16	3.14	3.12	3.12	3.08	0.030	0.110	0.057	0.807
d 0 to 105										
ADG, lb	1.92	1.95	1.96	1.95	1.96	1.93	0.022	0.573	0.249	0.264
ADFI, lb	5.35	5.42	5.44	5.38	5.42	5.24	0.064	0.045	0.916	0.208
F/G	2.79	2.79	2.78	2.76	2.76	2.72	0.022	0.048	0.124	0.925

[1]A total of 1,089 pigs (PIC 280 × 1050; initially 82.2 lb) were used with 25 or 26 pigs per pen and 7 pens per treatment in a 105-d growth study.
[2]The trace mineral premix was formulated to contribute 17 ppm of Cu from $CuSO_4$ to the complete basal diet.
[3]Copper sulfate ($CuSO_4$; Prince Agri. Products, Quincy, IL).
[4]Availa® Cu (Zinpro Corporation, Eden Prairie, MN).
[5]Main effect of Cu source (70 and 130 ppm, within source).

Table 6. Effects of increasing Cu from either $CuSO_4$ or combinations of $CuSO_4$ and Cu-AA on finishing pig carcass characteristics[1]

	Control[2]	$CuSO_4$[3], ppm		$CuSO_4$/Cu-AA[4], ppm				Probability, P <		
									Cu level	
Item	17	70	130	70	100	130	SEM	Cu Source[5]	Linear	Quadratic
Yield, %	72.36	72.57	71.91	72.66	72.61	72.44	0.333	0.329	0.796	0.179
HCW, lb	205.1	206.9	207.0	206.6	208.8	204.8	2.98	0.547	0.493	0.247
Backfat[6], in.	0.68	0.69	0.68	0.69	0.68	0.67	0.014	0.836	0.687	0.770
Loin depth[6], in.	2.51	2.50	2.49	2.51	2.49	2.57	0.042	0.201	0.790	0.617
Lean[6], %	55.91	55.84	55.82	55.81	55.98	56.22	0.264	0.363	0.605	0.581
HCW ADG, lb	1.37	1.38	1.38	1.38	1.40	1.37	0.017	0.552	0.519	0.229
Carcass F/G[7]	3.86	3.84	3.86	3.79	3.81	3.76	0.037	0.030	0.221	0.543
Adj. Carcass F/G[8]	3.98	3.92	3.98	3.87	3.87	3.86	0.059	0.143	0.285	0.233

[1]A total of 1,089 pigs (PIC 280 × 1050; initially 82.2 lb) were used with 25 or 26 pigs per pen and 7 pens per treatment in a 105-d growth study.
[2]The trace mineral premix was formulated to contribute 17 ppm of Cu from $CuSO_4$ to the complete basal diet.
[3]Copper sulfate ($CuSO_4$; Prince Agri. Products., Quincy, IL).
[4]Availa® Cu (Zinpro Corporation, Eden Prairie, MN).
[5]Main effect of Cu source (70 and 130 ppm, within source).
[6]Hot carcass weight was used as a covariate.
[7]Constant time basis
[8]Adjusted to constant final carcass weight of 210 lb. Adjusted using a factor of 0.005 for 1 lb change in carcass weight.

Table 7. Effects of increasing Cu from either $CuSO_4$ or combinations of $CuSO_4$ and Cu-AA on finishing pig economics[1]

	Control[2]	$CuSO_4$[3], ppm		$CuSO_4$/Cu-AA[4], ppm				Probability, $P <$		
									Cu level	
Item	17	70	130	70	100	130	SEM	Cu Source[5]	Linear	Quadratic
Constant day, $/pig										
Feed cost[6]	44.91	45.80	45.83	45.42	46.41	44.92	0.583	0.238	0.239	0.110
Cost/lb gain carcass wt.	0.316	0.315	0.319	0.313	0.316	0.313	0.0036	0.274	0.896	0.604
Carcass gain value[7]	151.78	154.13	153.04	153.81	155.53	152.57	2.337	0.814	0.382	0.122
IOFC[8]	106.87	108.33	107.22	108.39	109.12	107.66	1.928	0.849	0.529	0.186
Constant carcass wt, $/pig[9]										
Feed cost	47.65	47.08	47.79	46.89	46.88	47.12	1.009	0.525	0.694	0.295
Cost/lb gain carcass wt.	0.321	0.317	0.323	0.316	0.317	0.317	0.0048	0.471	0.824	0.334
Carcass gain value	156.35	156.35	156.35	156.35	156.35	156.35	---	---	---	---
IOFC	108.69	109.26	108.56	109.46	109.47	109.23	1.009	0.525	0.694	0.295
Facility cost[10]	12.06	11.79	11.91	11.84	11.64	11.96	0.250	0.775	0.342	0.116
IOFFC[11]	96.63	97.48	96.65	97.62	97.82	97.27	1.245	0.648	0.601	0.235

[1]A total of 1,089 pigs (PIC 280 × 1050; initially 82.2 lb) were used with 25 or 26 pigs per pen and 7 pens per treatment in a 105-d growth study. All economics were calculated based on a carcass price of 0.74 $/lb.
[2]The trace mineral premix was formulated to contribute 17 ppm of Cu from $CuSO_4$ to the complete basal diet.
[3]Copper sulfate ($CuSO_4$) (Prince Agri. Products., Quincy, IL).
[4]Availa® Cu (Zinpro Corporation, Eden Prairie, MN).
[5]Main effect of Cu source (70 and 130 ppm, within source).
[6]Corn, soybean-meal and DDGS were calculated at 0.06, 0.17 and 0.05 $/lb, respectively. Test ingredients used were Cu-AA (Availa® Cu) and $CuSO_4$ and calculated at 2.14 and 1.00 $/lb, respectively.
[7]Carcass gain value calculated using (total carcass gain × carcass price).
[8]Income over feed cost = carcass gain value – feed cost.
[9]Adjusted to constant final carcass weight of 210 lb.
[10]Facility cost at 0.11 $/hd/day.
[11]Income over feed and facility cost = IOFC – facility cost.