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Effects of Copper Source (Intellibond C or Copper Sulfate) on Growth Performance, Carcass Characteristics, Pen Cleanliness, and Economics in Finishing Pigs[1,2]

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Summary

A total of 1,143 pigs (PIC 337 × 1050, initially 55.3 lb) were used to determine the effects of tribasic copper chloride (TBCC; Intellibond C; Micronutrients Inc., Indianapolis, IN) or copper sulfate ($CuSO_4$) on growth performance, carcass characteristics, pen cleanliness, and economics in a 111-d study. Pens of pigs were randomly allotted to 1 of 6 dietary treatments and balanced based on average pen weight in a completely randomized design with 25 to 28 pigs per pen and 8 pens per treatment. Treatment diets included a corn-soybean meal positive control, a high by-product diet with 30% dried distillers grains with solubles (DDGS) and 15% bakery meal (negative control), or the negative control diet with 75 or 150 ppm copper from $CuSO_4$ or TBCC. All diets were formulated on a standardized ileal digestible (SID) amino acid basis and were 0.05% below the pig's estimated lysine requirement throughout the trial. Pigs fed the corn-soybean meal positive control diet had improved ($P < 0.01$) F/G and tended to have increased ADFI ($P < 0.08$) compared with those fed the negative control, high by-product diet. Pigs fed increasing copper had improved (linear, $P < 0.01$) ADG and ADFI but tended to have slightly poorer (quadratic, $P < 0.06$) F/G. Although no interactions were observed between copper source and level, pigs fed increasing $CuSO_4$ had increased (linear, $P < 0.02$) ADFI, whereas pigs fed increasing TBCC had increased ADG, ADFI, and final BW (linear, $P < 0.01$).

Increasing added copper improved (linear, $P < 0.02$) HCW and loin depth, with the greatest response in HCW for pigs fed TBCC (linear, $P < 0.01$). For pen characteristics, pigs fed the high by-product diet had greater ($P < 0.01$) manure buildup and longer wash time than those fed the corn-soybean meal control diet. Addition of copper to diets did not influence pen wash time and had no impact on manure buildup. Economics were calculated on both a constant days on feed and constant market weight basis. Pigs fed either source of copper to a constant days on feed had an increase in feed cost per pig (linear, $P < 0.01$) as well as a higher ($P < 0.10$) revenue per pig. When economics were calculated on feeding pigs to a constant BW, facility costs decreased (linear, $P < 0.05$) with feeding copper. Although no significant differences were detected in income over feed and facility cost for added copper, the greatest numerical

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Richard Brobjorg and Marty Heintz for their technical assistance.

[2] Appreciation is expressed to Micronutrients, Inc. (Indianapolis, IN) for funding of this experiment.

[3] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

advantage to individual copper sources occurred at 75 PPM for $CuSO_4$ ($0.26) and at 150 ppm for TBCC ($1.35 per pig).
In summary, feeding increased levels of copper sulfate or TBCC in diets formulated slightly below the estimated SID lysine requirement increased growth rate and feed intake, resulting in increased final BW and HCW. Pigs fed TBCC at 150 ppm had the highest final BW (+12.8 lb) and HCW (+7.7 lb). In addition, the use of added copper in the diets did not increase time required to wash pens. More research is needed to determine whether the amino acid concentration influences the response to copper source and level in diets for growing and finishing pigs.

Key words: finishing pig, copper sulfate, tribasic copper chloride, wash time

Introduction

Adding 250 ppm of copper from copper sulfate ($CuSO_4$) has been routine in nursery pig diets for many years. Due to the antimicrobial-like responses in growth performance in nursery pigs[4], copper is believed to serve as an antimicrobial-like agent in the gut. Although added copper in nursery diets is common, use of copper in the finishing stage has been relatively limited. Hastad et al. (2001[5]) reported that added $CuSO_4$ or copper chloride from approximately 74 to 135 lb improved ADG and F/G. However, these advantages were not maintained until market although copper was supplemented continuously, suggesting that supplementing copper in late finishing did not provide growth advantages.

Data on a relatively new source of supplemental copper, tribasic copper chloride (TBCC), are limited. Tribasic copper chloride may also offer improvements in finishing pig growth performance. Lastly, feeding diets high in by-product ingredients, as well as supplemental copper, are believed to increase manure buildup and therefore wash time, but few data are available to verify this speculation. Therefore, the objectives of this study were to evaluate the effects of TBCC and $CuSO_4$ on growth performance, carcass characteristics, pen wash time, and economics of finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research-finishing site in southwest Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits. Each pen was equipped with a 5-hole stainless steel feeder and cup waterer for ad libitum access to feed and water. Feed additions were made by a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that measured feed amounts for each individual pen.

A total of 1,143 mixed-sex pigs (PIC 1050 × 337, initially 55.3 lb) were used in a 111-d study. Prior to initiating the trial, pigs were fed on a common diet containing 186 ppm TBCC (Intellibond C; Micronutrients, Inc., Indianapolis, IN). Pens of pigs were allotted to 1 of 6 dietary treatments in a completely randomized design, with 25 to 28 pigs per pen and 8 replications per treatment. Treatments included a positive control, corn-

[4] Cromwell, G.L. 2001. Antimicrobial and promicrobial agents. In: A.J. Lewis and L.L. Southern, eds., Swine Nutrition, Second Edition. CRC Press LLC, Boca Raton, FL. pp. 401–426.
[5] Hastad, C.W et al., Swine Day 2001. Report of Progress 880, pp. 111–117.

soybean meal diet and a negative control diet containing 30% dried distillers grains with solubles (DDGS) and 15% bakery meal. The negative control diet also served as the base for the remaining 4 copper treatments. Those diets consisted of the negative control with 75 or 150 ppm added TBCC or $CuSO_4$. All diets contained 20 ppm Cu from copper sulfate in the premix and were formulated on a standardized ileal digestible (SID) lysine basis at 0.05% below the estimated requirement during each phase. Treatment diets were fed in 5 phases (Tables 1 and 2). During the last phase, all diets contained 4.5 g/ton of ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN.). Each treatment diet was sampled at the start and before the last day of each phase with samples mixed to form a composite sample. Diets were analyzed for copper (Table 3).

Pens of pigs were weighed and feed disappearance was recorded at d 27, 49, 71, 92, and 111 to determine ADG, ADFI, and F/G. On day 92, the 3 heaviest pigs in each pen were weighed and sold according to standard farm procedures. Prior to marketing, the remaining pigs were individually tattooed with a pen ID number to allow for carcass measurements to be recorded on a pen basis. On day 111, final pen weights were taken and pigs were transported to a commercial packing plant (JBS Swift and Company, Worthington, MN) for processing and carcass data collection. Carcass measurements taken at the plant included HCW, loin depth, backfat, and percentage lean. Also, percentage carcass yield was calculated by dividing the average pen HCW by average final live weight at the farm.

At the conclusion of the trial, a digital photo of each pen was taken to allow 3 independent observers to score manure texture and buildup and to assess pen cleanliness prior to power washing. The scores were averaged to determine a mean score, which was used for analysis. Manure textures were categorized as firm, medium, and loose with scores of 1, 2, and 3, respectively. Manure buildup was categorized as 1 for visual manure buildup and -1 for no visual manure buildup. Afterward, a professional power-washing crew recorded wash time for each pen with a stopwatch to determine the difference in wash time between treatments.

At the conclusion of the study, an economic analysis was calculated on both a constant days on feed or constant market weight basis to determine the value of feeding copper in two separate scenarios. For calculating on a constant days on feed basis, economics were determined using the treatment means from the trial. To determine the economics on a constant weight basis, feed efficiency was adjusted to a common final BW. This adjustment was calculated by plotting the final BW against overall F/G using data from all pens in the experiment. A linear regression equation was developed, and the slope (0.0034 per lb of final weight) was used as the adjustment factor for the F/G. The actual ADG and adjusted F/G were then used to determine the difference in total number of days and feed needed to reach a common weight of 275 lb. For the constant days on feed and constant weight economic evaluation, total feed cost per pig, cost per lb of gain, revenue, and income over feed cost (IOFC) were calculated. The total feed cost per pig was calculated by multiplying the ADFI by the feed cost per pound and the number of days in each respective period, then taking the sum of those values for each period. Cost per pound of gain was calculated by dividing the total feed cost per pig by the total pounds gained overall. Revenue per pig was calculated by multiplying the ADG times the total days in the trial times an assumed live price of $58.00 per cwt. To calculate

IOFC, total feed cost was subtracted from pig revenue. The income over feed and facility cost (IOFFC) was calculated for the constant market weight evaluation because pigs with a faster growth rate would reach 275 lb sooner, decreasing the cost of housing the pigs. Facility cost was calculated by multiplying the number of overall days the pigs needed to reach 275 lb based on their respective growth rate times \$0.10 per day.

The experimental data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) using pen was as the experimental unit. The main effect of copper source and linear and quadratic effects of copper level were tested. Hot carcass weight served as a covariate for the analysis of backfat, loin depth, and lean percentage. Results from the experiment were considered significant at $P \leq 0.05$ and considered a tendency between $P > 0.05$ and $P \leq 0.10$.

Results

All diets, during each phase, had analyzed copper concentrations similar to calculated values (Table 3). The vitamin trace mineral premix, included at a rate of 2 lb/ton, provided 20 ppm Cu from $CuSO_4$ to each complete diet. The analyzed values for the positive corn-soybean meal control and the negative high-by-product control were from 21 to 42 ppm, which were within acceptable analytical levels. For the 75-ppm treatment group, $CuSO_4$ had copper concentrations between 116 and 137 ppm, whereas the TBCC had analyzed concentrations between 77 and 134 ppm for the duration of the trial. In the 150-ppm treatment group, the $CuSO_4$ had analyzed copper concentrations between 192 and 267 ppm, whereas the TBCC had analyzed concentrations between 157 and 189 ppm throughout the trial.

Pigs fed the positive control, corn-soybean meal or negative control, high-by-product diet, had similar ADG from d 0 to 71, 71 to 111, and for the overall trial (Table 4). Feeding the high- by-product diet tended to increase ADFI from d 0 to 71 ($P < 0.06$) and for the overall trial ($P < 0.08$) and resulted in poorer F/G from d 71 to 111 ($P < 0.04$) and for the overall trial ($P < 0.01$) compared with pigs fed the positive control diet. For carcass traits, pigs fed the corn-soybean meal diet tended ($P < 0.08$) to have greater loin depth than pigs fed the high by-product diet. As expected, pens that held pigs fed the corn-soybean meal diet had less ($P < 0.01$) manure buildup and required less ($P < 0.01$) wash time than pens that held pigs fed the high by-product diet. With the ingredient and pig prices from the time of the experiment, there were no differences in economic response between the positive and negative control diets (Table 5).

No copper level × source interactions were observed for any response criteria. From d 0 to 71 and for the overall trial, pigs fed increasing copper had increased ADG (linear, $P < 0.04$), ADFI (linear $P < 0.01$), and final weight ($P < 0.03$; Table 6). Adding copper to the diets worsened (quadratic, $P < 0.01$) F/G from d 0 to 71 and for the overall trial (quadratic, $P < 0.06$); however, when adjusted for increased final weight, F/G was not affected (Table 7).

Within copper source, increasing TBCC increased or tended to increase ADG from d 0 to 71 (quadratic, $P < 0.04$), d 71 to 111 (linear, $P < 0.06$), and for the overall trial (linear, $P < 0.01$). The increase in ADG resulted from increases in ADFI from during

both periods (linear, $P < 0.03$) and the overall trial (quadratic, $P < 0.05$). Increasing $CuSO_4$ also increased (quadratic, $P < 0.03$) ADG from d 0 to 71 and tended to increase (linear, $P < 0.08$) ADG for the overall trial due to increases (linear, $P < 0.02$) in ADFI for those periods. Final weight was increased by feeding TBCC (linear, $P < 0.01$) and $CuSO_4$ (linear, $P < 0.05$). Although no interaction was detected among copper sources, pigs fed 150 ppm TBCC were 12.8 lb heavier than pigs fed the negative control diet, and those fed 150 ppm $CuSO_4$ were 7.1 lb heavier.

For carcass characteristics, the increased final weight combined with no differences in carcass yield ($P > 0.10$) led to an increase (linear, $P < 0.02$) in HCW for pigs fed increasing levels of copper. Within copper source, pigs fed TBCC had greater (linear, $P < 0.01$) HCW than pigs fed the control, with no significant improvement in pigs fed $CuSO_4$. Pigs fed $CuSO_4$ tended trend (quadratic, $P < 0.07$) to have decreased backfat. Added copper increased loin depth (linear, $P < 0.02$), and percentage lean tended to increase with increasing $CuSO_4$ (quadratic, $P < 0.07$) and TBCC (quadratic, $P < 0.09$).

For pen characteristics, there were no differences ($P > 0.10$) in manure texture among dietary treatments, which suggests that the consistency of manure was not affected when copper was added to the diet. Manure buildup responded in a quadratic manner ($P < 0.01$) as TBCC increased in the diet, with the lowest score for pigs fed the diet containing 75 ppm of TBCC. Adding copper to the diet did not influence wash time.

When economics were calculated on a constant number of days basis, no differences were found in total feed cost, revenue, or IOFC between sources of copper; yet, as added copper increased, feed cost and revenue increased (linear, $P < 0.01$) as well as cost per lb of gain (quadratic, $P < 0.03$; Table 6). Due to these increases in cost and revenue, however, no differences occurred in IOFC between 75 and 150 ppm copper. Nevertheless, the greatest numerical response in IOFC for the individual copper sources was $1.51 per pig for pigs fed 150 ppm TBCC and $0.82 per pig for pigs fed 75 ppm $CuSO_4$.

When the economics were calculated on a constant weight basis, feed cost per pig and cost per lb of gain tended to increase (quadratic, $P < 0.08$), whereas there was a tendency for IOFC to decrease (quadratic, $P < 0.08$) as copper level increased. Increasing copper decreased facility cost ($P < 0.01$). More specifically, facility savings (linear, $P < 0.01$) were generated from feeding 150 ppm TBCC because of the numerically greater ADG. Although no differences were observed in IOFFC, the greatest numerical advantage for each copper source occurred at 150 ppm for TBCC ($1.35 per pig) and at 75 ppm for $CuSO_4$ ($0.26 per pig) due to the decrease in feed and facility costs.

Discussion

Historically, growth promotional levels of added copper have been used in nursery diets, typically with 12% improvements in ADG and 8.4% increase in ADFI, which are thought to be a result of the antimicrobial-like properties of copper (Cromwell, 1997[6]). With finishing pigs, Hastad et al. (2001) reported that growth performance was primarily improved during the first few weeks of the early finishing period with the

[6] Cromwell, G.L. 1997. Copper as a nutrient for animals. In: H.W. Richardson, ed., Handbook of copper compounds and applications. Marcel Dekker, Inc., New York, New York. pp. 177–201.

addition of copper, similar to nursery pigs. Although similar responses were observed in initial growth performance in the present study, feed intake continued to increase past the early periods of the finishing trial and beyond 200 lb BW; specifically, TBCC continued to increase ADFI, resulting in an increase in ADG in the late finisher phase. The response to copper sulfate was not as consistent, with no response in the late finisher phase. The increase in growth observed in the pigs fed TBCC ultimately led to increased final BW and HCW. This response is similar to the reported increase in final BW reported by Hastad et al. (2001), but the response was much greater in the present experiment. The combination of decreasing the SID lysine and copper source may have caused the increased response; however, full explanation for the magnitude of response cannot be determined from this study.

Although increased feed intake was the driver of improved growth, few studies have been completed to fully explain the mechanisms responsible. Li et al. (2006[7]) reported an increase in neuropeptide Y (NPY) and mRNA expression for NPY in the hypothalamus of pigs fed copper. A more recent study suggest that pigs fed copper have increased mRNA expression levels for growth hormone-releasing hormone, which provides positive feedback to the hypothalamus to increase appetite (Yang et al., 2010[8]). Expression of mRNA of somatostatin, which provides negative feedback that decreases appetite, was also shown to decrease with the supplementation of copper. This information could offer an explanation for the effect of copper on intake. The magnitude of response to copper may be amplified in pigs fed diets deficient in lysine because the increased feed intake would increase lysine intake on a grams-per-day basis. Lysine levels may be decreased in diets containing growth promoter levels of copper because of the increased feed intake, but further study is needed to confirm this potential benefit.

In summary, adding supplemental copper in the form of either CuSO4 or TBCC improved growth in the grower and early finishing periods, but pigs fed TBCC continued to have an increased growth rate in late finishing, especially those fed 150 ppm added copper, whereas pigs fed $CuSO_4$ did not. This result ultimately led to an increase in final BW and HCW for pigs fed copper, with the greatest advantage in pigs fed TBCC.

[7] Li, J., L. Yan, X. Zheng, G. Liu, N. Zhang, and Z. Wang. 2008. Effect of high dietary copper on weight gain and neuropeptide Y level in the hypothalamus of pigs. J. Trace Elem. Med. Biol. 22:33–38.
[8] Yang, W., J. Wang, L. Liu, X. Zhu, X. Wang, Z. Liu, Z. Wang, L. Yang, and G. Liu. 2011. Effect of high dietary copper on somatostatin and growth hormone-releasing hormone levels in the hypothalamic of growing pigs. Biol. Trace Elem. Res. 143:893–900.

Table 1. Diet composition for Phases 1, 2, and 3 (as-fed basis)[1]

	Phase 1		Phase 2		Phase 3	
Item	Positive control	Negative control	Positive control	Negative control	Positive control	Negative control
Ingredient, %						
Corn	73.07	36.05	77.96	41.07	81.76	44.69
Soybean meal, 46.5 CP	23.98	16.51	19.47	11.80	15.80	8.24
DDGS[2]	-	30.00	-	30.00	-	30.00
Bakery meal	-	15.00	-	15.00	-	15.00
Limestone	1.18	1.25	1.11	1.17	1.08	1.15
Monocalcium P, 21 %	0.75	0.18	0.55	-	0.52	-
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin-trace mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Biolys[4]	0.460	0.565	0.400	0.515	0.360	0.470
L-threonine	0.060	-	0.040	-	0.030	-
MHA, dry[5]	0.055	-	0.015	-	-	-
Phytase[6]	0.005	0.005	0.005	0.005	0.005	0.005
Copper source[7]	-	-	-	-	-	-
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	1.00	1.00	0.86	0.86	0.75	0.75
Isoleucine:lysine	63	71	64	74	65	77
Leucine:lysine	138	177	148	193	158	210
Methinone:lysine	30	32	29	35	29	38
Met & Cys:lysine	55	59	56	64	58	69
Threonine:lysine	60	60	60	62	61	64
Tryptophan:lysine	18.0	18.0	18.0	18.0	18.0	18.0
Valine:lysine	70	82	72	87	75	92
Total lysine, %	1.13	1.20	0.97	1.04	0.85	0.93
ME, kcal, lb	1,494	1,537	1,500	1,543	1,502	1,545
SID lysine:ME, g/Mcal	3.04	2.95	2.60	2.53	2.26	2.20
CP, %	17.9	21.3	16.1	19.5	14.6	18.0
Ca, %	0.65	0.58	0.57	0.51	0.54	0.49
P, %	0.52	0.47	0.46	0.41	0.44	0.39
Available P, %	0.28	0.28	0.24	0.24	0.22	0.23

[1] Phase 1 diets fed from d 0 to 27, Phase 2 diets fed from d 27 to 49, and Phase 3 diets fed from d 49 to 71.
[2] Dried distillers grains with solubles (Valero, Aurora, SD).
[3] Vitamin and trace mineral premix provided all diets with 20 ppm copper from copper sulfate.
[4] Lysine source (Evonik, Inc., Kennesaw, GA).
[5] Methionine source (Novus International, Inc., St. Charles, MO).
[6] Optiphose 2000 (Enzyva LLC, Sheridan, IN) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[7] Supplemental copper provided in the form of $CuSO_4$ and TBCC (Intellibond C; Micronutrients, Inc., Indianapolis, IN) at either 75 or 150 ppm at the expense of corn to the negative control diet.

Table 2. Diet composition for phases 4 and 5 (as-fed basis)[1]

	Phase 4		Phase 5	
Item	Positive control	Negative control	Positive control	Negative control
Ingredient, %				
Corn	84.42	47.295	76.66	39.65
Soybean meal, 46.5 CP	13.25	5.690	20.79	13.13
DDGS[2]	-	30.000	-	30.00
Bakery meal	-	15.000	-	15.00
Limestone	1.05	1.125	1.08	1.18
Monocalcium P, 21 %	0.48	0.000	0.44	-
Salt	0.35	0.350	0.35	0.35
Vitamin-trace mineral premix[3]	0.10	0.100	0.10	0.10
Biolys[4]	0.325	0.435	0.415	0.530
L-Thr	0.025	-	0.090	0.035
MHA, dry[5]	-	-	0.050	-
Paylean, 9g/ton[6]	-	-	0.025	0.025
Phytase[7]	0.005	0.005	0.005	0.005
Copper source[8]	-	-	-	-
Total	100	100	100	100

continued

Table 2. Diet composition for phases 4 and 5 (as-fed basis)[1]

	Phase 4		Phase 5	
Item	Positive control	Negative control	Positive control	Negative control
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.67	0.67	0.90	0.90
Isoleucine:lysine	67	79	64	73
Leucine:lysine	169	226	145	188
Methinone:lysine	31	40	31	34
Met & Cys:lysine	61	74	58	63
Threonine:lysine	62	67	65	65
Tryptophan:lysine	18.0	18.0	18.0	18.0
Valine:lysine	78	97	72	85
Total lysine, %	0.77	0.84	1.02	1.09
ME, kcal, lb	1,505	1,546	1,502	1,542
SID lysine:ME, g/Mcal	2.02	1.97	2.72	2.65
CP, %	13.5	17.0	16.6	20.0
Ca, %	0.52	0.48	0.55	0.52
P, %	0.42	0.38	0.44	0.41
Available P, %	0.21	0.23	0.21	0.24

[1] Phase 4 diets fed from d 71 to 92, and Phase 5 diets fed from d 92 to 111.
[2] Dried distillers grains with solubles (Valero, Aurora, SD).
[3] Provided all diets with 20 ppm copper from copper sulfate.
[4] Lysine source (Evonik, Inc., Kennesaw, GA).
[5] Methionine source (Novus International, Inc., St. Charles, MO).
[6] Ractopamine HCl (Elanco Animal Health, Inc., Greenfield, IN).
[7] Optiphose 2000 (Enzyva LLC, Sheridan, IN) provided 1,816,000 phytase units (FTU)/lb, with a release of 0.10% available P.
[8] Supplemental copper provided in the form of $CuSO_4$ and TBCC (Intellibond C; Micronutrients, Inc., Indianapolis, IN) at either 75 or 150 ppm at the expense of corn to the negative control diet.

Table 3. Copper analysis of complete diets[1]

			$CuSO_4$, ppm		TBCC, ppm[2]	
Phase	Positive control	Negative control	75	150	75	150
1	27	21	137	208	83	180
2	24	38	129	192	77	157
3	28	38	116	200	134	172
4	27	37	136	267	104	187
5	42	32	135	257	129	189

[1] Values represent means from one composite sample, analyzed in duplicate.
[2] Intellibond C; Micronutrients, Inc., Indianapolis, IN.

Table 4. The effects of copper sulfate ($CuSO_4$) and tri-basic copper chloride (TBCC) on finishing pig growth performance, pen cleanup, and carcass characteristics[1]

								Probability, $P <$[3]				
			$CuSO_4$, ppm		TBCC, ppm[2]							
Item	Positive control	Negative control	75	150	75	150	SEM	Pos. vs. neg. control	$CuSO_4$ linear	$CuSO_4$ quadratic	TBCC linear	TBCC quadratic
BW, lb												
d 0	55.3	55.3	55.3	55.4	55.3	55.3	2.04	0.97	0.96	0.92	0.97	0.97
d 71	186.6	190.2	196.9	194.6	199.8	196.3	3.90	0.19	0.12	0.07	0.03	0.01
d 111	274.5	273.9	281.4	281.0	283.1	286.7	4.50	0.87	0.05	0.20	0.01	0.37
d 0 to 71												
ADG, lb	1.84	1.89	1.99	1.95	2.02	1.97	0.033	0.16	0.11	0.03	0.04	0.01
ADFI, lb	4.30	4.48	4.71	4.73	4.81	4.69	0.101	0.06	0.01	0.20	0.03	0.01
F/G	2.33	2.36	2.36	2.42	2.38	2.38	0.022	0.17	0.01	0.13	0.43	0.70
d 71 to 111												
ADG, lb	2.28	2.21	2.21	2.25	2.19	2.33	0.044	0.29	0.51	0.77	0.06	0.14
ADFI, lb	6.40	6.49	6.66	6.62	6.60	6.77	0.113	0.45	0.33	0.34	0.03	0.77
F/G	2.81	2.94	3.01	2.94	3.02	2.91	0.050	0.04	0.96	0.22	0.59	0.08
d 0 to 111												
ADG, lb	1.99	2.00	2.07	2.05	2.08	2.09	0.025	0.76	0.08	0.11	0.01	0.20
ADFI, lb	5.01	5.16	5.38	5.37	5.43	5.40	0.094	0.08	0.02	0.13	0.01	0.05
F/G	2.52	2.58	2.60	2.62	2.61	2.58	0.024	0.01	0.10	0.89	0.98	0.11
Carcass												
HCW, lb	203.8	202.5	205.6	205.2	206.4	210.2	2.61	0.59	0.29	0.42	0.01	0.99
Yield, %	73.3	72.8	72.4	72.5	72.5	72.9	0.40	0.35	0.60	0.68	0.84	0.48
Backfat, in.[4]	0.69	0.67	0.62	0.66	0.66	0.66	0.017	0.46	0.62	0.07	0.74	0.69
Loin depth, in.[4]	2.53	2.47	2.50	2.56	2.60	2.53	0.028	0.08	0.01	0.70	0.10	0.01
Lean, %[4]	55.9	56.0	56.8	56.5	56.7	56.3	2.90	0.78	0.13	0.07	0.38	0.09
Pen cleanup												
Texture[5]	2.00	2.09	1.86	1.81	1.80	2.19	0.214	0.77	0.35	0.71	0.73	0.19
Buildup[6]	-1.00	0.62	0.90	0.62	-0.05	1.00	0.206	0.01	1.00	0.23	0.16	0.01
Wash time, sec	268	417	413	383	373		21.5	0.01	0.27	0.63	0.36	0.26

[1] A total of 1,143 (PIC 337 × 1050) were used in a 111-day finishing trial with 27 pigs per pen and 7 reps per treatment.
[2] Intellibond C; Micronutrients, Inc., Indianapolis, IN.
[3] No copper level × source interactions ($P > 0.10$).
[4] HCW was used as a covariate.
[5] Categorized as firm, medium, or loose with scores of 1, 2, and 3, respectively.
[6] Based on a value of 1 for visual manure buildup and -1 for no visual manure buildup.

Table 5. The effects of copper sulfate ($CuSO_4$) and tri-basic copper chloride (TBCC) on growth economics to a constant market date or market weight[1]

			$CuSO_4$, ppm		TBCC, ppm[2]			Probability, $P<$[3]				
Item	Positive control	Negative control	75	150	75	150	SEM	Pos. vs. neg. control	$CuSO_4$ linear	$CuSO_4$ quadratic	TBCC linear	TBCC quadratic
Constant days												
Feed cost												
$/pig	79.82	80.29	83.81	84.10	84.47	84.69	1.413	0.71	0.01	0.15	0.01	0.08
$/lb gain	0.361	0.361	0.365	0.369	0.366	0.365	0.003	0.93	0.01	0.96	0.25	0.23
Revenue,[4] $/pig	128.21	128.79	133.13	132.22	133.87	134.71	1.605	0.76	0.08	0.11	0.01	0.20
IOFC, [5]$/pig	48.39	48.50	49.32	48.12	49.40	50.01	0.749	0.91	0.71	0.26	0.15	0.88
Constant BW[6]												
Adjusted F/G[7]	2.52	2.58	2.58	2.60	2.58	2.54	0.019	0.02	0.64	0.63	0.09	0.36
Feed cost, $/pig	78.66	78.82	78.91	79.65	79.02	78.06	0.572	0.85	0.30	0.64	0.34	0.40
Feed cost, $/lb gain	0.358	0.359	0.359	0.363	0.360	0.355	0.003	0.85	0.30	0.64	0.34	0.40
Revenue, $/pig[4]	127.43	127.43	127.43	127.43	127.43	127.43						
IOFC, $/pig[5]	48.76	48.61	48.52	47.77	48.40	49.37	0.572	0.85	0.30	0.64	0.34	0.40
Facility cost, $/pig[8]	11.13	11.16	10.81	10.84	10.73	10.57	0.207	0.82	0.05	0.17	0.01	0.31
IOFFC, $/pig[9]	37.64	37.45	37.71	36.93	37.68	38.80	0.616	0.83	0.56	0.50	0.13	0.56

[1] A total of 1,143 (PIC 337 × 1050) were used in a 111-d finishing trial with 27 pigs per pen and 7 reps per treatment.
[2] Intellibond C; Micronutrients, Inc., Indianapolis, IN.
[3] No copper level × source interactions ($P > 0.10$).
[4] Revenue based on $58.00/cwt live price.
[5] Income over feed cost.
[6] Adjusted to constant final weight of 275 lb.
[7] Adjusted using the slope of the overall F/G vs. final market weight.
[8] Facility cost at $0.10/hd/day.
[9] Income over feed and facility cost.

Table 6. Main effects of copper sulfate ($CuSO_4$) and tri-basic copper chloride (TBCC) on finishing pig growth performance, pen cleanup, and carcass characteristics[1]

	Copper source		Copper level, ppm				Probability, *P*<		
								Level	
Item	$CuSO_4$	TBCC[2]	0	75	150	SEM	Source	Linear	Quadratic
BW, lb									
d 0	55.3	55.3	55.3	55.3	55.3	2.00	0.99	0.99	0.93
d 71	195.8	198.1	190.2	198.4	195.5	3.65	0.25	0.03	0.56
d 111	281.2	284.9	273.9	282.2	283.8	4.14	0.14	0.01	0.82
d 0 to 71									
ADG, lb	1.97	2.00	1.89	2.01	1.96	0.028	0.33	0.04	0.55
ADFI, lb	4.72	4.75	4.48	4.76	4.71	0.090	0.64	0.01	0.08
F/G	2.39	2.38	2.36	2.37	2.40	0.019	0.40	0.05	0.01
d 71 to 111									
ADG, lb	2.23	2.26	2.21	2.20	2.29	0.032	0.53	0.14	0.72
ADFI, lb	6.64	6.69	6.49	6.63	6.69	0.095	0.56	0.07	0.87
F/G	2.98	2.97	2.94	3.02	2.93	0.039	0.85	0.74	0.80
d 0 to 111									
ADG, lb	2.06	2.09	2.00	2.07	2.07	2.061	0.23	0.01	0.77
ADFI, lb	5.38	5.41	5.16	5.40	5.39	5.377	0.57	0.01	0.20
F/G	2.61	2.59	2.58	2.61	2.60	2.608	0.37	0.34	0.06
Carcass									
HCW, lb	205.4	208.3	202.5	206.0	207.7	2.29	0.11	0.02	0.59
Yield, %	72.0	73.0	72.8	72.0	73.0	0.01	0.56	0.86	0.47
Backfat, in.[3]	0.64	0.66	0.67	0.64	0.66	0.012	0.31	0.63	0.70
Loin depth, in.[3]	2.53	2.56	2.46	2.55	2.55	0.020	0.23	0.02	0.06
Lean, %[3]	56.7	56.5	56.0	56.7	56.4	0.18	0.44	0.17	0.21
Pen cleanup									
Texture[4]	1.84	1.99	2.09	1.83	2.00	0.159	0.44	0.73	0.21
Buildup[5]	0.76	0.48	0.62	0.43	0.81	0.156	0.14	0.42	0.42
Wash time, sec	398	380	417	393	386	15.2	0.43	0.24	0.45

[1] A total of 1,143 (PIC 337 × 1050) were used in a 111-day finishing trial with 27 pigs per pen and 7 reps per treatment.
[2] Intellibond C; Micronutrients, Inc., Indianapolis, IN.
[3] HCW used as a covariate.
[4] Categorized as firm, medium, or loose with scores of 1, 2, and 3, respectively.
[5] Based on a value of 1 for visual manure buildup and -1 for no visual manure buildup.

Table 7. Main effects of copper sulfate ($CuSO_4$) and tri-basic copper chloride (TBCC) on growth economics to a constant market date or market weight[1]

	Copper source		Copper level, ppm				Probability, $P <$		
								Level	
Item	$CuSO_4$	TBCC[2]	0	75	150	SEM	Source	Linear	Quadratic
Constant days									
Feed cost									
$/pig	83.95	84.58	80.29	84.14	84.39	1.267	0.48	0.01	0.15
$/lb gain	0.367	0.365	0.361	0.365	0.367	0.003	0.46	0.04	0.03
Revenue, $[3]	132.68	134.29	128.79	133.50	133.46	1.306	0.23	0.01	0.77
IOFC, $[4]	48.72	49.71	48.50	49.36	49.07	0.552	0.18	0.52	0.20
Constant BW[5]									
Adjusted F/G[6]	2.59	2.56	2.58	2.58	2.57	0.014	0.16	0.47	0.13
Feed cost									
$/pig	79.28	78.54	78.82	78.97	78.85	0.416	0.19	0.96	0.08
$/lb gain	0.361	0.357	0.359	0.359	0.359	0.002	0.19	0.96	0.08
Revenue, $[3]	127.43	127.43	127.43	127.43	127.43				
IOFC, $[4]	48.14	48.89	48.61	48.46	48.57	0.416	0.19	0.96	0.08
Facility cost, $[7]	10.83	10.65	11.16	10.77	10.71	0.191	0.13	0.01	0.85
IOFFC, $[8]	37.32	38.24	37.45	37.69	37.86	0.435	0.15	0.58	0.12

[1] A total of 1,143 (PIC 337 × 1050) were used in a 111-day finishing trial with 27 pigs per pen and 7 reps per treatment.
[2] Intellibond C; Micronutrients, Inc., Indianapolis, IN.
[3] Revenue based on $58.00/cwt live price.
[4] Income over feed cost.
[5] Constant weight of 275 lb.
[6] Adjusted using the slope of the overall F/G vs. final market weight.
[7] Facility cost at $0.10/hd/day.
[8] Income over feed and facility cost.