EFFECTS OF COPPER SULFATE, TRI-BASIC COPPER CHLORIDE, AND ZINC OXIDE ON WEANLING PIG GROWTH AND PLASMA MINERAL CONCENTRATIONS[1]

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Summary

Two 28-d experiments were conducted to determine the effects of increasing dietary zinc and copper levels on weanling pig performance. In each experiment, 180 weanling pigs (PIC, 21 d of age, 12.5 lb in Exp. 1 and 13.2 lb in Exp. 2) were allotted to 1 of 6 treatments with 5 and 6 replications in Exp. 1 and 2, respectively. Diets were fed in 2 phases (d 0 to 14 and 14 to 28), and the trace mineral premix provided 165 ppm zinc and 16.5 ppm copper to all diets. In Exp. 1, treatments were arranged as a 2 × 3 factorial with 2 levels of added copper from tri-basic copper chloride (TBCC; 0 or 150 ppm) and 3 levels of added zinc from zinc oxide (0, 1,500, or 3,000 ppm from d 0 to 14 and 0, 1,000, or 2,000 ppm from d 14 to 28). In addition, blood collected on d 14 was analyzed for plasma zinc, copper, and phosphorus concentrations. No copper × zinc interactions were observed ($P > 0.25$) for any of the growth data. Addition of TBCC increased ($P < 0.03$) ADG and ADFI over control pigs from d 0 to 14, 14 to 28, and 0 to 28. Pigs fed increasing dietary zinc had increased (linear, $P < 0.003$) ADFI during both phases and increased ADG from d 0 to 14 and 0 to 28. No effects were observed for blood metabolites in plasma copper; however, copper × zinc interactions were observed ($P < 0.03$) for both plasma zinc and phosphorus. The interactions occurred because increasing dietary zinc oxide increased plasma zinc and phosphorus when TBCC was not included in the diet but had relatively little effect when TBCC was added to the diet.

In Exp. 2, treatments were arranged as a 2 × 3 factorial with 2 levels of added zinc from zinc oxide (0 or 3,000 ppm from d 0 to 14 and 0 or 2,000 from d 14 to 28) and 3 copper treatments (control, 125 ppm copper from TBCC, or 125 ppm copper from copper sulfate). In addition, blood collected on d 14 and 28 was analyzed for plasma zinc, copper, and phosphorus concentrations. Again, no copper × zinc interactions ($P > 0.10$) were observed for any performance data. Adding zinc oxide to the diet improved ($P < 0.03$) ADG, ADFI, and F/G from d 0 to 14 and ADG and ADFI from d 0 to 28. Adding copper to the diet increased ($P < 0.05$) ADG, ADFI, and F/G from d 0 to 14 and 0 to 28 with pigs fed copper sulfate having greater ($P < 0.02$) ADG and ADFI from d 0 to 14 than pigs fed TBCC. Similar to Exp. 1, plasma zinc was increased ($P < 0.001$) in pigs fed high levels of dietary zinc at d 14. Unlike many previous research trials, these two trials found additive effects to feeding high levels of dietary copper and zinc in diets for nursery pigs.

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Introduction

Zinc and copper are two minerals commonly added at pharmacological levels in weanling pig diets to serve as growth promoters. Nursery studies have demonstrated that increased dietary levels of zinc can promote growth rates and decrease diarrhea in weanling pigs. Typically, the greatest response to pharmacological levels of zinc is seen in the first 2 to 4 wk postweaning, and the most commonly used form is zinc oxide (ZnO). Dietary copper has also been shown to enhance growth rates in weanling pigs and growing pigs. Therefore, copper is typically added to late nursery and early grower diets; the most commonly used form is copper sulfate ($CuSO_4$). Research combining ZnO and $CuSO_4$ at high levels has shown growth rates similar to those when ZnO is used alone. Thus, early diets for nursery pigs often contain growth promoting levels of zinc without growth promoting levels of copper. Therefore, the objective of these trials was to characterize the effect of combining ZnO with a different copper source, tri-basic copper chloride (TBCC), as well as revaluate the response to utilizing both ZnO and $CuSO_4$ in weanling diets.

Procedures

The protocols used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. Each pen contained a 4-hole dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pens had wire-mesh floor and allowed for approximately 3 ft^2 per pig. Weights and feed disappearance were measured weekly to determine ADG, ADFI, and F/G.

Blood samples were collected from 2 pigs per pen (d 14 in Exp. 1 and d 14 and 28 in Exp. 2) by jugular venipuncture. Blood samples were chilled for approximately 1 h until they were centrifuged at 2,000 rpm for 20 min. Plasma was then collected from each sample, frozen, and sent to Michigan State University for mineral analysis. Copper and zinc levels were determined by atomic absorption spectrophotometry, and phosphorus was measured by color spectrophotometry. Feed samples from both experiments were collected and analyzed for copper and zinc levels.

Pen was used as the experimental unit for all analyses in both experiments, and data were analyzed by using the PROC MIXED procedure in SAS.

Experiment 1. A total of 180 weanling pigs (initially 12.5 lb and 21 d of age) were used in a 28-d growth trial to compare the effects of supplemental zinc and copper from ZnO and TBCC, respectively. Pigs were allotted by initial BW in a completely randomized block design. There were 5 pens per treatment with 6 pigs per pen. Treatments were arranged as a 2 × 3 factorial with 2 levels of added copper from TBCC (0 or 150 ppm) and 3 levels of added zinc from ZnO (none, moderate, or high; 0, 1,500, or 3,000 ppm from d 0 to 14 and 0, 1,000, or 2,000 ppm from d 14 to 28). Diets were fed in 2 phases (d 0 to 14 and 14 to 28; Table 1). Phase 1 (d 0 to 14) and 2 (d 14 to 28) diets were fed in meal form and were formulated to contain 1.41 and 1.31% standardized ileal digestible (SID) lysine, respectively (Table 1). Phase 1 diets contained 15% spray-dried whey and 3.75% fish meal, and phase 2 diets were corn soybean meal based. The trace mineral premix supplied 165 ppm zinc and 16.5 ppm copper to each of the diets. Zinc oxide and TBCC were then supplemented by replacing corn starch to achieve the desired zinc and copper levels.

Experiment 2. Similar procedures and diets (Table 2) were utilized in experiment 2. A total of 180 weanling pigs (initially 13.2 lb and 21 d of age) were used in this 28-d growth trial. Pigs were allotted in a completely randomized block design with blocks by weight and sex. There were 6 pens per treatment with 5 pigs per pen. Treatments were arranged as a 2 × 3 factorial with 2 levels of added zinc from ZnO (0 or 3,000 ppm from d 0 to 14 and 0 or 2,000 ppm from d 14 to 28) and 3 added copper sources (none, 125 ppm copper from TBCC, or 125 ppm copper from copper sulfate). All diets were supplemented with 165 ppm zinc and 16.5 ppm copper from the trace mineral premix.

Results and Discussion

Laboratory analysis of the diets indicated that nutrient levels were similar to those expected from diet formulation for Exp. 1 and 2 (Tables 3 and 4, respectively).

Experiment 1. No copper × zinc interactions (Table 5, $P > 0.25$) were observed for any of the performance criteria throughout the trial. An interaction was expected because previous research has found no response to added copper when high levels of ZnO are added to the diet. Similar to many earlier trials, ADG increased (linear, $P < 0.002$) as zinc concentration increased in the diet from d 0 to 14. The gain response was driven directly by increases in intake because ADFI increased (linear, $P < 0.003$) as dietary zinc was added. Dietary copper from TBCC also increased ($P < 0.02$) ADG and ADFI compared with non-copper-supplemented treatments. Dietary treatment did not influence F/G, which is in agreement with several previous trials. The greatest performance values were seen in treatments containing both high levels of zinc from ZnO and copper from TBCC.

From d 14 to 28, the addition of copper from TBCC continued to enhance ($P < 0.03$) both ADG and ADFI. Also, ADFI continued to increase (linear, $P < 0.002$) as dietary zinc increased. However, there was only a tendency ($P < 0.10$) for a change in ADG as dietary zinc increased. This agrees with other trials that showed the greatest response to zinc is typically found in the early phases postweaning.

Because of the responses during each phase, overall ADG and ADFI were improved ($P < 0.007$) for pigs supplemented with added copper from TBCC. Pigs fed TBCC weighed approximately 2.2 lb more on d 28 postweaning than pigs not supplemented with TBCC. Also, ADG and ADFI increased (linear, $P < 0.003$) as dietary zinc was added from ZnO. Again, pigs that received both added copper and a high level of zinc had the greatest gain and feed intake; no differences were observed in overall F/G.

From d 0 to 14, dietary treatments had no effect on feed cost per pound of gain, but income over feed cost (IOFC) increased as ZnO (linear, $P < 0.01$) and TBCC ($P < 0.02$) were added to the diet. Adding zinc to the diet increased ($P < 0.03$) feed cost per pound of gain from d 14 to 28 but also resulted in a linear increase ($P < 0.02$) in IFOC because of the increased growth rate of pigs fed high levels of ZnO. Adding TBCC to the diet tended ($P < 0.07$) to increase IOFC without changing feed cost per pound of gain. Overall, adding ZnO to the diet linearly increased ($P < 0.02$) feed cost per pound of gain. Despite the increase in feed cost per pound of gain, IOFC increased (linear, $P < 0.02$) as supplemental zinc was added. The response was due to the growth improvements from ZnO. Adding TBCC to the diet also increased ($P < 0.02$) IOFC by approximately \$0.75/pig over pigs not supplemented with any added copper.

There were no treatment differences for plasma copper levels (Table 6). However, copper × zinc interactions were detected ($P < 0.03$) for both plasma zinc and phosphorus. The plasma zinc interaction occurred because a more dramatic increase in plasma zinc was seen in diets containing no supplemental copper when zinc level increased in the diet. The phosphorus interaction was due to plasma phosphorus increasing as dietary zinc increased in diets without supplemental copper and plasma phosphorus decreasing as zinc was increased in diets receiving supplemental copper.

Experiment 2. No copper × zinc interactions were observed (Table 7, $P > 0.10$) for any of the growth criteria in this trial. From d 0 to 14, ADG, ADFI, and F/G were increased ($P < 0.03$) with zinc supplementation. Some studies have shown improvements in F/G with added zinc; however, most have shown gain responses related to increased ADFI. Pharmacological levels of copper also improved ($P < 0.02$) ADG, ADFI, and F/G, with copper sulfate improving ($P < 0.02$) ADG and ADFI more than TBCC.

From d 14 to 28, no differences were observed ($P > 0.10$) for ADG; however, numerical increases were observed for pigs fed either copper source. Daily feed intake increased ($P < 0.02$) in pigs supplemented with zinc. Added copper also improved ($P < 0.05$) F/G; copper sulfate improved ($P < 0.03$) and TBCC treatments tended to improve ($P < 0.06$) F/G compared with control treatments.

Over the entire 28-d trial, added zinc resulted in increases ($P < 0.02$) in ADG and ADFI. Copper supplementation also improved ($P < 0.05$) ADG, ADFI, and F/G. Copper sulfate increased ($P < 0.02$) ADG, ADFI, and F/G compared with the controls, and TBCC produced intermediate results that were numerically higher ($P < 0.07$) than controls in ADG and F/G.

Because of improvements in feed efficiency, zinc supplementation decreased ($P < 0.001$) feed cost per pound of gain from d 0 to 14. Copper sulfate also decreased ($P < 0.003$) feed cost per pound of gain compared with control pigs. Zinc and copper supplementation also increased ($P < 0.0001$) IOFC. From d 14 to 28, ZnO increased ($P < 0.02$) feed cost per pound of gain, which ultimately negated the lower cost during the first phase, resulting in no difference ($P > 0.67$) for the overall trial. However, both copper sources decreased ($P < 0.05$) feed cost per pound of gain. Copper sulfate increased ($P < 0.003$) IOFC for the entire 28-d trial. On average, copper sulfate and TBCC increased IOFC by $1.43 and $0.73/pig, respectively, compared with control pigs. Zinc supplementation also increased ($P < 0.06$) IOFC by approximately $0.69/pig, with the entire benefit occurring during the first 14 d after weaning.

No dietary effects were observed (Table 8, $P > 0.41$) for plasma phosphorus at either bleeding time. Plasma zinc was increased ($P < 0.001$) on d 14 and tended ($P < 0.09$) to be higher at d 28 for pigs supplemented with ZnO. There was no effect seen for plasma copper on d 14, but a copper × zinc interaction was observed ($P < 0.02$) on d 28. In diets containing no added zinc, plasma copper increased when TBCC was added to the diet but decreased when copper sulfate was added to the diet. The opposite occurred in diets containing supplemental zinc; plasma copper decreased as TBCC was added to the diet and increased when copper sulfate was added.

Both trials showed additive responses to feeding pharmacological levels of copper and zinc to weanling pigs; in the second experiment, pigs had a greater response to copper sulfate than to TBCC. These findings are in contrast to previous research that did not find additive responses to added dietary copper and zinc. The reason we found additive responses is not clear. However, the majority of the early research used 250 ppm added dietary copper when testing for additive responses, whereas we used 125 and 150 ppm. More research is needed to determine the reasons for these additive effects and explain factors that influence the level of response to growth promoting levels of copper and zinc.

Table 1. Composition of diets in Exp. 1[1]

Item, %	Phase 1[2]	Phase 2[3]
Corn	48.75	60.75
Soybean meal (46.5% CP)	29.01	35.00
Spray-dried whey	15.00	---
Select menhaden fish meal	3.75	---
Monocalcium P (21% P)	1.05	1.60
Limestone	0.70	1.10
Salt	0.33	0.33
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Lysine HCl	0.30	0.30
DL-methionine	0.175	0.125
L-threonine	0.125	0.110
Corn starch[4]	0.410	0.283
Total	100.00	100.00
Calculated Analysis		
SID[5] amino acids, %		
Lysine	1.41	1.31
Isoleucine:lysine	60	63
Leucine:lysine	120	129
Methionine:lysine	36	33
Met & Cys:lysine	58	58
Threonine:lysine	62	62
Tryptophan:lysine	17	18
Valine:lysine	65	69
ME, kcal/lb	1,495	1,495
SID Lysine:ME, g/Mcal	4.28	3.97
CP, %	22.3	21.9
Ca, %	0.88	0.85
P, %	0.78	0.75
Available P, %	0.50	0.42

[1] A total of 180 weanling pigs (PIC, initially 12.5 lb and 21 d of age) were used in a 28-d experiment.
[2] Pigs were fed phase 1 from d 0 to 14.
[3] Pigs were fed phase 2 from d 14 to 28.
[4] Corn starch was replaced with zinc oxide and tri-basic copper chloride to create treatment diets.
[5] SID = Standard ileal digestible (SID).

Table 2. Composition of diets in Exp. 2[1]

Item, %	Phase 1[2]	Phase 2[3]
Corn	48.72	60.74
Soybean meal (46.5% CP)	29.01	35.00
Spray-dried whey	15.00	---
Select menhaden fish meal	3.75	---
Monocalcium P (21% P)	1.05	1.60
Limestone	0.70	1.10
Salt	0.33	0.33
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Lysine HCl	0.30	0.30
DL-methionine	0.175	0.125
L-threonine	0.125	0.110
Corn starch[4]	0.435	0.307
Total	100.00	100.00
Calculated Analysis		
SID[5] amino acids, %		
Lysine	1.41	1.31
Isoleucine:lysine	60	63
Leucine:lysine	120	129
Methionine:lysine	36	33
Met & Cys:lysine	58	58
Threonine:lysine	62	62
Tryptophan:lysine	17	18
Valine:lysine	65	69
ME, kcal/lb	1,495	1,495
SID Lysine:ME ratio, g/mcal	4.28	3.97
CP, %	22.3	21.9
Ca, %	0.88	0.85
P, %	0.78	0.75
Available P, %	0.50	0.42

[1] A total of 180 weanling pigs (PIC, initially 13.2 lb and 21 d of age) were used in a 28-d experiment.
[2] Pigs were fed phase 1 from d 0 to 14.
[3] Pigs were fed phase 2 from d 14 to 28.
[4] Corn starch was replaced with zinc oxide, copper sulfate, and/or tri-basic copper chloride to create treatment diets.
[5] SID = Standard ileal digestible (SID).

Table 3. Analyzed chemical composition of diets (Exp. 1)[1]

	Added copper[2]					
	No			Yes		
Added zinc[3]	None	Medium	High	None	Medium	High
Phase 1[4]						
CP, %	22.4	22.3	22.7	22.0	22.6	22.0
Zinc, ppm	212	1,472	2,519	190	1,431	2,831
Copper, ppm	23.2	22.4	23.6	196.1	169.8	191.0
Calcium, %	0.98	0.82	0.82	1.04	0.78	0.86
Phosphorus, %	0.75	0.83	0.84	0.82	0.83	0.87
Phase 2[5]						
CP, %	23.5	21.8	22.0	21.6	20.9	21.6
Zinc, ppm	217	1,201	1,993	427	840	1,713
Copper, ppm	26.0	19.3	62.7	124.2	137.1	169.1
Calcium, %	0.83	0.91	0.99	0.81	0.69	1.09
Phosphorus, %	0.76	0.77	0.89	0.77	0.71	0.82

[1] A total of 180 weanling pigs (PIC, initially 12.5 lb and 21 d of age) were used in a 28-d experiment.
[2] Added copper from tri-basic copper chloride was supplied at no (0 ppm) or yes (150 ppm) levels to the basal diet (16.5 ppm Cu).
[3] Added zinc from zinc oxide was supplied at none (0 ppm), medium (1,500 ppm in phase 1 and 1,000 in phase 2), or high (3,000 ppm in phase 1 and 2,000 in phase 2) levels to the basal diet (165 ppm Zn).
[4] Pigs were fed phase 1 from d 0 to 14.
[5] Pigs were fed phase 2 from d 14 to 28.

Table 4. Analyzed chemical composition of diets (Exp. 2)[1]

	Added zinc[2]					
	No			Yes		
Copper source[3]	None	TBCC	SO_4	None	TBCC	SO_4
Phase 1[4]						
CP, %	21.7	22.5	22.8	22.6	22.3	22.7
Zinc, ppm	286	183	197	2,798	2,721	2,599
Copper, ppm	28.4	152.3	149.4	27.3	156.4	140.9
Calcium, %	1.01	0.93	0.88	0.88	0.95	0.81
Phosphorus, %	0.85	0.82	0.85	0.82	0.83	0.80
Phase 2[5]						
CP, %	22.3	21.0	22.0	19.6	20.6	22.6
Zinc, ppm	183	229	176	2,360	1,897	1,930
Copper, ppm	24.6	177.9	188.1	47.6	140.1	144.2
Calcium, %	1.15	0.90	0.95	0.93	0.88	0.92
Phosphorus, %	0.81	0.78	0.88	0.77	0.78	0.81

[1] A total of 180 weanling pigs (PIC, initially 13.2 lb and 21 d of age) were used in a 28-d experiment.
[2] Added zinc from zinc oxide was supplied at no (0 ppm) or yes (3,000 ppm in phase 1 and 2,000 ppm in phase 2) levels to the basal diet (165 ppm Zn).
[3] Copper sources included none, tri-basic copper chloride (TBCC, 125 ppm) and copper sulfate (SO_4, 125ppm) and were supplemented to the basal diet (16.5 ppm Cu).
[4] Pigs were fed phase 1 from d 0 to 14.
[5] Pigs were fed phase 2 from d 14 to 28.

Table 5. Effects of dietary zinc oxide and tri-basic copper chloride on weanling pig performance and economics (Exp. 1)[1]

	Added copper[2]							*P* <				
	No			Yes							Zinc	
Added zinc[3]	None	Medium	High	None	Medium	High	SE	Zn × Cu	Cu	Zn	linear	quadratic
Initial wt (d 0), lb	12.4	12.5	12.5	12.5	12.5	12.5	0.76	0.45	0.29	0.40	0.26	0.45
d 0 to 14												
ADG, lb	0.35	0.40	0.50	0.47	0.45	0.53	0.04	0.30	0.02	0.004	0.002	0.18
ADFI, lb	0.44	0.48	0.61	0.56	0.57	0.62	0.04	0.26	0.02	0.006	0.003	0.29
F/G	1.28	1.27	1.22	1.21	1.27	1.18	0.06	0.74	0.30	0.38	0.37	0.28
Feed cost/lb gain, $[4]	0.286	0.286	0.278	0.270	0.286	0.269	0.013	0.75	0.36	0.51	0.69	0.28
IOMFC, $/pig[4,5]	1.55	1.81	2.26	2.17	2.00	2.44	0.233	0.32	0.02	0.02	0.01	0.17
d 14 to 28												
ADG, lb	1.05	1.10	1.16	1.15	1.16	1.22	0.06	0.78	0.03	0.10	0.04	0.68
ADFI, lb	1.48	1.54	1.66	1.61	1.64	1.75	0.08	0.87	0.01	0.005	0.002	0.32
F/G	1.42	1.39	1.44	1.40	1.41	1.44	0.02	0.72	0.94	0.24	0.19	0.29
Feed cost/lb gain, $	0.181	0.180	0.187	0.180	0.183	0.189	0.003	0.73	0.60	0.03	0.16	0.84
IOMFC, $/pig	6.15	6.47	6.69	6.79	6.75	7.00	0.336	0.75	0.07	0.36	0.02	0.29
d 0 to 28												
ADG, lb	0.70	0.75	0.83	0.81	0.80	0.87	0.05	0.38	0.007	0.008	0.003	0.34
ADFI, lb	0.96	1.01	1.14	1.09	1.10	1.18	0.06	0.43	0.005	0.002	0.001	0.26
F/G	1.38	1.35	1.37	1.34	1.37	1.36	0.02	0.29	0.49	0.94	0.76	0.86
Feed cost/lb gain, $	0.206	0.205	0.214	0.205	0.212	0.213	0.003	0.41	0.49	0.04	0.02	0.41
IOMFC, $/pig	7.69	8.28	8.95	8.96	8.75	9.45	0.511	0.43	0.02	0.05	0.02	0.60
Final wt (d 28), lb	31.9	33.4	35.7	35.1	35.0	37.5	1.87	0.61	0.006	0.006	0.003	0.29

[1] A total of 180 weanling pigs (PIC, initially 12.5 lb and 21 d of age) were used in a 28-d experiment.
[2] Added copper from tri-basic copper chloride was supplied at no (0 ppm) or yes (150 ppm) levels to the basal diet (16.5 ppm Cu).
[3] Added zinc from zinc oxide was supplied at none (0 ppm), medium (1,500 ppm from d 0 to 14 and 1,000 from d 14 to 28), or high (3,000 ppm from d 0 to 14 and 2,000 from d 14 to 28) levels to the basal diet (165 ppm Zn).
[4] Feed costs were based on corn at $5.00/bu, soybean meal at $350/ton, TBCC at $300/cwt and ZnO at $121.87/cwt.
[5] IOFC = Income over marginal feed costs (weight gain × $0.60/lb - feed cost).

Table 6. Effects of dietary zinc oxide and tri-basic copper chloride on plasma mineral levels in weanling pigs (Exp. 1)[1]

	Added copper[2]							*P* <				
	No			Yes							Zinc	
Added zinc[3]	None	Medium	High	None	Medium	High	SE	Zn × Cu	Cu	Zn	linear	quadratic
Plasma concentrations[4]												
Copper, µg/mL	1.88	1.88	1.81	1.81	1.98	1.89	0.10	0.58	0.63	0.57	0.97	0.30
Zinc, µg/mL	0.64	0.77	1.08	0.81	0.81	0.93	0.06	0.03	0.68	0.001	0.001	0.14
Phosphorus, mg/mL	0.070	0.083	0.085	0.081	0.080	0.077	0.002	0.003	0.95	0.05	0.03	0.21

[1] A total of 180 weanling pigs (PIC, initially 12.5 lb and 21 d of age) were used in a 28-d experiment.
[2] Added copper from tri-basic copper chloride was supplied at no (0 ppm) or yes (150 ppm) levels to the basal diet (16.5 ppm Cu).
[3] Added zinc from zinc oxide was supplied at none (0 ppm), medium (1,500 ppm from d 0 to 14 and 1,000 from d 14 to 28), or high (3,000 ppm from d 0 to 14 and 2,000 from d 14 to 28) levels to the basal diet (165ppm Zn).
[4] Plasma was collected on d 14 from 2 pigs per pen.

Table 7. Effects of zinc oxide, tri-basic copper chloride, and copper sulfate on weanling pig performance and economics (Exp. 2)[1]

	Added zinc[2]							*P* <					
	No			Yes							Copper source effects		
								Zn ×			None vs.		SO_4 vs.
Copper source[3]	None	TBCC	SO_4	None	TBCC	SO_4	SE	Cu	Zn	Cu	SO_4	TBCC	TBCC
Initial wt (d 0), lb	13.2	13.2	13.2	13.2	13.2	13.2	0.7	0.89	0.94	0.95	0.78	0.78	0.99
d 0 to 14													
ADG, lb	0.33	0.37	0.46	0.45	0.46	0.57	0.04	0.87	0.001	0.002	0.001	0.49	0.004
ADFI, lb	0.47	0.48	0.55	0.52	0.54	0.62	0.04	0.95	0.03	0.02	0.008	0.78	0.02
F/G	1.46	1.30	1.22	1.16	1.18	1.10	0.05	0.10	0.001	0.01	0.003	0.12	0.10
Feed cost/lb gain, $[4]	0.325	0.290	0.272	0.236	0.267	0.249	0.010	0.10	0.001	0.01	0.003	0.13	0.09
IOMFC, $/pig[4,5]	1.29	1.61	2.14	2.13	2.14	2.84	0.223	0.73	0.001	0.01	0.001	0.41	0.001
d 14 to 28													
ADG, lb	0.98	1.04	1.03	0.97	1.07	1.09	0.05	0.75	0.40	0.11	0.06	0.08	0.88
ADFI, lb	1.57	1.62	1.54	1.61	1.69	1.74	0.06	0.22	0.02	0.47	0.37	0.25	0.79
F/G	1.63	1.56	1.49	1.69	1.57	1.60	0.05	0.62	0.13	0.05	0.03	0.06	0.65
Feed cost/lb gain, $	0.208	0.200	0.191	0.220	0.206	0.209	0.006	0.63	0.02	0.08	0.03	0.08	0.65
IOMFC, $/pig	5.39	5.81	5.90	5.20	5.92	5.99	0.329	0.88	0.99	0.10	0.05	0.09	0.80
d 0 to 28													
ADG, lb	0.64	0.70	0.75	0.71	0.77	0.83	0.04	0.93	0.02	0.01	0.002	0.07	0.11
ADFI, lb	0.99	1.05	1.04	1.06	1.11	1.18	0.05	0.47	0.004	0.05	0.02	0.13	0.33
F/G	1.58	1.49	1.41	1.51	1.45	1.42	0.04	0.56	0.38	0.01	0.003	0.07	0.16
Feed cost/lb gain, $	0.236	0.223	0.215	0.233	0.224	0.223	0.005	0.61	0.68	0.02	0.005	0.05	0.37
IOMFC, $/pig	6.68	7.42	8.05	7.33	8.06	8.82	0.484	0.99	0.06	0.01	0.003	0.10	0.12
Final wt (d 28), lb	31.8	32.9	34.0	33.3	34.6	36.5	1.5	0.85	0.02	0.03	0.01	0.22	0.11

[1] A total of 180 weanling pigs (PIC, initially 13.2 lb and 21 d of age) were used in a 28-d experiment.

[2] Added zinc from zinc oxide was supplied at no (0 ppm) or yes (3,000 ppm from d 0 to 14 and 2,000 from d 14 to 28) levels to the basal diet (165 ppm Zn).

[3] Copper sources included none, tri-basic copper chloride (TBCC, 125 ppm Cu), and copper sulfate (SO_4, 125 ppm Cu).

[4] Feed costs were based on corn at $5.00/bu, 46.5% soybean meal at $350/ton, TBCC at $3.00/lb, copper sulfate at $1.19/lb, and zinc oxide at $1.22/lb.

[5] IOFC = Income over marginal feed costs (weight gain × $0.60/lb - feed cost).

Table 8. Effects of dietary zinc oxide, tri-basic copper chloride, and copper sulfate on weanling pig plasma mineral levels (Exp. 2)[1]

	Added zinc[2]							*P* <					
	No			Yes							Copper source effects		
											None vs.		
Copper source[3]	None	TBCC	SO_4	None	TBCC	SO_4	SE	Zn × Cu	Zn	Cu	SO_4	TBCC	SO_4 vs. TBCC
Plasma concentrations[4]													
d 14													
Copper, µg/mL	1.73	1.68	1.47	1.66	1.60	1.61	0.072	0.26	0.99	0.12	0.05	0.49	0.18
Zinc, µg/mL	0.68	0.63	0.60	1.11	1.12	1.21	0.059	0.31	0.001	0.88	0.84	0.77	0.62
Phosphorus, mg/mL	0.064	0.063	0.063	0.061	0.063	0.065	0.002	0.67	0.82	0.69	0.42	0.87	0.52
d 28													
Copper, µg/mL	1.78	1.88	1.56	1.75	1.61	1.82	0.085	0.02	0.86	0.71	0.42	0.83	0.56
Zinc, µg/mL	0.87	0.89	0.87	0.90	0.95	0.96	0.040	0.72	0.09	0.69	0.50	0.42	0.90
Phosphorus, mg/mL	0.074	0.073	0.073	0.072	0.075	0.070	0.002	0.48	0.42	0.52	0.48	0.68	0.26

[1] A total of 180 weanling pigs (PIC, initially 13.2 lb and 21 d of age) were used in a 28-d experiment.
[2] Added zinc from zinc oxide was supplied at no (0 ppm) or yes (3,000 ppm from d 0 to 14 and 2,000 from d 14 to 28) levels to the basal diet (165 ppm Zn).
[3] Copper sources included none, tri-basic copper chloride (TBCC, 125 ppm copper), and copper sulfate (SO_4, 125 ppm copper).
[4] Plasma was collected on d 14 and 28 from the same two pigs in each pen.