Effects of Copper Sulfate and Zinc Oxide on Weanling Pig Growth and Plasma Mineral Levels

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Summary

A total of 216 weanling pigs (PIC TR4 × 1050, initially 13.6 lb and 21 d of age) were used in a 42-d growth trial to compare the effects of supplemental zinc and copper and changing mineral regimens on growth performance and plasma mineral levels. The 6 dietary treatments included a 2 × 2 factorial arrangement with main effects of added copper from copper sulfate (0 or 125 ppm) and added zinc from zinc oxide (0 or 3,000 ppm from d 0 to 14 and 0 or 2,000 ppm from d 14 to 42). For the final 2 treatments, either zinc oxide alone or the combinations of zinc and copper were fed from d 0 to 14, with copper sulfate fed from d 14 to 42. There were 6 pens per treatment with 6 pigs per pen. All diets were supplemented with an additional 165 ppm zinc and 16.5 ppm copper from the trace mineral premix. Plasma was collected from 2 pigs per pen on d 14 and 42. From d 0 to 14, ADG, ADFI, and F/G were improved ($P < 0.04$) with the addition of dietary zinc. Copper supplementation also tended to increase ($P < 0.07$) ADFI from d 0 to 14. From d 14 to 42, added copper increased ($P < 0.003$) ADG and ADFI. Over the entire trial, continuous supplemental zinc increased ($P < 0.03$) ADG and tended to increase ($P < 0.09$) ADFI. Dietary copper also increased ($P < 0.004$) ADG and ADFI when fed from d 0 to 42. The most advantageous values for ADG and ADFI were seen in the treatment containing high levels of zinc from d 0 to 14 and high copper levels from d 14 to 42. The addition of either zinc or copper increased ($P < 0.02$) feed cost per pound of gain. However, income over feed cost was improved ($P < 0.006$) with the addition of copper, with the greatest value obtained when high zinc was fed from d 0 to 14 and high copper was fed from d 14 to 42. Plasma zinc levels were increased ($P < 0.001$) with zinc supplementation on d 14. These results indicate the optimal mineral regimen was supplementing zinc oxide from d 0 to 14 and copper sulfate from d 14 to 42.

Key words: copper, growth promotion, zinc

Introduction

Zinc and copper are two minerals commonly added at pharmacological levels in weanling pig diets to serve as growth promoters. Research has shown that increased dietary zinc can increase growth rates and decrease the incidence of diarrhea for the first 2 to 4 wk after weaning. Zinc oxide (ZnO) is the most commonly used form of zinc. Dietary copper has also been shown to enhance growth rates in weanling pigs and growing pigs. Copper sulfate ($CuSO_4$) is the most common form. Historically, research on combining ZnO and $CuSO_4$ at pharmacological levels has shown growth rates similar to those

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when ZnO is used alone. However, Shelton et al. (2008[4]) reported additive effects to using pharmacological levels of both zinc from ZnO and copper from either $CuSO_4$ or tri-basic copper chloride. Therefore, the objective of this trial was to evaluate the effects of the addition of dietary copper or zinc for a longer duration than in past trials and to determine the impact of changing mineral regimens by using pharmacological levels of zinc early after weaning and high levels of dietary copper later in the nursery period.

Procedures

The protocol used in this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan.

A total of 216 weanling pigs (PIC TR4 × 1050, initially 13.6 lb and 21-d of age) were used in a 42-d growth trial to compare the effects of supplemental zinc and copper and to observe the effects of changing mineral regimens for pigs from weaning to 50 lb. Pigs were allotted to pens by initial BW, and pens were assigned to treatments in a randomized complete block design, with both weight and location in the nursery serving as blocking factors. There were 6 pens per treatment with 6 pigs per pen. Treatments were arranged in a 2 × 2 factorial design with main effects of added copper from $CuSO_4$ (0 or 125 ppm) and added zinc from ZnO (0 or 3,000 ppm from d 0 to 14 and 0 or 2,000 ppm from d 14 to 42).Two additional treatments were included in which the added ZnO or ZnO and $CuSO_4$ diet was fed from d 0 to 14 with added $CuSO_4$ fed from d 14 to 42. The diets were fed in 2 phases: Phase 1 from d 0 to 14 and Phase 2 from d 14 to 42 (Table 1). Phase 1 and 2 diets were fed in meal form and formulated to contain 1.41% and 1.31% standardized ileal digestible lysine, respectively. 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. Added copper and zinc levels were achieved by replacing cornstarch with ZnO or $CuSO_4$.

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/pig. Weights and feed disappearance were measured every 14 d to determine ADG, ADFI, and F/G.

Blood samples were collected by jugular venipuncture from 2 randomly selected pigs per pen on d 14 and 42. Blood samples were chilled for approximately 1 h until they were centrifuged at 1,600 × *g* 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. Phosphorus was measured by color spectrophotometry.

Feed cost per pound of gain, feed cost per pig, and income over feed cost were also calculated. Income over feed cost was calculated by assessing a value of $0.50 per pound of gain and subtracting the feed cost.

[4] Shelton et al., Swine Day 2008, Report of Progress 1001, pp. 62-73.

Pen was used as the experimental unit for all analysis, and data were analyzed using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC). Main effects and potential interactions for added copper and zinc were tested using contrast statements. For Phase 1, both dietary treatments that were fed either the high zinc or high copper and zinc diet were pooled together to determine the main effects of copper and zinc. In Phase 2 as well as for the overall trial, only treatments that remained on the same mineral regimen for the entire trial were used to determine the main effects of copper and zinc.

Results and Discussion

Laboratory analysis of the diets indicated that diet copper and zinc levels were similar to those expected from diet formulation (Table 2).

Over the first phase (d 0 to 14), zinc supplementation improved ($P < 0.04$) ADG, ADFI, and F/G (Table 3). The addition of copper did not affect ADG or F/G but tended to increase ($P < 0.07$) ADFI from d 0 to 14. The greatest ADG and ADFI responses were seen when combining both added zinc and copper; however, they were only numerically greater (3%) than responses to zinc used alone.

From d 14 to 28, dietary zinc increased ($P < 0.04$) ADFI but not ADG. Thus, F/G became worse ($P < 0.02$) when zinc was included in the diet. Dietary copper also increased ($P < 0.003$) ADG and ADFI and tended to improve ($P < 0.06$) F/G. Adding copper and zinc together did not provide any benefit over feeding copper alone. As pigs were switched from supplemental zinc to added copper, an improvement ($P < 0.05$) in ADG was observed compared with maintaining a high level of zinc. Conversely, when switching from high levels of added copper and zinc to added copper, performance was not improved compared with the treatment containing both minerals.

A trend for a copper × zinc interaction was observed ($P < 0.06$) for ADG from d 28 to 42. This interaction is reflective of the numeric decrease in ADG when copper and zinc were used in combination compared with each used singularly. The addition of copper also resulted in an increase ($P < 0.04$) in ADFI and worsened F/G.

From d 14 to 42, added $CuSO_4$ increased ($P < 0.003$) ADG and ADFI. Added zinc worsened ($P < 0.05$) F/G and had no effect ($P > 0.10$) on ADG or ADFI. Average daily gain and ADFI were increased ($P < 0.05$) for pigs that were fed high levels of zinc from d 0 to 14 and then switched to high copper for d 14 to 42 compared with pigs fed high zinc in both phases.

Feeding pharmacological zinc continuously over the entire 42-d trial increased ($P < 0.03$) ADG and tended to increase ($P < 0.09$) ADFI. Copper supplementation also increased ($P < 0.004$) ADG and ADFI from d 0 to 42. These results agree with earlier research that indicated that improvements in growth performance from high levels of dietary copper or zinc were mostly due to improvements in feed intake. The most advantageous values for ADG and ADFI were observed in the treatment containing high levels of zinc in Phase 1 and high levels of copper in Phase 2. Pigs fed this treatment were 2.1 lb heavier than pigs fed only ZnO in both phases and 5.7 lb heavier than pigs fed the control diet.

For the entire trial, feed cost per pound of gain was increased (Table 4; $P < 0.02$) with the addition of copper or zinc as a result of the increase in diet cost with no improvements in F/G. Income over feed cost was improved ($P < 0.006$) with the addition of copper, with the greatest return obtained when high zinc was fed in Phase 1 and high copper in Phase 2. Adding zinc from d 0 to 14 and copper from d 14 to 28 resulted in \$0.56 to \$1.77 higher income over feed cost per pig than the other treatments.

No dietary effects were observed (Table 4; $P > 0.41$) for plasma copper level at d 14. However, plasma zinc levels were increased ($P < 0.001$) with added dietary zinc. Even more interesting was that treatments that were switched from either high zinc or high copper and zinc to high levels of copper had decreased plasma zinc levels than the treatments that remained on the same mineral regiment in both phases. On d 14, pigs were weighed and diets were switched at approximately 8:00 am, and then plasma was not collected until 1:00 p.m. The 5-h period in which pigs were allowed to eat the Phase 2 diet may have generated the decrease in plasma zinc. No dietary main effects were observed ($P > 0.16$) for plasma phosphorus at either d 14 or 42. On d 42, trends for a copper × zinc interaction were detected ($P < 0.08$) for both plasma copper and zinc. The plasma copper interaction was due to a numeric increase in plasma copper when copper was added to the diet alone, and compared with the control diet, no difference was observed when copper and zinc were both added. The plasma zinc interaction was due to the increase in plasma zinc when zinc was added alone in the diet, and there was no change when both copper and zinc were added.

The results from the first 28 d of this trial match results from our earlier study (Shelton et al., 2008), in which increases in ADG and ADFI were observed to adding both copper and zinc compared with adding each alone. However, the copper × zinc interaction for ADG observed from d 28 to 42 matches historical research showing reduced performance when combining zinc and copper compared with using either alone. Even though an additive response to copper and zinc was observed during the early portion of this trial, the regimen that achieved the greatest growth performance and economic return was the treatment in which zinc was fed in Phase 1 and copper was fed in Phase 2. This treatment regimen resulted in a 0.50 lb heavier pig and a return value of approximately \$0.56 more per pig compared with adding both zinc and copper to the diets.

Table 1. Composition of diets[1]

Ingredient, %	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
Cornstarch[4]	0.435	0.307
Total	100	100
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
Total lysine, %	1.55	1.45
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
Available P:calorie, g/Mcal	1.51	1.26

[1] A total of 216 weanling pigs (PIC, initially 13.6 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment.
[2] Pigs were fed Phase 1 from d 0 to 14.
[3] Pigs were fed Phase 2 from d 14 to 42.
[4] Cornstarch was replaced with ZnO at 7.7 lb/ton in Phase 1 and 5.1 lb/ton in Phase 2 and/or $CuSO_4$ at 1 lb/ton to create treatment diets.
[5] Standardized ileal digestible.

Table 2. Analyzed chemical composition of diets[1]

Added copper[2]:	No	Yes	No	Yes
Added zinc[3]:	No	No	Yes	Yes
Phase 1[4]				
Zinc, ppm	69 (196)	286 (196)	3,031 (3,196)	3,099 (3,196)
Copper, ppm	73.7 (26.2)	161.4 (151.2)	10.5 (26.2)	182.8 (151.2)
Phase 2[5]				
Zinc, ppm	204 (194)	256 (194)	1,823 (2,194)	1,819 (2,194)
Copper, ppm	19.1 (25.4)	162.3 (150.4)	26.1 (25.4)	180.0 (150.4)

Values in parentheses indicate the calculated expected value.

[1] A total of 216 weanling pigs (PIC, initially 13.6 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment.

[2] Added copper from $CuSO_4$ was supplied at no (0 ppm) or yes (125 ppm) levels to that provided by the trace mineral premix supplementation of the basal diet (16.5 ppm Cu).

[3] Added zinc from ZnO was supplied at no (0 ppm) or yes (3,000 ppm in Phase 1 and 2,000 in Phase 2) levels to that provided by the trace mineral premix supplementation of the basal diet (165 ppm Zn from ZnO).

[4] Pigs were fed Phase 1 from d 0 to 14.

[5] Pigs were fed Phase 2 from d 14 to 42.

Table 3. Effects of zinc oxide and copper sulfate on weanling pig growth performance[1]

Phase 1 diet[2]:	Control	Cu	Zn	Cu and Zn	Zn	Cu and Zn		Probability, $P <$		
Phase 2 diet[3]:	Control	Cu	Zn	Cu and Zn	Cu	Cu	SEM	Zinc × Copper	Zinc	Copper
Initial wt, lb	13.6	13.6	13.6	13.6	13.6	13.6	0.74	0.12	0.49	0.59
d 0 to 14										
ADG, lb	0.32^{a}	0.40^{b}	0.47^{bc}	0.49^{c}	0.48^{bc}	0.49^{c}	0.029	0.23	0.001	0.14
ADFI, lb	0.49^{a}	0.58^{b}	0.57^{ab}	0.60^{b}	0.59^{b}	0.60^{b}	0.320	0.25	0.04	0.07
F/G	1.52^{a}	1.45^{a}	1.22^{b}	1.23^{b}	1.24^{b}	1.24^{b}	0.043	0.35	0.001	0.59
wt on d 14, lb	18.1^{a}	19.3^{ab}	20.2^{bc}	20.5^{c}	20.3^{bc}	20.5^{c}	0.96	0.22	0.001	0.14
d 14 to 28										
ADG, lb	1.03^{a}	1.17^{c}	1.06^{ab}	1.21^{c}	1.20^{c}	1.13^{bc}	0.047	0.80	0.29	0.001
ADFI, lb	1.45^{a}	1.61^{bc}	1.55^{ab}	1.72^{c}	1.65^{bc}	1.58^{abc}	0.069	0.99	0.04	0.003
F/G	1.40^{a}	1.37^{a}	1.47^{b}	1.42^{ab}	1.38^{a}	1.40^{a}	0.021	0.62	0.02	0.06
d 28 to 42										
ADG, lb	1.55^{a}	1.62^{ab}	1.62^{ab}	1.57^{ab}	1.64^{b}	1.60^{ab}	0.041	0.06	0.77	0.69
ADFI, lb	2.56^{a}	2.74^{b}	2.68^{ab}	2.71^{b}	2.75^{b}	2.72^{b}	0.090	0.17	0.40	0.04
F/G	1.65^{a}	1.69^{abc}	1.66^{ab}	1.73^{c}	1.68^{abc}	1.70^{bc}	0.026	0.58	0.24	0.003
d 14 to 42										
ADG, lb	1.29^{a}	1.40^{c}	1.33^{ab}	1.39^{bc}	1.42^{bc}	1.36^{bc}	0.039	0.32	0.39	0.001
ADFI, lb	2.01^{a}	2.17^{b}	2.11^{ab}	2.22^{b}	2.20^{b}	2.15^{b}	0.076	0.47	0.10	0.003
F/G	1.55	1.56	1.58	1.59	1.55	1.57	0.019	0.98	0.05	0.56
d 0 to 42										
ADG, lb	0.97^{a}	1.07^{bc}	1.04^{b}	1.09^{bc}	1.11^{c}	1.07^{bc}	0.033	0.30	0.03	0.003
ADFI, lb	1.50^{a}	1.64^{b}	1.59^{ab}	1.68^{b}	1.66^{b}	1.63^{b}	0.059	0.47	0.09	0.004
F/G	1.54	1.54	1.52	1.54	1.50	1.52	0.018	0.65	0.39	0.69
Final wt, lb	54.3^{a}	58.4^{b}	57.9^{b}	59.5^{b}	60.0^{b}	59.2^{b}	1.89	0.19	0.02	0.004

[1] A total of 216 weanling pigs (PIC, initially 13.6 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment.

[2] Phase 1 diets were fed from d 0 to 14 after weaning: control (basal diet with no added Cu or Zn), Cu (125 ppm of added Cu from $CuSO_4$), Zn (3,000 ppm of added Zn from ZnO), and Cu and Zn (125 ppm of added Cu from $CuSO_4$ and 3,000 ppm of added Zn from ZnO).

[3] Phase 2 diets were fed from d 14 to 42 after weaning: control (basal diet with no added Cu or Zn), Cu (125 ppm of added Cu from $CuSO_4$), Zn (2,000 ppm of added Zn from ZnO), and Cu and Zn (125 ppm of added Cu from $CuSO_4$ and 2,000 ppm of added Zn from ZnO).

[abc] Within a row, means without a common superscript differ ($P < 0.05$).

Table 4. Effects of zinc oxide and copper sulfate on the economics and plasma mineral concentrations of weanling pigs[1]

Phase 1 diet[2]:	Control	Cu	Zn	Cu and Zn	Zn	Cu and Zn		Probability, $P <$		
Phase 2 diet[3]:	Control	Cu	Zn	Cu and Zn	Cu	Cu	SEM	Zinc × Copper	Zinc	Copper
Economics, d 0 to 42										
Feed cost/lb gain, $[4]	0.212[ab]	0.214[ab]	0.216[b]	0.218[b]	0.210[a]	0.213[ab]	0.003	0.44	0.02	0.004
Feed cost/pig, $[4]	8.65[a]	9.57[b]	9.46[b]	10.02[b]	9.74[b]	9.61[b]	0.354	0.97	0.07	0.37
IOFC, $/pig[4,5]	11.70[a]	12.79[bc]	12.43[b]	12.91[bc]	13.47[c]	12.90[bc]	0.365	0.27	0.12	0.006
Plasma mineral concentrations										
d 14										
Copper, µg/mL	1.87	1.89	1.86	1.88	1.75	1.86	0.08	0.68	0.51	0.42
Zinc, µg/mL	0.53[a]	0.55[a]	0.95[c]	0.93[c]	0.74[b]	0.73[b]	0.066	0.81	0.001	0.92
Phosphorus, mg/mL	0.084[ab]	0.083[a]	0.086[ab]	0.086[ab]	0.094[b]	0.086[ab]	0.004	0.71	0.17	0.28
d 42										
Copper, µg/mL	1.94	2.13	2.06	1.97	1.97	2.10	0.077	0.08	0.78	0.54
Zinc, µg/mL	1.04[a]	1.08[a]	1.24[b]	1.12[ab]	1.13[ab]	1.06[a]	0.043	0.07	0.01	0.42
Phosphorus, mg/mL	0.092[a]	0.089[a]	0.092[a]	0.092[a]	0.098[b]	0.088[a]	0.002	0.42	0.38	0.38

[1] A total of 216 weanling pigs (PIC, initially 13.6 lb and 21 d of age) were used in a 42-d experiment with 6 pens per treatment.

[2] Phase 1 diets were fed from d 0 to 14 after weaning: control (basal diet with no added Cu or Zn), Cu (125 ppm of added Cu from $CuSO_4$), Zn (3,000 ppm of added Zn from ZnO), and Cu and Zn (125 ppm of added Cu from $CuSO_4$ and 3,000 ppm of added Zn from ZnO).

[3] Phase 2 diets were fed from d 14 to 42 after weaning: control (basal diet with no added Cu or Zn), Cu (125 ppm of added Cu from $CuSO_4$), Zn (2,000 ppm of added Zn from ZnO), and Cu and Zn (125 ppm of added Cu from $CuSO_4$ and 2,000 ppm of added Zn from ZnO).

[4] Feed costs were based on corn at $5.00/bu, soybean meal at $350/ton, zinc oxide at $121.87/cwt, and copper sulfate at $118.75/cwt.

[5] Income over feed cost = (Weight gain per pig × $0.50/lb) - feed cost per pig.

[abc] Within a row, means without a common superscript differ ($P < 0.05$).