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Evaluating the Effects of Pharmacological Levels of Zinc Oxide, Diet Acidification and Dietary Crude Protein on Growth Performance of Nursery Pigs

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Abstract

A total of 360 weaned pigs (DNA 200 × 400; initially 12.9 lb BW) were used in a 42-d growth study to evaluate the effects of pharmacological levels of zinc oxide (ZnO), diet acidification, and dietary crude protein (CP) on pig performance. Pigs were weaned at approximately 21-d of age and were randomly assigned to pens (5 pigs per pen) and allotted to 1 of 8 dietary treatments with 9 pens per treatment. Experimental diets were fed from d 0 to 21 with a common diet fed from d 21 to 42. The eight treatment diets were arranged as a 2 × 2 × 2 factorial with main effects of Zn from ZnO (110 ppm from d 0 to 21 or 3,000 ppm from d 0 to 7, and 2,000 ppm from d 7 to 21), diet acidification, (without or with 1.2% sodium diformate), and dietary CP (21 or 18%, [1.40 vs. 1.20% standardized ileal digestible Lys, respectively]). Fecal samples were collected weekly to determine dry matter content. No 2- or 3-way interactions ($P > 0.05$) were observed throughout the 42-d growth study for growth performance; however, there was a ZnO × acidifier × CP interaction ($P < 0.05$) for fecal dry matter on d 7 and overall, where reducing CP without acidification increased fecal DM when ZnO was not in the diet, but had little effect when ZnO was present in the diet. From d 0 to 21, pigs fed added ZnO had improved ($P < 0.05$) average daily gain (ADG), average daily feed intake (ADFI), feed efficiency (F/G), and increased d 21 body weight (BW) compared to those fed 110 ppm Zn. Added sodium diformate improved ($P < 0.05$), ADG, F/G, and BW. Pigs fed 21% CP had improved ($P < 0.05$) ADG and F/G and tended ($P < 0.10$) to have increased d 21 BW. In the subsequent period (d 21 to 42) after the experimental diets were fed, there was no evidence of difference in growth performance among treatments. Overall (d 0 to 42), adding ZnO or sodium diformate from d 0 to 21 tended to increase ADG ($P \leq 0.10$) with no evidence of difference in ADFI and F/G. Increasing dietary CP from 18 to 21% from d 0 to 21 improved ($P < 0.05$) overall F/G. In summary, dietary addition of ZnO or sodium diformate independently improved nursery pig performance.

Keywords

zinc, acidification, crude protein, nursery pigs

Authors

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Evaluating the Effects of Pharmacological Levels of Zinc Oxide, Diet Acidification and Dietary Crude Protein on Growth Performance of Nursery Pigs

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Summary

A total of 360 weaned pigs (DNA 200 × 400; initially 12.9 lb BW) were used in a 42-d growth study to evaluate the effects of pharmacological levels of zinc oxide (ZnO), diet acidification, and dietary crude protein (CP) on pig performance. Pigs were weaned at approximately 21-d of age and were randomly assigned to pens (5 pigs per pen) and allotted to 1 of 8 dietary treatments with 9 pens per treatment. Experimental diets were fed from d 0 to 21 with a common diet fed from d 21 to 42. The eight treatment diets were arranged as a 2 × 2 × 2 factorial with main effects of Zn from ZnO (110 ppm from d 0 to 21 or 3,000 ppm from d 0 to 7, and 2,000 ppm from d 7 to 21), diet acidification, (without or with 1.2% sodium diformate), and dietary CP (21 or 18%, [1.40 vs. 1.20% standardized ileal digestible Lys, respectively]). Fecal samples were collected weekly to determine dry matter content. No 2- or 3-way interactions ($P > 0.05$) were observed throughout the 42-d growth study for growth performance; however, there was a ZnO × acidifier × CP interaction ($P < 0.05$) for fecal dry matter on d 7 and overall, where reducing CP without acidification increased fecal DM when ZnO was not in the diet, but had little effect when ZnO was present in the diet. From d 0 to 21, pigs fed added ZnO had improved ($P < 0.05$) average daily gain (ADG), average daily feed intake (ADFI), feed efficiency (F/G), and increased d 21 body weight (BW) compared to those fed 110 ppm Zn. Added sodium diformate improved ($P < 0.05$), ADG, F/G, and BW. Pigs fed 21% CP had improved ($P < 0.05$) ADG and F/G and tended ($P < 0.10$) to have increased d 21 BW. In the subsequent period (d 21 to 42) after the experimental diets were fed, there was no evidence of difference in growth performance among treatments. Overall (d 0 to 42), adding ZnO or sodium diformate from d 0 to 21 tended to increase ADG ($P \leq 0.10$) with no evidence of difference in ADFI and F/G. Increasing dietary CP from 18 to 21% from d 0 to 21 improved ($P < 0.05$) overall F/G. In summary, dietary addition of ZnO or sodium diformate independently improved nursery pig performance.

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Introduction

Zinc oxide has been widely used at pharmacological levels in nursery diets because of its ability to reduce or prevent post-weaning diarrhea and has a positive impact on growth performance. However, because of growing concerns for high concentrations of Zn in swine waste, the use of ZnO is now regulated in many countries. An alternative feed additive offering similar physiological and growth benefits to nursery pigs therefore would be of great interest to the swine industry.

Acidifiers have the potential to decrease stomach pH, protect the host from pathogenic invasion, and improve nutrient digestibility and growth performance.[3] Growth performance and the incidence of post-weaning diarrhea can also be affected by feeding high protein diets. A low crude protein diet could be an effective way to mitigate stress on weaned pigs and their gastrointestinal tract by reducing excess nitrogen fermentation and improving fecal dry matter.[4] Therefore, the objective of this study was to determine the interactive effects of added ZnO, diet acidification, and CP level on growth performance, and fecal dry matter in weanling pigs.

Procedures

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

A total of 360 weaned pigs, at approximately 21 days of age (DNA; 200 × 400, Columbus, NE; initial BW = 12.9 lb) were used in a 42-d growth study. Following the arrival to the research facility, pigs were placed in pens with 5 pigs per pen. Within each barn, pigs were weighed and assigned to pens in a completely randomized design. Each pen of pigs was randomly allotted to 1 of 8 treatments with 9 replicate pens per treatment, 5 replications in one barn and 4 replications in the other barn. Experimental diets were fed from d 0 to 21 with a common diet fed from d 21 to 42 (Tables 1, 2, and 3). The eight treatment diets were arranged as a 2 × 2 × 2 factorial with main effects of Zn from ZnO (3,000 ppm from d 0 to 7, and 2,000 ppm from d 7 to 21, or 110 ppm from d 0 to 21), diet acidification (without or with 1.2% sodium diformate, [Formi-NDF, Addcon; St. Peters, MN]), and dietary crude protein (21 or 18% CP corresponding to 1.40 or 1.20% SID Lys for phase 1 and 1.35 or 1.20% SID Lys in phase 2). Diets also contained 4% wheat bran in phases 1 and 2. To balance for sodium chloride, diets containing the acidifier had lower inclusion levels of sodium chloride. The diet fed from d 0 to 7 was pelleted and the following diets were fed as meal.

[3] Kil DY, Kwon WB, Kim BG. Dietary acidifiers in weanling pig diets: a review. Rev Colomb Cienc Pecu. 2011; 24:231-247.

[4] Zhou J, Wang Y, Zeng X, Zhang T, Li P, Yoa B, Wang L, Qiao A, Zeng X. Effect of antibiotic-free, low-protein diet with specific amino acid compositions on growth and intestinal flora in weaned pigs. Food Funct., 2019, DOI: 10.1039/C9FO02724F.

Nursery diets were made at the Kansas State University O.H. Kruse Feed Technology Innovation Center, Manhattan, KS. Samples of each diet were collected at the time of manufacturing. Composite samples were kept refrigerated at the Kansas State University Swine Lab for storage until analysis. Complete diet samples were sent for proximate analysis to the Agricultural Experiment Station Chemical Laboratories, University of Missouri-Columbia, MO (Table 4). For the pelleted phase 1 diet, average conditioning temperature target was 123°F and the average hot pellet temperature was 161.3°F. Retention time was 30 s using a 3/16 × 1 ¼ inch die (L/D = 6.0) with a 1,560 lb/h production rate and approximately 72.8°F ambient temperature.

Pigs were weighed and feed disappearance recorded weekly for the 42-d study to determine ADG, ADFI, and F/G. Fecal samples were collected from the same three piglets from each pen on d 7, 14, 21, 28, and 35 of the trial. Three fecal samples from the same pen were pooled to determine fecal dry matter. To determine fecal DM percentage, samples were completely dried in a 105.8°F oven for 48 hours.

Experimental data were analyzed using R Studio (Version 3.5.2, R Core Team. Vienna, Austria) with pen serving as the experimental unit. Main effects and interactions of ZnO, sodium diformate, and crude protein were analyzed. Dry matter was analyzed as repeated measures. Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results and Discussion

The chemical analyses of the experimental diets were similar to those calculated from diet formulation in respect of Zn concentration and crude protein (Table 4).

There were no 2- or 3-way interactions ($P > 0.05$) observed throughout the 42-d study for ADG, ADFI, and F/G (Tables 5).

For the main effect of ZnO, from d 0 to 7 there was no evidence of differences ($P > 0.05$) for ADG, ADFI, F/G, or d 7 BW. However, from d 7 to 21 and 0 to 21, ADG, ADFI, F/G, and BW were improved ($P < 0.05$) for pigs fed pharmacological levels of Zn compared to those fed 110 ppm. For subsequent performance (d 21 to 42), there was no evidence of difference ($P > 0.05$) in ADG, ADFI, or F/G. For the overall period, there was a tendency ($P = 0.061$) for improved overall ADG for pigs fed added ZnO from d 0 to 21, but no significant effects on ADFI or F/G. On d 42, pigs fed pharmacological levels of added Zn from d 0 to 21 had increased ($P < 0.05$) BW compared with those fed 110 ppm.

From d 0 to 7, pigs fed added sodium diformate had increased ($P < 0.05$) ADG and d 7 BW with no evidence of difference in ADFI or F/G. Pigs fed sodium diformate had improved ADG, and F/G from d 7 to 21 and d 0 to 21 and increased BW on d 21 ($P < 0.05$). From d 21 to 42 during the post-treatment period, there was no evidence of difference ($P > 0.05$) in pigs previously fed sodium diformate for ADG, ADFI, and F/G. For the overall period (d 0 to 42) a tendency ($P < 0.10$) was observed for pigs fed sodium diformate in the treatment phase to have increased ADG and d 42 BW with no evidence of difference in ADFI or F/G.

For the main effect of CP, from d 0 to 7 there was no evidence of difference ($P < 0.10$) in ADG, ADFI, or F/G among pigs fed either 21 or 18% CP. From d 7 to 21, there was no evidence of difference ($P > 0.10$) between pigs fed either 21 or 18% CP for ADG or ADFI; however, pigs fed 21% CP had improved ($P = 0.002$) F/G and a trend ($P \leq 0.10$) for increased BW on d 21. From d 0 to 21, there was a trend observed where pigs fed 21% CP diets had increased ADG ($P = 0.065$) compared with pigs fed 18% CP diets. There was no evidence of difference between pigs fed 21 or 18% CP in ADFI, but pigs provided 21% CP had improved F/G ($P < 0.05$) compared with those fed 18% CP diets. For the subsequent performance (d 21 to 42) there was no evidence of difference ($P > 0.10$) in ADG, ADFI, F/G, or BW due to crude protein level previously fed from d 0 to 21. Finally, overall there was no evidence of difference in ADG and ADFI; however, pigs fed 21% CP from d 0 to 21 had improved ($P = 0.001$) F/G compared with those fed 18% CP.

There was a ZnO × sodium diformate × CP interaction ($P < 0.05$) observed for fecal dry matter on d 7 and the overall mean (average of the weekly samples). When ZnO was in the diet, adding sodium diformate or reducing CP had little effect on fecal DM; however, without added ZnO in the diet, lowering CP without acidification improved the fecal dry matter, but with acidification, high CP increased fecal dry matter. Fecal DM was also improved on d 42 where pigs provided diets with high CP and acidification without ZnO had greater ($P < 0.05$) fecal DM than pigs provided diets with ZnO on a low CP diet without acidification with other treatments being intermediate.

In conclusion, reducing CP without acidification increased fecal DM when ZnO was not in the diet, but had little effect when ZnO was present in the diet. If ZnO has to be removed from the diet due to regulations, reducing CP could be a useful practice for improving fecal DM in nursery pigs. When fed to nursery pigs, ZnO improved ADG, ADFI, F/G, and BW. The results of this study indicate that adding an acidifier independent of ZnO also improved nursery pig growth performance, exhibited by improved ADG, F/G, and BW without an effect on ADFI. Results of this study also indicate that pigs provided a high CP diet have improved BW, ADG, and F/G without an effect on ADFI and fecal DM. The addition of an acidifier with or without ZnO could be a useful practice to improve nursery pig growth performance and warrants more research.

Table 1. Phase 1 diet composition (as-fed basis)[1]

	No added zinc oxide				Added zinc oxide			
	No acidifier		Added acidifier[2]		No acidifier		Added acidifier[2]	
Item	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP
Ingredient %								
Corn	41.19	48.63	40.14	47.58	40.79	48.23	39.74	47.18
Soybean meal	17.75	10.25	17.75	10.25	17.75	10.25	17.75	10.25
Dried whey	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Fish meal	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Wheat bran	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
HP 300[3]	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75
Soybean oil	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Calcium carbonate	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Monocalcium phosphate	0.30	0.40	0.30	0.40	0.30	0.40	0.30	0.40
Sodium chloride	0.30	0.30	0.15	0.15	0.30	0.30	0.15	0.15
L-Lysine-HCL	0.43	0.41	0.43	0.41	0.43	0.41	0.43	0.41
DL-Methionine	0.21	0.17	0.21	0.17	0.21	0.17	0.21	0.17
L-Threonine	0.20	0.19	0.20	0.19	0.20	0.19	0.20	0.19
L-Tryptophan	0.06	0.07	0.06	0.07	0.06	0.07	0.06	0.07
L-Valine	0.10	0.13	0.10	0.13	0.10	0.13	0.10	0.13
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[4]	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Zinc oxide	---	---	---	---	0.40	0.40	0.40	0.40
Sodium diformate	---	---	1.20	1.20	---	---	1.20	1.20
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

continued

Table 1. Phase 1 diet composition (as-fed basis)[1]

	No added zinc oxide				Added zinc oxide			
	No acidifier		Added acidifier[2]		No acidifier		Added acidifier[2]	
Item	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP
Calculated analysis								
Standardized ileal digestible (SID) amino acids								
Lysine	1.40	1.20	1.40	1.20	1.40	1.20	1.40	1.20
Isoleucine:lysine	56	55	56	55	56	55	56	55
Leucine:lysine	108	112	108	111	108	112	108	111
Methionine:lysine	37	37	37	36	37	37	37	36
Methionine and cysteine:lysine	58	58	58	58	58	58	58	58
Threonine:lysine	64	65	64	65	64	65	64	65
Tryptophan:lysine	20.1	21.2	20.1	21.2	20.1	21.2	20.1	21.2
Valine:lysine	67	70	67	70	67	70	67	70
Total Lys, %	1.54	1.32	1.54	1.32	1.54	1.32	1.53	1.32
ME,[5] kcal/lb	1,541	1,543	1,525	1,527	1,535	1,537	1,519	1,520
NE, kcal/lb	1,158	1,177	1,146	1,164	1,153	1,172	1,141	1,159
SID Lys:NE, g/Mcal	5.48	4.62	5.54	4.67	5.5	4.64	5.56	4.69
Crude protein,[6] %	21.1	18.1	21.0	18.0	21.1	18.1	21.0	18.0
Ca, %	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
P, %	0.67	0.66	0.67	0.66	0.67	0.66	0.67	0.66
STTD P,[7] %	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Na, %	0.40	0.39	0.59	0.59	0.40	0.39	0.59	0.59
Cl, %	0.67	0.66	0.58	0.57	0.67	0.66	0.58	0.57
Zinc, ppm	110	110	110	110	2,990	2,990	2,990	2,990

[1] Phase 1 diets were fed from d 0 to d 7.
[2] Sodium diformate (Formi-NDF, Addcon, St. Peters, MN) was included in the diet at 1.2% from d 0 to d 21.
[3] HP 300 (Hamlet Protein, Findlay, OH).
[4] HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) provided an estimated release of 0.12% STTD P.
[5] ME = metabolizable energy. NE = net energy.
[6] CP = crude protein.
[7] STTD P = standardized total tract digestible phosphorus.

Table 2. Phase 2 diet composition (as-fed basis)[1]

	No added zinc oxide				Added zinc oxide			
	No acidifier		Added acidifier[2]		No acidifier		Added acidifier[2]	
Item	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP
Ingredient, %								
Corn	53.41	60.54	52.40	59.54	53.16	60.30	52.16	59.29
Soybean meal	28.75	21.35	28.75	21.35	28.75	21.35	28.75	21.35
Milk, whey powder	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Wheat bran	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Calcium carbonate	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Calcium phosphate	0.80	0.90	0.80	0.90	0.80	0.90	0.80	0.90
Sodium chloride	0.55	0.55	0.35	0.35	0.55	0.55	0.35	0.35
L-Lysine-HCL	0.50	0.54	0.50	0.54	0.50	0.54	0.50	0.54
DL-Methionine	0.20	0.23	0.20	0.23	0.20	0.23	0.20	0.23
L-Threonine	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
L-Tryptophan	0.04	0.07	0.04	0.07	0.04	0.07	0.04	0.07
L-Valine	0.10	0.17	0.10	0.17	0.10	0.17	0.10	0.17
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[3]	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Zinc oxide	---	---	---	---	0.25	0.25	0.25	0.25
Sodium diformate	---	---	1.20	1.20	---	---	1.20	1.20
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

continued

Table 2. Phase 2 diet composition (as-fed basis)[1]

	No added zinc oxide				Added zinc oxide			
	No acidifier		Added acidifier[2]		No acidifier		Added acidifier[2]	
Item	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP
Calculated analysis								
Standardized ileal digestible (SID) amino acids								
Lysine	1.35	1.20	1.35	1.20	1.35	1.20	1.35	1.20
Isoleucine:lysine	55	52	55	52	55	52	55	52
Leucine:lysine	111	110	110	110	110	110	110	110
Methionine:lysine	35	39	35	39	35	39	35	39
Methionine and cysteine:lysine	57	61	57	61	57	61	57	61
Threonine:lysine	65	65	65	65	65	65	65	65
Tryptophan:lysine	19.1	21	19.1	21	19.1	21	19.1	21
Valine:lysine	67	70	66	70	67	70	66	70
Total lysine, %	1.49	1.32	1.48	1.32	1.49	1.32	1.48	1.31
ME,[4] kcal/lb	1,471	1,475	1,456	1,459	1,467	1,471	1,452	1,455
NE, kcal/lb	1,089	1,109	1,077	1,097	1,086	1,106	1,074	1,094
SID Lys:NE, g/Mcal	5.63	4.91	5.68	4.96	5.64	4.92	5.7	4.97
Crude protein,[5] %	20.7	17.9	20.7	17.9	20.7	17.9	20.6	17.9
Ca, %	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
P, %	0.62	0.61	0.62	0.61	0.62	0.61	0.62	0.61
STTD P,[6] %	0.51	0.51	0.51	0.51	0.51	0.51	0.50	0.50
Na, %	0.35	0.34	0.52	0.52	0.35	0.34	0.52	0.52
Cl, %	0.60	0.61	0.49	0.49	0.60	0.61	0.49	0.49
Zinc, ppm	110	110	110	110	1,910	1,910	1,910	1,910

[1] Phase 1 diets were fed from d 7 to d 21
[2] Sodium diformate (Formi-NDF, Addcon, St. Peters, MN) was included in the diet at 1.2% from d 0 to d 21.
[3] HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) provided an estimated release of 0.13% STTD P.
[4] ME = metabolizable energy. NE = net energy.
[5] CP = crude protein.
[6] STTD P = standardized total tract digestible phosphorus.

Table 3. Phase 3 common diet composition, (as-fed basis)[1]

Item	Common diet
Ingredients, %	
Corn	65.47
Soybean meal	28.30
Fat	2.00
Calcium carbonate	0.75
Monocalcium phosphate	1.10
Sodium chloride	0.60
L-Lysine-HCl	0.55
DL-Methionine	0.25
L-Threonine	0.23
L-Tryptophan	0.05
L-Valine	0.16
Vitamin premix	0.25
Trace mineral premix	0.15
Alltech All-Bind HD	0.15
Total	100.00
Standardized ileal digestible (SID) amino acids, %	
Lysine	1.30
Isoleucine:lysine	53
Leucine:lysine	111
Methionine:lysine	39
Methionine and cysteine:lysine	60
Threonine:lysine	63
Tryptophan:lysine	19.3
Valine:lysine	70
Histidine:lysine	35
Net energy, kcal/lb	1,152
Crude protein, %	19.9
Calcium, %	0.65
STTD P,[2] %	0.48

[1] Phase 3 common diets were fed from d 21 to 42.
[2] STTD P = standardized total tract digestible phosphorus.

Table 4. Analyzed diet composition (as-fed basis)[1]

Analyzed composition %[4,5]	No added zinc oxide				Added zinc oxide[2]			
	No acidifier		Added acidifier[3]		No acidifier		Added acidifier[3]	
	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP
Phase 1								
Crude protein	20.52	17.48	20.52	17.81	20.92	18.20	20.49	17.76
Zinc	181	154	191	101	2,450	2,820	2,650	2,620
Phase 2								
Crude protein	20.06	17.01	20.57	17.76	20.04	17.40	20.03	17.26
Zinc	77.6	231	148	156	2,020	1,750	1,440	1,490

[1] Diets were fed in 3 phases from d 0 to 7, 7 to 21, and 21 to 42 for phases 1, 2, and 3, respectively.
[2] Zinc oxide was included in the diet at 3,000 ppm of Zn from d 0 to 7; 2,000 ppm of Zn from d 7 to 21; and no additional Zn other than that from the TM premix from d 21 to 42.
[3] Sodium diformate (Formi-NDF, Addcon, St. Peters, MN) was included in the diet at 1.2% from d 0 to d 21.
[4] Complete diet samples were taken at manufacture. Samples were stored at -20°C until they were homogenized, subsampled, and submitted to the Agricultural Experiment Station Chemical Laboratories, University of Missouri-Columbia, MO, for proximate analysis.
[5] CP = crude protein.

Table 5. Evaluating the effects of pharmacological levels of zinc oxide, sodium diformate, and crude protein on growth performance of nursery pigs[1]

	No added zinc oxide				Added zinc oxide[2]					Probability $P <$		
	No acidifier		Added acidifier[3]		No acidifier		Added acidifier[3]					
Item[5,6]	21% CP[4]	18% CP	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP	SEM	ZnO	Acidifier	Crude protein
Body weight, lb												
d 0	12.92	12.90	12.89	12.89	12.91	12.87	12.87	12.92	0.030	0.794	0.754	1.000
d 7	13.79	13.64	14.26	14.01	13.86	13.90	14.16	13.93	0.147	0.717	0.007	0.160
d 21	23.31	22.21	24.12	24.01	24.83	24.45	25.81	24.96	0.507	<0.001	0.006	0.094
d 42	51.22	49.72	52.81	53.14	53.43	52.77	54.67	52.56	1.143	0.048	0.066	0.228
d 0 to 7												
ADG, lb	0.13	0.11	0.20	0.16	0.14	0.15	0.18	0.14	0.022	0.682	0.007	0.172
ADFI, lb	0.19	0.18	0.20	0.21	0.17	0.21	0.20	0.18	0.015	0.629	0.257	0.771
F/G	2.41	1.83	1.07	1.44	1.43	1.62	1.18	1.74	0.488	0.574	0.184	0.699
d 7 to 21												
ADG, lb	0.68	0.59	0.70	0.71	0.78	0.75	0.83	0.79	0.033	<0.001	0.017	0.110
ADFI, lb	1.00	0.98	1.03	1.09	1.13	1.17	1.12	1.13	0.048	0.002	0.506	0.542
F/G	1.49	1.66	1.47	1.52	1.44	1.54	1.37	1.44	0.043	0.005	0.010	0.002
d 0 to 21												
ADG, lb	0.50	0.43	0.53	0.53	0.57	0.55	0.62	0.57	0.025	<0.001	0.004	0.065
ADFI, lb	0.73	0.71	0.75	0.79	0.81	0.84	0.81	0.82	0.035	0.004	0.409	0.582
F/G	1.49	1.67	1.42	1.50	1.42	1.54	1.34	1.43	0.040	0.003	<0.001	<0.001
d 21 to 42												
ADG, lb	1.33	1.31	1.37	1.39	1.36	1.35	1.36	1.31	0.041	0.949	0.495	0.621
ADFI, lb	1.93	1.91	1.98	2.03	1.95	1.99	2.03	1.95	0.055	0.598	0.176	0.891
F/G	1.45	1.46	1.45	1.46	1.44	1.47	1.50	1.48	0.016	0.124	0.108	0.365
Overall (d 0 to 42)												
ADG, lb	0.91	0.87	0.95	0.96	0.96	0.95	0.98	0.94	0.028	0.061	0.069	0.231
ADFI, lb	1.33	1.30	1.37	1.41	1.38	1.41	1.42	1.38	0.040	0.113	0.197	0.897
F/G	1.46	1.51	1.44	1.47	1.43	1.49	1.45	1.46	0.016	0.387	0.166	0.001

[1] A total of 360 pigs (initial BW of 12.9 ± 0.1 lb) were used in a 42-d growth study with 5 pigs per pen and 9 pens per treatment.
[2] Zinc oxide was included in the diet to provide 3,000 ppm of Zn from d 0 to 7; 2,000 ppm of Zn from d 7 to 21; and no additional Zn other than that from the TM premix from d 21 to 42.
[3] Sodium diformate (Formi-NDF, Addcon, St. Peters, MN) was included in the diet at 1.2% from d 0 to d 21.
[4] Dietary CP 21 or 18% CP corresponding to 1.40 or 1.20% SID Lys for phase 1 and 1.35 or 1.20% SID Lys in phase 2 respectively.
[5] All interactions were found to be nonsignificant ($P > 0.125$).
[6] CP = crude protein. BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed efficiency.

Table 6. Main effects of pharmacological levels of zinc oxide, sodium diformate, and crude protein on growth performance of nursery pigs[1]

	Zinc oxide[2]				Acidifier[3]				Crude protein[4]			
Item[5,6,7]	None	With	SEM	*P* <	None	With	SEM	*P* <	21%	18%	SEM	*P* <
Body weight, lb												
d 0	12.90	12.89	0.015	0.794	12.90	12.89	0.015	0.754	12.90	12.90	0.015	1.000
d 7	13.93	13.96	0.074	0.717	13.80	14.09	0.074	0.007	14.02	13.87	0.074	0.160
d 21	23.41	25.01	0.254	<0.001	23.70	24.72	0.254	0.006	24.52	23.91	0.254	0.094
d 42	51.72	53.36	0.572	0.048	51.78	53.29	0.572	0.066	53.03	52.05	0.572	0.228
d 0 to 7												
ADG, lb	0.15	0.15	0.011	0.682	0.13	0.17	0.011	0.007	0.16	0.14	0.011	0.172
ADFI, lb	0.20	0.19	0.008	0.629	0.19	0.20	0.008	0.257	0.19	0.20	0.008	0.771
F/G	1.69	1.49	0.244	0.574	1.82	1.36	0.244	0.184	1.52	1.66	0.244	0.699
d 7 to 21												
ADG, lb	0.67	0.79	0.017	<0.001	0.70	0.76	0.017	0.017	0.75	0.71	0.017	0.110
ADFI, lb	1.02	1.14	0.024	0.002	1.07	1.09	0.024	0.506	1.07	1.09	0.024	0.542
F/G	1.53	1.44	0.022	0.005	1.53	1.45	0.022	0.010	1.44	1.54	0.022	0.002
d 0 to 21												
ADG, lb	0.50	0.58	0.013	<0.001	0.51	0.56	0.013	0.004	0.55	0.52	0.013	0.065
ADFI, lb	0.75	0.82	0.018	0.004	0.77	0.79	0.018	0.409	0.78	0.79	0.018	0.582
F/G	1.52	1.43	0.020	0.003	1.53	1.42	0.020	<0.001	1.42	1.53	0.020	<0.001
d 21 to 42												
ADG, lb	1.35	1.35	0.021	0.949	1.34	1.36	0.021	0.495	1.35	1.34	0.021	0.621
ADFI, lb	1.96	1.98	0.028	0.598	1.94	2.00	0.028	0.176	1.97	1.97	0.028	0.891
F/G	1.46	1.47	0.008	0.124	1.45	1.47	0.008	0.108	1.46	1.47	0.008	0.365
Overall (d 0 to 42)												
ADG, lb	0.92	0.96	0.014	0.061	0.92	0.96	0.014	0.069	0.95	0.93	0.014	0.231
ADFI, lb	1.35	1.40	0.020	0.113	1.36	1.39	0.020	0.197	1.37	1.38	0.020	0.897
F/G	1.47	1.46	0.008	0.387	1.47	1.46	0.008	0.166	1.44	1.48	0.008	0.001

[1] A total of 360 pigs (initial BW of 12.9 ± 0.1 lb) were used in a 42-d growth study with 5 pigs per pen and 9 pens per treatment.
[2] Zinc oxide was included in the diet to provide 3,000 ppm of Zn from d 0 to 7; 2,000 ppm of Zn from d 7 to 21; and no additional Zn other than that from the TM premix from d 21 to 42.
[3] Sodium diformate (Formi-NDF, Addcon, St. Peters, MN) was included in the diet at 1.2% from d 0 to d 21.
[4] Dietary CP 21 or 18% CP corresponding to 1.40 or 1.20% SID lysine for phase 1 and 1.35 or 1.20% SID Lys in phase 2 respectively.
[5] All interactions were found to be nonsignificant ($P > 0.125$).
[6] CP = crude protein. BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed efficiency.
[7] Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Table 7. Effects of pharmacological levels of zinc oxide, sodium diformate, and crude protein (CP) in nursery diets on fecal dry matter[1]

	No added zinc oxide				Added zinc oxide[2]							Probability $P <$	
	No acidifier		Added acidifier[3]		No acidifier		Added acidifier[3]						
Item[5,6]	21% CP[4]	18% CP	21% CP	18% CP	21% CP	18% CP	21% CP	18% CP	SEM	Interaction[7]	ZnO[8]	Acid[9]	Crude protein[10]
d 7	24.4	28.1	26.3	25.2	25.7	23.8	24.8	25.6	0.01	**0.011**	0.185	0.939	0.603
d 14	23.1	24.9	24.7	22.8	22.6	24.8	23.5	25.5	0.01	0.236	0.766	0.717	0.161
d 21	23.9	25.6	24.3	24.1	23.1	23.4	23.6	23.7	0.01	0.578	0.154	0.948	0.539
d 28	25.8	25.1	25.8	22.7	24.6	24.6	24.5	25.4	0.01	0.255	0.892	0.559	0.321
d 35	26.0	27.2	26.8	25.6	26.1	25.4	25.9	24.6	0.01	0.523	0.234	0.546	0.504
d 42	28.7^{ab}	26.5^{ab}	29.2^{a}	25.8^{ab}	27.5^{ab}	24.5^{b}	26.7^{ab}	27.1^{ab}	0.01	0.105	0.130	0.549	**0.006**
Overall[11]	25.3	26.2	26.2	24.4	24.9	24.4	24.8	25.3	0.006	**0.023**	0.113	0.912	0.556

[1] A total of 360 pigs (initial BW of 12.9 ± 0.1 lb) were used in a 42-d growth study with 5 pigs per pen and 9 pens per treatment.
[2] Zinc oxide was included in the diet to provide 3,000 ppm of Zn from d 0 to 7; 2,000 ppm of Zn from d 7 to 21; and no additional Zn other than that from the TM premix from d 21 to 42.
[3] Sodium diformate (Formi-NDF, Addcon, St. Peters, MN) was included in the diet at 1.2% from d 0 to d 21.
[4] Dietary CP 21 or 18% CP corresponding to 1.40 or 1.20% SID Lys for phase 1 and 1.35 or 1.20% SID Lys in phase 2, respectively.
[5] d = day of collection.
[6] Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$ represented in bold.
[7] Interaction ZnO × acidifier × crude protein. All 2-way interactions were found to be nonsignificant ($P \geq 0.111$).
[8] Main effect of adding ZnO.
[9] Main effect of adding an acidifier.
[10] Main effect of high or low crude protein.
[11] Represents the mean fecal dry matter across every week.
[ab] Means within row with different superscripts differ ($P < 0.05$).