Kansas Agricultural Experiment Station Research Reports

Volume 5
Issue 8 *Swine Day*

Article 23

2019

Determining the Effects of Manganese Source and Level on Growth Performance, Carcass Characteristics, and Economics of Growing-Finishing Pigs

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Determining the Effects of Manganese Source and Level on Growth Performance, Carcass Characteristics, and Economics of Growing-Finishing Pigs

Abstract

A total of 1,944 mixed sex growing-finishing pigs (PIC; 337 × 1050; initially 76.0 ± 3.71 lb) were used in a 107-d growth trial to determine the effects of increasing levels of two different manganese sources on the performance of growing-finishing pigs from 76 to 295 lb. Pens were assigned to 1 of 6 treatments in a randomized complete block design with initial weight as a blocking factor. There were 12 replicate pens per treatment and 27 pigs per pen. The experimental diets were corn-soybean meal-based and were fed in 4 phases. The 6 dietary treatments were arranged in a 2 × 3 factorial with main effects of Mn source, ($MnSO_4$ or Mn hydroxychloride: IBM), and 3 added Mn concentrations (8, 16, or 32 ppm). The trace mineral premix was formulated to contain no added Mn. There were no Mn source × level interactions ($P > 0.10$) observed for any of the individual dietary phases. For the overall period (d 0 to 107), there was a Mn source × level interaction (quadratic, $P = 0.048$) for feed efficiency (F/G), with F/G improving for the lowest and highest level of Mn supplementation from IntelliBond M (IBM) whereas F/G tended to improve with increasing Mn from $MnSO_4$. For the main effect of level, the intermediate dietary level of Mn had the poorest (quadratic, $P < 0.097$) average daily gain (ADG) in phases 1 and 4, which resulted in the poorest overall ADG and final body weight (BW) (quadratic, $P < 0.05$). There was no evidence for differences in pigs fed either Mn source for ADG or ADFI. There was a tendency for Mn source × level interaction (quadratic, $P = 0.075$) for carcass yield, where yield did not change by added $MnSO_4$, but increased then decreased for pigs fed diets with IBM. Loin depth increased (linear, $P = 0.035$) for pigs fed increasing amounts of Mn from $MnSO_4$ but decreased when Mn was increased from IBM. Pigs fed the intermediate level of Mn also had the lightest HCW (quadratic, $P = 0.071$) and decreased loin depth (quadratic, $P = 0.044$). No differences were observed in economics except for revenue (quadratic, $P = 0.093$) being the lowest for pigs fed the intermediate level of Mn. No evidence of difference ($P > 0.10$) was observed for Mn source × level inter- actions on the concentration of Cu, Mn, and Zn in the liver. Manganese concentration increased (linear, $P = 0.015$) as added Mn increased and liver Mn tended to be greater (P = 0.075) when Mn was supplied by $MnSO_4$ compared to IBM. There was no evidence of difference ($P > 0.10$) for Mn source or level influence on liver Cu and Zn concentrations. In conclusion, these data suggest little difference among Mn sources but did show improvements in growth performance for dietary levels of 8 and 32 ppm of Mn compared with 16 ppm. Further research is needed to understand why pigs fed the intermediate level of Mn had decreased ADG.

Keywords

finishing pig, growth performance, manganese

Cover Page Footnote

Appreciation is expressed to Micronutrients (Indianapolis, IN) for providing technical and financial support.

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Determining the Effects of Manganese Source and Level on Growth Performance, Carcass Characteristics, and Economics of Growing-Finishing Pigs[1]

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Summary

A total of 1,944 mixed sex growing-finishing pigs (PIC; 337 × 1050; initially 76.0 ± 3.71 lb) were used in a 107-d growth trial to determine the effects of increasing levels of two different manganese sources on the performance of growing-finishing pigs from 76 to 295 lb. Pens were assigned to 1 of 6 treatments in a randomized complete block design with initial weight as a blocking factor. There were 12 replicate pens per treatment and 27 pigs per pen. The experimental diets were corn-soybean meal-based and were fed in 4 phases. The 6 dietary treatments were arranged in a 2 × 3 factorial with main effects of Mn source, ($MnSO_4$ or Mn hydroxychloride: IBM), and 3 added Mn concentrations (8, 16, or 32 ppm). The trace mineral premix was formulated to contain no added Mn. There were no Mn source × level interactions ($P > 0.10$) observed for any of the individual dietary phases. For the overall period (d 0 to 107), there was a Mn source × level interaction (quadratic, $P = 0.048$) for feed efficiency (F/G), with F/G improving for the lowest and highest level of Mn supplementation from IntelliBond M (IBM) whereas F/G tended to improve with increasing Mn from $MnSO_4$. For the main effect of level, the intermediate dietary level of Mn had the poorest (quadratic, $P < 0.097$) average daily gain (ADG) in phases 1 and 4, which resulted in the poorest overall ADG and final body weight (BW) (quadratic, $P < 0.05$). There was no evidence for differences in pigs fed either Mn source for ADG or ADFI. There was a tendency for Mn source × level interaction (quadratic, $P = 0.075$) for carcass yield, where yield did not change by added $MnSO_4$, but increased then decreased for pigs fed diets with IBM. Loin depth increased (linear, $P = 0.035$) for pigs fed increasing amounts of Mn from $MnSO_4$ but decreased when Mn was increased from IBM. Pigs fed the intermediate level of Mn also had the lightest HCW (quadratic, $P = 0.071$) and decreased loin depth (quadratic, $P = 0.044$). No differences were observed in economics except for revenue (quadratic, $P = 0.093$) being the lowest for pigs fed the intermediate level of Mn. No evidence of difference ($P > 0.10$) was observed for Mn source × level inter-

[1] Appreciation is expressed to Micronutrients (Indianapolis, IN) for providing technical and financial support.
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actions on the concentration of Cu, Mn, and Zn in the liver. Manganese concentration increased (linear, $P = 0.015$) as added Mn increased and liver Mn tended to be greater (P = 0.075) when Mn was supplied by $MnSO_4$ compared to IBM. There was no evidence of difference ($P > 0.10$) for Mn source or level influence on liver Cu and Zn concentrations. In conclusion, these data suggest little difference among Mn sources but did show improvements in growth performance for dietary levels of 8 and 32 ppm of Mn compared with 16 ppm. Further research is needed to understand why pigs fed the intermediate level of Mn had decreased ADG.

Introduction

Manganese is an essential trace mineral added to swine diets that is a key component in carbohydrate, lipid, and protein metabolism. It also plays a role in increasing mitochondrial superoxide dismutase (Mn SOD) activity and bone development. According to the NRC,[3] the requirement for Mn for nursery and finishing diets ranges from 2 to 4 ppm. Toxicity for Mn is rare and is associated with dietary levels of 500 to greater than 2000 ppm. Many swine diets today meet the NRC estimated requirement for Mn from the normal dietary ingredients, assuming bioavailability is not a concern. However, because of the unknown bioavailability of the innate Mn in feedstuffs, swine diets typically contain added Mn through trace mineral premixes. A commercial survey conducted by Flohr et al.[4] found that Mn levels supplemented throughout the entire finishing period ranged as low as 3.3 ppm and as high as 40 ppm. To our knowledge, little current research is available to evaluate Mn and its effects on grow-finish pig performance. Furthermore, little information is available to determine if different sources of Mn affect pig performance. Therefore, the objective of this study was to determine the effects of increasing Mn and the source of Mn on growth performance, carcass characteristics, and economics of growing-finishing pigs raised in a commercial environment.

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 barn was naturally ventilated and double-curtain-sided. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a bowl waterer for *ad libitum* access to feed and water.

Two groups of approximately 972 pigs (1,944 total pigs; PIC, 337 × 1050; initially 76.0 ± 3.7 lb) were used in a 107 d growth trial. Pigs were housed in mixed gender pens with 27 pigs per pen and 12 pens per treatment (6 replications per barn). Daily feed additions to each pen were accomplished using a robotic feeding system (FeedPro, Feedlogic Corp., Wilmar, MN) able to record feed amounts for individual pens. The treatments were structured as a randomized complete block design and arranged in a 2 × 3 factorial with main effects of Mn source ($MnSO_4$, Eurochem, Veracruz, Mexico; or Mn hydroxychloride, IntelliBond M, Micronutrients, Indianapolis, IN, US), and increasing Mn

[3] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.
[4] Flohr J. R., J. M. DeRouchey, J. C. Woodworth, M. D. Tokach, R. D. Goodband, S. S. Dritz. 2016. A Survey of current feeding regimens for vitamins and trace minerals in the US swine industry. J Swine Health Prod. 2016;24(60:290-303).

levels (8, 16, or 32 ppm). A trace mineral premix without Mn was used for all experimental diets. Dietary treatments were offered in 4 phases (Table 1).

Pigs were weighed approximately every 14 days from d 0 to 107 of the trial to determine ADG, ADFI, and F/G. On d 86, the 3 heaviest pigs in each pen were selected and marketed. These pigs were included in the growth performance data but not in carcass data. On the last day of the trial, final pen weights were taken, and the remaining pigs were tattooed with a pen identification number and transported to a USDA-inspected packing plant (JBS Swift, Worthington, MN) for carcass data collection. Carcass measurements included HCW, loin depth, backfat, and percentage lean. Percentage lean was calculated from a plant proprietary equation. Carcass yield was calculated by taking the pen average HCW divided by the pen average final live weight obtained at the farm.

Mineral content of the liver was also determined. Liver samples were collected from 3 pigs per pen from pigs marketed at the end of the study in the second group. Each liver sample was collected from the same location of the liver on each individual pig. The liver samples were dried and homogenized before analysis by inductively coupled plasma mass spectrometry.

Data were analyzed as a randomized complete block design for one-way ANOVA using the lmer function from the lme4 package in R (version 3.5.1 (2018-07-02), R Foundation for Statistical Computing, Vienna, Austria) with pen considered the experimental unit, BW as blocking factor, and treatment as fixed effect. Predetermined orthogonal contrasts were used to evaluate the interactive effects of Mn source × level interaction among treatments. Interactive interactions $P \leq 0.10$ were evaluated linearly or quadratically within source. All results were considered significant at $P \leq 0.05$ and marginally significant between $P > 0.05$ and $P \leq 0.10$

Results and Discussion

As expected, chemical analysis of complete diets revealed no notable differences among treatments (Table 2.). The analyzed level of dietary manganese followed the target addition rates.

There were no Mn source × level interactions observed for any of the individual dietary phases (Table 3.). However, for the overall period, a Mn source × level interaction (quadratic, $P = 0.048$) was observed for F/G with F/G improving as Mn increased when supplied by $MnSO_4$, but increased then decreased when Mn was supplied by IBM. For main effects of Mn source, the only difference observed was a tendency ($P = 0.089$) for poorer F/G in phase 3 when Mn was supplied by IBM compared to $MnSO_4$ (Table 4). Average daily gain tended to be poorest (quadratic, $P < 0.097$) for the intermediate level of supplemental Mn in phase 1 and 4, which resulted in the poorest overall ADG and final BW (quadratic, $P < 0.05$) observed for pigs fed the intermediate level of Mn supplementation. There was no evidence for differences between Mn sources for ADG or ADFI.

For carcass characteristics there was a tendency for a Mn source × level interaction (quadratic, $P = 0.075$) for carcass yield where yield did not change when Mn was supplied by $MnSO_4$, but increased then decreased when increasing levels of Mn were supplied by IBM. There was also a source × level interaction (linear, $P = 0.035$) for loin depth which was a result of increasing loin depth as Mn increased from $MnSO_4$, but decreasing loin depth when Mn was increased from IBM. Pigs fed the intermediate level of Mn had the lightest HCW (quadratic, $P = 0.071$) and lowest loin depth (quadratic, $P = 0.044$). Economics were basically unaffected by treatment except for the lowest revenue (quadratic, $P = 0.093$) occurring with pigs fed the intermediate level of Mn.

For micromineral analysis of the liver, no evidence of difference ($P > 0.10$) was observed for Mn source × level interactions on the concentration of Cu, Mn, and Zn (Table 5). Manganese concentration in the liver increased (linear, $P = 0.015$) as Mn supplementation increased and liver Mn tended to be greater (P = 0.075) when Mn was supplied by $MnSO_4$ compared to IBM (Table 6). There was no evidence of difference ($P > 0.10$) for Mn source or level influence on Cu and Zn levels within the liver.

In conclusion, these data suggest there was little overall difference between Mn sources on growth performance. However, pigs that were fed 8 or 32 ppm of Mn had heavier ending BW, increased ADG, and deeper loin depth than those fed 16 ppm Mn. This response was not expected and warrants further investigation.

Table 1. Composition of basal diets (as-fed basis)[1]

Items	Phase 1	Phase 2	Phase 3	Phase 4
Ingredients, %				
Corn	58.80	66.88	72.51	80.66
Soybean meal (46.5% CP)	26.60	18.77	13.29	15.35
DDGS[2]	10.00	10.00	10.00	0.00
Beef tallow	1.50	1.50	1.50	1.50
Limestone, ground	1.08	1.00	0.95	0.73
Monocalcium phosphate (21% P)	0.90	0.75	0.65	0.75
Salt	0.35	0.35	0.35	0.35
L-Lysine-HCl	0.37	0.39	0.39	0.30
DL-Methionine	0.06	0.03	0.01	0.02
L-Threonine	0.09	0.09	0.10	0.10
L-Tryptophan	0.02	0.03	0.03	0.03
Phytase[3]	0.04	0.04	0.04	0.04
Vitamin-trace mineral premix[4]	0.15	0.15	0.15	0.15
Copper hydroxychloride[5]	0.003	0.003	0.003	0.003
Zn hydroxychloride[5]	0.01	0.01	0.01	0.01
Mn source[6]	+/-	+/-	+/-	+/-
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	1.15	0.97	0.84	0.79
Isoleucine:lysine	63	61	59	60
Leucine:lysine	140	147	155	147
Methionine:lysine	31	30	29	29
Methionine and cysteine:lysine	55	55	56	56
Threonine:lysine	62	62	64	65
Tryptophan:lysine	19	19	19	20
Valine:lysine	70	70	70	70
Lysine:net energy, g/Mcal	4.62	3.82	3.26	3.05
Net energy, kcal/lb	1,128	1,152	1,168	1,177
Crude protein, %	20.8	17.8	15.6	14.4
Calcium, %	0.73	0.63	0.57	0.52
STTD P, %	0.52	0.47	0.41	0.39

[1]Phases 1, 2, 3, and 4 were fed from 67 to 125, 125 to 160, 160 to 220, and 220 lb to marketing, respectively.
[2]DDGS = dried distillers grains with solubles.
[3]Optiphos 2000 (Huvepharma Inc. Peachtree City, GA) provided 389.6 units of phytase FTY/lb of diet with an assumed release of 0.12 available P.
[4]Provided per lb of diet: 111 ppm Fe, 0.33 ppm I, 0.30 ppm Se, 2400 IU vitamin A, 600 IU vitamin D, 12 IU vitamin E, 1.2 mg vitamin K, 22.5 mg niacin, 7.5 mg pantothenic acid, 2.25 mg riboflavin, and 10.5 mg vitamin B12.
[5]Copper hydroxychloride (IntelliBond Copper[II]) and Zn hydroxychloride (IntelliBond Z), Micronutrients, Indianapolis, IN.
[6]Mn hydroxychloride (IntelliBond M, Micronutrients, Indianapolis, IN); or Mn sulfate ($MnSO_4$, Erachem, Veracruz, Mexico).

Table 2. Chemical analysis of experimental diets (as-fed basis)[1]

	$MnSO_4$, ppm			IBM, ppm		
Mineral, ppm	8	16	32	8	16	32
Cu	40.1	31.3	33.4	32.6	33.0	39.8
Mn	29.9	35.9	50.8	29.8	38.4	50.5
Zn	120.8	117.4	125.44	121.9	116.1	121.3

[1]Values represent means from 16 composite samples (4 per phase). For each treatment, samples were collected from multiple feeders, blended, subsampled, ground, and analyzed (Cumberland Valley Analytical Services, Hagerstown, MD). IntelliBond M (IBM, Micronutrients, Indianapolis, IN).

Table 3. Interactive effects of Mn source and level on grow-finish pig growth performance, carcass characteristics, and economics[1]

	$MnSO_4$, ppm			IBM, ppm				Probability, $P =$	
Item[2]	8	16	32	8	16	32	SEM	Source × linear	Source × quadratic
BW, lb									
Initial	76.1	75.9	75.9	76.0	76.0	76.0	1.10	0.846	0.646
Ending	294.6	291.8	296.5	297.2	292.0	296.2	2.63	0.483	0.485
Phase 1[3]									
ADG, lb	2.02	1.99	2.02	2.03	2.00	2.04	0.030	0.807	0.750
ADFI, lb	3.92	3.89	3.91	3.91	3.91	3.96	0.069	0.590	0.827
F/G	1.95	1.95	1.94	1.93	1.96	1.94	0.022	0.629	0.529
Phase 2[4]									
ADG, lb	2.02	2.08	2.05	2.11	2.12	2.03	0.053	0.287	0.987
ADFI, lb	4.92	4.98	4.89	5.05	4.32	4.19	0.104	0.622	0.533
F/G	2.44	2.41	2.39	2.41	2.36	2.43	0.042	0.285	0.470
Phase 3[5]									
ADG, lb	2.20	2.18	2.20	2.19	2.18	2.17	0.036	0.691	0.794
ADFI, lb	6.02	5.86	5.91	6.00	5.97	5.94	0.075	0.780	0.273
F/G	2.74	2.69	2.68	2.74	2.75	2.75	0.035	0.357	0.511
Phase 4[6]									
ADG, lb	2.04	2.00	2.09	2.03	1.96	2.07	0.049	0.988	0.599
ADFI, lb	6.72	6.57	6.71	6.61	6.62	6.58	0.087	0.673	0.239
F/G	3.30	3.28	3.23	3.28	3.40	3.18	0.073	0.575	0.203

continued

Table 3. Interactive effects of Mn source and level on grow-finish pig growth performance, carcass characteristics, and economics[1]

	$MnSO_4$, ppm			IBM, ppm				Probability, P =	
Item[2]	8	16	32	8	16	32	SEM	Source × linear	Source × quadratic
Overall									
ADG, lb	2.09	2.06	2.11	2.11	2.06	2.10	0.017	0.351	0.593
ADFI, lb	5.52	5.42	5.48	5.50	5.48	5.46	0.056	0.904	0.289
F/G[7]	2.65	2.63	2.60	2.61	2.66	2.60	0.020	0.342	0.048
Carcass characteristics									
HCW, lb	216.9	213.7	217.0	218.0	216.8	217.3	1.70	0.600	0.329
Carcass yield, %[8]	73.5	73.3	73.2	73.4	74.2	73.3	0.30	0.970	0.075
Backfat depth, in[10]	0.67	0.65	0.67	0.67	0.67	0.67	0.012	0.981	0.108
Loin depth, in[9,10]	2.67	2.68	2.72	2.73	2.69	2.71	0.018	0.035	0.633
Lean, %[10]	56.6	56.9	56.8	56.8	56.6	56.8	0.199	0.564	0.115
Economics, $/pig marketed									
Feed cost	57.45	56.44	57.02	57.18	57.06	56.96	0.592	0.970	0.328
Feed cost/lb gain[11]	0.254	0.252	0.250	0.252	0.255	0.251	0.002	0.550	0.285
Revenue[12]	103.82	101.99	104.06	104.74	103.86	104.14	0.934	0.518	0.420
IOFC[13]	46.27	45.55	47.04	47.51	46.08	47.10	0.734	0.332	0.725

[1]A total of 1,944 pigs (initial BW of 76 lb) were used in two groups with 27 pigs per pen and 12 replicates per treatment. Mn sources were Mn sulfate ($MnSO_4$, Erachem, Veracruz, Mexico) or IntelliBond M (IBM, Micronutrients, Indianapolis, IN).
[2]BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio. HCW = hot carcass weight.
[3]Phase 1 was from d 0 to 27 in group 1 and from d 0 to 28 in group 2.
[4]Phase 2 was from d 27 to 48 in group 1 and from d 28 to 39 in group 2.
[5]Phase 3 was from d 48 to 72 in group 1 and from d 39 to 72 in group 2.
[6]Phase 4 was from d 72 to 106 in group 1 and from d 72 to 107 in group 2.
[7]Within source of $MnSO_4$, quadratic P = 0. 970. Within source of IBM, quadratic P = 0.010.
[8]Within source of $MnSO_4$, quadratic P = 0.790. Within source of IBM, quadratic P = 0.030.
[9]Within source of $MnSO_4$, linear P = 0. 020. Within source of IBM, linear P = 0.640.
[10]Adjusted using HCW as covariate.
[11]Feed cost/lb gain = total feed cost per pig divided by total gain per pig.
[12]Revenue = (HCW × $0.65) – (d 0 BW × 0.75 × $0.65).
[13]Income over feed cost = revenue – feed cost.

Table 4. Main effects of Mn source and level on growth performance, carcass characteristics, and economics[1]

	Source			Probability,	Level, ppm				Probability, P =	
Item[2]	$MnSO_4$	IBM	SEM	P =	8	16	32	SEM	Linear	Quadratic
BW, lb										
Initial	76.0	76.0	1.09	0.711	76.0	75.9	76.0	1.10	0.753	0.663
Ending	294.3	295.2	1.98	0.712	295.9	291.9	296.3	2.10	0.485	0.016
Phase 1[3]										
ADG, lb	2.01	2.02	0.023	0.391	2.03	1.99	2.03	0.02	0.522	0.069
ADFI, lb	3.91	3.93	0.056	0.526	3.95	3.90	3.98	0.06	0.607	0.557
F/G	1.95	1.94	0.013	0.821	1.94	1.96	1.94	0.02	0.935	0.283
Phase 2[4]										
ADG, lb	2.05	2.09	0.034	0.306	2.07	2.10	2.04	0.04	0.464	0.287
ADFI, lb	4.93	4.99	0.077	0.354	4.98	4.98	4.90	0.08	0.298	0.663
F/G	2.41	2.40	0.024	0.694	2.42	2.38	2.41	0.03	0.897	0.276
Phase 3[5]										
ADG, lb	2.20	2.18	0.022	0.465	2.20	2.18	2.19	0.02	0.751	0.632
ADFI, lb	5.93	5.97	0.050	0.440	6.01	5.91	5.92	0.06	0.238	0.209
F/G	2.70	2.75	0.021	0.089	2.74	2.72	2.72	0.02	0.525	0.535
Phase 4[6]										
ADG, lb	2.05	2.02	0.027	0.470	2.05	1.97	2.08	0.03	0.184	0.097
ADFI, lb	6.67	6.60	0.052	0.321	6.66	6.60	6.65	0.06	0.986	0.354
F/G	3.26	3.29	0.05	0.614	3.29	3.34	3.20	0.05	0.105	0.182

continued

Table 4. Main effects of Mn source and level on growth performance, carcass characteristics, and economics[1]

	Source			Probability,	Level, ppm				Probability, $P =$	
Item[2]	$MnSO_4$	IBM	SEM	$P =$	8	16	32	SEM	Linear	Quadratic
Overall										
ADG, lb	2.09	2.09	0.010	0.625	2.10	2.06	2.10	0.012	0.366	0.009
ADFI, lb	5.47	5.48	0.039	0.788	5.41	5.44	5.47	0.043	0.449	0.225
F/G	3.27	3.29	0.045	0.729	2.63	2.64	2.60	0.015	0.054	0.163
Carcass characteristics										
HCW, lb	215.9	217.4	1.22	0.167	217.5	215.2	217.2	1.36	0.899	0.071
Carcass yield, %	73.3	73.7	0.20	0.118	73.5	73.8	73.3	0.002	0.394	0.217
Backfat depth, in[7]	0.66	0.67	0.008	0.522	0.67	0.66	0.67	0.010	0.932	0.258
Loin depth, in[7]	2.69	2.71	0.014	0.127	2.70	2.68	2.72	0.016	0.109	0.044
Lean, %[7]	56.8	56.7	0.12	0.126	56.7	56.8	56.8	0.15	0.623	0.544
Economics, $/pig marketed										
Feed cost	56.97	57.07	0.413	0.798	57.32	56.75	56.99	0.456	0.615	0.269
Feed cost/lb gain[8]	0.252	0.253	0.002	0.447	0.253	0.253	0.251	0.002	0.128	0.506
Revenue[9]	103.29	104.25	0.524	0.180	104.28	102.93	104.01	0.634	0.911	0.093
IOFC[10]	46.29	47.14	0.435	0.118	46.89	46.18	47.07	0.500	0.586	0.185

[1]A total of 1,944 pigs (initial BW of 76 lb) were used in two groups with 27 pigs per pen and 12 replicates per treatment. Mn sources were Mn sulfate ($MnSO_4$, Erachem, Veracruz, Mexico) or IntelliBond M (IBM, Micronutrients, Indianapolis, IN).
[2]BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio. HCW = hot carcass weight.
[3]Phase 1 was from d 0 to 27 in group 1 and from d 0 to 28 in group 2.
[4]Phase 2 was from d 27 to 48 in group 1 and from d 28 to 39 in group 2.
[5]Phase 3 was from d 48 to 72 in group 1 and from d 39 to 72 in group 2.
[6]Phase 4 was from d 72 to 106 in group 1 and from d 72 to 107 in group 2.
[7]Adjusted using HCW as covariate.
[8]Feed cost/lb gain = total feed cost per pig divided by total gain per pig.
[9]Revenue = (HCW × $0.65) – (d 0 BW × 0.75 × $0.65).
[10]Income over feed cost = revenue – feed cost.

Table 5. Interactive effects of Mn source and level on grow-finish pig micromineral liver concentrations[1,2]

	$MnSO_4$, ppm			IBM, ppm				Probability, *P* =	
Item	8	16	32	8	16	32	SEM	Source × linear	Source × quadratic
Micromineral, ppm									
Cu	38.9	38.1	40.0	38.3	39.4	38.0	4.27	0.815	0.752
Mn	8.63	8.88	9.87	8.07	8.51	8.88	0.44	0.560	0.663
Zn	242.1	243.6	244.4	203.7	238.7	232.0	17.5	0.521	0.380

[1]A total of 36 pens were used in the second marketed group with 3 pigs per pen and 6 replicates per treatment. Mn sources were Mn sulfate ($MnSO_4$, Erachem, Veracruz, Mexico) or IntelliBond M (IBM, Micronutrients, Indianapolis, IN).
[2]Liver micromineral analysis done by ICP-MS.

Table 6. Main effects of manganese source and level on grow-finish pig micromineral liver concentrations[1,2]

	Source			Probability,	Level, ppm				Probability, *P* =	
Item	$MnSO_4$	IBM	SEM	*P* =	8	16	32	SEM	Linear	Quadratic
Micromineral, ppm										
Cu	39.0	38.6	2.43	0.902	38.6	38.7	39.0	2.92	0.925	0.994
Mn	9.1	8.5	0.25	0.075	8.5	8.7	9.4	0.30	0.015	0.989
Zn	243.3	224.9	11.7	0.166	222.9	241.1	238.2	13.3	0.427	0.346

[1]A total of 36 pens were used in the second marketed group with 3 pigs per pen and 18 replicates per source and 12 replicates per level. Mn sources were Mn sulfate ($MnSO_4$, Erachem, Veracruz, Mexico) or IntelliBond M (IBM, Micronutrients, Indianapolis, IN).
[2]Liver micromineral analysis done by ICP-MS.