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

H. R. Kerkaert  
*Kansas State University*, kerkaert@k-state.edu

J. C. Woodworth  
*Kansas State University*, jwoodworth@ksu.edu

J. M. DeRouchey  
*Kansas State University, Manhattan*, jderouch@k-state.edu

See next page for additional authors  
Follow this and additional works at: [https://newprairiepress.org/kaesrr](https://newprairiepress.org/kaesrr)  
Part of the Other Animal Sciences Commons

Recommended Citation  
Kerkaert, H. R.; Woodworth, J. C.; DeRouchey, J. M.; Dritz, S. S.; Tokach, M. D.; and Goodband, R. D. (2019) "Determining the Effects of Manganese Source and Level on Growth Performance, Carcass Characteristics, and Economics of Growing-Finishing Pigs," *Kansas Agricultural Experiment Station Research Reports*: Vol. 5: Iss. 8. [https://doi.org/10.4148/2378-5977.7853](https://doi.org/10.4148/2378-5977.7853)
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, (MnSO₄ 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 MnSO₄. 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 MnSO₄, 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 MnSO₄ 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 interactions 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 MnSO₄ 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

Creative Commons License
This work is licensed under a Creative Commons Attribution 4.0 License.

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

Authors
H. R. Kerkaert, J. C. Woodworth, J. M. DeRouchey, S. S. Dritz, M. D. Tokach, and R. D. Goodband

This finishing pig nutrition and management is available in Kansas Agricultural Experiment Station Research Reports: https://newprairiepress.org/kaesrr/vol5/iss8/23
Determining the Effects of Manganese Source and Level on Growth Performance, Carcass Characteristics, and Economics of Growing-Finishing Pigs

Hayden R. Kerkaert, Jason C. Woodworth, Joel M. DeRouchey, Steve S. Dritz, Mike D. Tokach, and Robert D. Goodband

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, (MnSO₄ 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 MnSO₄. 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 MnSO₄, 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 MnSO₄, 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.
2 Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.
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, \(337 \times 10^5\); 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 \(\times\) 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.
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 MnSO₄, 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 MnSO₄, 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 MnSO₄ 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.

*Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Persons using such products assume responsibility for their use in accordance with current label directions of the manufacturer.*
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, %

|                        | Phase 1  | Phase 2  | Phase 3  | Phase 4  |
|------------------------|----------|----------|----------|----------|
| 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\(^5\)) 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)\(^1\)

| Mineral, ppm | MnSO\(_4\), ppm | IBM, 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\(^1\)

| Item\(^3\) | MnSO\(_4\), ppm | IBM, ppm | Probability, \(P =\) |
|------------|----------------|----------|-----------------------|
|            | 8   | 16 | 32 | 8   | 16 | 32 | SEM | Source × linear | Source × quadratic |
| BW, lb     |     |     |     | 76.1 | 75.9 | 75.9 | 76.0 | 76.0 | 76.0 | 1.10 | 0.846 | 0.646 |
| Initial    |     |     |     | 294.6 | 291.8 | 296.5 | 297.2 | 292.0 | 296.2 | 2.63 | 0.483 | 0.485 |
| Ending     |     |     |     |     |     |     |     |     |     |     |     |     |
| 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

| Item                      | MnSO₄, ppm | IBM, ppm | Probability, P |
|---------------------------|------------|----------|----------------|
|                           | 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/G⁷                      | 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, in¹²       | 0.67       | 0.65     | 0.67           | 0.67       | 0.67     | 0.67           | 0.012       | 0.981           | 0.108              |
| Loin depth, in⁹,¹¹         | 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 gain¹¹       | 0.254      | 0.252    | 0.250           | 0.252      | 0.255    | 0.251           | 0.002       | 0.550           | 0.285              |
| Revenue¹²                 | 103.82     | 101.99   | 104.06          | 104.74     | 103.86   | 104.14          | 0.934       | 0.518           | 0.420              |
| IOFC¹³                    | 46.27      | 45.55    | 47.04           | 47.51      | 46.08    | 47.10           | 0.734       | 0.332           | 0.725              |

¹A 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 (MnSO₄, Erachem, Veracruz, Mexico) or IntelliBond M (IBM, Micronutrients, Indianapolis, IN).
²BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio. HCW = hot carcass weight.
³Phase 1 was from d 0 to 27 in group 1 and from d 0 to 28 in group 2.
⁴Phase 2 was from d 27 to 48 in group 1 and from d 28 to 39 in group 2.
⁵Phase 3 was from d 48 to 72 in group 1 and from d 39 to 72 in group 2.
⁶Phase 4 was from d 72 to 106 in group 1 and from d 72 to 107 in group 2.
⁷Within source of MnSO₄, quadratic P = 0.970. Within source of IBM, quadratic P = 0.010.
⁸Within source of MnSO₄, linear P = 0.020. Within source of IBM, linear P = 0.640.
⁹Adjusted using HCW as covariate.
¹⁰Feed cost/lb gain = total feed cost per pig divided by total gain per pig.
¹¹Revenue = (HCW × $0.65) – (d 0 BW × 0.75 × $0.65).
¹²Income over feed cost = revenue – feed cost.
Table 4. Main effects of Mn source and level on growth performance, carcass characteristics, and economics

| Item² | Source | Probability, $P =$ | Level, ppm | Probability, $P =$ |
|-------|--------|--------------------|-----------|--------------------|
|       | MnSO₄  | IBM                | SEM       | SEM                |
| 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 1³ | 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 2⁴ | 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 3⁵ | 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 4⁶ | 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

| Item               | Source     | Probability, \( P = \) | Level, ppm | Probability, \( P = \) |
|--------------------|------------|-------------------------|------------|-------------------------|
|                    | MnSO\(_4\) | IBM                     | 8          | 16                      | 32          |
|                    |            | SEM                     |            | 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  | 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$^{1,2}$

| Micromineral, ppm | MnSO$_4$, ppm | IBM, ppm | Probability, $P =$ | Source $\times$ linear | Source $\times$ quadratic |
|-------------------|---------------|----------|---------------------|------------------------|--------------------------|
| Item              | 8 | 16 | 32 | 8 | 16 | 32 | SEM |
| 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$^{1,2}$

| Micromineral, ppm | Source | Probability, $P =$ | Level, ppm | Probability, $P =$ |
|-------------------|--------|---------------------|------------|---------------------|
| Item              | MnSO$_4$, IBM | SEM | Linear | Quadratic |
| 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.