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Effect of Inorganic and Organic Trace Mineral Supplementation on the Performance, Carcass Characteristics, and Fecal Mineral Excretion of Phase-fed, Grow-finish Swine

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Abstract

Concentrated livestock production has led to soil nutrient accumulation concerns. To reduce the environmental impact, it is necessary to understand current recommended livestock feeding practices. Two experiments were conducted to compare the effects of trace mineral supplementation on performance, carcass composition, and fecal mineral excretion of phase-fed, grow-finish pigs. Crossbred pigs (Experiment 1 (Exp. 1), (n = 528); Experiment 2 (Exp. 2), (n = 560)) were housed in totally-slatted, confinement barns, blocked by weight, penned by sex, and randomly assigned to pens at approximately 18 kg BW. Treatments were allocated in a randomized complete block design (12 replicate pens per treatment) with 9 to 12 pigs per pen throughout the grow-finish period. In Exp. 1, the control diet (Io100) contained Cu as CuSO4, Fe as FeSO4, and Zn (of which 25% was ZnO and 75% was ZnO4) at concentrations of 63 and 378 mg/kg, respectively. Treatment 2 (O100) contained supplemental Cu, Fe, and Zn from organic sources (Bioplex, Alltech Inc., Nicholasville, KY) at concentrations of 19, 131, and 91 mg/kg, respectively, which are the commercially recommended dietary inclusion levels for these organic trace minerals. Organic Cu, Fe, and Zn concentrations from O100 were reduced by 25% and 50% to form treatments 3 (O75) and 4 (O50-1), respectively. In Exp. 2, treatment 5 (Io25) contained 25% of the Cu, Fe, and Zn (inorganic sources) concentrations found in Io100. Treatment 6 (O50-2) was identical to the O50-1 diet from Exp. 1. Treatment 7 (O25) contained the experimental microminerals reduced by 75% from concentrations found in O100. Treatment 8 (O0) contained no trace mineral supplementation and served as a negative control for Exp. 2. In Exp. 1, tenth-rib backfat, loin muscle area and ADG did not differ ($p>0.05$) between treatments. Pigs fed the control diet (Io100) consumed less feed ($p<0.01$) compared to pigs fed diets containing organic trace minerals, thus, G:F was greater ($p = 0.03$). In Exp. 2, there were no differences among treatment means for loin muscle area, but pigs fed the reduced organic trace mineral diets consumed less ($p<0.05$) feed and tended ($p = 0.10$) to have less tenth-rib backfat compared to pigs fed the reduced inorganic trace mineral diet. Considering that performance and feed intake of pigs was not affected by lower dietary trace mineral inclusion, mineral excretion could be reduced during the grow-finish phase by reducing dietary trace mineral concentration.

Keywords

Fecal Excretion, Performance, Pigs, Trace Minerals

Disciplines

Agriculture | Animal Sciences | Statistical Methodology

Comments

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ABSTRACT : Concentrated livestock production has led to soil nutrient accumulation concerns. To reduce the environmental impact, it is necessary to understand current recommended livestock feeding practices. Two experiments were conducted to compare the effects of trace mineral supplementation on performance, carcass composition, and fecal mineral excretion of phase-fed, grow-finish pigs. Crossbred pigs (Experiment 1 (Exp. 1), (n = 528); Experiment 2 (Exp. 2), (n = 560)) were housed in totally-slatted, confinement barns, blocked by weight, penned by sex, and randomly assigned to pens at approximately 18 kg BW. Treatments were allocated in a randomized complete block design (12 replicate pens per treatment) with 9 to 12 pigs per pen throughout the grow-finish period. In Exp. 1, the control diet (Io100) contained Cu as $CuSO_4$, Fe as $FeSO_4$, and Zn (of which 25% was ZnO and 75% was ZnO_4) at concentrations of 63 and 378 mg/kg, respectively. Treatment 2 (O100) contained supplemental Cu, Fe, and Zn from organic sources (Bioplex, Alltech Inc., Nicholasville, KY) at concentrations of 19, 131, and 91 mg/kg, respectively, which are the commercially recommended dietary inclusion levels for these organic trace minerals. Organic Cu, Fe, and Zn concentrations from O100 were reduced by 25% and 50% to form treatments 3 (O75) and 4 (O50-1), respectively. In Exp. 2, treatment 5 (Io25) contained 25% of the Cu, Fe, and Zn (inorganic sources) concentrations found in Io100. Treatment 6 (O50-2) was identical to the O50-1 diet from Exp. 1. Treatment 7 (O25) contained the experimental microminerals reduced by 75% from concentrations found in O100. Treatment 8 (O0) contained no trace mineral supplementation and served as a negative control for Exp. 2. In Exp. 1, tenth-rib backfat, loin muscle area and ADG did not differ ($p>0.05$) between treatments. Pigs fed the control diet (Io100) consumed less feed ($p<0.01$) compared to pigs fed diets containing organic trace minerals, thus, G:F was greater ($p = 0.03$). In Exp. 2, there were no differences among treatment means for loin muscle area, but pigs fed the reduced organic trace mineral diets consumed less ($p<0.05$) feed and tended ($p = 0.10$) to have less tenth-rib backfat compared to pigs fed the reduced inorganic trace mineral diet. Considering that performance and feed intake of pigs was not affected by lower dietary trace mineral inclusion, mineral excretion could be reduced during the grow-finish phase by reducing dietary trace mineral concentration. (**Key Words :** Fecal Excretion, Performance, Pigs, Trace Minerals)

INTRODUCTION

Environmental awareness has resulted in increased concern of dietary trace mineral use in swine production systems. It is a common practice in the swine industry to formulate diets that are in excess of the NRC (1998) recommendations for many nutrients. Additionally, pig diets are supplemented with excess trace minerals, often exceeding their physiological requirements (Carlson et al., 1999; Hill et al., 2000). Since trace mineral concentrations are highly regulated in the tissue by homeostatic mechanisms, large amounts of these minerals are excreted in the waste (Spears, 1996), which can lead to bioaccumulation in the soil and potentially threaten water sources due to runoff (Besser, 2001).

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Diet formulation with mineral concentrations close to the pig's requirements would seem to be an appropriate means of reducing concentrations of Zn, Cu, and other nutrients in waste without affecting animal performance. However, mineral requirements of these animals are not easily determined. Another strategy for reducing trace mineral concentrations in diets is the inclusion of mineral sources that may have greater bioavailability than the alternative inorganic form. Results have been variable, but some studies have shown organic trace minerals can be introduced in livestock diets and be more bioavailable than inorganic forms (Wedekind et al., 1992; Spears, 1996). This study was designed to: i) Determine whether the performance, carcass composition, and fecal mineral excretion was affected by the inclusion of inorganic or organic trace minerals at commercially recommended levels; ii) If inclusion of these trace minerals at levels lower than the current industry standards or recommendations would result in comparable performance in grow-finish pigs; and iii) Determine if these mineral sources would result in altered fecal mineral excretion.

MATERIALS AND METHODS

Two experiments were conducted to evaluate the effect of differing concentrations and source of trace mineral supplementation (Cu, Fe, and Zn) on the fecal excretion and apparent digestibility of grow-finish pigs. Pigs fed diets containing reduced concentrations of organic Cu, Fe, and Zn were compared to pigs fed diets supplemented with a commercially available inorganic trace mineral premix at or in excess of NRC recommendations for trace mineral supplementation. All protocols in these experiments were approved by the Iowa State University Animal Care and Use Committee.

Animals

In both experiments, crossbred pigs (all pigs were a four way cross of Yorkshire, Landrace, Hampshire, and Duroc) (Experiment 1 (Exp. 1), Iowa State University Lauren Christian Farm, Atlantic, IA (n = 528); Experiment 2 (Exp. 2), Wilson's Prairie View Farms, Burlington, WI (n = 560)) were blocked by weight, penned by sex, individually identified with an eartag (Allflex, Dallas, TX), and randomly assigned to treatment pens at approximately 18 kg BW. Each pen began the experiment with 9 to 12 pigs per pen.

Housing

Pigs were housed in 2 adjacent, totally-slatted, environmentally controlled (mechanically heated with a propane fired heater, and power ventilated with computer controlled exhaust fans) confinement facilities under continuous artificial lighting. During each production phase, the environment was controlled to meet pigs recommended ambient temperature requirements (National Pork Board, 2003). Each building had two identical rooms with 12 pens per room (6 pens per side, with an alley down the middle). Two 1.2 by 3.6 m hospital pens per room (1 pen per side) were provided to house any pigs removed from test. Pigs were observed twice daily for health and management problems. Each pen of pigs was provided free access to feed through a 2-hole feeder (fresh feed was provided daily) and to water through a 2-nipple hanging drinker in each pen. Each pig was provided 0.9 to 1.3 m^2 of floor space in a 2.4 by 3.6 m pen. An anthelminthic (Ivermectin, Merial Inc., Duluth, GA) was used in both experiments to treat pigs for internal and external parasites prior to initiation of the test period. Pigs that were unhealthy or injured during the experiments were removed from the test. Number of pigs removed and reason for removal was documented to make comparisons of treatment effects.

Dietary treatments

A 4-phase, grow-finish feeding program was used for all pigs in each experiment according to the following regimen: early grower (18 to 37 kg BW), late grower (37 to 55 kg BW), early finisher (55 to 82 kg BW), and late finisher (82 to 118 kg BW). Within each phase, a complete basal diet was formulated to meet or exceed NRC (1998) nutrient recommendations (Table 1). Different sources and concentrations of Cu, Fe, and Zn were supplemented to the basal diet in order to develop the experimental dietary treatments. In Exp. 1, the control diet (Io100) contained supplemental Cu as $CuSO_4$, Fe as $FeSO_4$, and Zn (of which 25% was ZnO and 75% was $ZnSO_4$) at concentrations of 63, 378, and 157 mg/kg, at industry recommended levels. Treatment 2 (O100) contained supplemental Cu, Fe, and Zn from organic sources (Bioplex, Alltech Inc., Nicholasville, KY) at concentrations of 19, 131, and 91 mg/kg, respectively, which are the commercially recommended dietary inclusion levels for these organic trace minerals. Organic Cu, Fe, and Zn concentrations from O100 were reduced by 25% and 50% for treatments 3 (O75) and 4 (O50-1), respectively. In Exp. 2, treatment 5 (Io25) contained 25% of the Cu, Fe, and Zn (inorganic sources) concentrations found in Io100. Treatment 6 (O50-2) contained the experimental microminerals at concentrations that were identical to O50-1 from Exp. 1. Treatment 7 (O25) contained Cu, Fe, and Zn concentrations that were reduced by 75% from the levels found in O100 of Exp. 1. Treatment 8 (O0) contained no supplemental microminerals and served as a negative control for Exp. 2. Diatomaceous earth (Celite, World Minerals Inc., Santa Barbara, CA) was

Table 1. Composition (as-fed basis) of the basal diet for 2 experiments in a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn on the performance and carcass characteristics of phase-fed, grow-finish swine (18 to 118 kg BW)

	Phase 1	Phase 2	Phase 3	Phase 4
	18 to 37 kg	37 to 55 kg	55 to 82 kg	82 to 118 kg
Ingredient composition				
Ground yellow dent corn (%)	67.25	69.50	73.50	78.75
Soybean meal (47.5%)	26.75	24.50	21.00	15.75
Trace mineral mix [1] (%)	3.00	3.00	2.50	2.50
Choice white grease (%)	2.00	2.00	2.00	2.00
Celite[2] (%)	1.00	1.00	1.00	1.00
Total	100.00	100.00	100.00	100.00
Formulated content[3]				
Crude fat (%)	4.91	4.97	5.09	5.24
Crude fiber (%)	2.74	2.73	2.71	2.68
Lysine (%)	1.12	1.05	0.93	0.79
Trp (%)	0.22	0.21	0.19	0.15
Thr (%)	0.75	0.71	0.66	0.59
Met (%)	0.32	0.31	0.29	0.27
Ash (%)	5.00	4.90	4.34	4.11
NaCl (%)	0.52	0.52	0.45	0.45
Analyzed content				
DM (%)	87.50	86.56	85.66	83.83
CP (%)	17.23	17.93	15.33	13.88
Ca (%)	0.72	0.71	0.68	0.64
P (%)	0.55	0.55	0.53	0.51
Mg (%)	0.14	0.14	0.13	0.12
K (%)	0.83	0.85	0.72	0.64
Na (%)	0.20	0.20	0.21	0.20
Mn (mg/kg)	23.88	22.88	22.00	20.38
Mo (%)	1.43	1.31	1.08	0.51
ME (kcal/kg)	3,410	3,420	3,380	3,340

[1] Inorganic trace minerals were supplemented from a commercially available trace mineral premix which contained Cu as $CuSO_4$, Fe as $FeSO_4$, and Zn (of which 25% was ZnO and 75% was $ZnSO_4$). Organic trace minerals (Cu, Fe, and Zn) were supplemented in the form of Bioplex[TM] products (Alltech Inc., Nicholasville, KY).

[2] Celite diatomaceous earth was added as an indigestible marker (World Minerals Inc., Santa Barbara, CA).

[3] Diets were formulated to meet or exceed NRC (1998) nutrient recommendations according to commercial manufacturer mixing procedures for their commercially available pig rations.

added to all diets at 1% inclusion rate as an indigestible marker (AIA). Experimental trace mineral premixes were manufactured commercially (Kent Feeds Inc., Muscatine, IA) and the diets were mixed by a commercial feed manufacturer (Nevada Feed and Seed, Nevada, IA) and fed in meal form.

Measurements

Pigs were weighed and feed disappearance (ADFI) was recorded at 2-wk intervals to monitor growth and performance as well as feed utilization (G:F). Pigs completed the experiment and were removed on a pen basis at mean BW of 118 kg. A National Swine Improvement Federation-certified (Bates and Christian, 1994) technician collected ultrasonic measurements of backfat thickness (BF10) and loin muscle area (LMA) at the 10th rib. Measurements were collected with the use of an Aloka 500 V ultrasound machine equipped with a 12.5 cm, 3.5 MHz linear array transducer (Corometrics Medical Systems, Inc., Wallingford, CT).

Fecal grab samples (approximately 100 g of DM) were collected, a minimum of one week after diet acclamation and as close to end of dietary phase as possible, from every pig in both experiments during each of the four growth phases. Samples were obtained by personnel entering the pen early in the morning of each collection day and waiting until pigs voluntarily dunged. Fecal samples were individually captured (approx. 200 g) and placed in a plastic container. Fecal samples were dried in an oven at 55°C for 48 h and pooled by pen and experiment on equal weight basis. Fecal samples were pooled by pen and ground in a sample mill through a 1 mm screen to achieve a homogenous sample for compositional analysis.

Multiple feed samples were obtain during each dietary phase for each treatment and stored at -20°C for further analysis. Feed samples were composited by treatment for

Table 2. Analyzed concentration of Cu, Fe, and Zn (DM basis) from the diets in two experiments of a study comparing the effects of source (inorganic vs. organic) and concentration of trace mineral supplementation on the performance and carcass characteristics of phase-fed, grow-finish swine (18 kg to 118 kg BW)

	Treatment[2]	Phase[1]			
		Early grower	Late grower	Early finishing	Late finishing
Experiment 1					
Copper (mg/kg)	Io100	63	53	65	66
	O100	21	24	19	23
	O75	15	16	21	17
	O50-1	13	17	12	13
Iron (mg/kg)	Io100	378	378	303	276
	O100	277	288	337	269
	O75	259	264	282	284
	O50-1	303	254	267	232
Zinc (mg/kg)	Io100	157	136	141	133
	O100	79	98	98	140
	O75	84	75	113	98
	O50-1	70	78	70	61
Experiment 2					
Copper (mg/kg)	Io25	23	21	14	13
	O50-2	12	14	12	14
	O25	10	11	8	10
	O0	7	8	6	5
Iron (mg/kg)	Io25	263	306	264	250
	O50-2	321	337	278	255
	O25	251	302	249	237
	O0	274	259	291	231
Zinc (mg/kg)	Io25	64	77	77	65
	O50-2	67	86	79	83
	O25	81	72	51	59
	O0	36	68	33	33

[1] Early grower diet fed from 18-37 kg BW; later grower diet fed from 37-55 kg BW; early finishing diet fed from 55-82 kg BW; late finishing diet fed from 82-118 kg BW.

[2] Io100 (control) 100% of Cu, Fe, and Zn from inorganic sources (Cu as $CuSO_4$, Fe as $FeSO_4$, and Zn (25% as ZnO and 75% as $ZnSO_4$)); O100, 100% of Cu, Fe, and Zn from organic sources; O75, 25% reduction in micromineral concentration from O100; O50-1, 50% reduction in micromineral concentration from O100. Io25, 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as $CuSO_4$, Fe as $FeSO_4$, and Zn (25% as ZnO and 75% as $ZnSO_4$)) of those concentrations found in Io100; O50-2, 50% reduction of organic Cu, Fe, and Zn concentrations of those found in O100; O25, 25% reduction in micromineral concentration from O50-2; O0, no Cu, Fe, Zn, and Se supplementation. (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY.).

the respective phase before compositional analysis. Samples of all diets and fecal samples from both experiments were sent to Dairy One Inc. (Ithaca, NY) for trace mineral analyses and evaluation of DM content. All experimental minerals were analyzed using a Thermo Jarrell Ash IRIS Advantage HX Inductively Coupled Plasma (ICP) Radial Spectrometer (Thermo Electron Corporation, Waltham, MA). Dry matter of feed and fecal samples was evaluated by Near Infrared Reflectance Spectroscopy (NIRS) (AOAC 991.03, 1995).

Apparent nutrient digestibility (ANP) for each mineral during each collection phase was calculated using the following formula: (copper (Cu) is used as an example)

$$ANP_{Cu\ digestibilty} = 100 \times \left[\frac{Cu_{\text{int}\,ake} - Cu_{excretion}}{Cu_{\text{int}\,ake}} \right].$$

Where, Cu intake (g) equals Cu intake calculated from records of feed intake and dietary Cu content, and Cu excretion (g) equals Cu excretion calculated from feed Cu content and total fecal excretion. Total fecal excretion (FM) was calculated using the following formula:

$$FM = \frac{(AIA_{feed} \times FI)}{AIA_{feces}}.$$

Table 3. Experiment 1 performance and fecal mineral excretion of phase-fed, grow-finish pigs (18 kg to 118 kg BW) fed diets containing different sources (inorganic vs. organic) and concentrations of Cu, Fe, and Zn[1]

Item[3]	Treatment[2]				Pooled SEM	p-value			
						Io100 vs. O100	Io vs. O	Organic trace minerals	
	Io100	O100	O75	O50-1				Linear	Quadratic
Growth and carcass[3]									
LMA (cm^2)	41.5	41.2	41.1	41.4	0.5	0.60	0.56	0.75	0.70
BF10 (mm)	21.2	21.5	21.6	21.5	0.4	0.70	0.56	0.96	0.84
ADG (kg/d)	0.907	0.924	0.907	0.923	0.009	0.20	0.30	0.94	0.16
ADFI (kg/d)	2.22	2.29	2.26	2.27	0.02	<0.01	<0.01	0.47	0.39
G:F	0.387	0.383	0.379	0.384	0.002	0.12	0.03	0.73	0.18
Fecal output by phase[4] (mg/pig/d)									
Copper									
Early grower	99	29	22	20	3.2	<0.01	<0.01	0.06	0.57
Late grower	125	29	21	19	6.2	<0.01	<0.01	0.23	0.73
Early finishing	149	38	34	27	2.1	<0.01	<0.01	<0.01	0.43
Late finishing	174	59	38	28	3.6	<0.01	<0.01	<0.01	0.22
Grow-finish	137	39	29	23	2.3	<0.01	<0.01	<0.01	0.47
Iron									
Early grower	407	390	349	329	13.3	0.36	<0.01	<0.01	0.53
Late grower	539	426	404	354	33.5	0.02	<0.01	0.13	0.73
Early finishing	623	522	577	528	14.3	<0.01	<0.01	0.77	<0.01
Late finishing	686	667	613	514	16.7	0.41	<0.01	<0.01	0.28
Grow-finish	564	501	489	431	12.2	<0.01	<0.01	<0.01	0.13
Zinc									
Early grower	201	133	100	81	6.2	<0.01	<0.01	<0.01	0.40
Late grower	248	133	103	81	12.8	<0.01	<0.01	<0.01	0.80
Early finishing	294	180	169	127	4.7	<0.01	<0.01	<0.01	<0.01
Late finishing	351	251	188	131	7.4	<0.01	<0.01	<0.01	0.75
Grow-finish	274	174	140	105	5.2	<0.01	<0.01	<0.01	0.92

[1] Means reported for all performance traits only reflect pigs that remained in the experiment for the entire test period.
[2] Io100 (control) 100% of Cu, Fe, and Zn from inorganic sources (Cu as $CuSO_4$, Fe as $FeSO_4$, and Zn (25% as ZnO and 75% as $ZnSO_4$)); O100, 100% of Cu, Fe, and Zn from organic sources; O75, 25% reduction in micromineral concentration from O100; O50-1, 50% reduction in micromineral concentration from O100. (All organic minerals were BioplexTM products, Alltech Inc., Nicholasville, KY.).
[3] Loin muscle area (LMA), tenth-rib backfat (BF10), average daily gain (ADG), average daily feed intake (ADFI), gain:feed (G:F).
[4] Early grower (18 to 37 kg BW); Late grower (37 to 55 kg BW); Early finishing (55 to 82 kg BW); Late finishing (82 to 118 kg BW); Grow-finish (18 to 118 kg BW).

Fecal mineral output was calculated from fecal mass multiplied by analyzed feed mineral concentration (data not shown).

Statistical analysis

Pigs were allocated in a randomized complete block design with 4 dietary treatments and 12 replicate pens per treatment within each experiment. Pen was the experimental unit in all analyses. Data were analyzed using the GLM procedures of SAS. The model performance traits included treatment, barn, sex, and all 2- and 3-way main effect interactions. Traits measured on individual pigs were analyzed using a random effect of pen nested within barn, sex, and treatment. Ending BW was a covariate for the analyses of BF10 and LMA. Initial BW was a covariate in the analyses of ADG, ADFI, and G:F. The model for fecal excretion included the fixed effects of treatment, barn, sex, and phase and all 2- and 3-way main effect interactions. Average daily feed intake was a covariate for the analyses of fecal mineral concentrations. Interactions of main effects found to be non-significant were eliminated from the final models. Single-df contrasts were used to compare i) Io100 vs. O100; and ii) inorganic vs. organic in Exp. 1; iii) Io25 vs. O25; and iv) reduced inorganic vs. reduced organic in Exp. 2. Data from pigs removed from each treatment in the experiment were analyzed using a Chi-Squared procedure

Table 4. Experiment 2 performance and fecal mineral excretion of phase-fed, grow-finish pigs (18 kg to 118 kg BW) fed diets containing different sources (inorganic vs. organic) and concentrations of Cu, Fe, and Zn[1]

Item	Treatment[2]				Pooled SEM	p-value			
						Io25 vs. O25	Io vs. O	Organic trace minerals	
	Io25	O50-2	O25	O0				Linear	Quadratic
Growth and carcass[3]									
LMA (cm^2)	39.7	39.9	40.0	39.7	0.4	0.50	0.58	0.69	0.73
BF10 (mm)	24.7	23.9	23.8	24.2	0.4	0.08	0.10	0.63	0.50
ADG (kg/d)	0.886	0.887	0.878	0.836	0.009	0.51	0.07	<0.01	0.16
ADFI (kg/d)	2.24	2.21	2.20	2.13	0.02	0.28	0.03	0.02	0.24
G:F	0.353	0.355	0.356	0.342	0.003	0.41	0.50	<0.01	0.02
Fecal output by phase[4] (mg/pig/d)									
Copper									
Early grower	37	22	15	11	0.6	<0.01	<0.01	<0.01	0.16
Late grower	50	24	18	10	1.2	<0.01	<0.01	<0.01	0.81
Early finishing	53	25	17	10	1.0	<0.01	<0.01	<0.01	0.70
Late finishing	47	25	15	10	2.1	<0.01	<0.01	<0.01	0.44
Grow-finish	47	24	16	10	0.8	<0.01	<0.01	<0.01	0.40
Iron									
Early grower	346	359	336	316	8.9	0.43	0.40	<0.01	0.85
Late grower	538	517	477	451	15.5	<0.01	<0.01	<0.01	0.71
Early finishing	552	518	473	433	15.1	<0.01	<0.01	<0.01	0.91
Late finishing	449	501	541	601	39.3	0.10	0.03	0.07	0.83
Grow-finish	472	474	457	450	12.5	0.38	0.41	0.18	0.72
Zinc									
Early grower	74	86	62	42	1.2	<0.01	<0.01	<0.01	0.14
Late grower	116	118	88	52	3.6	<0.01	<0.01	<0.01	0.59
Early finishing	145	124	87	53	4.3	<0.01	<0.01	<0.01	0.78
Late finishing	101	131	87	58	5.7	0.10	0.20	<0.01	0.29
Grow-finish	109	115	81	51	2.5	<0.01	<0.01	<0.01	0.48

[1] Means reported for all performance traits only reflect pigs that remained in the experiment for the entire test period.
[2] Io25, 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as $CuSO_4$, Fe as $FeSO_4$, and Zn (25% as ZnO and 75% as $ZnSO_4$)) of those concentrations found in Io100; O50-2, 50% reduction of organic Cu, Fe, and Zn concentrations of those found in O100; O25, 25% reduction in micromineral concentration from O50-2; O0, no Cu, Fe, Zn, and Se supplementation (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY.).
[3] Loin muscle area (LMA), tenth-rib backfat (BF10), average daily gain (ADG), average daily feed intake (ADFI), gain:feed (G:F).
[4] Early grower (18 to 37 kg BW); Late grower (37 to 55 kg BW); Early finishing (55 to 82 kg BW); Late finishing (82 to 118 kg BW); Grow-finish (18 to 118 kg BW).

(PROC FREQ, SAS). Significance was declared at p<0.05.

RESULTS

Performance

In Exp. 1, there were no differences among treatment means (p = 0.56) for tenth-rib backfat, loin muscle area, and average daily gain (Table 3). However, the control pigs consumed less feed (p<0.01) compared to pigs fed diets containing organic trace minerals, thus, G:F was greater (p = 0.03).

In Exp. 2, there were no differences among treatment means for loin muscle area, but pigs fed the reduced organic trace mineral diets consumed less (p<0.05) feed and tended (p = 0.10) to have less tenth-rib backfat compared to pigs fed the reduced inorganic trace mineral diet (Table 4). However, there was no difference (p>0.05) among treatment means for G:F, pigs fed the reduced inorganic trace mineral diet tended (p = 0.07) to have greater ADG when compared to pigs fed diets containing reduced trace mineral concentrations. The decrease in ADG, ADFI, G:F, for pigs fed the organic trace mineral diets was linear (p<0.05).

Fecal mineral excretion

Pigs in both experiments fed diets containing reduced levels of organic trace minerals excreted less (p<0.01) Cu, Fe, Zn by phase and throughout the entire grow-finish

Table 5. Experiment 1 apparent fecal digestibility of Cu, Fe, and Zn from phase-fed[1], grow-finish pigs (18 to 118 kg BW) fed diets containing differing sources (inorganic vs. organic) and concentrations of trace minerals (Cu, Fe, Zn)

Item	Treatment[2]				Pooled SEM	p-value			
						Io100 vs. O100	Io vs. O	Organic trace minerals	
	Io100	O100	O75	O50-1				Linear	Quadratic
Apparent fecal digestibility[3]									
Copper									
Early grower	-0.06	0.06	-0.01	-0.09	0.04	0.07	0.42	0.02	0.93
Late grower	-0.12	0.41	0.37	0.47	0.04	<0.01	<0.01	0.34	0.20
Early finishing	0.05	0.20	0.34	0.13	0.04	0.01	<0.01	0.20	<0.01
Late finishing	-0.47	0.30	0.19	0.28	0.11	<0.01	<0.01	0.91	0.47
Grow-finish	-0.15	0.24	0.22	0.19	0.03	<0.01	<0.01	0.33	0.92
Iron									
Early grower	0.30	0.05	0.10	0.29	0.04	<0.01	<0.01	<0.01	0.15
Late grower	0.29	0.30	0.28	0.34	0.03	0.83	0.64	0.36	0.30
Early finishing	0.17	0.39	0.20	0.21	0.02	<0.01	<0.01	<0.01	<0.01
Late finishing	0.11	0.15	0.24	0.23	0.02	0.24	<0.01	<0.01	0.07
Grow-finish	0.22	0.22	0.20	0.27	0.01	0.69	0.33	0.03	0.02
Zinc									
Early grower	0.15	-0.17	0.20	0.24	0.04	<0.01	0.23	<0.01	<0.01
Late grower	0.10	0.36	0.35	0.50	0.05	<0.01	<0.01	0.05	0.20
Early finishing	0.16	0.29	0.40	0.27	0.01	<0.01	<0.01	0.31	<0.01
Late finishing	0.07	0.36	0.31	0.25	0.03	<0.01	<0.01	<0.01	0.93
Grow-finish	0.12	0.21	0.32	0.32	0.02	<0.01	<0.01	<0.01	0.02

[1] Early grower (18 to 37 kg BW); Late grower (37 to 55 kg BW); Early finishing (55 to 82 kg BW); Late finishing (82 to 118 kg BW); Grow-finish (18 to 118 kg BW).

[2] Io100 (control) 100% of Cu, Fe, and Zn from inorganic sources (Cu as $CuSO_4$, Fe as $FeSO_4$, and Zn (25% as ZnO and 75% as $ZnSO_4$)); O100, 100% of Cu, Fe, and Zn from organic sources; O75, 25% reduction in micromineral concentration from O100; O50-1, 50% reduction in micromineral concentration from O100 (All organic minerals were BioplexTM products, Alltech Inc., Nicholasville, KY.).

[3] Total tract fecal digestibility.

period when compared to pigs fed diets containing the inorganic mineral sources (Tables 5 and 6). Additionally, apparent fecal Cu and Zn digestabilities were significantly reduced when pigs were fed diets containing inorganic sources of supplemental trace minerals as compared to the pigs fed diets containing supplemental organic trace minerals. In Exp. 1, there were no differences in fecal Fe digestibility when pigs were fed the inorganic or organic supplemental sources of this mineral. However, in Exp. 2 fecal Fe digestibility was greater for pigs fed organic supplemental sources when compared to pigs fed the supplemental inorganic sources.

DISCUSSION

Reducing the amounts of Cu, Fe, and Zn supplemented to diets in the current study did not adversely affect performance of grow-finish pigs from 18-118 kg BW. Based on NRC (1998) recommendations and analyzed mineral concentrations in the reduced trace mineral diets (Table 2), all diets with supplemental trace minerals met or exceeded requirements and thus were should not have limited pig performance.

In the present the study, pigs were extremely healthy as suggested by attained performance. It is unclear how performance may have been affected when pigs were fed reduced mineral concentrations and experienced any type of health challenge. However, in Exp. 1 of the present study, pigs exhibited clinical signs of ileitis and were treated per veterinary recommendations. It is possible that the ileitis outbreak could have influenced Fe digestibility results and fecal mineral excretion. Increased fecal output of the heme portion of blood as a result of ileitis infection may explain the Fe digestibility differences between Exp. 1 and Exp. 2.

Creech et al. (2004) reported pigs fed the control diets tended to have lower ADG and ADFI than did pigs fed the reduced organic trace mineral diets during gilt development (approximately 108 kg). These results support the present findings, although dietary treatments between the two studies were formulated for different production phases (gilt development vs. grow-finish). Similarly, Acda et al. (2002) reported that nursery pigs from dams that were fed organic trace mineral sources of Cu, Fe, Zn, and Mn had a 21%

Table 6. Experiment 2 apparent fecal digestibility of Cu, Fe, and Zn from phase-fed[1], grow-finish pigs (18 to 118 kg BW) fed diets containing differing sources (inorganic vs. organic) and concentrations of trace minerals (Cu, Fe, Zn)

Item	Treatment[2]				Pooled SEM	p-value			
						Io25 vs. O25	Io vs. O	Organic trace minerals	
	Io25	O50-2	O25	O0				Linear	Quadratic
Apparent fecal digestibility[3]									
Copper									
Early grower	-0.47	-0.17	0.01	-0.19	0.10	<0.01	<0.01	0.90	0.15
Late grower	-0.13	0.14	0.21	0.21	0.03	<0.01	<0.01	0.07	0.29
Early finishing	-0.51	0.18	0.19	0.33	0.03	<0.01	<0.01	<0.01	0.11
Late finishing	-0.34	0.40	0.37	0.29	0.02	<0.01	<0.01	0.02	0.41
Grow-finish	-0.36	0.14	0.19	0.16	0.03	<0.01	<0.01	0.59	0.26
Iron									
Early grower	0.08	0.22	0.08	0.22	0.03	0.97	0.02	0.93	<0.01
Late grower	0.19	0.24	0.23	0.43	0.04	0.48	0.02	<0.01	0.05
Early finishing	0.18	0.27	0.23	0.38	0.04	0.38	<0.01	0.03	0.03
Late finishing	0.31	0.29	0.04	0.08	0.04	<0.01	<0.01	0.02	<0.01
Grow-finish	0.19	0.25	0.15	0.28	0.03	0.23	0.17	0.52	<0.01
Zinc									
Early grower	0.21	0.11	0.42	0.23	0.03	<0.01	0.11	<0.01	<0.01
Late grower	0.32	0.33	0.42	0.60	0.02	<0.01	<0.01	<0.01	0.02
Early finishing	0.24	0.38	0.31	0.35	0.02	<0.01	<0.01	0.18	<0.01
Late finishing	0.42	0.45	0.39	0.38	0.01	0.12	0.26	<0.01	0.25
Grow-finish	0.30	0.32	0.39	0.39	0.01	<0.01	<0.01	<0.01	0.03

[1] Early Grower (18 to 37 kg BW); Late grower (37 to 55 kg BW); Early finishing (55 to 82 kg BW); Late finishing (82 to 118 kg BW); Grow-finish (18 to 118 kg BW).

[2] Io25, 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as $CuSO_4$, Fe as $FeSO_4$, and Zn (25% as ZnO and 75% as $ZnSO_4$)) of those concentrations found in Io100; O50-2, 50% reduction of organic Cu, Fe, and Zn concentrations of those found in O100; O25, 25% reduction in micromineral concentration from O50-2; O0, no Cu, Fe, Zn, and Se supplementation (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY.).

[3] Total tract fecal digestibility.

improvement in ADG and ADFI compared to pigs from sows receiving diets containing the inorganic forms of these trace minerals.

Very little research has focused on total replacement of inorganic trace minerals Cu, Fe, and Zn with the organic forms in a large scale production experiment. When minerals are supplemented in excess of the animal's requirement, more is excreted due to the decreased efficiency of utilization for that mineral (Spears, 1996). The current study clearly indicates that reducing dietary Cu, Fe, and Zn, based on growth, is an effective means of reducing excretion of these minerals in swine manure. Fecal mineral output of Zn and Cu (mg/pig/d) could be reduced by 50% or more in pigs fed reduced dietary concentrations of Zn and Cu. Decreasing Zn and Cu in swine waste is important because soil accumulation of these minerals can lead difficulty meeting manure management plans for large swine operations.

Previous studies indicate that Zn requirements of growing and finishing pigs, based on growth, do not exceed 50 mg/kg diet (Creech et al., 2004). In the current study, diets formulated with no trace mineral supplementation (O0) were the only diets not meeting or exceeding these Zn requirements. Hence, performance was affected only in pigs fed the O0 diet. Previous work indicated that the addition of Zn (50 mg Zn/kg diet) to a corn-soybean meal-based diet containing 35 mg Zn/kg did not affect performance of growing and finishing pigs (Hill and Miller, 1983). The addition of Zn to a corn-soybean meal-based diet containing 23 to 27 mg Zn/kg also did not improve performance of pigs during the nursery or growing phase (Hill et al., 1986).

Bioavailability of Zn may be limited by high dietary Ca. When Ca concentrations are increased in a diet with dietary Zn, the incidence of parakeratosis is increased dramatically (Lewis et al., 1956; Luecke et al., 1956). In the current study, pigs fed diets containing no trace mineral supplementation (O0) exhibited classic signs of parakaratosis. This deficiency of Zn observed in pigs from Exp. 2 in the current study, is in agreement with Creech et al. (2004).

Results of the current study and those reported by others (Creech et al., 2004; van Heugten et al., 2004) suggest that concentrations of trace minerals currently supplemented in the industry may be reduced to levels closer to NRC (1998) recommendations without negative impact on performance or carcass characteristics in grow-finish swine.

Considering that performance and feed intake of pigs fed diets containing reduced levels of supplemental trace minerals did not appear to be affected, mineral excretion could be lowered substantially by utilizing diets containing lower concentrations of either organic or inorganic supplemental trace minerals throughout the grow-finish period. In agreement with Creech et al. (2004) pigs fed diets containing trace mineral supplements in the inorganic form had greater fecal Cu concentration than did pigs fed the experimental diets containing organic trace minerals.

Dietary reduction of organic trace minerals is a viable means of reducing fecal mineral excretion without negatively impacting production traits. When manure from pigs fed the reduced trace mineral diets is land applied, rate of soil accumulation over time can be reduced. Organic trace mineral supplementation in grow-finish swine diets can be used as a feeding strategy to reduce the environmental impact of commercial pork production.

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