

The Effect of Inorganic, Organic and No Trace Mineral Supplementation on Growth Performance, Fecal Excretion and Digestibility of Grow-Finish Swine

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Summary and Implications

Fecal analysis, off-test weights, and ultrasonic measurements were used to determine the response of inorganic, organic (Bioplex™), and no trace mineral supplementation on the fecal mineral excretion (Cu, Fe, and Zn) and growth performance traits measured on live pigs (n=560) throughout the grow-finish period. Based on data from the current study, the use of Bioplex™ mineral supplementation for phase-fed, grow-finish pigs could potentially decrease the concentration of fecal Cu, Fe and Zn without impacting the overall performance of the animal. Diets containing no trace mineral supplementation fed to pigs throughout the entire grow-finish period had an adverse effect on performance and culling rate in the experiment. Organic mineral supplements can ultimately be fed to finishing swine without having a significant effect on percent lean (live or carcass), loin muscle area (LMA), backfat (BF10), average daily gain (ADG), or feed efficiency (FE). The use of Bioplex™ (Alltech Inc., Nicholasville, KY) trace minerals has the potential to reduce the environmental impact of swine production without any loss of production efficiency to the producer. Lower excretions of these metals by swine could help prevent bioaccumulation where swine waste is applied. Further investigation into the trace mineral requirements of pigs during times of health and other biological and environmental stresses is warranted.

Introduction

Modern lean genetic lines of pigs require nutritionally dense diets to meet their requirements for lean tissue deposition (Schinckel and deLange, 1996; Thompson et al., 1996). Pigs have generally been fed highly concentrated diets formulated to typically provide an excess margin of nutrients to maximize performance. However, until recently producers have not been concerned with the concentration of nutrients excreted.

Leeson (2003) reported that chelated trace minerals (e.g. Bioplex™) are at least 30% more bioavailable when compared to inorganic trace mineral salts when fed to

broilers. The inclusion of organically complex or chelated trace mineral products into mineral supplements for grow-finish swine diets has been suggested due to their increased bioavailability over inorganic mineral salts. Burkett et al. (2004) reported a reduction in micromineral (namely Cu, Fe, and Zn) excretion, with no adverse effects on performance, by pigs fed organic trace mineral supplements (Bioplex™) when compared to pigs fed diets containing inorganic forms of the minerals.

The objective of the current study was to compare the performance, carcass composition, fecal excretion, and apparent digestibility of nutrients (Cu, Fe, and Zn) in pigs fed diets containing inorganic, organic, and no trace mineral supplementation throughout the grow-finish phase of production.

Materials and Methods

Animals. Crossbred pigs [(n=560) Wilson's Prairie View Farms, Burlington, WI] were blocked by weight, penned by sex, and randomly assigned to treatment pens at approximately 18 kg BW. Pigs were allocated in a completely randomized design with four dietary treatments and 12 replicates per treatment. Each replicate included 9-12 pigs per pen throughout the grow-finish period.

Housing. Pigs were housed in two adjacent, totally-slatted, environmentally controlled confinement facilities. Ad libitum access to feed was provided through a two-hole feeder and to water through a 2-nipple hanging drinker in each pen. Pigs were provided 0.9 to 1.3 m² of floor space in each pen and were treated with an anthelmintic (Ivermectin, Merial Inc., Duluth, GA, USA) prior to the initiation of the test period. Unhealthy or injured pigs were removed from the experiment. Number of pigs removed and reason for removal was documented and utilized to make comparisons of treatment effects.

Dietary Treatments. A four-phase grow-finish feeding program was utilized for all pigs in the experiment according to the following regimen: Phase 1 (18 to 37 kg), Phase 2 (37 to 55 kg), Phase 3 (55 to 82 kg) and Phase 4 (82 to 118 kg). Total lysine content of the diets was 1.12%, 1.05%, 0.93%, and 0.79% during the four phases, respectively.

A complete basal diet (meal form) was formulated and different sources and concentrations of Cu, Fe, and Zn were supplemented in order to develop the experimental dietary treatments. Treatment 1 (TRT1) contained inorganic Cu, Fe, and Zn (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) at

concentrations of 26, 95, and 64 mg/kg, respectively. Treatment 2 (TRT2) contained organic Cu, Fe, and Zn (Bioplex™) at concentrations of 13, 101, and 60 mg/kg, respectively. Treatment 3 (TRT3) contained supplemental microminerals at 25% of the concentrations found in TRT2. Treatment 4 served as a negative control for the experiment and contained no micromineral supplementation. Supplemental Se, I, and Mg were added in TRT1, TRT2, and TRT3 to meet or exceed NRC (1998) requirements.

Measurements: Pigs were weighed and feed disappearance was recorded at two-week intervals to monitor growth performance and feed efficiency. Fecal grab samples (approximately 100 g of DM) were collected from every pig during each of the four growth phases. Fecal samples were dried in an oven at 55°C for 48 h. The dried samples were pooled by pen on an equal weight basis and the pooled sample was stored for mineral analysis and DM content. Feed samples were collected prior to fecal collection in order to analyze the diet being consumed prior to collection. Feed samples were ground to achieve a homogenous sample for analyses.

Samples of all experimental diets and fecal grab samples were analyzed (Dairy One Inc., Ithaca, NY) for trace mineral and DM content. All experimental dietary microminerals (Cu, Fe, and Zn) were analyzed using a Thermo Jarrell Ash IRIS Advantage HX Inductively Coupled Plasma (ICP) Radial Spectrometer (Thermo Instrument Systems, Inc., Waltham, MA). Dry matter analysis of feed samples was performed by Near Infrared Reflectance Spectroscopy (NIRS) (AOAC 991.03).

The apparent nutrient digestibility (APD) for each mineral during each collection phase was calculated using the following formula.

$$APD = 100 * \frac{\text{period feed intake} - \text{period feces excretion}}{\text{period feed intake}}$$

Off-test weights and ultrasonic tenth rib backfat (BF) and loin muscle area (LMA) measurements were collected on all pigs prior to harvest at a mean live weight of 118 kg. Average daily gain (ADG) and average daily lean growth on test (LGOT) were calculated from the data collected on the individuals. Pen feed intake was calculated by feed weigh-back to determine average daily feed intake (ADFI), feed efficiency (FE), and efficiency of lean gain (LE). Additionally, percent lean calculated on a live basis (PLL), percent lean calculated on a carcass basis (PLC), and kilograms of lean (LW) were calculated from ultrasonic measurements using the NPPC formula (National Pork Producers Council, 2000).

Statistical Analysis: Pen was the experimental unit in all analyses. Performance and carcass composition traits were analyzed using the PROC MIXED procedure in SAS (SAS Inst., Cary, NC). The model included the fixed

effects of replication, treatment, sex and all two- and three-way main effect interactions. Pen nested within barn, sex, and treatment was included as a random effect. Off-test weight was included as a covariate for the analyses of BF10 and LMA. On-test weight was included as a covariate in the analyses of ADG, LGOT, ADFI, FE, and LE. Treatment differences for fecal concentrations and apparent digestibility of Cu, Fe, and Zn were assessed by the use of a mixed model that included fixed effects of replication, treatment, phase, and sex. Feed consumption was included as a covariate in the model. Interactions of main effects found to be non-significant were eliminated from the final model used in the analyses. When a model effect was a significant source of variation, least squares means were compared using the PDIF option of SAS. Pigs removed from test by treatment were analyzed using the PROC FREQ procedure in SAS (SAS Inst., Cary, NC).

Results and Discussion

Least squares means for performance and carcass traits by treatment are presented in Table 1. Least squares means for fecal mineral concentrations, apparent digestibility, fecal mass, and fecal dry matter for Cu, Fe, and Zn are presented in Tables 2, 3, 4, and 5.

Performance Traits: Pigs fed diets containing no micromineral supplementation (TRT4) had lower ADG ($P < 0.05$) when compared to pigs fed the other three experimental diets. No differences ($P > 0.05$) in ADG were observed among the three diets containing Cu, Fe, and Zn supplementation, regardless of source. Barrows had significantly greater ADG when compared to gilts while having poorer conversion of feed to lean ($P < 0.05$).

Pigs fed diets containing no trace mineral supplementation had lower ADFI ($P < 0.05$) when compared to pigs fed TRT1 and TRT2. Furthermore, pigs fed TRT3 consumed less feed ($P < 0.05$) when compared to pigs fed TRT1. Pigs fed TRT4 that showed signs of parakeratosis, listlessness, and weight loss were removed from the experiment. The number of pigs removed from test by treatment was not different for TRT1 ($n=1$), TRT2 ($n=3$), TRT3 ($n=4$), however, all three were different from TRT4 ($n=38$) ($P < 0.01$).

Carcass Composition: No differences were observed for BF10, LMA, PLL, PLC and KL ($P > 0.05$). Pigs fed TRT4 had the lowest LGOT and the poorest LE and G:F ($P < 0.05$). Barrows were fatter and had less LMA ($P < 0.05$) when compared to gilts, however, gilts had more KL, and higher PLL and PLC ($P < 0.05$).

Fecal Excretion and Digestibility.

Copper. No differences among treatment means for fecal Cu excretion were observed by phase, however, pigs fed TRT4 excreted the lowest concentration of fecal Cu overall ($P < 0.05$) when compared to pigs fed diets containing supplemental trace minerals. Pigs fed TRT1 (inorganic minerals) excreted the greatest overall

concentration of Cu for the trial when compared to pigs fed the other experimental diets. Apparent digestibility of Cu was the lowest and least favorable ($P < 0.05$) for pigs fed diets containing the inorganic trace mineral supplements (TRT1). Pigs fed TRT3 experienced the best overall apparent digestibility for Cu.

Zinc. Pigs fed TRT2 excreted the highest concentration ($P < 0.05$) of Zn for the entire grow-finish period. Pigs fed no trace mineral supplementation (TRT4) excreted the lowest ($P < 0.05$) concentration of Zn in the feces, however, some pigs receiving this treatment experienced symptoms of parakeratosis and were removed from test upon diagnosis. On a percentage

bases, pigs fed TRT 5 experienced the lowest and least favorable ($P < 0.05$) apparent digestibility.

Iron. During the grow-finish period, pigs fed TRT4 excreted the lowest fecal concentration of Fe throughout phase collections 1, 2, 3, and overall. No differences among overall treatment means for fecal Fe excretion were observed, however, pigs receiving no trace mineral supplementation excreted the lowest fecal concentration of Fe during phase collections 1, 2, and 3 and also had the best overall apparent digestibility.

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Table 1. Least squares means (\pm SE), on a pen basis, for performance and carcass traits in a study comparing the effect of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn supplementation in the diets of phase-fed, grow-finish swine (18 kg to 118 kg of BW).

Traits ^b	Treatment ^a			
	1	2	3	4
LMA, cm ²	39.65 \pm 0.379	39.94 \pm 0.384	39.99 \pm 0.384	39.74 \pm 0.440
BF10, mm	24.66 \pm 0.356	23.93 \pm 0.361	23.76 \pm 0.361	24.20 \pm 0.419
ADG, kg/day	0.89 ^c \pm 0.009	0.89 ^c \pm 0.009	0.88 ^c \pm 0.009	0.84 ^d \pm 0.010
LGOT, kg/day	0.32 ^c \pm 0.003	0.33 ^c \pm 0.003	0.32 ^c \pm 0.003	0.31 ^d \pm 0.004
ADFI, kg/day	2.47 ^c \pm 0.039	2.42 ^{cd} \pm 0.039	2.34 ^d \pm 0.039	2.03 ^e \pm 0.039
LE	3.77 ^c \pm 0.145	3.77 ^c \pm 0.145	3.71 ^c \pm 0.146	4.50 ^d \pm 0.146
G:F	1.29 ^c \pm 0.010	1.28 ^c \pm 0.010	1.28 ^c \pm 0.010	1.33 ^d \pm 0.010
KL, kg	40.77 \pm 0.323	41.14 \pm 0.326	41.08 \pm 0.328	40.04 \pm 0.374
PLL, %	36.52 \pm 0.222	36.80 \pm 0.225	36.86 \pm 0.227	36.86 \pm 0.253
PLC, %	49.35 \pm 0.300	49.74 \pm 0.303	49.81 \pm 0.305	49.82 \pm 0.342

^aTreatment 1 – (TRT1) contained inorganic Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) at concentrations of 26, 95, and 64 mg/kg, respectively; Treatment 2 – (TRT2) contained organic Cu, Fe, and Zn (BioplexTM) at concentrations of 13, 101, and 60 mg/kg, respectively; Treatment 3 – (TRT3) 25% reduction in micromineral concentration from TRT 2; Treatment 4 – No dietary micromineral supplementation.

(All organic forms were BioplexTM products, Alltech Inc., Nicholasville, KY).

^bLMA = loin muscle area, BF10 = tenth-rib backfat, ADG = average daily gain, LGOT = lean gain on test, ADFI = average daily feed intake, LE = lean efficiency, FE = feed efficiency, KL = kilograms of lean, PLL = percent lean live, PLC = percent lean carcass.

^{cde}Means with different superscripts within a row differ ($P < 0.05$).

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Table 2. Least squares means (\pm SE) of fecal Cu concentrations (dry matter basis) and apparent digestibility (Cu) measured in a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn supplementation to the diet of phase-fed grow-finish swine (18 to 118 kg LW).

Traits	Treatment ^b	Phase ^a				Overall
		1	2	3	4	
Fecal Cu, mg/kg	1	151.59 \pm 4.43	145.54 \pm 3.01	132.34 \pm 3.37	132.89 \pm 3.85	140.59 ^d \pm 1.51
	2	87.94 \pm 4.42	68.20 \pm 3.10	66.32 \pm 3.34	63.58 \pm 3.92	71.51 ^e \pm 1.51
	3	67.13 \pm 4.40	55.39 \pm 3.10	45.72 \pm 3.35	40.38 \pm 3.74	52.15 ^d \pm 1.51
	4	49.02 \pm 4.40	32.53 \pm 3.19	26.08 \pm 3.39	24.55 \pm 3.30	33.05 ^c \pm 1.55
Apparent Digestibility, %	1	-47.05 ^e \pm 6.30	-12.80 ^d \pm 6.30	-51.50 ^d \pm 6.30	-33.90 ^d \pm 6.30	-36.31 ^d \pm 3.15
	2	-17.02 ^d \pm 6.30	13.80 ^c \pm 6.30	18.35 ^c \pm 6.30	39.74 ^c \pm 6.30	13.72 ^c \pm 3.15
	3	0.88 ^c \pm 6.31	20.99 ^c \pm 6.31	18.42 ^c \pm 6.31	36.74 ^c \pm 6.31	19.26 ^c \pm 3.16
	4	-18.65 ^d \pm 6.31	20.98 ^c \pm 6.31	32.90 ^c \pm 6.31	29.23 ^c \pm 6.31	16.12 ^c \pm 3.16

^aPhase 1 - diet fed from 18-37 kg of BW; Phase 2 - diet fed from 37-55 kg of BW; Phase 3 - fed from 55-82 kg of BW; Phase 4 - diet fed from 82-118 kg of BW.

^bTreatment 1 – (TRT1) contained inorganic Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) at concentrations of 26, 95, and 64 mg/kg, respectively; Treatment 2 – (TRT2) contained organic Cu, Fe, and Zn (BioplexTM) at concentrations of 13, 101, and 60 mg/kg, respectively; Treatment 3 – (TRT3) 25% reduction in micromineral concentration from TRT 2; Treatment 4 – No dietary micromineral supplementation. (All organic mineral forms were BioplexTM products, Alltech Inc., Nicholasville, KY).

^{cdef}Least squares means with different superscripts within a column (phase) and trait differ (P < 0.05).

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Table 3. Least squares means (\pm SE) of fecal Fe concentrations (dry matter basis) and apparent digestibility (Fe) measured in a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn supplementation to the diet of phase-fed grow-finish swine (18 to 118 kg LW).

Traits	Treatment ^b	Phase ^a				Overall
		1	2	3	4	
Fecal Fe, mg/kg	1	1504.99 \pm 71.52	1565.09 ^d \pm 48.74	1348.64 ^d \pm 54.66	1244.09 ^c \pm 64.21	1415.70 \pm 24.74
	2	1543.05 \pm 71.21	1510.49 ^{cd} \pm 50.01	1354.91 ^d \pm 54.15	1263.36 ^c \pm 63.61	1417.95 \pm 24.35
	3	1522.13 \pm 70.98	1493.42 ^{cd} \pm 49.53	1253.49 ^d \pm 54.34	1350.70 ^c \pm 60.56	1404.93 \pm 24.43
	4	1409.47 \pm 70.89	1379.02 ^c \pm 51.51	1109.05 ^c \pm 55.02	1570.96 ^d \pm 53.52	1352.13 \pm 24.96
Apparent Digestibility, %	1	8.02 ^c \pm 4.89	19.13 ^d \pm 4.89	18.11 ^d \pm 4.89	29.24 ^c \pm 5.11	18.62 ^{de} \pm 2.47
	2	21.93 ^{cd} \pm 4.89	24.18 ^d \pm 4.89	26.76 ^{cd} \pm 4.89	29.06 ^c \pm 4.89	25.48 ^{cd} \pm 2.45
	3	8.88 ^{de} \pm 4.90	23.21 ^d \pm 4.90	22.28 ^d \pm 4.90	3.48 ^d \pm 4.90	14.46 ^e \pm 2.46
	4	23.02 ^c \pm 4.90	42.65 ^c \pm 4.90	37.92 ^c \pm 4.90	7.19 ^d \pm 4.90	27.70 ^c \pm 2.46

^aPhase 1 - diet fed from 18-37 kg of BW; Phase 2 - diet fed from 37-55 kg of BW; Phase 3 - fed from 55-82 kg of BW; Phase 4 - diet fed from 82-118 kg of BW.

^bTreatment 1 – (TRT1) contained inorganic Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) at concentrations of 26, 95, and 64 mg/kg, respectively; Treatment 2 – (TRT2) contained organic Cu, Fe, and Zn (BioplexTM) at concentrations of 13, 101, and 60 mg/kg, respectively; Treatment 3 – (TRT3) 25% reduction in micromineral concentration from TRT 2; Treatment 4 – No dietary micromineral supplementation. (All organic mineral forms were BioplexTM products, Alltech Inc., Nicholasville, KY).

^{cd}^eLeast squares means with different superscripts within a column (phase) and trait differ (P < 0.05).

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Table 4. Least squares means (\pm SE) of fecal Zn concentrations (dry matter basis) and apparent digestibility (Zn) measured in a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn supplementation to the diet of phase-fed grow-finish swine (18 to 118 kg LW).

Traits	Treatment ^b	Phase ^a				Overall
		1	2	3	4	
Fecal Zn, mg/kg	1	308.64 ^e \pm 14.51	335.85 ^e \pm 10.00	362.71 ^f \pm 11.04	278.02 ^c \pm 12.61	321.31 ^e \pm 4.95
	2	351.71 ^f \pm 14.45	335.63 ^e \pm 10.13	333.90 ^e \pm 10.93	340.19 ^f \pm 12.84	340.36 ^f \pm 4.93
	3	270.94 ^d \pm 14.40	275.27 ^d \pm 10.03	236.57 ^d \pm 10.97	234.01 ^d \pm 12.23	254.20 ^d \pm 4.95
	4	184.19 ^c \pm 14.39	161.07 ^c \pm 10.44	140.12 ^c \pm 11.11	148.45 ^c \pm 10.81	158.46 ^c \pm 5.06
Apparent Digestibility, %	1	20.58 ^d \pm 2.37	31.57 ^c \pm 2.37	24.38 ^e \pm 2.37	42.21 \pm 2.37	29.68 ^d \pm 1.19
	2	11.49 ^e \pm 2.37	33.26 ^c \pm 2.37	38.04 ^c \pm 2.37	44.51 \pm 2.37	31.82 ^d \pm 1.19
	3	42.18 ^c \pm 2.38	41.62 ^d \pm 2.38	30.79 ^{de} \pm 2.38	39.47 \pm 2.38	38.51 ^c \pm 1.19
	4	22.74 ^d \pm 2.38	59.99 ^c \pm 2.38	34.93 ^{cd} \pm 2.38	37.90 \pm 2.38	38.89 ^c \pm 1.19

^aPhase 1 - diet fed from 18-37 kg of BW; Phase 2 - diet fed from 37-55 kg of BW; Phase 3 - fed from 55-82 kg of BW; Phase 4 - diet fed from 82-118 kg of BW.

^bTreatment 1 – (TRT1) contained inorganic Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) at concentrations of 26, 95, and 64 mg/kg, respectively; Treatment 2 – (TRT2) contained organic Cu, Fe, and Zn (BioplexTM) at concentrations of 13, 101, and 60 mg/kg, respectively; Treatment 3 – (TRT3) 25% reduction in micromineral concentration from TRT 2; Treatment 4 – No dietary micromineral supplementation. (All organic mineral forms were BioplexTM products, Alltech Inc., Nicholasville, KY).

^{cdef}Least squares means with different superscripts within a column (phase) and trait differ (P < 0.05).

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Table 5. Least squares means (\pm SE) of mass and dry matter content (%) of feces from a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn supplementation to the diet of phase-fed grow-finish swine (18 to 118 kg LW).

Trait	Treatment ^b	Phase ^a				Overall
		1	2	3	4	
Fecal Dry Matter (%)	1	24.60 \pm 0.405	26.30 \pm 0.405	29.20 \pm 0.405	31.00 \pm 0.405	27.80 \pm 0.202
	2	24.40 \pm 0.405	26.20 \pm 0.405	28.30 \pm 0.405	30.30 \pm 0.405	27.40 \pm 0.202
	3	25.00 \pm 0.412	25.40 \pm 0.412	29.50 \pm 0.412	30.20 \pm 0.412	27.50 \pm 0.210
	4	24.50 \pm 0.412	25.70 \pm 0.412	29.40 \pm 0.412	31.30 \pm 0.412	27.80 \pm 0.210
Fecal Mass (kg, DM basis)	1	0.25 \pm 0.011	0.34 \pm 0.011	0.39 \pm 0.011	0.35 \pm 0.011	0.33 \pm 0.006
	2	0.26 \pm 0.011	0.35 \pm 0.011	0.36 \pm 0.011	0.37 \pm 0.011	0.34 \pm 0.006
	3	0.24 \pm 0.012	0.33 \pm 0.012	0.36 \pm 0.012	0.37 \pm 0.012	0.33 \pm 0.006
	4	0.25 \pm 0.012	0.34 \pm 0.012	0.37 \pm 0.012	0.38 \pm 0.012	0.33 \pm 0.006

^aPhase 1 - diet fed from 18-37 kg of BW; Phase 2 - diet fed from 37-55 kg of BW; Phase 3 - fed from 55-82 kg of BW; Phase 4 - diet fed from 82-118 kg of BW.

^bTreatment 1 – (TRT1) contained inorganic Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) at concentrations of 26, 95, and 64 mg/kg, respectively; Treatment 2 – (TRT2) contained organic Cu, Fe, and Zn (BioplexTM) at concentrations of 13, 101, and 60 mg/kg, respectively; Treatment 3 – (TRT3) 25% reduction in micromineral concentration from TRT 2; Treatment 4 – No dietary micromineral supplementation. (All organic mineral forms were BioplexTM products, Alltech Inc., Nicholasville, KY).