REFEREED

SUPPLEMENTATION OF BROODMARES WITH COPPER, ZINC, IRON, MANGANESE, COBALT, IODINE, AND SELENIUM

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SUMMARY

In experiment 1, 6 pregnant mares received a concentrate that contained a trace mineral premix that provided 14.3 mg Cu, 40 mg Zn, 28 mg Fe, 28 mg Mn, 0.08 mg Co, 0.16 mg I, and 0.16 mg Se/kg concentrate (group A). Seven mares received the same concentrate plus 502 mg Zn and 127 mg Cu once daily (group B). No differences ($P > .05$) in foal growth data, or Cu, Zn, and Fe concentrations of mare milk, mare serum, or foal serum were observed. In experiment 2, 6 pregnant mares received the same concentrate as group A (group C), and 8 mares received the same concentrate fortified with 4× the trace mineral premix (group D). Group C mares had higher serum Zn concentration at 1 day ($P < 0.01$) and 56 days ($P < 0.04$). Group C mares had higher milk Fe concentration at 28 days ($P < .01$), and group D mares had higher milk Cu concentration at 56 days ($P < .01$). Group C foals had higher serum Cu concentration at 14 days ($P < .03$). The results from this study provide no evidence to indicate that supplementing late gestating and lactating mares with higher dietary trace mineral levels than those recommended currently by NRC has any influence on foal growth and development, or on the Cu, Zn, and Fe concentrations of the mare milk, mare serum, or foal serum.

INTRODUCTION

Most of the fetal Ca and P deposition occurs during the last 2 months of gestation, which suggests that most of the fetal skeletal development occurs at that time. Meyer and Ahlswede[1] reported that in the foal almost half of the Zn, Cu, and Mn deposited in the developing fetus occurs during the last 2 months of gestation and suggested that the diet of the gestating mare might influence fetal tissue mineral deposition. Liu et al[2] reported that Mn deficiency can occur in the developing fetus, and as a result, the developing fetus may have limited endochondral bone growth resulting in skeletal abnormalities and chondrodystrophy.

After birth, the neonatal foal obtains its required minerals from body reserves (ie, liver), mare's milk, forages, the mare's concentrate, and creep feed. Research indicates that neonatal foals have low levels of serum Cu concentrations, which reach normal adult horse values at about 28 days.[3-5] Bridges[6] suggested that developmental problems in equine species, such as osteochondrosis, could be caused by nutritional deficiencies in Zn and Cu. Foals exhibit a sudden drop in iron concentration within the first 24 hours after birth, and several weeks are required for Fe to return to normal values.[3] Modest supplementation of the mare with inorganic trace minerals or use of chelated minerals does not appear to influence the mineral status of the foal.[4]

The objective of the current experiments was to investigate whether supplementing mares during late gestation and lactation with high levels of trace minerals would impact the foal's growth and development and/or mineral status of the mares and foals.

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MATERIALS AND METHODS

Experiment 1

Thirteen pregnant thoroughbred and quarter horse mares were assigned at random, within breed and expected foaling date, to 1 of 2 experimental groups 84 days before expected

Table **1.** Composition and nutrient content of basal concentrate

Ingredient	Percent
Corn, cracked	34.25
Oats, crimped	26.50
Soybean meal, 48% CP	10.00
Wheat bran	10.00
Molasses, blackstrap	8.00
Alfalfa meal pellets, 17% CP	7.50
Limestone, ground	1.50
Monocalcium phosphate	0.80
Salt	0.75
Vitamin premix[a]	0.30
Vitamin E[b]	0.15
Lysine 98%	0.05
Luprosil (Mold inhibitor)	0.10
Trace mineral premix[c]	0.10
Nutrient	**Amount[d]**
Dry matter (%)	88.12
Digestible energy (Mcal/kg)	3.29
Crude protein (%)	15.87
Lysine (%)	0.73
Calcium (%)	1.05
Phosphorus (%)	0.60
Magnesium (%)	0.27

[a]Provided 4,400,000 IU Vit A, 440,000 IU Vit D, and 35,200 IU Vit E/kg premix.
[b]Provided 44,200 IU Vit E/kg premix.
[c]Provided 7,200 mg Cu, 28,000 mg Zn, 28,000 mg Fe, 28,000 mg Mn, 80 mg Co, 80 mg I, and 80 mg Se/kg premix.
[d]Based on 100% dry matter basis, except for dry matter which is expressed on as fed basis.

date of parturition and were fed the experimental diets until 112 days postparturition. Group A received a concentrate (Table 1) formulated to meet or exceed the requirements of late gestating and lactating mares based on NRC[7] recommendations and contained a trace mineral premix that provided 14.3 mg Cu, 40 mg Zn, 28 mg Fe, 28 mg Mn, 0.08 mg Co, 0.16 mg I, and 0.16 mg Se/kg concentrate. This concentrate was top dressed with 28.4 g of soybean meal once daily. Group B mares received the same concentrate as group A plus 27.27 g of soybean meal,

Table **2.** Trace mineral supplementation (mg/d)[a,b]

	Experiment 1		Experiment 2	
Trace Mineral	Group A[c]	Group B[c]	Group C[c]	Group D[c]
Copper	54	181	54	214
Zinc	150	650	150	600
Iron	105	105	105	420
Manganese	105	105	105	420
Cobalt	0.3	0.3	0.3	1.2
Iodine	0.6	0.6	0.6	2.4
Selenium	0.6	0.6	0.6	2.4

[a]Based on a 500 kg mare receiving 0.75 kg concentrate/100 kg body weight.
[b]Does not include minerals in the natural ingredients in the concentrate or forage.
[c]Group A (basal concentrate), group B (basal concentrate + zinc oxide and copper sulfate), group C (basal concentrate), and group D (basal concentrate + 4× trace mineral premix).

0.625 g zinc oxide (502 mg Zn), and 0.500 g copper sulfate heptahydrate (127 mg Cu) top dressed on the feed once daily. The mares were fed ad libitum Coastal Bermudagrass hay (Cynodon dactylon) and/or bahiagrass (Paspalum notatum) pasture in season. Plain salt blocks and fresh water were available at all times.

The mares and foals were weighed, and the foals were measured for withers height; body length; hip height; and heart girth at 1, 28, 56, 84, and 112 days. Jugular blood samples were collected from the mares at 1, 28, and 112 days and from the foals at 1, 7, 14, 28, 56, and 112 days. The serum samples were stored at −20°C until analyzed for Cu, Zn, and Fe by atomic absorption spectrophotometry[8] using 1:1 dilution with deionized water. Milk samples were obtained from mares at 1, 28, and 56 days and analyzed for Cu, Zn, and Fe concentrations by atomic absorption spectrophotometry.[8]

Experiment 2

Fourteen pregnant thoroughbred and quarter horse mares were assigned at random within breed and expected foaling date to 1 of 2 experimental groups 84 days before expected date

Table **3.** Influence of diet on growth and development of foals[a]

	Experiment 1		Experiment 2	
Measurement	Group A[b]	Group B[b]	Group C[b]	Group D[b]
Day 1 weight, kg	55.1 ± 3.0	53.3 ± 1.8	50.5 ± 2.3	52.5 ± 2.0
Day 112 weight, kg	207.4 ± 6.0	209.7 ± 4.0	180.6 ± 7.3	176.6 ± 6.7
Day 1 withers height, cm	101.9 ± 2.0	101.2 ± 1.2	98.3 ± 2.0	99.1 ± 1.6
Day 112 withers height, cm	127.0 ± 1.9	127.4 ± 1.5	122.3 ± 1.7	123.3 ± 1.4
Day 1 length, cm	72.9 ± 1.3	72.9 ± 1.2	70.3 ± 1.1	73.4 ± 0.9
Day 112 length, cm	116.4 ± 1.4	117.1 ± 1.9	111.7 ± 2.1	110.7 ± 1.8
Day 1 hip height, cm	104.1 ± 1.4	103.6 ± 0.6	102.2 ± 2.6	101.7 ± 2.3
Day 112 hip height, cm	131.6 ± 2.1	132.2 ± 1.4	127.4 ± 2.0	128.8 ± 1.9
Day 1 heart girth, cm	82.8 ± 1.8	81.7 ± 0.8	80.0 ± 1.3	81.7 ± 1.0
Day 112 heart girth, cm	130.5 ± 2.0	132.7 ± 0.9	126.9 ± 2.0	125.0 ± 1.7

[a]All values are LSMEAN ± standard error.
[b]Group A (basal concentrate), group B (basal concentrate + zinc oxide and copper sulfate), group C (basal concentrate), and group D (basal concentrate + 4× trace mineral premix).

Table **4.** Influence of diet on Cu, Zn, and Fe concentration of mare serum[a,b]

	Experiment 1					
	Copper		Zinc		Iron	
	Group A[c]	Group B[c]	Group A[c]	Group B[c]	Group A[c]	Group B[c]
Day 1	1.37 ± 0.11	1.40 ± 0.12	0.72 ± 0.06	0.74 ± 0.07	2.82 ± 0.30	2.99 ± 0.33
Day 28	1.49 ± 0.08	1.54 ± 0.11	0.69 ± 0.03	0.62 ± 0.04	2.71 ± 0.26	2.83 ± 0.30
Day 112	1.37 ± 0.09	1.44 ± 0.10	0.77 ± 0.03	0.71 ± 0.04	1.86 ± 0.12	2.17 ± 0.15

	Experiment 2					
	Copper		Zinc		Iron	
	Group C[c]	Group D[c]	Group C[c]	Group D[c]	Group C[c]	Group D[c]
Day 1	1.31 ± 0.09	1.20 ± 0.08	1.16 ± 0.06[d]	0.91 ± 0.05[e]	3.46 ± 0.43	2.85 ± 0.37
Day 28	1.27 ± 0.12	1.31 ± 0.11	0.81 ± 0.15	0.88 ± 0.13	2.08 ± 0.12	2.17 ± 0.10
Day 56	1.40 ± 0.09	1.27 ± 0.08	1.19 ± 0.14[f]	0.76 ± 0.12[g]	1.88 ± 0.22	2.22 ± 0.19
Day 84	1.30 ± 0.17	1.28 ± 0.15	0.78 ± 0.13	0.84 ± 0.11	1.75 ± 0.22	1.67 ± 0.19
Day 112	1.37 ± 0.09	1.17 ± 0.08	0.45 ± 0.03	0.38 ± 0.03	1.71 ± 0.11	1.65 ± 0.10

[a]Units are in mg/L.
[b]All values are LSMEAN ± standard error.
[c]Group A (basal concentrate), group B (basal concentrate + zinc oxide and copper sulfate), group C (basal concentrate), and group D (basal concentrate + 4× trace mineral premix).
[d,e,f,g]Values within the same mineral and row with different superscripts differ ($P < .05$).

of parturition and were fed the experimental diets until 112 days postparturition. Group C received the same concentrate as group A in experiment 1. Group D was fed a concentrate with the same formulation as group C but fortified with 4× the same trace mineral premix. The mares were fed ad libitum Coastal Bermudagrass hay (*Qvnodon dactylon*), and/or bahiagrass (*Paspalum notatum*) pasture in season. Plain salt blocks and fresh water were available at all times.

The mares and foals were weighed, and the foals were measured for withers height; body length; hip height; and heart girth at 1, 28, 56, 84, and 112 days. Jugular blood samples were collected from the mares and foals at 1, 14 (foal blood only), 28, 56, 84, and 112 days, and serum samples were stored at −20°C. Serum samples for both mares and foals were analyzed for Cu, Zn, and Fe concentrations. Foal serum was analyzed for bone specific alkaline phosphatase (Metra Biosystem Inc, Mountain View, CA) at 1, 14, and 28 days. Milk samples were obtained from mares at 1, 28, 56, 84, and 112 days and analyzed for Cu, Zn, and Fe concentrations. A VR40 radiograph machine (Vet-Ray, Inc, Meridian, ID) was used to take radiographs of the left third metacarpal of each foal at 1, 56, and 112 days. A 10-step aluminum stepwedge taped to the cassette parallel to the cannon bone was used as a standard in estimating the bone mineral content. A 2-cm cross-section of the third metacarpal, 1 cm below the nutrient foramen, was compared with the standard using the image analyzer (Micro Southern Instrument Inc, Marietta, GA) and bone mineral content was estimated.[9,10]

Both protocols were approved by the Institutional Animal Care and Use Committee of the University of Florida.

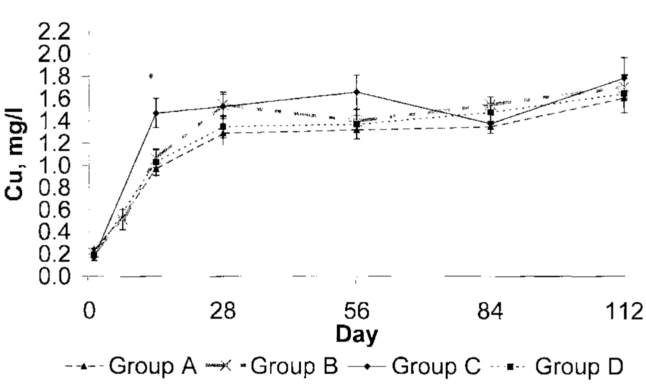

Fig **1.** Serum Cu concentration in foals from group A (basal concentrate), group B (basal concentrate + zinc oxide and copper sulfate), group C (basal concentrate), and group D (basal concentrate + 4× trace mineral premix). *$P < .05$ between group C and group D.

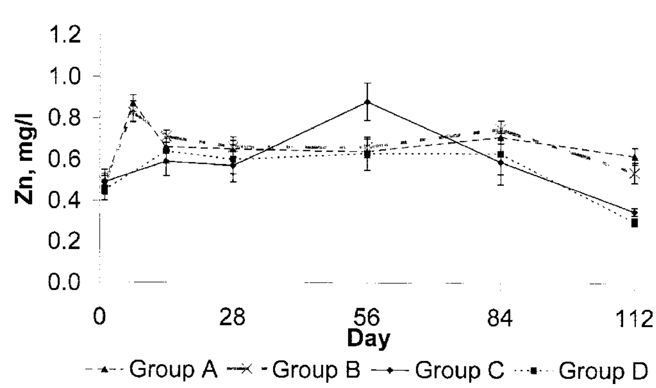

Fig **2.** Serum Zn concentration in foals from group A (basal concentrate), group B (basal concentrate + zinc oxide and copper sulfate), group C (basal concentrate), and group D (basal concentrate + 4× trace mineral premix).

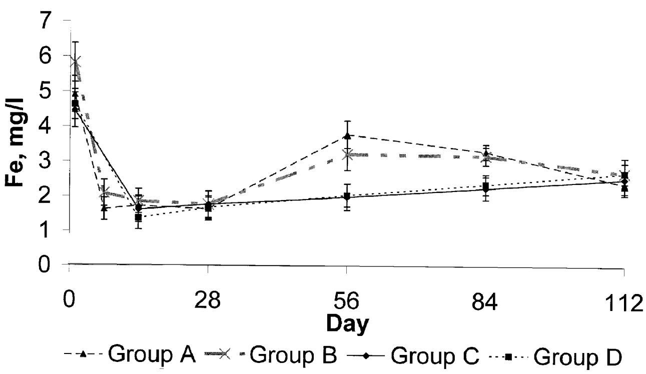

Fig **3.** Serum Fe concentration in foals from group A (basal concentrate), group B (basal concentrate + zinc oxide and copper sulfate), group C (basal concentrate), and group D (basal concentrate + 4× trace mineral premix).

STATISTICAL ANALYSES

Growth measurements, mare and foal serum Cu, Zn, and Fe concentrations, milk Cu, Zn, and Fe concentrations, foal serum bone specific alkaline phosphatase, and foal bone mineral content were analyzed using the GLM Procedures of SAS[11] with diet as main effect. An $\alpha < .05$ was set as statistically significant.

RESULTS AND DISCUSSION

The calculated intake of trace minerals provided by the supplement is shown in Table 2. In experiment 1, no differences ($P > .05$) in foal growth (Table 3), mare serum (Table 4), or foal serum (Figs 1-3) Cu, Zn, and Fe concentrations were observed. Colostrum (1 day), from both groups, was higher ($P < .05$) in Cu and Zn concentrations than milk samples obtained at 28 and 56 days postpartum. There were no differences ($P > .05$) between groups for mare milk Cu, Zn, and Fe concentrations (Table 5).

In experiment 2, there were no differences ($P > .05$) for any of the growth data (Table 3). The Cu, Zn, and Fe concentrations of the mare serum are shown in Table 4. Group C mares had higher serum Zn concentration at 1 day ($P < .01$) and 56 days ($P < .04$) but not at 28, 84, or 112 days. No mare serum Cu or Fe concentration differences ($P > .05$) were detected between the 2 groups. The Cu, Zn, and Fe concentrations of the foal serum are shown in Figures 1, 2, and 3, respectively. Group C foals had higher serum Cu concentration at 14 days ($P < .03$) but not at the other collection times. The Cu, Zn, and Fe concentrations of mare milk are shown in Table 5. Group C mares had higher Fe concentration at 28 days ($P < .01$), and group D mares had higher Cu concentration at 56 days ($P < .01$). No other differences ($P > .05$) were detected between the groups. Serum bone specific alkaline phosphatase concentrations and estimated bone mineral content (Table 6) did not differ ($P > .05$) between treatments.

The average daily gains of the foals were consistent with previously published data[4,12] with no significant differences between groups. Foal serum Cu values were low at birth and required several weeks to reach normal values, which is consistent with other published data.[3,4] Foal serum Fe concentrations dropped during the first 14 days of the foal's life and then gradually increased, reaching normal adult values at 112 days of age. Data from this and previously published studies show that supplementing late gestating and lactating mares with trace minerals at levels higher than those indicated by NRC[7] do not influence the serum Cu, Zn, and Fe concentration of mares or their foals.[13]

Table **5.** Influence of diet on Cu, Zn, and Fe concentration of mare milk[a,b]

	Experiment 1					
	Copper		Zinc		Iron	
	Group A[c]	Group B[c]	Group A[c]	Group B[c]	Group A[c]	Group B[c]
Day 1	1.11 ± 0.09	1.27 ± 0.08	2.88 ± 0.49	3.95 ± 0.45	0.99 ± 0.11	1.11 ± 0.11
Day 28	0.35 ± 0.04	0.44 ± 0.04	1.74 ± 0.14	1.78 ± 0.14	0.81 ± 0.17	0.99 ± 0.17
Day 56	0.33 ± 0.04	0.38 ± 0.04	1.78 ± 0.14	1.74 ± 0.15	1.48 ± 0.43	1.01 ± 0.49

	Experiment 2					
	Copper		Zinc		Iron	
	Group C[c]	Group D[c]	Group C[c]	Group D[c]	Group C[c]	Group D[c]
Day 1	1.07 ± 0.09	1.25 ± 0.08	2.65 ± 0.54	2.23 ± 0.47	1.02 ± 0.24	0.74 ± 0.21
Day 28	0.40 ± 0.04	0.39 ± 0.03	1.57 ± 0.16	1.87 ± 0.14	1.10 ± 0.11[f]	0.60 ± 0.10[g]
Day 56	0.32 ± 0.02[d]	0.39 ± 0.01[e]	1.92 ± 0.16	1.73 ± 0.14	0.76 ± 0.13	0.96 ± 0.11
Day 84	0.28 ± 0.02	0.29 ± 0.02	1.96 ± 0.19	2.11 ± 0.17	0.41 ± 0.04	0.42 ± 0.03
Day 112	0.29 ± 0.02	0.25 ± 0.02	1.71 ± 0.15	1.63 ± 0.14	0.58 ± 0.08	0.44 ± 0.07

[a]Units are in μg/g of fluid milk.
[b]All values are LSMEAN ± standard error.
[c]Group A (basal concentrate), group B (basal concentrate + zinc oxide and copper sulfate), group C (basal concentrate), and group D (basal concentrate + 4× trace mineral premix).
[d,e,f,g]Values within the same mineral and row with different superscripts differ ($P < .05$).

Table **6.** Influence of diet on foal serum BALP and foal BMC[a]

	BALP (U/L)			BMC (g/2 cm)	
	Group C[b]	Group D[b]		Group C[b]	Group D[b]
Day 1	897.3 ± 79.5	783.4 ± 68.8	Day 1	7.9 ± 0.5	8.2 ± 0.4
Day 14	171.7 ± 34.9	195.5 ± 30.2	Day 56	10.3 ± 0.6	10.1 ± 0.5
Day 28	231.0 ± 27.1	163.0 ± 23.5	Day 112	13.6 ± 0.7	12.6 ± 0.7

Abbreviations: BALP, bone specific alkaline phosphatase; BMC, bone mineral content.
[a]All values are LSMEAN ± standard error.
[b]Group C (basal concentrate) and group D (basal concentrate + 4× trace mineral premix).

Baucus et al[13] reported that increasing the Zn level from 24 to 53 ppm and the Cu level from 4 to 12 ppm in the diet of broodmares did not change the Zn or Cu concentrations of mare milk. Mare milk is low in Fe, and research has indicated that the level couldn't be increased by feeding higher concentrations of Fe to the lactating mare.[14] The results of this study are in agreement with previously published research,[15,16] which indicated that the concentrations of Cu, Zn, and Fe in mare milk could not be elevated by providing higher dietary levels of trace minerals during late gestation and lactation.

The concentration of Cu, Zn, and Fe in mare milk significantly decreased throughout the first 16 weeks of lactation. Grace et al[15] indicated that mare milk provides adequate amounts of Zn but inadequate quantities of Cu and Fe for the suckling foal. The foal, therefore, is in a negative plane of nutrition for Cu and must mobilize Cu from the liver stores until Cu intake is increased by the consumption of other feeds. To meet its Fe requirement, the foal was dependent on Fe stores in soft tissue and/or its ability to conserve Fe until intake was increased. It is emphasized that foals should have access to dry feed as early as possible for the foal to meet its nutrient requirements.[15]

CONCLUSIONS

When mares were supplemented with trace minerals at levels higher than those currently recommended by NRC, no differences on foal growth and development; mare milk; mare and foal serum Cu, Zn, and Fe concentrations; foal serum bone specific alkaline phosphatase; or foal bone mineral content were detected. The horses' homeostatic system maintains the serum concentration of trace minerals within very narrow levels. Because no adverse effects were observed, supplementation may serve as insurance against deficiencies, especially during periods when the forage might be low in these nutrients.

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