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FACTORS AFFECTING MINERAL DIGESTIBILITY IN HORSES

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Mineral requirements for horses are usually calculated using information about the horse's body weight, age, weight gain, physiological status (pregnancy, lactation, etc.) and level of activity. Rarely are other factors that affect digestibility taken into consideration. In most cases, other substances in the ration don't significantly alter mineral utilization, but there are cases where the presence of other minerals or inhibitory compounds should be considered when formulating a horse ration. This paper will review some of the most important factors affecting the digestibility of minerals in horses and will use data from a series of digestion trials conducted by Kentucky Equine Research to illustrate how relevant nutrient interactions are in typical horse rations.

Studying Mineral Digestibility

Kentucky Equine Research has conducted a large number of digestibility studies with a wide variety of feedstuffs. A summary of 30 of these studies has been published (Pagan, 1998) and these data will be further evaluated in the present paper. The diets evaluated ranged from pure alfalfa hay to a combination of sweet feed and fescue hay to pelleted concentrates fed with timothy hay. Table 1 lists the average concentration of each nutrient measured along with the standard deviation, maximum and minimum ranges. As Table 2 illustrates, these combined experiments represent a wide range of nutrient intakes for mature horses.

The majority of horses used in these studies have been Thoroughbreds, although Quarter Horses, Appaloosas, and warmbloods have also been included. Most of these horses have averaged between 500-600 kg of body weight.

Mineral Digestibility

Mineral digestibility can be expressed in two different ways. One way is as apparent digestibility. Using this calculation, the amount of a specific mineral that is recovered in the feces is subtracted from the total daily intake of that mineral. The amount that disappeared (intake - feces) is divided by the total daily intake to produce a percentage of intake. Apparent digestibility is a fairly crude way to evaluate digestibility since it only measures the total amount of a particular nutrient in the feces. There are two possible sources of these fecal nutrients. Some of the nutrient could be the undigested residue left from the feed, but some may have actually been excreted into the digestive tract from the horse's system or it might have sloughed off the intestinal wall. The fecal substances that originate from inside the horse are considered *endogenous* in nature and they result in an underestimation of *true* nutrient digestibility.

Table 1. Average nutrient concentrations of diets studied (100% dry matter basis).

Nutrient	*Average concentration*	*Standard deviation*	*Maximum*	*Minimum*
Crude protein	13.1 %	2.6 %	20.4 %	9.6 %
ADF	28.8 %	4.6 %	40.6 %	20.6 %
NDF	46.9 %	5.4 %	57.4 %	38.3 %
Hemicellulose	18.1 %	4.7 %	24.1 %	6.0 %
Crude fiber	22.8 %	3.9 %	31.8 %	15.4 %
Soluble CHO	28.9 %	5.0 %	36.9 %	18.3 %
Fat	3.6 %	0.8 %	5.5 %	2.1 %
Calcium	0.89 %	0.24 %	1.50 %	0.55 %
Phosphorus	0.39 %	0.09 %	0.58 %	0.20 %
Magnesium	0.22 %	0.03 %	0.29 %	0.17 %
Potassium	1.63 %	0.54 %	3.29 %	0.98 %
Iron	287 ppm	119 ppm	753 ppm	127 ppm
Zinc	84 ppm	38 ppm	147 ppm	20 ppm
Copper	22 ppm	8 ppm	38 ppm	7 ppm
Manganese	83 ppm	29 ppm	127 ppm	29 ppm
Ash	7.45 %	1.53 %	11.62 %	5.99 %

Table 2. Average nutrient intakes of diets studied.

Nutrient	*Average concentration*	*Standard deviation*	*Maximum*	*Minimum*
Dry matter	7,119 grams	1,464 grams	10,541grams	4,777 grams
Crude protein	946 grams	326 grams	1,808 grams	572 grams
ADF	2,097 grams	709 grams	4,266 grams	984 grams
NDF	3,371 grams	927 grams	5,427 grams	1,968 grams
Hemicellulose	1,275 grams	411 grams	2,191 grams	393 grams
Soluble CHO	2,007 grams	285 grams	2,627 grams	1,195 grams
Fat	254 grams	66 grams	469 grams	144 grams
Calcium	64 grams	27 grams	158 grams	33 grams
Phosphorus	28 grams	9 grams	57 grams	13 grams
Magnesium	16 grams	5 grams	27 grams	9 grams
Potassium	119 grams	53 grams	269 grams	47 grams
Iron	2,059 mg	1,250 mg	7,912 mg	773 mg
Zinc	567 mg	216 mg	885 mg	131 mg
Copper	149 mg	57 mg	282 mg	46 mg
Manganese	572 mg	201 mg	1,179 mg	210 mg
Ash	540 grams	199 grams	1,136 grams	299 grams

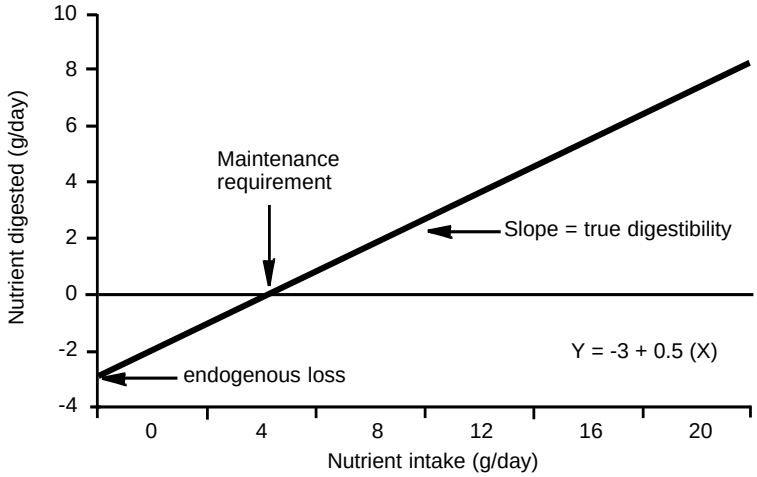

Figure 1. Lucas test for determining true digestibility and endogenous fecal losses.

To overcome the interference of endogenous losses in the determination of digestibility, a statistical procedure called a Lucas test can be utilized. In this test, a range of nutrient intakes are studied. The amount of nutrient that is digested is regressed against its corresponding level of intake. This procedure is illustrated in Figure 1. If there are real endogenous losses associated with a particular nutrient, then the calculated level of nutrient digested at a nutrient intake of zero will be a negative number. The slope of the regression line represents the *estimated true digestibility* for the nutrient. If the regression line intersects the vertical axis at or above zero, then there are no endogenous losses for that particular substance.

Table 3 shows the estimated true digestibilities of several minerals along with their calculated endogenous losses. These endogenous losses can in turn be used to calculate the true digestibility of each mineral in an individual digestibility trial.

Table 3. Estimated true digestibility and endogenous losses for each mineral measured.

Nutrient	*True digestibility*	*Endogenous loss*	*Endogenous loss real*[a]	R^2
Calcium	74.7 %	17.4 g/d	yes	0.94
Phosphorus	25.2 %	4.7 g/d	yes	0.33
Magnesium	51.8%	2.2 g/d	yes	0.76
Zinc	20.8 %	54 mg/d	yes	0.57
Copper	40.0 %	38 mg/d	yes	0.71
Manganese	28.5 %	110 mg/d	yes	0.40

[a]intercept of regression equation significantly different from zero ($p<0.05$)

Calcium

Requirement

Horses are generally very efficient at digesting and absorbing calcium. The upper half of the small intestine is the major site of calcium absorption. In calculating the maintenance requirement of calcium, the 1989 NRC assumes an endogenous loss of 20 mg of calcium/kg of body weight/day based on metabolism studies at Cornell University (Schryver et al., 1970, 1971). The efficiency of absorption of calcium was assumed to be 50%, leading to a daily requirement of 22 grams of calcium for a 550 kg BW horse.

The relationship between calcium intake and digested calcium is shown in Figure 2. The true digestibility of calcium from these rations was 75% and the daily endogenous loss was 17.4 grams, or 29-34 mg calcium/kg BW/day. Using these data, the daily requirement for a 550 kg horse would be around 23 grams/day, a figure almost identical to the NRC estimate.

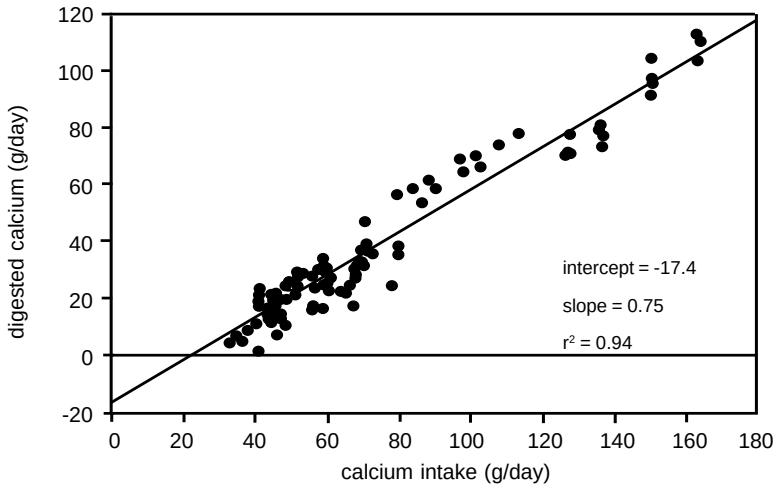

Figure 2. Lucas test for calcium digestibilty.

Factors Affecting Calcium Digestibility

To evaluate whether the concentration of other substances in the horse's ration affects calcium digestibility, linear regressions were calculated between estimated true calcium digestibility and the concentration of several other nutrients in the rations. The coefficients generated from these regressions are listed in Table 4. If an interaction exists between a nutrient and calcium digestibility, then the slope of the regression equation should be significantly different from zero. There were no interactions between calcium digestibility and the concentration of protein, fat, magnesium, iron, zinc, copper, or manganese.

Figure 3 shows the regression between calcium digestibility and iron. There was no relationship between the level of iron in the diets and the true digestibility of calcium. On the other hand, calcium digestibility was negatively correlated with NDF and phosphorus concentration. The relationship between dietary phosphorus and calcium digestibility is shown in Figure 4.

Table 4. Regression coefficients between true calcium digestibility and other substances in the ration.

Nutrient	*Intercept*	*Slope*	*Slope real*[a]	R^2
Crude protein	.67	0.006	no	0.02
NDF	1.08	-0.007	yes	0.13
Soluble CHO	.60	0.005	yes	0.07
Fat	.81	-0.02	no	0.02
Calcium	.68	0.07	yes	0.04
Phosphorus	1.00	-.65	yes	0.35
Ca:P ratio	.68	0.03	yes	0.13
Magnesium	.71	0.13	no	0.00
Iron	.70	0.0002	no	0.02
Zinc	.72	0.0004	no	0.02
Copper	.77	-.001	no	0.01
Manganese	.73	0.0002	no	0.01

[a] slope of regression equation significantly different from zero ($p<0.05$)

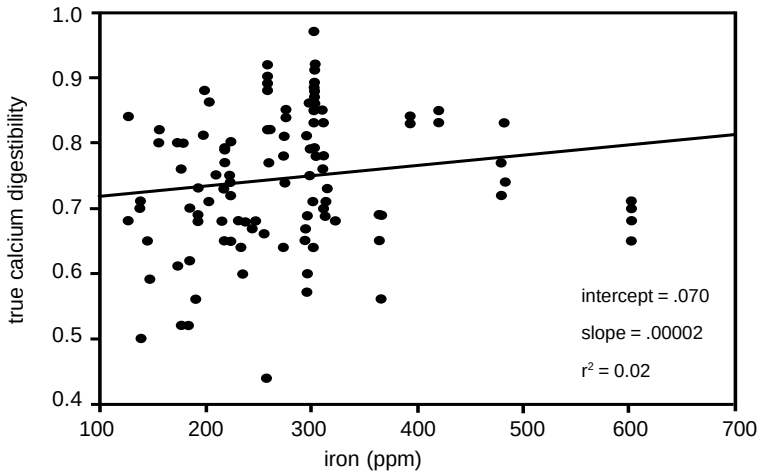

Figure 3. Relationship between iron concentration and true calcium digestibility. The slope of the regression is not significantly different from zero.

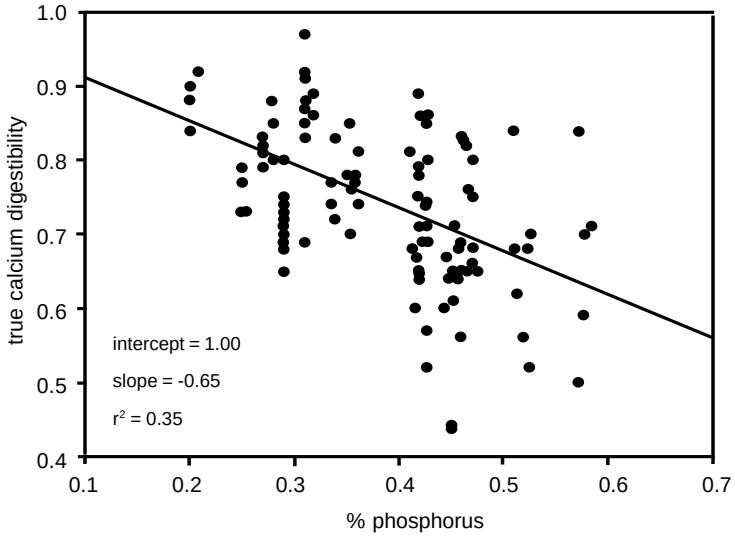

Figure 4. Relationship between phosphorus concentration and true calcium digestibility. The slope of the regression is significantly different from zero ($p<.05$).

Phosphorus

Requirement

The NRC estimates that mature idle horses absorb phosphorus with an efficiency of 35 percent and that endogenous losses equal 10 mg/kg BW/day. Therefore, a 550 kg horse would require 15.7 grams of phosphorus/day. In the present study, the horses digested phosphorus with an estimated efficiency of 25% and had endogenous losses equal to 4.7 g/day (~8.5 mg/kg BW/day)(Figure 5). Using these data, a 550 kg horse's maintenance phosphorus requirement would equal 18.7 grams/day, only slightly higher than the NRC estimates.

Factors Affecting Phosphorus Digestibility

Coefficients generated from linear regressions of true phosphorus digestibility against other nutrients are shown in Table 5. Phosphorus digestibility, as a function of intake, was much more variable than calcium digestibility and several nutrients in the diet appeared to influence digestibility. There was no relationship between protein, calcium or calcium:phosphorus ratio and phosphorus digestibility. True phosphorus digestibility regressed against Ca:P ratio is shown in Figure 6. True phosphorus digestibility was negatively correlated with fiber content. This relationship is presented graphically in Figure 7.

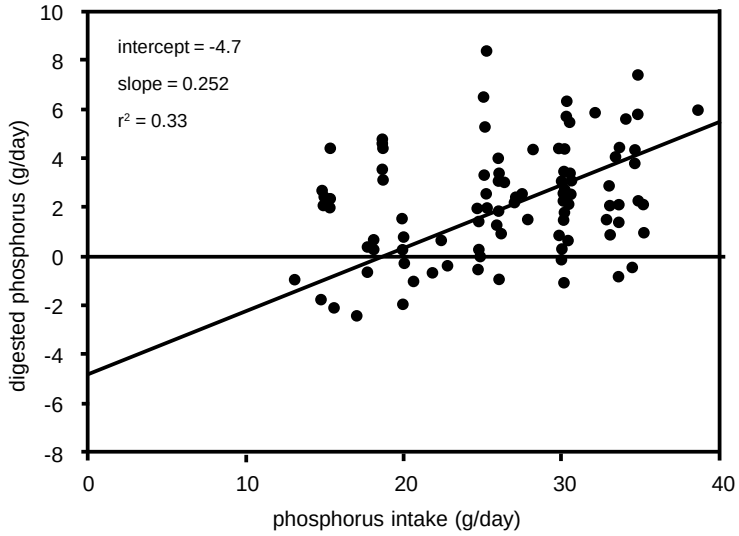

Figure 5. Lucas test for phosphorus digestibility.

Table 5. Regression coefficients between true phosphorus digestibility and other substances in the ration.

Nutrient	*Intercept*	*Slope*	*Slope real*[a]	*R* ²
Crude protein	.34	-0.005	no	0.02
NDF	.72	-0.01	yes	0.23
Soluble CHO	-.57	0.012	yes	0.36
Fat	.14	0.04	yes	0.08
Calcium	.31	-0.04	no	0.01
Phosphorus	.38	-0.28	yes	0.07
Ca:P ratio	.28	-0.002	no	0.001
Magnesium	.57	-1.29	yes	0.14
Iron	.22	0.0002	yes	0.04
Zinc	.16	0.0015	yes	0.31
Copper	.22	0.002	yes	0.04
Manganese	.18	0.001	yes	0.15

[a]slope of regression equation significantly different from zero ($p<0.05$)

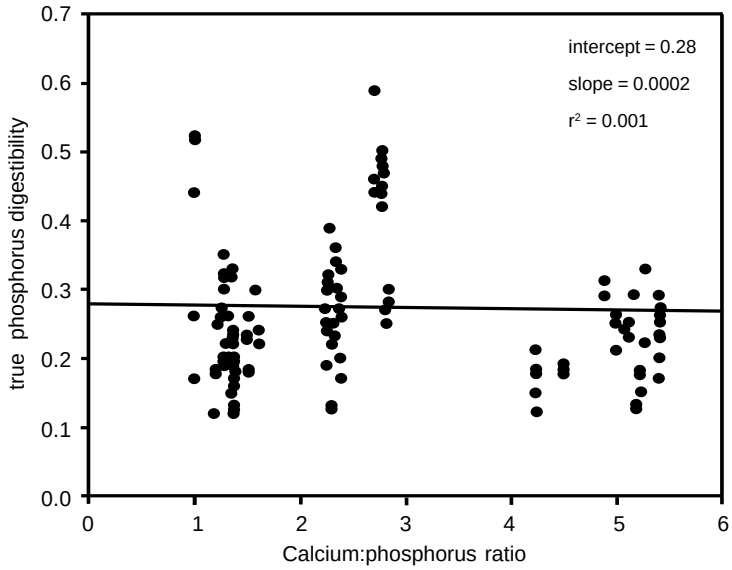

Figure 6. Relationship between Ca:P and true phosphorus digestibility. The slope regression is not significantly different from zero.

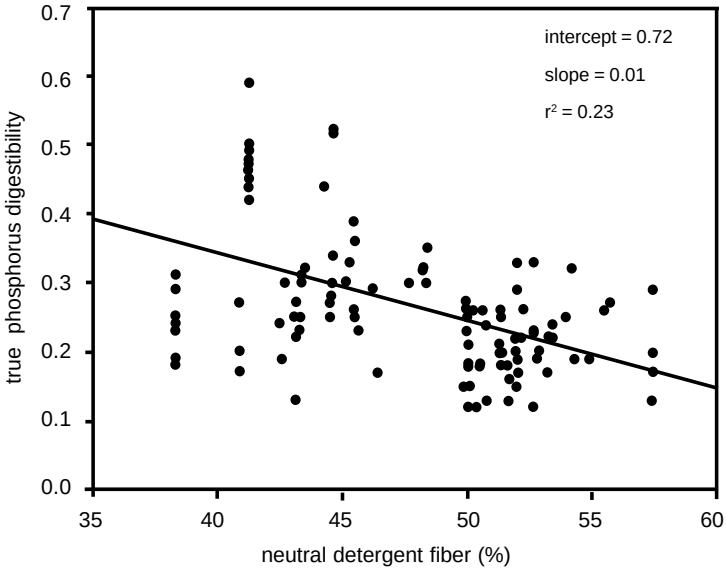

Figure 7. Relationship between neutral detergent fiber (NDF) and true digestibility. The slope of the regression is significantly different from zero ($p<.05$).

Magnesium

Requirement

The NRC uses a true absorption efficiency of 40 percent and endogenous losses of 6 mg/kg BW/day to calculate the magnesium requirement of the adult horse leading to a daily requirement of 8.25 grams of magnesium for a 550 kg animal. Our data suggest an efficiency of absorption of 52% and endogenous losses of only 2.2 grams/day (~4 mg/kg BW/day)(Figure 8). Using these figures, a mature 550 kg horse would require only about 4.2 grams of magnesium per day.

Factors Affecting Magnesium Digestibility

Coefficients generated from linear regressions of true magnesium digestibility against other nutrients are shown in Table 6. There was no relationship between protein, fat, magnesium, iron, copper, or manganese and true magnesium digestibility. There was a significant negative correlation between fiber and phosphorus levels in the diet and magnesium digestibility. Calcium content and calcium:phosphorus ratio were positively correlated with magnesium digestibility.

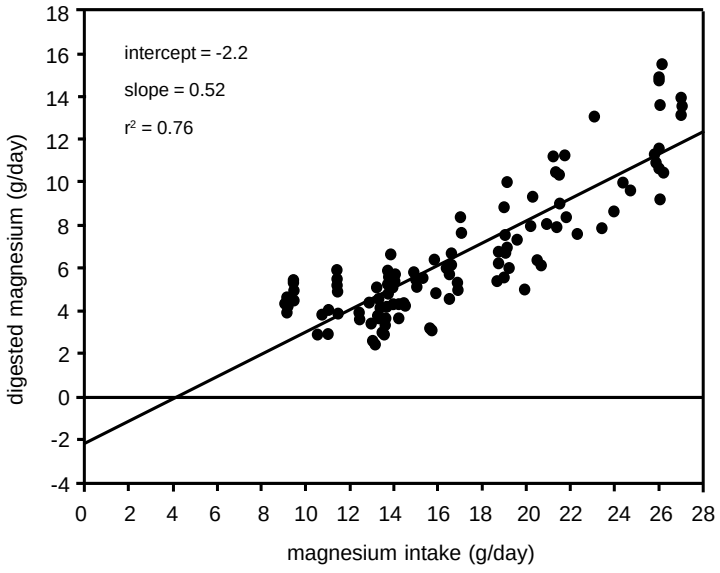

Figure 8. Lucas test for magnesium digestibility.

Table 6. Regression coefficients between true magnesium digestibility and other substances in the ration.

Nutrient	*Intercept*	*Slope*	*Slope real*[a]	R^2
Crude protein	.44	0.006	no	0.03
NDF	.85	-0.007	yes	0.14
Soluble CHO	.39	0.005	yes	0.07
Fat	.58	-0.02	no	0.02
Calcium	.43	0.106	yes	0.10
Phosphorus	.73	-0.54	yes	0.28
Ca:P ratio	.45	0.027	yes	0.16
Magnesium	.59	-0.29	no	0.01
Iron	.51	0.00004	no	0.002
Zinc	.49	0.0004	no	0.03
Copper	.53	-0.0006	no	0.003
Manganese	.51	0.0002	no	0.005

[a]slope of regression equation significantly different from zero ($p<0.05$)

Zinc

Requirement

The NRC estimates that zinc absorption is around 5-10% and that mature horses require 40 ppm zinc in their diets. A 550 kg horse would therefore require around 330 mg zinc/day. In our study, the horses digested zinc with an average efficiency of 21% with endogenous losses of 54 mg/day (.1 mg/kg BW/day)(Figure 9). Using these data, a 550 kg horse would require about 260 mg zinc per day.

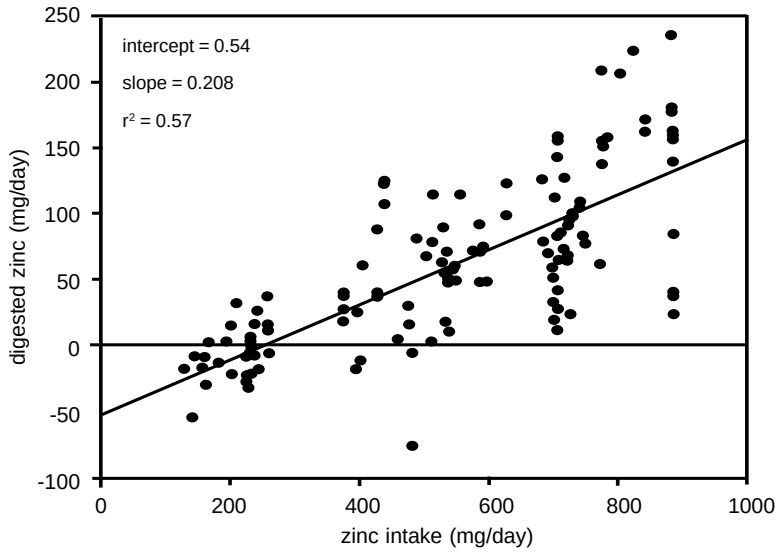

Figure 9. Lucas test for zinc digestibility.

Factors Affecting Zinc Digestibility

Coefficients generated from linear regressions of true zinc digestibility against other nutrients are presented in Table 7. The only nutrient that was significantly correlated to zinc digestibility was magnesium (Figure 10). None of the trace minerals, including iron (Figure 11), affected zinc digestibility.

Table 7. Regression coefficients between true zinc digestibility and other substances in the ration.

Nutrient	*Intercept*	*Slope*	*Slope real*[a]	R^2
Crude protein	.14	0.005	no	0.03
NDF	.22	-0.0002	no	0.0002
Soluble CHO	.27	-0.002	no	0.02
Fat	.20	0.003	no	0.001
Calcium	.18	0.04	no	0.02
Phosphorus	.21	-0.007	no	0.0001
Ca:P ratio	.20	0.006	no	0.01
Magnesium	.05	0.73	yes	0.08
Iron	.23	0.00008	no	0.01
Zinc	.23	-0.0003	no	0.02
Copper	.23	-0.001	no	0.02
Manganese	.23	-0.0002	no	0.009

[a]slope of regression equation significantly different from zero ($p<0.05$)

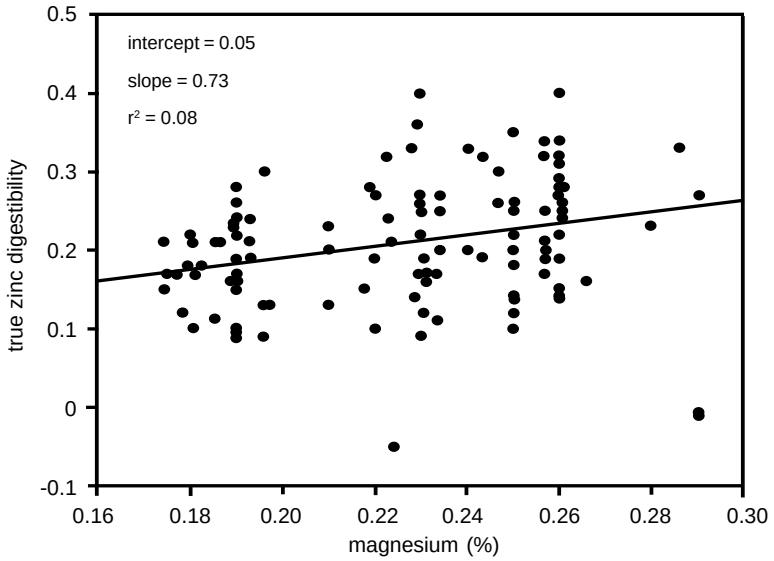

Figure 10. Relationship between magnesium content and zinc digestibility. The slope regression is significantly different from zero ($p > .05$).

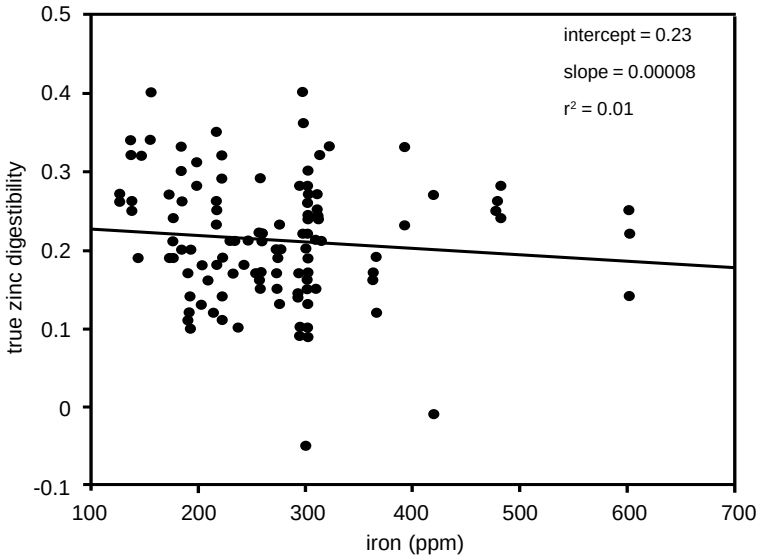

Figure 11. Relationship between iron and zinc digestibility. The slope regression is not significantly different from zero.

Copper

Requirement

The NRC recommends that mature horses should receive 10 ppm copper in their diets or around 85 mg copper/day. In the present study, true copper digestibility was estimated to be 40% and endogenous losses equaled 38 mg/day (~.07 mg/kg BW/ day). Using these figures, daily maintenance copper requirements for a 550 kg horse would equal around 95 mg/day.

Factors Affecting Copper Digestibility

Coefficients generated from linear regressions of true copper digestibility against other nutrients are presented in Table 8. Protein and calcium were negatively correlated to copper digestibility. The relationship between calcium and copper digestibility is shown in Figure 12. Iron level in the diet did not affect copper digestibility (Figure 13).

Table 8. Regression coefficients between true copper digestibility and other substances in the ratio.

Nutrient	*Intercept*	*Slope*	*Slope real*[a]	R^2
Crude protein	.62	-0.02	yes	0.15
NDF	.30	0.002	no	0.008
Soluble CHO	.27	0.004	yes	0.04
Fat	.40	-0.0001	no	0.000
Calcium	.51	-0.13	yes	0.09
Phosphorus	.36	0.10	no	0.007
Ca:P ratio	.45	-0.02	yes	0.05
Magnesium	.38	-0.06	no	0.0002
Iron	.37	0.00009	no	0.006
Zinc	.32	0.0009	yes	0.09
Copper	.36	0.001	no	0.01
Manganese	.28	0.001	yes	0.15

[a] slope of regression equation significantly different from zero ($p<0.05$)

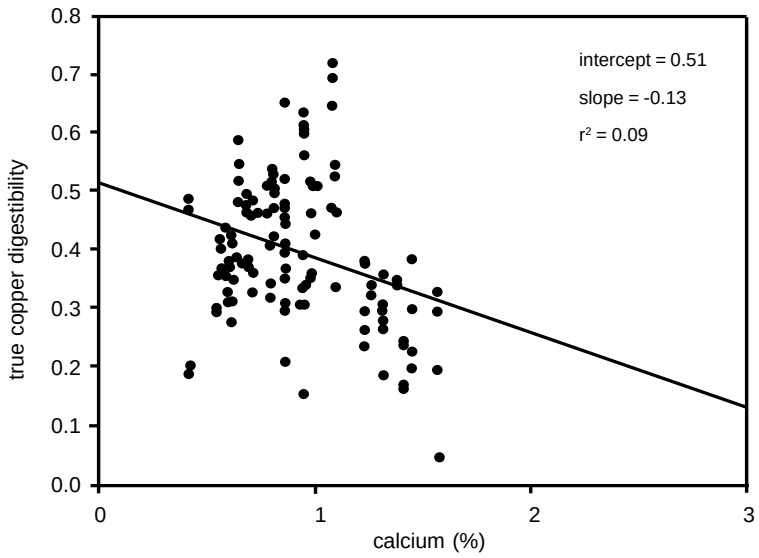

Figure 12. Relationship between calcium and copper digestibility. The slope of the regression is significantly different from zero ($p<.05$).

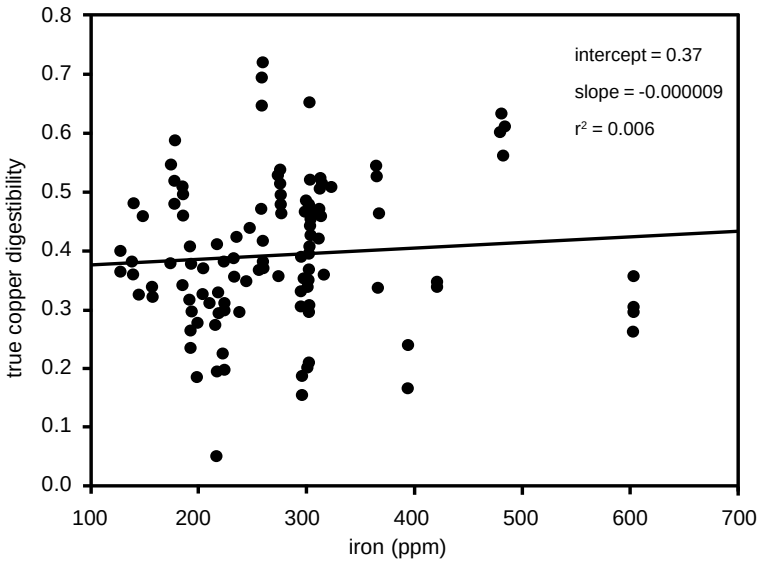

Figure 13. Relationship between iron and copper digestibility. The slope of the regression is not significantly different from zero.

Conclusions

The mineral requirements calculated for mature horses in the present study generally agree with the requirements suggested by the 1989 NRC. True calcium digestibility was negatively correlated with the phosphorus content of the diet. Phosphorus digestibility, as a function of intake, was much more variable than calcium digestibility and several nutrients in the diet appeared to influence digestibility. Magnesium digestibility was negatively correlated to dietary phosphorus content. Zinc digestibility was unaffected by all other nutrients in the diet, other than magnesium, which was positively related to zinc digestibility. Calcium was negatively correlated with copper digestibility. Surprisingly, iron content did not affect the digestibility of any of the minerals in this study, even though the content of iron in the diets was fairly high (127 ppm-753 ppm). Most of this iron was not supplemented and was probably in the form of iron oxide, so it remains to be determined whether supplemental sources of iron have a greater effect.

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