IMPACT OF TRACE MINERAL VARIATION WITHIN FORAGES ON THE RATION FORMULATION PROCESS

J. R. Knapp
Fox Hollow Consulting, LLC
Columbus, Ohio

INTRODUCTION

While trace mineral (TM) concentrations of forages are often lower than the TM requirements of most domestic livestock, they are not negligible. Endogenous minerals in forages are highly available upon digestion, while minerals arising from soil contamination are poorly available. Frequently, dairy rations are balanced either assuming the TM are zero or using standard reference values, e.g. NRC (2001). If forage TM concentrations are not considered in the feed formulation process, it is not likely that the targeted dietary concentrations will be met. There is a greater risk of excess minerals in the ration than deficiency due to the skewed distributions in forage TM concentrations (Figure 1) or if the forage minerals are set to zero. This risk is of concern especially with Cu, where liver accumulation occurs when dairy cattle consume diets with 20 mg/kg Cu (Balemi et al., 2010) and may be detrimental to animal health and performance (Weiss & Faulkner, 2015). Using TM concentrations for forages and other basal feed ingredients will reduce the risk of mineral imbalances, will improve the efficacy of TM supplementation, and can reduce TM excretion into the environment via manure. The objectives of this research were to: 1) quantify the variation in trace mineral concentrations in forages, 2) evaluate the contribution of U.S. geographical location and harvest season to the TM variation, and 3) determine how variation in forage TM concentrations affects ration TM concentrations under different supplementation strategies.

GEOGRAPHICAL DIFFERENCES

Data from Cumberland Valley Analytical Services for forages from the 2009 to 2014 growing seasons with concentrations of major nutrients as well as mineral concentrations were used. Data were statistically filtered to remove misidentified feeds and outliers based on macronutrient concentrations using the procedures outlined in Yoder et al., 2014. After this step, the corn silage, legume hay, mixed mostly legume (MML) silage, and mixed mostly grass (MMG) silage data sets contained 20654, 8856, 8631, and 2914 observations, respectively.

As expected, TM concentrations for corn silage, legume hay, MML silage, and MMG silage displayed skewed distributions (Figure 1). TM values were log normalized before analysis of variance with location, season, and their interaction as independent effects and total ash concentration as a covariate (Proc Mixed, SAS/STAT 9.4). Geographical variation in copper and zinc concentrations were graphed using Proc Gmap (SAS/GRAPH 9.4) and a zip code data set (U.S. Census Bureau).

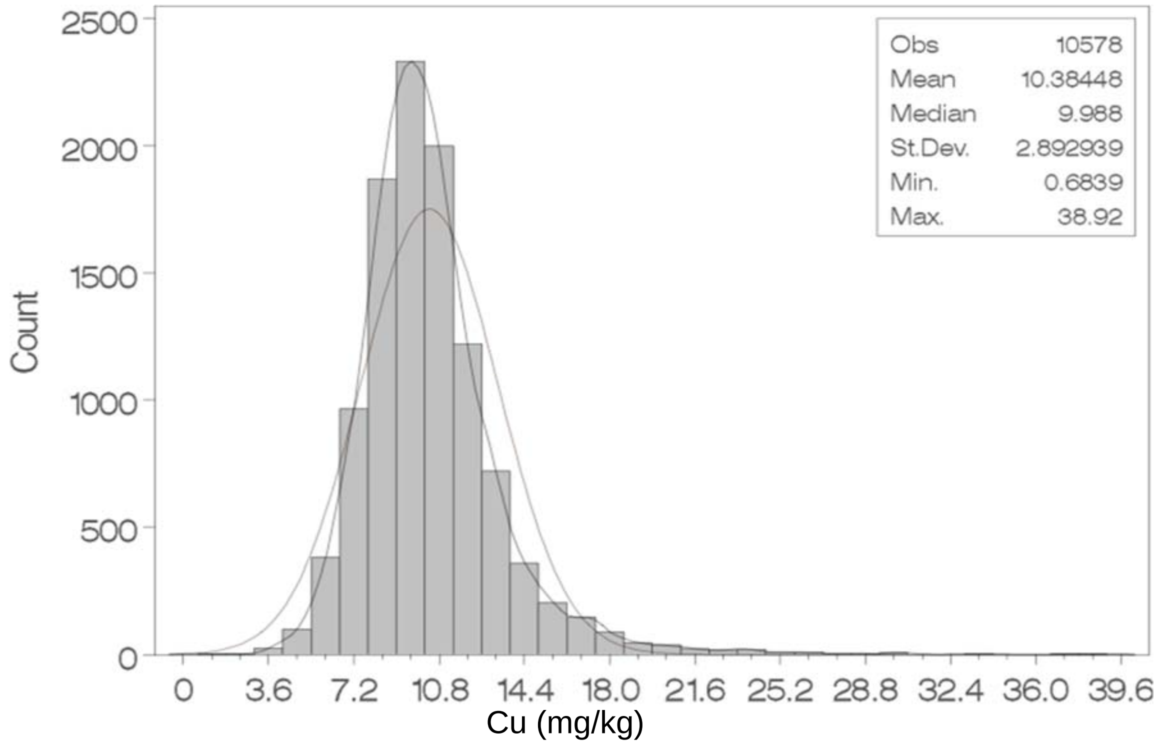

Figure 1. Representative histogram showing skewed distribution of trace mineral concentrations in forages before normalization.

Geographical location and total ash content were the largest sources of variation in forage TM concentrations ($p<0.0001$). Differences between median values for lowest and higest variation in TM concentrations are small, but the range between the 5th and 95th percentiles is illustrative of the large differences in TM consistency (Table 1). Ranges in TM concentrations of forages from the most variable regions of the U.S. were 4 to 10 times greater than the more consistent forages grown in other regions (Table 1). Growing season was often a non-significant ($p>0.20$) contribution to total TM variation, while the interaction between location and season was significant ($p<0.05$). The interaction implies that a portion of the variation attributed to geographical area is dependent on weather conditions during the growing season, e.g. dust carried by winds, or harvesting and storage practices that differ between regions.

Soil contamination can contribute to higher TM concentrations, especially Mn and Fe. Titanium (Ti) concentration in forages is considered by agronomists to be the gold standard in determining soil contamination of forages. However, Ti is not measured in routine nutrient analysis of feed ingredients. Soil contamination of forages reduces the concentration of organic nutrients, and soil Fe can decrease the absorption and utilization of dietary copper and perhaps other minerals (NRC, 2001; references within Hansen & Spears, 2009 and Spears, 2013). In the past, Fe from soil contamination has been assumed to be non-reactive and not interfere with absorption of other trace minerals (TM). However, *in vitro* studies have shown that soil Fe solubility and bioavailability can be increased during ensiling (Hansen & Spears, 2009).

Soil contamination in forages was estimated using a modification of the residual ash (RA) calculation from Cary et al. (1986):

RA (%DM) = total ash – ($CaO + K_2O + MgO + Na_2O + P_2O_5 + SO_4 + Cl$)

Few corn silage samples showed more than 4% soil contamination, but 10 to 23% of legume hay, MML and MMG silages had levels greater than 4% (Table 2). These levels of soil contamination are associated with Fe concentrations greater than 800 mg/kg with the most extreme samples exceeding 2000 mg/kg. Both total ash and Fe concentration are highly correlated with the level of soil contamination estimated by residual ash (R^2 ranging from 0.47 to 0.75).

Table 1. Geographical areas with the highest variation in forage copper and zinc concentrations (mg/kg) have ranges that are 4 to 10 times greater than those in more consistent forages (lowest variation) although differences between median concentrations are small. p5 = 5th percentile, p95 = 95th percentile back calculated from log normalized data. Reference values from Table 15.3 (NRC, 2001) given in last column for comparison.

Cu	Lowest variation			Highest variation			
	median	**p5**	**p95**	**median**	**p5**	**p95**	**NRC 2001**
Corn silage	6.0	4.9	7.3	7.4	3.2	16.4	6
Legume hay	9.6	7.2	11.4	8.2	6.0	34.0	9
MML silage	7.8	5.7	9.6	10.9	5.7	30.1	9
MMG silage	8.8	6.1	9.4	7.8	4.7	37.9	9

Zn	Lowest variation			Highest variation			
	median	**p5**	**p95**	**median**	**p5**	**p95**	**NRC 2001**
Corn silage	23.2	21.4	28.5	26.6	15.3	60.7	24
Legume hay	24.0	21.1	29.5	27.8	20.9	49.2	24
MML silage	28.3	25.8	35.0	35.7	21.8	69.7	28
MMG silage	23.8	20.0	27.6	29.1	18.4	97.5	30

Table 2. Percentage of samples in arbitrarily defined levels of soil contamination based on Residual Ash and the associated Total Ash (% DM), and Fe concentrations (mg/kg) of commonly used dairy forages, given as mean ± SD. However, note that ash and Fe concentrations are not normally distributed within a forage type. MML= Mixed Mostly Legume, MMG = Mixed Mostly Grass.

Level of Soil Contamination		Corn Silage	Legume Hay	MML Silage	MMG Silage
<1%	Percentage	63.5	18.3	8.3	19.3
	Total Ash	3.28 ± 0.47	9.20 ± 1.24	9.21 ± 1.19	6.08 ± 1.56
	Fe	133 ± 83	212 ± 128	265 ± 151	219 ± 170
1 to 4%	Percentage	36.0	71.9	78.1	57.6
	Total Ash	5.39 ± 0.94	10.68 ± 1.25	10.55 ± 1.24	8.41 ± 1.77
	Fe	234 ± 139	353 ± 238	423 ± 261	355 ± 252
> 4%	Percentage	0.5	9.8	13.6	23.1
	Total Ash	8.02 ± 0.60	13.35 ± 1.35	13.51 ± 1.56	12.07 ± 2.03
	Fe	555 ± 313	872 ± 553	1155 ± 576	850 ± 605

RATION FORMULATION AND TM SUPPLEMENTATION

Nutritionists want to know how to best manage the variation in forages to reduce variation in the finished rations. They also want to know how to supplement under conditions of varying TM concentrations in ingredients. The first step is to know how much variation is occurring. This requires appropriate sampling and testing. Frequency of sampling will be determined by how much variation there is in forages and how often forage ingredients are changed in the ration (Figure 2), with more variation requiring more sampling and analysis. Amount of TM supplementation will depend on the median TM concentrations in the forages (Figure 2).

This data on forage variation when combined with data on TM concentrations in grains and protein meals allows us to predict TM concentrations in rations. Mixing feeds together always reduces nutrient variation compared to the variation in individual ingredients, and using more variable ingredients at lower inclusion rates can also reduce variation. Most dairy rations in the U.S. do require supplementation with Cu, Zn, and Mn to reduce the incidence of deficiencies (Table 3). Supplementing in the range of 11-14 for Cu, 30-50 for Zn, and 40-60 for Mn (mg/kg) should nearly eliminate the possibility of any individual rations being deficient (Table 3).

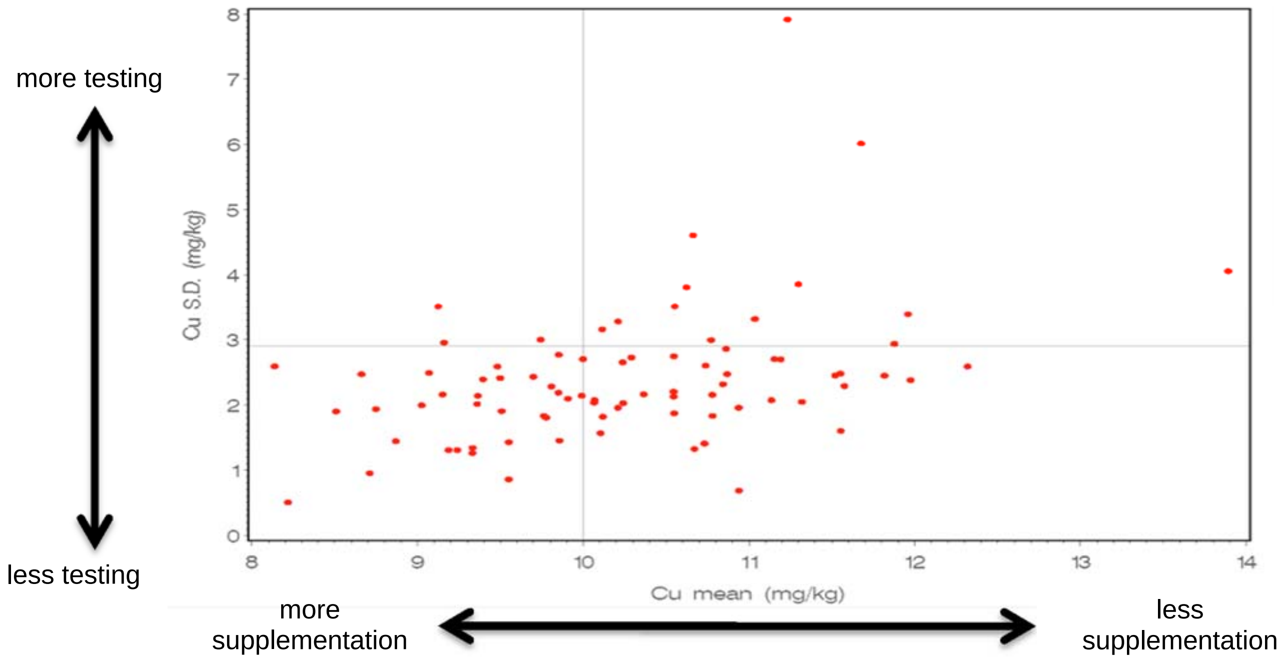

Figure 2. Recommendations for testing and supplementation will vary according to the observed variation in TM concentrations. Example given is in legume hay, median Cu = 10.0, S.D. = 2.9 mg/kg. Each dot represents an individual mailing center, an area defined by the first 3 digits of a zip code.

Table 3. Feed mixing reduces TM variation in finished rations. Predicted TM concentrations in total mixed rations with 0, 1x, or 1.5 supplementation of basal ingredients. Dietary levels (mg/kg) of 11, 52, 40, and 17 were set as minimums for Cu, Zn, Mn, and Fe, respectively (NRC, 2001).

Supplementation Level	Zero	1x	1.5 x	S.D.
Cu ave	6.0	17.0	23.0	1.9
Cu < 11 mg/kg % failures	99.58	0.05	0	
Cu > 30 mg/kg % failures	0	0	0.01	
Zn ave	33.2	85.2	111.2	8.5
Zn < 52 mg/kg % failures	98.75	0	0	
Mn ave	35.1	75.1	95.1	10.0
Mn < 40 mg/kg % failures	69.02	0.01	0	
Fe ave	204	221	230	86.2
Fe < 17 mg/kg % failures	0.06	0.01	0	

Basal ingredients: corn silage, legume hay, flaked corn, dried distillers' grains, corn gluten feed, soybean meal

1x supplementation (mg/kg): 11 Cu, 52 Zn, 40 Mn, 17 Fe added

1.5 x supplementation (mg/kg): 17 Cu, 78 Zn, 60 Mn, 25.5 Fe added

Knowing the basal TM concentrations in forages is key to accurate and precise supplementation! Higher levels of copper supplementation should be avoided to reduce long-term Cu accumulation in liver and potential chronic Cu toxicity (Weiss and Faulkner, 2015). Obviously, excess supplementation of other minerals should be avoided to reduce feed costs, and also to reduce excretion into the environment.

CONCLUSIONS

Geographical location and total ash content are significant sources of variation in TM concentrations in commonly used dairy forages. There are areas in the U.S. that have consistently low TM concentrations, while forages in other areas have high concentrations with high variation. Soil contamination may contribute to variation and can be attributed to weather patterns, soil types, and harvesting and storage practices. Variation in TM concentrations can be reduced with standard feed mixing protocols, but requires knowledge of concentrations for accurate and precise formulation of dietary TM levels. These results support sampling and analysis of forages and formulation of dairy rations for TM based on analytical results rather than reference values.

ACKNOWLEDGEMENTS

This work was supported by Micronutrients, LLC and the forage mineral data was kindly provided by Cumberland Valley Analytical Services. The author thanks Dr. Bill Weiss for contributing valuable insights into this research.

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