Maximizing the value of the mineral in your feed program

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Sixty-six percent of dairy nutritionists in Canada are intentionally over formulating mineral inclusion in their rations (Duplessis et al., 2023). Specific to individual minerals, copper was 52% above NRC 2001 requirement, manganese was 372% above requirement, and zinc was 65% above requirement in 100 Canadian dairy herds (Duplessis et al., 2021). Meanwhile in Wisconsin, 50% of surveyed total mixed rations exceed Zn requirement and 94% of surveyed total mixed rations exceed Cu requirements (Li et al., 2005). Finally, in another study with six Idaho dairies, copper and zinc concentrations were far above recommendations (Hristov et al., 2007). With minerals being such an important part of the ration, whether acting as constituents of enzymes and hormones, or being incorporated into necessary substances for life including bone, connective tissue, hemoglobin, or immune cells (Goff, 2018) it begs the question: are we providing too much and contributing to inefficiencies? More specifically, why are we overfeeding minerals?

Are we overfeeding mineral because we do not routinely measure trace minerals in feedstuffs?

In the survey of Canadian dairy nutritionists, 51% of respondents stated they did not routinely analyze feedstuffs for trace mineral concentrations (Duplessis et al., 2023). This is reflected in an earlier study conducted in California with 39 dairies. In that study, ration samples and water source samples were collected and analyzed for trace minerals. Median total copper concentration was 18.0 mg/kg of diet dry matter, while median total manganese concentration was 73.0 mg/kg of diet dry matter, and median total zinc concentration was 74.1 mg/kg of diet dry matter (Castillo et al., 2013). These data suggest that frequent analysis of minerals in feedstuffs, including water, can help increase the efficiency of mineral utilization. When the basal mineral levels in the ration are known, supplemental minerals can then be specifically targeted to the production and biological needs of the cow and reduce the risk of over supplementation that can lead to mineral inefficiencies.

Are we overfeeding mineral because there is not a simple means to measure bioavailability?

Numerous methods have been suggested for determining mineral availability, absorption, and utilization, collectively termed “bioavailability”, by the animal. For example, plasma, though easily sampled and sensitive to mineral nutrition, is mobilized because of metabolic redistribution, making it an unsuitable marker (King, 2011). When we specifically consider zinc, things are further complicated as plasma zinc is replaced approximately 150 times per day when zinc is sufficient (King et al., 2001). This high turnover makes it difficult to determine proper timing for sampling, as well as what the value obtained for analysis means to the cow. Deposition of minerals in selected tissues has also become common with use of liver biopsy. However, as zinc has no specialized storage system across bodily tissues (Rink and Gabriel, 2000; Herdt and Hoff, 2011), its sensitivity is also a concern. This contrasts with copper which utilizes the liver as a primary storage site, highlighting the need to determine what are the primary minerals of interest and their respective storage sites to obtain an accurate representation of bioavailability for each mineral.

Due to lack of sensitivity in the above measures, other more intensive methods such as expression of metallothionein, a zinc and copper chaperone in intestinal enterocytes, and use of tracers have been explored. Metallothionein serves as a marker for cellular zinc status due to its role as an intracellular Zn storage protein (Davis and Cousins, 2000). Though metallothionein is shown to be sensitive to zinc and copper supply to the intestine and subsequent uptake into the intestinal cells, it is not an ideal measure for whole-body zinc status due to this (Wood, 2000). As for tracers, two options have been explored: radioactive and stable isotopes. Radioactive tracers were used in initial exploration of trace mineral metabolism, however, the associated risk with radiation exposure limits the application of such a sensitive and useful tool in modern research settings (Fairweather-Tait and Dainty, 2002; Turnlund, 2006). Finally, stable isotopes have been used throughout human nutrition as the lack of exposure to radioactivity and precision of traceability demonstrated an overwhelming advantage (Turnlund, 2006).

Recent work has demonstrated that the usefulness of stable isotopes can also be applied to livestock, and more specifically, cattle. When zinc sources are compared using stable isotopes, results have shown that the degree of the bonding between mineral and ligand results in greater availability of the mineral to the cow for subsequent utilization (**Table 1**). NOVUS recently completed a 10-year initiative utilizing stable isotopes to better understand zinc nutrition and the utilization of MINTREX® bis-chelated trace minerals. MINTREX® is chemically unique in that it is a bis-chelate mineral (**Figure 1**). This means that MINTREX® has two ligands of the methionine source, HMTBa, bound to one mineral with four coordinative bonds attached to the mineral. This unique structure creates a molecule with a neutral charge, resulting in the greater relative stability of the molecule throughout the gastrointestinal tract. Non-bis-chelated minerals, where the mineral is bound to one ligand, need to be balanced by a sulfate or chloride, for example, to achieve a neutral charge. In the case of non-bis-chelates, when in the gastrointestinal tract or solution, the mineral possesses a charge as the bond to the counter ion breaks. Once a charge is present, the mineral is defenseless to chemical attack from oppositely charged molecules which can result in lower absorption and subsequent utilization by the cow. Understanding how bioavailability can be altered and selecting a mineral source with greater bioavailability, you can enhance the efficiency of mineral utilization in your rations.

Table 1. Effect of different zinc sources on tissue enrichment compared to MINTREX® Zn. Those values that are bolded represent values that are statistically greater with MINTREX® Zn compared to zinc from the other source.

	% Improvement with MINTREX® Zn				
Mineral Source	Zinc Oxide	Zinc Sulfate	Zinc Glycinate	Zinc Methionine	Non-Specific Amino Acid Zinc Complex
Animal Model	Cow	Cow	Cow	Cow	Pig
Rumen	-	**122.3**	**146.8**	91.4	-
Reticulum	-	**182.6**	**134.0**	104.4	-
Omasum	**156.3**	**152.3**	**148.0**	93.4	-
Abomasum	**589.0**	**232.5**	**132.4**	**115.8**	-
Duodenum	**184.7**	**135.1**	**138.1**	136.9	**197**
Jejunum	**445.9**	**119.6**	**155.8**	114.2	**156**
Ileum	**297.5**	**127.7**	**135.0**	101.7	**163**
Liver	**803.5**	119.4	113.1	77.6	**157**
Pancreas	**1550.8**	**370.6**	132.4	99.0	**148**
Thymus	**346.9**	142.9	**146.8**	74.0	**184**
Spleen	-	**141.4**	**136.2**	112.1	**142**
Kidney	-	**125.4**	**137.9**	96.2	**173**
Lung	-	**133.5**	**156.5**	40.9	105
Heart	-	**126.2**	**151.8**	99.7	**144**
Muscle	**405.8**	**141.2**	101.1	55.5	101
Tibia	**222.0**	**221.6**	104.0	18.5	169
Skin	-	**325.4**	-	206.4	109
Hoof	-	**161.8**	502.7	35.3	**213**
Uterus	-	-	-	-	**205**
Average	500.2	171.2	157.2	92.1	154

Sources: Tucker et al., 2016; Tucker and Provin, 2020; Tucker et al., 2022; Acosta et al., 2023

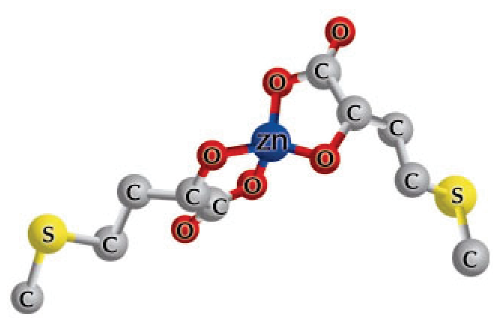

Figure 1. Structure of MINTREX® showing two ligands of the methionine source, HMTBa, bound to one mineral with four coordinative bonds

Are we overfeeding mineral due to dietary antagonisms?

In the previously mentioned survey of Canadian dairy nutritionists, 60% of respondents stated that they considered ruminal mineral interactions when formulating a diet (Duplessis et al., 2023). A very common antagonist is sulfur. High dietary sulfur has been shown to negatively impact utilization of both copper and zinc. A beef study evaluated the effect of high-sulfur diets on mineral retention in feed animals when feeding a high-sulfur diet for 28 d (0.68% sulfur compared to 0.24 % sulfur). In this study, it was observed that the high sulfur diet significantly reduced zinc retention in steers (16.2 ± 25.7 mg/d of Zn for high sulfur diet compared to 106.5 ± 25.7 mg/d of zinc for low sulfur diet; Pogge et al., 2014). When using stable isotopes of zinc and mimicking the high dietary sulfur levels used in Pogge et al. (2014), plasma levels of zinc are not altered with high dietary sulfur. Despite the lack of effect observed in plasma zinc, tissue enrichment is significantly reduced with high dietary sulfur (**Table 2**; Tucker and Provin, 2020). This suggests that not only do we need to consider the level of the mineral we are trying to supplement in the ration and its bioavailability but also increase consideration of other minerals that can antagonize the minerals of interest (**Figure 2**).

Table 2. Effect of dietary sulfur level on tissue appearance of Zinc isotopes

	Dietary Sulfur Level		SE	*P* - value
	Low	High		
Rumen	0.711	0.277	0.050	< 0.01
Reticulum	0.844	0.379	0.065	< 0.01
Omasum	0.502	0.330	0.024	< 0.01
Abomasum	0.301	0.297	0.021	0.90
Microbial Pellet	0.665	-0.133	0.212	0.01
Duodenum	0.672	0.472	0.041	< 0.01
Jejunum	0.482	0.310	0.038	< 0.01
Ileum	0.445	0.356	0.020	< 0.01
Liver	-0.239	0.093	0.307	0.43
Kidney	0.528	0.383	0.021	< 0.01
Lung	0.208	0.068	0.023	< 0.01
Heart	0.211	0.162	0.028	0.21
Muscle	0.028	0.030	0.006	0.76
Spleen	0.419	0.327	0.036	0.07
Thymus	0.109	0.151	0.017	0.08
Pancreas	0.382	0.038	0.204	0.22
Hoof	0.056	0.025	0.047	0.63
Bone	0.148	-0.081	0.141	0.24
Skin	0.048	0.031	0.059	0.83

Source: Tucker and Provin, 2020

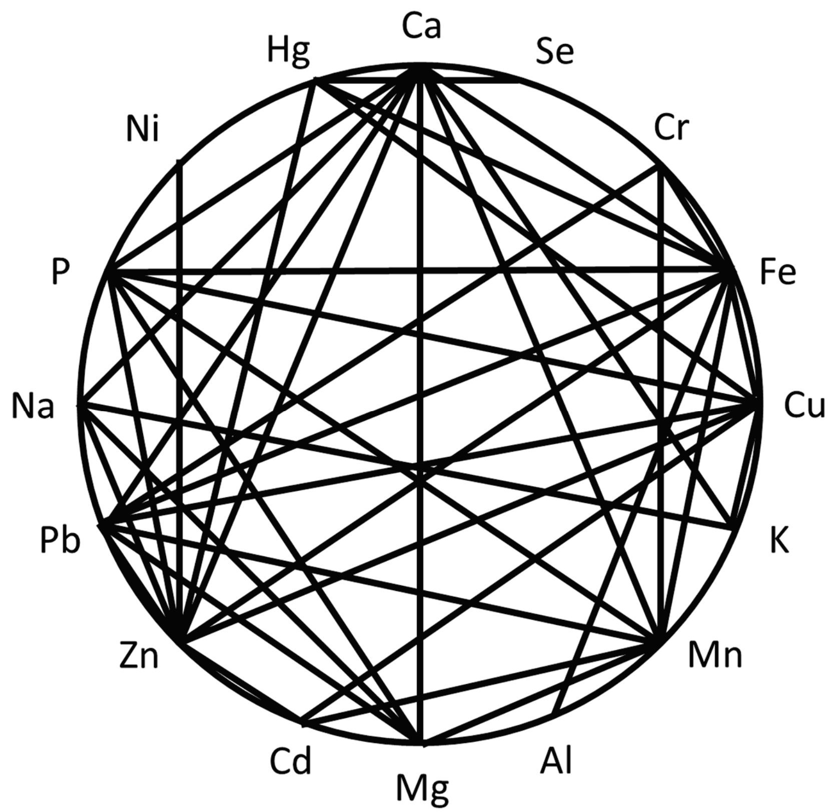

Figure 2. Mineral antagonisms. Adapted from Watts, 1990.

What can we do to improve mineral efficiency in feed rations?

As demonstrated, there are a plethora of factors that impact mineral use by the cow. Despite this, starting off on the right hoof with the ration's foundation is where maximizing mineral efficiency can start. This means analyzing feedstuffs, including water, regularly, allowing for feed libraries to be updated. With accurate basal mineral values within the feed library, the ration can then be formulated to meet the needs of the individual dairy. Once the major nutritional targets are met, an approach similar to what has been taken for precision amino acid formulation should be taken for minerals. This results in a change in approach to mineral supplementation. Leaving generalized supplementation rates in the past and shifting toward targeted supplementation of minerals to meet requirements on an individual ration basis can further increase the efficiency of minerals in the ration.

When precision mineral formulation is used, antagonisms can be considered and over supplementation of minerals can be avoided. Often, mineral formulations include a certain safety margin above requirements to ensure key minerals are not undersupplied due to low absorption. There is minimal consideration that these safety margins can also lead to potential over supplementation or negatively impact other minerals from antagonism. To lower supplementation rates without sacrificing poor absorption, the bioavailability of the mineral source should also be considered. Often, the balance between lowering inclusion levels and bioavailability results in lowering mineral supplementation rates through supplementing a highly bioavailable mineral source. This allows for supplementation near requirement, allowing for optimization of production, long term health of the animal, while improving mineral use due to greater efficiency.

Key Takeaways

- Assay feedstuffs for mineral content
- Precision balance minerals
- Use a highly bioavailable mineral source

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