Mineral Tolerances of Animals

William P. Weiss[1]
Department of Animal Sciences
Ohio Agricultural Research and Development Center
The Ohio State University

Abstract

Everything, including required nutrients, is toxic when consumed in great enough quantities. Signs of toxicity range from the mild (slightly reduced milk yields) to the most extreme (death). The maximum tolerable level **(MTL)** is the highest 'dose' of something that does not cause any adverse effects on an animal. Dose can be defined as quantity consumed over time or per unit of body weight (e.g., grams/day or grams/lb), or concentration in the diet or drinking water (e.g., % or ppm). In 2005, the National Research Council published a book that summarized the scientific literature on mineral tolerances of animals. The book includes information on 39 minerals (although information for some is extremely limited) that could be consumed by animals via a 'normal diet', a contaminated diet, and/or via drinking water. The committee that wrote the report established MTL for those 39 minerals (plus nitrate) based on changes in production, intake, and adverse health effects. Some of the MTL that are of practical importance include copper at 40 ppm (all values are on a dietary dry matter basis); selenium at 5 ppm, sulfur at 0.3 to 0.6%, and sodium chloride (salt) at 3%; however, numerous factors influence the MTL and these MTL should only be considered as guidelines. This paper will discuss the MTL of some of the minerals that are of practical significance in the tri-state area and provide an overview of some of the more important points in the publication.

Introduction

Excessive consumption of a mineral or minerals is not uncommon. A cow can consume too much mineral because of errors in feed mixing at the farm or mill (for example, 100 lb of mineral premixed added at to the TMR instead of 10 lb), the use of feedstuffs that have high concentrations of a mineral (for example, some distillers grains can have very high concentrations of sulfur), over zealous supplementation of minerals, and by contaminated drinking water. For most minerals, slight or even moderate over consumption (relative to requirement) does not cause any adverse effects on the animal. As over consumption becomes greater and perhaps of longer duration, cows can start showing signs of toxicity. Adverse effects to excessive consumption of minerals include:

1. A reduction in feed or water intake, thereby reducing milk production or growth rates (example: salty water reduces water intake which reduces milk production),

2. A secondary deficiency of another mineral (example: high intake of molybdenum can induce a copper deficiency),

3. Physiological or clinical damage (example: excessive consumption of copper can cause liver necrosis, and

[1]Contact at: 1680 Madison Ave., Wooster OH 44691, (330) 263-3622; FAX: (330) 263-3949, Email: weiss.1@osu.edu

4. Production of milk or meat with mineral concentrations that may be deleterious to humans when we consume the product (concentration of iodine in milk increases linearly with increasing consumption of iodine by the cow). This potentially adverse effect was not considered by the NRC subcommittee when it established the mineral tolerances.

The NRC subcommittee that wrote the mineral tolerance book was charged with reviewing the scientific literature on the effects of over consumption of minerals on animals and to establish MTL for as many minerals as possible and for different species or classes of animals. The book is 496 pages long, and this paper will not attempt to review the entire book. Mixing errors usually results in excessive consumption for only a short period of time (perhaps only one feeding or one day) and the adverse effects, if any, will be acute, and unless the effects are severe, they will likely not be ascribed to excessive mineral intake. Therefore, this paper will emphasize chronic exposure caused by longer term (weeks) consumption of diets and/or water with high concentrations of the mineral. In addition, this paper will discuss only minerals in which over consumption is likely and which cause significant problems to cattle (Table 1).

Maximum Tolerable Levels

The MTL of a mineral is defined as the maximum dietary *level* of a specific mineral that will not cause any adverse effects (including reduced productivity and health) when fed for a specific period of time. Level is a purposely ambiguous term that can mean concentration in diet or water (e.g., %, ppm, or g/L) or intake (e.g., grams/day). Numerous factors affect MTL and because of the almost infinite number of possible combinations, MTL cannot be established for all situations. Readers of the book must be aware of these factors and make educated estimates of what the MTL might be for specific situations based on available data.

The major factors that affect the dietary MTL include:

1. Duration of over consumption. If adequate data were available, the subcommittee established MTL for single dose, acute (10 days or less) and chronic (more than 10 days) exposure. The MTL of a mineral determined based on experiments that fed it for 11 days may be very different from an MTL determined from experiments that lasted months. For many (but not all) minerals, the MTL usually decreases as duration of exposure increases.

2. Chemical form or source of the mineral. Some adverse effects of minerals occur at the cell or tissue level and must be absorbed from the digestive tract prior to having an effect. A mineral provided by a source or form that is poorly absorbed will have a higher MTL than the same mineral provided from a highly bioavailable form. For example, the MTL from iron that is provided by iron oxide is much higher than the MTL from iron provided by iron sulfate. Determination of the actual chemical form of a mineral in a diet or water can be exceedingly expensive (hundreds to thousands of dollars per sample). In the field, you will usually not know the chemical form of all sources of mineral in the diet and in the water.

3. Composition of the total diet. Numerous interactions exist among minerals that affect the absorption of minerals and their bioactivity once absorbed. For example, increased intake of copper can overcome some of the problems associated with excess intake of iron. High levels of calcium are less of a problem when high levels of phosphorus are fed. Interactions also exist between minerals and other dietary components. For example, the MTL for sulfur is lower for high grain diets than for high forage diets.

4. Consumption of minerals via water. The dietary MTL generally assume that water is not a

significant source of the mineral of interest, and for many minerals, this is a reasonable assumption. However, in specific locations, water contains appreciable amounts of sulfate, nitrate, salt, iron, and manganese which could greatly influence the dietary MTL for those minerals. Water should be sampled and analyzed routinely (perhaps annually) to determine whether water is a substantial source of a specific mineral(s). If so, then the dietary MDL for that mineral(s) should be lowered.

The MTL does not include a 'safety factor'. The measured concentrations of many of the minerals of interest (especially trace minerals) in diets are extremely variable because of analytical problems, sampling errors, and natural variation. This means that the average concentration of a mineral may be substantially different from the value obtained from a single sample or even the mean of a few samples. Because of this uncertainty, the MTL may be too high for minerals that cause substantial adverse effects on productivity and animal health.

MTL for Specific Minerals

The NRC established MTL for numerous minerals (Table 1), but dairy cows in the Tri-state area are extremely unlikely to be exposed to excessive levels of 14 of those, and those minerals will not be discussed. Of the remaining 14 minerals, four (cobalt, iodine, manganese, and magnesium) are extremely unlikely to cause any significant adverse effects. The MTL for cobalt, iodine, manganese, and magnesium are about 200, 100, 80, and 3 times greater than NRC (2001) requirement for dairy cows. The MTL for magnesium (0.6% of diet dry matter) is lower than concentrations shown experimentally to cause adverse effects (1 to 1.5%), but because no data were available between 0.6 and 1%, the MTL was set at 0.6%. The most likely adverse effect to feeding Mg at rates slightly above the MTL is diarrhea.

Minerals with Medium Health Concerns

Five minerals (calcium, iron, phosphorus, potassium, and zinc) cause moderately adverse effects when overfed for longer periods of time.

Calcium

The MTL for calcium is 1.5% of dietary DM (approximately 2 times the NRC requirement for dairy cows). The only adverse effect reported at that concentration is slightly reduced feed intake. As the calcium concentration increases, a greater depression in intake is expected, which should result in reduced milk yields.

Iron

The MTL for iron is 500 ppm which is about 10 times the NRC requirement. The most likely adverse effect of feeding more than 500 ppm of Fe is a secondary copper deficiency and perhaps a secondary deficiency of selenium and vitamin E. The MTL for Fe is probably lower than 500 ppm when high Fe is fed for long periods of time and if dietary copper is marginal (the high Fe causes depletion of liver copper, eventually leading to copper deficiency). The chemical form of the Fe must be considered when evaluating Fe. Silages and hays can have extremely high concentrations of Fe (> 500 ppm), but this Fe is almost always caused by soil contamination and is likely Fe oxide which is almost unavailable to animals and will cause few, if any, adverse effects. Iron from sources such as Fe sulfate and Fe chloride are readily available, and the MTL was established from experiments in which those types of Fe were fed.

Phosphorus

The MTL for phosphorus is 0.7% or approximately twice the NRC requirement. Adverse effects of feeding P at concentrations slightly higher than the MTL include reduced magnesium absorption, and in some studies, slightly reduced milk yields. Overall, adverse effects on the cow are unlikely when P is fed at rates slightly higher than the MTL. Phosphorus pollution caused by overfeeding P was considered by the committee when it established the MTL for P.

Potassium

The MTL for potassium was set at 2% or approximately twice the NRC requirement. The main reason for setting the MTL at 2% was because of the negative effect that high K diets have on magnesium absorption and because high K diets increase the prevalence of milk fever. Diets with more than 2% K can be fed to lactating cows without adverse effects if magnesium supplementation is increased.

Zinc

The MTL for zinc was set at 500 ppm or about 10 times the NRC requirement. High concentrations of dietary Zn can lead to a secondary copper deficiency, and rates of gain in cattle were reduced when diets contained greater than 500 ppm of Zn.

Minerals with Substantial Health Concerns

Over consumption for longer periods of time of copper, molybdenum, selenium, salt (sodium chloride), and sulfur can cause substantial health problems in cattle, and diets should contain less than the MTL for those minerals.

Copper

The MTL for copper is 40 ppm or about 4 times the NRC requirement. Chronic consumption of excessive amounts of Cu causes Cu to accumulate in the liver. Copper can continue to accumulate over months or even years until it reaches a critical concentration (approximately 1000 mg/kg of liver dry matter). Then a triggering event (unclear what this actually is) causes the liver to release massive amounts of Cu which causes breakdown of red blood cells and other cells and usually results in death. Long term feeding of diets with 40 ppm of Cu are potentially fatal, but it requires months of overfeeding. Certain breeds of cattle are more likely to accumulate liver copper (Jersey cows accumulate more liver Cu than Holstein cows). The MTL for Cu will be higher for diets with high concentrations of sulfur and molybdenum. Form of Cu also must be considered. Copper oxide is essentially unavailable to cows, and diets can have very high concentrations of Cu from that source. The MTL was established from studies using available sources of Cu, such as Cu sulfate and Cu chloride.

Molybdenum

The MTL for molybdenum was set at 5 ppm (no dietary requirement for Mo has been established). Although the NRC set the health concern for excessive Mo intake as 'high', in reality, this MTL was set because of the negative effects that Mo has on copper absorption which often leads to a copper deficiency. True Mo toxicity probably occurs at dietary concentrations around 100 ppm. Copper deficiency caused by excessive consumption of Mo are not uncommon in the field, and the adverse effects of a copper deficiency can be substantial. However, in most situations, simply increasing copper supplementation will eliminate the negative effects of feeding diets with high concentrations of Mo.

Selenium

The MTL for selenium was set at 5 ppm, which is about 17 times its requirement. Selenium can be extremely toxic to animals, often leading to death within hours of consuming a toxic dose. Chronic exposure to much lower dietary concentrations of Se also can lead to death (blind staggers). The problem with the original research claiming extreme toxicity of selenium was that the actual toxicity was not caused by selenium per se but rather by very specific selenium compounds found only in selenium accumulator plants (these plants are extremely rare to non-existent in the Tri-State area). The toxicity of selenium is much lower when Se is provided by sodium selenite, sodium selenate, and selenium yeast. When those sources of Se are fed to cattle, Se concentrations greater than 10 ppm have not caused adverse production or heath effects in most studies. The MTL was set at 5 ppm mostly because of data from animals consuming Se accumulator plants.

Salt (sodium chloride)

The MTL for salt was set at 3% of dietary DM. Based on the sodium requirement of cows, this is about 5 times its requirement. Diets with high concentrations of salt can substantially limit feed intake, and when dietary concentrations of salt exceed the MTL, feed intake by dairy cows is often reduced leading to reduced milk production. However, if low salinity water is readily available, cows can tolerate higher dietary concentrations of salt with little adverse effects. Cattle are much less able to tolerate saline water. Water with 0.25% salt caused significant reductions in milk yields.

Sulfur

The MTL for sulfur was set at 0.3% for high concentrate diets and 0.6% for high forage diets. The requirement for dietary sulfur is 0.2%. High dietary concentration of sulfur can cause a secondary deficiency of copper and selenium, but the primary reason for the health concerns is polioencephalomalacia **(PEM)**. In the rumen, several different forms of dietary sulfur can be converted to sulfide. When hydrogen sulfide is belched out, some is inhaled and absorbed through the lungs. Hydrogen sulfide has severe adverse effects on the central nervous system, causing seizures, convulsions, and death. In some cases (but not commonly), sulfur can lead to destruction of thiamine, producing a thiamine deficiency which causes similar clinical signs. High concentrations of sulfur are more likely to cause PEM when fed in a high concentrate diet because the bacterial population in the rumen is more likely to produce sulfide than when a high forage diet is fed.

Conclusions

The 2005 NRC book on mineral tolerances is an important reference for animal nutritionists. It contains several tables, listing responses various animals have had to high dietary concentrations of numerous minerals. The book also points out the large gaps in knowledge we have regarding overfeeding of minerals. An overriding conclusion that can be drawn from the book is that all minerals can cause adverse responses, and for some minerals, the difference between adequate and deleterious concentrations is not large. For minerals, as for all nutrients, feed enough but not too much and twice as much does not mean twice as good.

Ordering information for this book can be found at: www.nap.edu. Then type “Mineral tolerance of animals” (without quotes) into the search box. The price as of March, 2008 was $89.95

References

National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

National Research Council. 2005. Mineral Tolerance of Animals. Vol. 2nd rev. ed. Natl. Acad. Press, Washington, DC.

Table 1. Minerals with a maximum tolerable level (MTL) established for cattle by NRC (2005)[1].

Mineral	Health Concern[2]	Dietary MTL[3]	Mineral	Health Concern[2]	Dietary MTL[3]
Excessive exposure possible			Excessive exposure is rare		
Calcium (Ca)	Medium	1.5%	Aluminum (Al)	Low	1000 ppm
Cobalt (Co)	Low	25 ppm	Boron (B)	Medium	150 ppm
Copper (Cu)	High	40 ppm	Bromine (Br)	Medium	200 ppm
Iodine (I)	Low	50 ppm	Cadmium (Cd)	High	10 ppm
Iron (Fe)	Medium	500 ppm	Chromium (Cr)	Low	100 ppm
Magnesium (Mg)	Low	0.6%	Lead (Pb)	High	100 ppm
Manganese (Mn)	Low	2000 ppm	Lithium (Li)	Low	25 ppm
Molybdenum (Mo)	High	5 ppm	Mercury (Hg)	High	2 ppm
Phosphorus (P)	Medium	0.7%	Nickel (Ni)	Low	100 ppm
Potassium (K)	Medium	2%	Silicon (Si)	Low	0.2%
Selenium (Se)	High	5 ppm	Strontium (Sr)	Low	2000 ppm
Salt (NaCl)	High	3.0%	Tin (Sn)	Low	100 ppm
Sulfur (S)	High	0.4%	Tungsten (W)	Low	20 ppm
Zinc (Zn)	Medium	500 ppm	Vanadium (V)	Low	500 ppm

[1]The NRC established MTL for antimony, barium, bismuth, rare earth elements, rubidium, silver, titanium, and uranium for some species of animals but not cattle.
[2]Concern considers both the likelihood of a toxic exposure (including accidental) and severity of animal response.
[3]The MTL are for cattle and are on a dry matter basis. Numerous factors affect MTL including bioavailability of mineral, duration of exposure, animal factors, and water concentrations. Data in this table should not be the sole source of information; readers should consult the appropriate section of NRC (2005) .