

Trace Mineral Nutrition and Interrelationships as Applied to Dairy Cattle

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Some 15 trace mineral elements have been shown to be essential for animals including dairy cattle (Mills, 1985; Underwood, 1977, 1981). Deficiencies of seven have been observed under some practical condition. These are cobalt, copper, iodine, iron, manganese, selenium and zinc. Although some of the others can be important practical problems as toxic elements, interest in them as essential nutrients is primarily academic. They are chromium, fluorine, molybdenum, nickel silicon, tin, vanadium, and arsenic.

As is true of all nutrients, every essential trace element can be harmful when fed in too great numbers.

Objective in Feeding Trace Minerals to Dairy Cattle

Since trace elements are needed in very small quantities, the total cost of supplying them to dairy cattle is small. However, when performance or health of the animals is affected by a deficiency, toxicity or imbalance, the economic cost can be high.

The trace element content is seldom a factor in choosing the major ingredients fed to dairy cattle. Normally, the feeding program is first designed to meet the energy, protein and fiber needs of the cattle. Supplemental minerals are added as needed to fill that requirement. In mineral and trace mineral feeding the objective is to provide amounts that will permit maximum animal performance and health with minimum expense and effort.

A typical response curve for a trace element plotted against performance is shown in Figure 1. With most trace elements, over a broad range of intakes animal performance is not limited. Generally, one should attempt to stay well above the point where too little lowers performance but perhaps further still from the point of adverse effects due to excess.

Trace Mineral Requirements of Dairy Cattle

The trace mineral requirements of cattle can be affected by many things (Miller, 1979b). Determination of the amounts needed is never an exact process. However, reasonable good estimates have been made for each of the seven trace elements shown to cause practical deficiency problems (NRC, 1978).

The two most widely quoted sources of information, on

the trace mineral needs of dairy cattle are publication known as the NRC and the ARC. The NRC (National Research Council) bulletin entitled; "Nutrient Requirements of Dairy Cattle" is revised periodically, with the most recent edition in 1978 (NRC, 1978). Another edition may be published soon. The ARC is the Agricultural Research Council of Great Britain. The publication is "The Nutrient Requirements of Ruminant Livestock" (ARC, 1980).

Often values in the NRC and the ARC are materially different even though both are based on the same research. The primary reason for the differences are the objectives. The ARC values are intended to be the minimum values under ideal or experimental conditions without safety margin. In contrast, mineral requirement values in the 1978 NRC dairy bulletin (1978) include some safety margin. They are intended to be the minimum amounts which can be fed under a variety of practical conditions without adverse effects due to inadequate intake. However, not all NRC publications include safety margins (Jorgensen and Hemken, 1986). Table 1 illustrates the trace element needs for lactating dairy cows (NRC, 1978).

The NRC values are a good place to begin in planning a trace mineral feeding program. The requirements in Table 1

FIGURE 1. Typical response curve for animals fed varying amounts of an essential trace element. The pharmacological effect is not present in most situations.

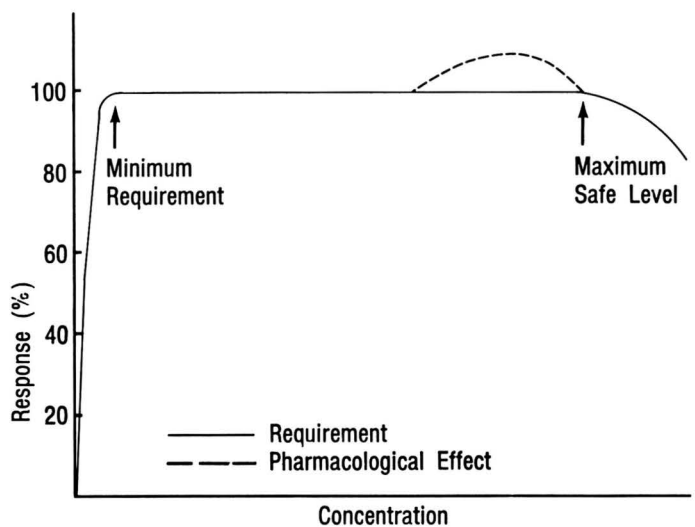


TABLE 1. Trace element requirements and maximum safe levels of lactating dairy cows NRC (1978). Values as ppm in total diet dry matter.

	Recommended Minimum	Maximum Safe Level
Iron	50	1000
Cobalt	.10	10
Copper	10	80
Manganese	40	1000
Zinc	40	500
Iodine	.50	50
Selenium	.10	5

Some of values are expected to be changed in next revision. For example the selenium values may be 0.20 and 2.

are shown as ppm in the ration dry matter. There is a school of thought which says that all nutrient needs should be expressed on a weight basis rather than as a dietary concentration. While this is a complex subject, trace mineral requirements are not defined with enough precision to make this theoretical refinement very meaningful. For use in feeding animals, expressing nutrient needs as a diet concentration such as ppm is far more convenient.

Trace mineral requirements of dairy cattle can not be defined exactly for several reasons. The amounts needed are affected by such factors as interactions among nutrients, genetics and performance level of the animal, and varying bioavailability of the element in different sources. In many situations, there are insufficient research data to permit exact definitions of requirements.

Practical Approach to Trace Mineral Nutrition of Dairy Cattle

To develop a practical trace mineral feeding program for dairy cattle one needs to understand a few other basic concepts.

Each mineral element is a separate story in several different ways (Miller, 1979b). They are considered and supplied together in a package, only for convenience. Otherwise, each is very different.

Under experimental conditions, frequently, a severe deficiency can be diagnosed without great difficulty. With typical farm condition, even a severe trace mineral element deficiency, toxicity or imbalance often is very hard to diagnose (Miller, 1979b).

Diagnosing borderline problems is very difficult with the best of experimental circumstances. Under farm conditions an accurate diagnosis often is impossible. Most of the trace mineral problems encountered on dairy farms are borderline in nature and can be extremely costly in economic terms.

The most logical practical approach involves feeding trace minerals in such a way as to avoid problems. This is easier stated than accomplished. Further, the trace element needs should be met with as little cost and efforts as possible. How can this be done?

In planning a trace mineral feeding program, one needs to know what problems are likely to occur and how to prevent them. At the same time it is important to know those things which are unlikely to be of practical concern.

Earlier, it was mentioned that, so far as we know, only seven trace elements cause practical deficiency problems with dairy cattle. Except for calves fed only milk for long periods, iron should never be deficient for dairy cattle. Thus, one only needs to provide supplements with six trace mineral elements.

Often it is much easier and economical to provide sufficient trace elements to meet minimum needs of the cattle than to analyze numerous samples, etc. to determine whether a supplement is even needed. This is partially based on the fact that the maximum safe level of these six elements is many times the minimum needs.

The trace mineral content of most feed ingredients vary over a rather wide range (Miller, 1979b). Typically, for the same ingredients there is at least a 10 fold range in different samples.

Trace Element Which May Be Deficient on Practical Dairy Farms

Iron (Fe)

Milk is quite low in iron. Thus, dairy calves fed only milk for long periods will become iron deficient. Almost all sources of concentrates and forages contain more than enough iron to meet the needs of dairy cattle. Likewise, cattle are able to store sufficient iron to meet their needs for a substantial period. Also, many soils contain appreciable iron. Although most trace mineral supplements contain iron, it is almost never needed for dairy cattle other than calves fed only milk for a long period.

Zinc (Zn)

The extent to which a Zn deficiency is likely to be a borderline practical problem on dairy farms is not well defined. Certainly, the need for supplemental Zn with dairy cattle is not nearly as great as for swine, poultry and probably people (Miller, 1970, 1979b).

The Zn content of feed ingredients varies widely. Generally, it is most closely associated with protein. However, non-protein sources of nitrogen such as urea contain little Zn.

The NRC requirement value for Zn is 40 ppm in the total diet dry matter (NRC, 1978). This contains some safety margin. There is no indication of any adverse effect of excess Zn below 500 ppm. Few, if any practical feed ingredients would approach this level. There are no present definitive biochemical or clinical measures for reliably detecting a borderline Zn deficiency (Miller, 1983a). A practical approach is to provide supplemental zinc to furnish around 40 ppm in the total dry matter.

In contrast to iron where the oxide has low availability, zinc oxide is a good source of supplemental Zn and generally

more economical and desirable than the sulfate form (Miller, 1983c).

Cobalt (Co)

The essential function of Co is as a component of vitamin B-12 which is synthesized by rumen microbes. The clinical effects of Co deficiency, including ill-thrift, are not definitive. In many areas of the world, the Co content of feeds is not sufficient for maximum performance of ruminants (Underwood, 1977, 1981). The minimum Co requirement of cattle is listed as 0.1 ppm in the diet dry matter (NRC, 1978). The range between minimum needs and maximum safe levels is very wide (Miller, 1979b). The tolerance of more than 20 ppm is some 200 times the minimum requirement. A practical approach is to provide around 0.2 ppm supplemental Co in dairy cattle feeds.

Manganese (Mn)

The Mn requirement for cattle is not well defined. The NRC estimated value of 40 ppm in the diet dry matter is believed to provide some safety margin (Miller, 1979b; NRC, 1978). There are no good biochemical measures to define a borderline manganese deficiency (Miller, 1979b; 1983a). Current evidence suggests that the highest requirement is for normal reproduction including birth of healthy calves. Apparently, there have been no critical and sensitive experiments to determine the amount of Mn needed to prevent borderline reproductive abnormalities in cattle (Miller, 1979b).

Corn grain is very low in Mn with a typical value of 6 ppm. Many ingredients have 100s of ppm Mn with forages typically containing more than grains. The maximum safe level of dietary Mn is quite high with no adverse effect reported below 1000 ppm.

A practical approach seems to be to include some 40 ppm supplemental Mn in dairy cattle diets.

Iodine (I)

Both too much and too little iodine are practical problems with dairy cows. Without supplemental iodine, certainly many calves would be born deficient. In many areas of the U.S. locally grown feeds do not have sufficient iodine. Also, many feeds contain goitrogenic substances which increase the I requirement. Included are such common feedstuffs as soybean meal (Hemken, 1970).

There is considerable concern by regulatory agencies when the iodine content of milk exceeds certain levels. In contrast to all the other essential trace elements, the iodine content of milk reflects the intake of the cow in an almost linear manner with an average of about 8% so secreted (Miller, et al. 1975). The percentage may increase with higher milk production. Until a few years ago substantial amounts of iodine products were used for therapeutic and other non-nutritional purposes. One of the main products was EDDI (ethylenediamine dihydriodide).

As a practical approach, unless one is certain that the

iodine intake from the natural feeds is sufficient, probably at least 0.50 ppm supplemental iodine should be added in the total diet dry matter. This is the NRC requirement for dairy cows (NRC, 1978). The maximum safe level is 100 times as high at 50 ppm. With iodine more than most other trace mineral elements, it is important to make sure the source of supplemental iodine is both stable in the feed and is utilized by the animal. Generally, iodine compounds are absorbed by animals (Miller, 1979b).

Copper (Cu)

Copper deficiency of cattle is a major practical problem in numerous countries; it has the highest frequency of any trace element (Mills, 1985; Underwood, 1981). This deficiency usually ranks from 5th to 7th among all cattle diseases with a positive diagnosis (Mills, 1985).

Copper is a highly versatile but exceedingly complex element. In spite of an enormous amount of research, there are still many uncertainties relative to practical Cu related problems (Mills 1985). One reason is the large number of nutrients which interact with Cu. In one review, 16 such interactions between Cu and other elements were listed (van Ryssen, 1982). Another reason for the complexity is the wide variations in clinical and biochemical effects of a Cu deficiency (Miller, 1979a, 1979b; Mills, 1986). At least part of the variability in effects exhibited is related to interacting factors.

Many different signs have been observed in Cu deficient cattle. From an economic standpoint, probably the most important are performance measures such as slower growth, and decreased reproductive efficiency.

In contrast to zinc and manganese, there are reasonably good biochemical measures of the Cu status of cattle (Miller 1979a, 1983a). The most definitive one in general use is liver Cu which reflects both a deficiency and excess. Plasma Cu will reflect a deficiency but not an excess. Also, plasma ceruloplasmin is very useful in determining Cu status.

Unlike most of the other essential trace elements, dietary Cu often is not a very good indicator of the Cu status of cattle. The NRC requirement values of 10 ppm and the a maximum safe level of 80 ppm are beginning points but do not ensure freedom from practical problems.

With most of essential trace elements, the borderline effects of excessive intake is a reduced performance. Excessive Cu intake, apparently, has no adverse effects until just before the development of the hemolytic crisis (Miller, 1979a and 1979b). When the crisis develops a substantial percentage of the animals may die.

Selenium Se

In many ways Se is a most unusual element. Toxicity was described in the middle ages, but its role as a essential nutrient was established relatively recently (Schwarz and Foltz, 1957). Yet Se deficiency is a much more widespread and serious practical problem than toxicity. In some older literature excess Se was accused of causing cancer, resulting

in Se nutrition being a political consideration. More recent evidence suggest that the cancer incidence is increased by an inadequate intake of Se (Miller, 1979b).

Most of the U.S. east of the Mississippi River is at least borderline deficient in Se (Ammerman and Miller, 1975). Also, the Pacific Northwest is a deficiency area.

Selenium with its multivalences is a very complex element with many interactions (NRC, 1983). Because knowledge of its essentiality is relatively new plus difficulties of analyses, much important research remains to be done on its nutrition and metabolism.

One of the most interesting effects of inadequate Se intake is retained placenta in dairy cows.

The 1978 NRC listed the minimum Se requirement as 0.1 ppm. Apparently, this will be increased to perhaps 0.2 ppm in the next edition. This change reflects a better understanding of its nutrition. Also, the maximum safe level probably will be reduced from 5 to 2 ppm.

Because of difficulties in analyses plus effects of many interacting factors, there is considerable interest in glutathione peroxidase (GSH) as an indicator of Se status of animals.

In areas known to be borderline Se deficient, it seems wise to provide supplemental Se to meet the requirement of cattle. However, one must always be aware of the current legal status of this addition. Most feed mills, premix suppliers and others generally purchase a selenium premix from a specialty supplier. Reasons for this include the regulatory aspect, cost efficiency and the human safety factor in working with Se compounds.

Toxicity Problems with Essential and Non-Essential Trace Elements

All substances have adverse effects when consumed in sufficient amounts. However, a few trace elements frequently cause toxicity problems.

Fluorine (F)

Although an essential element, the only known practical problem with cattle is due to excessive intake. Toxic amounts of F are obtained by cattle from the environment near certain types of industrial plants which use this most reactive of elements (Miller, 1979b). Also, some mineral supplements, especially certain phosphorus compounds can contain excessive F (Miller, 1979b).

When large amounts of F are consumed it accumulates in the bones and teeth. The adverse effects are on the bones and teeth, which then indirectly affect the performance of the animals. For practical purposes, the detrimental effects are permanent. However, the safety of the meat and milk are not affected.

Changes in the teeth are definitive for F toxicity, as apparently, nothing else causes the same type changes. Over an extended period F in the total feed dry matter for dairy cattle should not exceed 30 ppm (Miller, 1979b, NRC, 1978).

Lead

Lead toxicity is a relatively common problem which primarily results from accidental consumption. It accumulates in the bone and remains there for long periods.

Cadmium

Cadmium toxicity has received considerable attention but apparently is not a major practical problem. It accumulates in the liver and kidney and is retained for a long time.

Arsenic (As)

Arsenic toxicity like lead poisoning primarily results from accidental consumption. However, in contrast to fluorine, lead, cadmium and mercury, the damage by the As is short lived. Once the excessive intake ceases, the adverse affects soon stop.

Mercury (Hg)

In earlier years, considerable Hg was used for such purposes as treating seeds. Apparently, Hg toxicity is a less frequent practical problem now. This element illustrates the enormous effect of chemical form on metabolism and toxicity (Neathery and Miller 1975; Stake et al, 1975). Inorganic Hg is very caustic, poorly absorbed and locates primarily in the kidney with some in the liver. Very little enters the muscle or milk. In contrast, organic Hg compounds such as methyl Hg are not very caustic, are well absorbed with much going to kidney and liver, but also, substantial amounts found in muscle and milk (Miller, 1979b).

Molybdenum (Mo)

This essential element is of interest because of its toxicity and its close interaction with copper and sulfate (Underwood, 1981). The copper requirement of cattle is greatly affected by the intake of Mo.

Interrelationships of Trace Elements in Dairy Cattle Nutrition

The interrelationships involving trace mineral elements can be classified as a) interactions between and among mineral elements, b) interactions between the trace element and organic constituents of the diet and c) other interactions (Miller, 1983b).

Many interrelationships affect the requirement and or maximum safe level of the trace mineral. As an example, higher dietary intakes of molybdenum increase the amount of copper required. Also, higher molybdenum intakes increase the maximum safe level of copper which can be fed.

One of the more important interactions of a trace mineral and an organic component of the diet is that between vitamin E and selenium. Higher intakes of vitamin E lowers the need for selenium and vice versa. Vitamin E is more expensive than selenium.

An example of the third type of interactions is that between the chemical form of the element and the response criteria. In studies with chicks, the bioavailability of selenium was greatly affected by the response criteria used (Miller, 1983c).

Other Practical Considerations

Too often those attempting to evaluate the adequacy of a trace mineral supplement only look at the total amount present. With many of the elements, there is considerable range in the bioavailability of trace element ingredients (Miller, 1983c; Mills, 1985). As an example, the bioavailability of iron from iron oxide (ferric oxide or red iron oxide) is very low. It is estimated to be approximately 10% as available for ruminants as iron in ferrous sulfate which is a good source (Miller, 1983c). It is even less available for monogastric species.

In addition to bioavailability, some trace mineral ingredients contain high amounts of toxic elements such as lead. It seems that the practical approach is to buy from a manufacturer that used high quality ingredients and has good quality control.

There is still a widespread practice of feeding minerals and trace minerals free choice to dairy cattle including the lactating cows. Often this approach is based on the erroneous belief that cows know what is good for them and will eat accordingly. Research has shown that the major factor determining how much mineral a cow eats is the palatability of the product (Miller, 1979b). Also, inherent in the free choice approach is the concept that cows will not eat more than is good for them. With few exceptions, the amount of a mineral element chosen is not affected by whether or not the animal is deficient.

In situations where it is feasible, the most desirable practice in providing trace elements is to include it in the total feed of the lactating cows. As suggested earlier, it is prudent to provide a moderate excess over minimum needs to cover such variables as interactions with other nutrients.

A question, often asked relates to the value of chelated minerals, especially trace elements. Since there is considerable misunderstanding, perhaps a definition is appropriate. A chelate is a cyclic or complex ring structure in which a divalent or multivalent metal atom is held through two or more bonds in coordination complex (Miller, 1983b). Such rings are often five or six membered. Generally, chelates are chemically more stable than complexes in which the mineral element is held through only one chemical bond.

Irrespective of whether special chelates are added, chelation has a role in trace mineral nutrition. Most feed-stuffs contain appreciable amount of chelating substances including such compounds as proteins, amino acids, polyphosphates, sugars, starches, cellulose, organic acids and many other organic substances.

The metabolism of trace elements is affected by the

chelation complexes formed. Both absorption and metabolism after absorption can be affected in various ways. While some of the principles and concepts are known, an enormous amount of detail is possible but has not been fully developed (Miller, 1983b).

Specialty chelated and sequestered minerals are marketed for dairy cattle. Some use specialty chemical chelators such as EDTA (ethylenediaminetetraacetic acid), mineral-amino acid complexes, or preparations involving natural materials such as kelp or carbohydrate products.

The practical questions concerning the specialty chelated mineral supplements is whether their use will make animal production more or less profitable than using alternative sources (inorganic) of mineral supplements. Will their use improve animal performance? Generally, the cost of chelated trace elements is substantially higher than good inorganic sources.

Specialty chelators often affect tissue distribution and excretion routes of trace minerals. However, unless health and/or performance are improved there is little practical significance to such changes. Numerous variables affect mineral absorption, tissue distribution, turnover rate and excretion without having any obvious practical importance.

Good inorganic sources of the essential trace elements with high biological availability are readily available commercially at competitive prices.

What is Needed in the Future

Generally, attempts to measure the trace mineral status of animals has centered on chemical parameters such as the content in the blood. These are of some benefit but leave much to be desired (Mills, 1986).

Since biochemical changes obviously precede changes in health and performance, markers are needed which permit easy and accurate determination of borderline trace mineral problems before they occur. Such measures as enzyme concentrations offer promise as markers with some now in use such as plasma ceruloplasmin for copper and glutathionine peroxidase for selenium (Underwood, 1981).

Summary

Some 15 trace elements have been shown to be essential for animals. Deficiencies of seven have been observed in dairy cattle under practical conditions.

Trace elements interact with numerous substances greatly complicating practical trace element nutrition. In total, borderline problems are a far more serious economic problem than severe deficiencies and toxicities. While there are some useful biochemical measures for evaluating trace mineral status of cattle, with most of the elements, it is difficult or impossible to accurately determine whether or not a borderline problem exist.

To practice good trace mineral nutrition, it is important to understand the particular problems which may or

may not arise in your particular area with the feeding systems employed. Except for milk fed calves, dairy cattle do not require supplemental iron. Unless it is known that a deficiency does not occur in your area, under many practical farm conditions it is often desirable to include supplemental copper, cobalt, manganese, zinc, iodine and selenium. Generally, the amounts to use would be approximately that needed to meet NRC minimum requirements. The trace elements which most often appear to be inadequate for dairy cattle are copper, cobalt, iodine and selenium.

Including the needed trace minerals for lactating dairy cows in the total mixed ration as part of the concentrate, generally is more desirable than using free choice mineral supplements.

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