Micronutrients in Soils and Plants in Relation to Animal Nutrition

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Plants frequently grow well without accumulating certain elements in their tissue in sufficient amounts to meet the requirements of many animals. Cobalt can apparently fill the requirement of the plant although it may be present in amounts totally insufficient to sustain the animal. In other cases, the plant requirement is high enough to ensure a sufficiency of an element for animal nutrition. Thus, manganese is required by the animal but only in rare cases will there be insufficient manganese in the plant to meet animal demands. Species variations also play an important part. Only nonruminant species are observed to suffer from a zinc deficiency on a natural diet and then only when certain species of vegetation comprise the bulk of the diet. The micronutrient content and requirement of plants and animals are discussed with a view toward problems of animal nutrition and control of micronutrient deficiency.

The development and reproduction of plants and animals is dependent upon a large number of mineral elements. N, Mg, Ca, K, P, S, Cu, Zn, Fe, Mn, Co, and Cl are now considered to be required by both plants and animals. B and Mo are required by plants, but their essentiality to animals has not been established; whereas, Na, I, and possibly Se are required by animals, but have not been shown to be essential for plants. The current methodology for determining mineral requirements for plants permits study of lower concentrations than do methods of studying mineral requirements of animals.

Problems of animal nutrition result from a differential requirement of the animal over that of the plant or the unavailability of a nutrient for animal assimilation. The problems are broadened by the fact that throughout the route of mineral transport from the soil to the plant to the animal, there are important variations among plant species in their tendency to accumulate minerals, and among animal species in their mineral requirements and types of plant materials consumed. Still other difficulties may be related to the uptake by plants of elements toxic to animals.

Copper

Organic soils and very sandy soils are likely to supply insufficient available Cu, either for maximum plant growth or for the requirements of forage-consuming animals. Since Cu is bound very tightly in all but sandy soils, fairly large additions of Cu are required to bring about relatively small increases in Cu concentrations within the plant.

Plant species vary considerably in their uptake of Cu. Mitchell, Reith, and Johnston (*20*) observed variation of from 1.7 to 12.3 p.p.m. of Cu in clover, while grasses growing with the clover varied only from 2.0 to 4.3 p.p.m. Cu values in legumes commonly go as high as 20 p.p.m. or even higher, while values for grasses are rarely found much higher than the values reported by Mitchell and coworkers. Cu content of grain, like grass, does not rise to very high values. Corn is especially low. Rarely does the Cu content of corn grain rise above 4.5 p.p.m., and it commonly averages around 2 to 2.5 p.p.m. (*19*).

Evaluation of the critical levels for Cu in animal diets is complicated by "conditioned copper deficiencies" where the functioning of dietary Cu is inhibited. Even so, the critical minimum levels of Cu in plants and the critical dietary levels for uncomplicated Cu deficiency in grazing animals are reasonably similar and are in the general range of 1 to 4 p.p.m., dry weight.

The most common conditioned Cu deficiency in animals is caused by high levels of Mo in the feed. This problem is severe in parts of western U. S. and in several foreign countries, and is generally termed Mo toxicity or molybdenosis. It is most often encountered on imperfectly drained neutral and alkaline soils high in organic matter (*13*). Animals consuming forages having Mo concentrations in excess of 15 to 20 p.p.m. show symptoms of Cu deficiency, and respond dramatically to Cu therapy, even though the forage may contain Cu in concentrations well in excess of 5 p.p.m. Inorganic sulfate in the diet increases the severity of Mo toxicity (*4*).

There are apparently other conditioned Cu deficiencies in which unidentified factors are responsible for low availability of plant Cu to animals (*28*).

Cu deficiencies in animals may be treated by additions of Cu, usually as $CuSO_4$, to the feed, salt, or mineral mixture for direct consumption by animals, or by topdressing pastures with Cu salts. Injection of cattle with copper glycinate has been very successful in counteracting molybdenosis in western U. S. (*6*). Cu fertilizers are used in the U. S. primarily where an economic response in plant growth results, and are added to soils only rarely to supply the Cu needs of animals. Excessive Cu concentrations may be toxic to both plants and animals, but naturally occurring areas of Cu toxicity apparently are rare in the U. S.

Zinc

Zinc deficiency of plants is usually restricted to deciduous fruit trees, citrus, tung, pecan, pineapple, and corn, and is not common in forage crops. The uptake of Zn varies considerably between different plant species with certain weeds accumulating very high levels of Zn. Grasses and legumes, however, are notably similar in their Zn content. For most forage species Zn content commonly ranges from 15 to 40 p.p.m. Even in deficient plants, the Zn content rarely drops much below 10 p.p.m.

Zn deficiency in farm livestock is confined to poultry and swine. There are no known occurrences of Zn deficiency in grazing animals. In this instance, as in some others, the ingestion of mineral soils by grazing animals may significantly supplement the minerals in the plants.

The primary Zn problem in animal nutrition is not one of total Zn content, but one of Zn availability. Zn associated with certain plant proteins is quite unavailable to swine and poultry. The research of O'Dell and coworkers (*23*) indicates that phytic acid is the factor responsible for this observation. Additions of phytic acid to casein resulted in properties similar to those observed with soybean protein—such as an increased Zn requirement and the antagonism of Zn by excess dietary Ca.

Supplementation of the ration with $ZnSO_4$ is the common method of meeting the Zn requirements of swine and poultry, and fertilizers containing Zn are used only to meet the requirements of the plant for optimum growth.

Iron

The so-called trace element, Fe, is more abundant in the earth's crust than are the macronutrient elements Ca, Mg, K, P, S, and N. The tendency of Fe to form insoluble oxides and phosphates causes it to be so unavailable that plants may suffer from Fe deficiency even though the roots are surrounded by Fe coatings on many soil surfaces.

Plants vary considerably in their ability to extract Fe from the soil. Even different varieties of the same species may represent opposite extremes in their ability to utilize Fe (*3*). The Fe content of cultivated grasses and legumes usually ranges from 100 to 700 p.p.m., although values in excess of 1000 p.p.m. have been reported (*1*). Grasses do not vary so widely in Fe content and generally have slightly smaller amounts than do legumes. Grains are uniformly much lower in Fe. Corn, barley, oats, and wheat all average about 60 to 130 p.p.m. of Fe in the grain (*19*).

The function of Fe in the plant is antagonized by the element, Mn. According to Somers and Shive (*31*), plants will remain healthy over a 1000-fold variation in Fe and Mn concentration as long as the ratio of the two elements remains within the limits of 1.5 to 2.5 p.p.m.

Since most natural feedstuffs contain sufficient Fe to meet animal needs, quantitive animal requirements are not well established. Hill and Matrone (*12*) have reported that chicks require 40 p.p.m. of Fe in the diet for optimum growth and blood formation. In the case of suckling pigs maintained on concrete without access to soil, direct addition of Fe to the animal apparently is necessary, regardless of the Fe content of the feed consumed by the sow. For animals with access to soil, direct ingestion of mineral soil undoubtedly is an important source of dietary Fe.

Manganese

Of the micronutrient elements, Mn is second only to Fe in abundance in the earth's crust. But, like Fe, under most soil conditions it exists as an insoluble oxide so that Mn deficiency in plants often is encountered on well drained neutral or alkaline soils (*15*). The availability of soil Mn may vary widely during the crop season.

Oats and soybeans, among the field crops, are most commonly affected by Mn deficiency. Samuel and Piper (*29*) consider 14 p.p.m. of Mn to be about the minimum level of Mn in healthy oats at the flowering stage, but Gerretsen (*8*) has reported that under sterile conditions, the Mn content of oats may be as low as 5 p.p.m. without the appearance of the grey speck disease, characteristic of Mn deficiency. Mederski and Hoff (*18*) report that soybeans containing less than 15 p.p.m. of Mn will respond to Mn applications.

The Mn content of plants probably varies more than for any other essential metal. Beeson (*1*) reports a range of from 14 to 936 p.p.m. of Mn in alfalfa, and from 79 to 510 p.p.m. in red top. Certain grains are lower in Mn. The National Science Foundation gives averages of 773 corn analyses as 6 p.p.m. of Mn. Oats and wheat are much higher with averages of 19.5 and 24.9 p.p.m., respectively, while barley is intermediate (*19*).

Mn is a very important element in poultry nutrition as it prevents a leg weakness known as perosis. Gallup and Norris (*7*) indicate that 30 to 50 p.p.m. of Mn in the feed is required to prevent this disease.

The Mn requirement of pigs is reported as 1 to 1.5 p.p.m. of feed by some workers (*26*) and as high as 40 p.p.m. by others (*9*). Apparently, there is an interaction with other dietary constituents and the utilization of Mn. Twenty parts per million are reported as adequate for dairy cattle (*2*). Cases of Mn deficiency in dairy cattle have been reported in Holland.

Mn toxicity to plants is reported on acid soils, but animals apparently can tolerate large quantities of Mn (*33*).

Applications of Mn in the form of fertilizer or foliar sprays adequate for optimum plant growth should result in plant contents of Mn adequate for all animals except poultry. In the U. S., commercial poultry feeds generally are supplemented with 0.05% Mn.

Cobalt

The pathways and functions of Co in the soil-plant-animal chain are particularly unique. Co is required by *Rhizobia*, the symbiotic organisms that fix nitrogen in the nodules of legumes (*16*), but apparently it plays no other role in the physiology of higher plants. In the ruminant, Co is required for the synthesis of vitamin B_{12} by rumen microorganisms. Monogastric animals require Co in the form of vitamin B_{12}. Thus, the plant functions primarily as an accumulator of Co for conversion to vitamin B_{12} by microorganisms, with the B_{12} then playing an essential role in animal nutrition.

Only very small amounts of Co are required for effective functioning of the nodule bacteria. Field observations indicate that many legumes grow normally and fix nitrogen, even though the concentration of Co in the above-ground part of the plant is too low to meet the requirements of grazing ruminants.

The requirements of grazing ruminant animals for Co are more precisely defined than for most of the trace elements. When the Co content of pasture herbage is less than 0.07 to 0.10 p.p.m., dry weight, grazing animals are likely to suffer from Co deficiency, unless they receive other feeds or supplements higher in Co.

Legumes and certain browse plants are very important in the Co cycle because they will accumulate Co in concentrations well above the requirements of the animal, if sufficient available Co is present in the soil. On the other hand, the Co content of grasses does not reflect the level of available Co in the soil, and only rarely do grasses contain Co in concentrations much in excess of those required by grazing animals. Shifting the type of pasture from a pure stand of grasses to a grass-legume mixture may be an efficient method of increasing Co intake by grazing animals under certain conditions.

In New Zealand and Australia, cobaltized superphosphate, prepared by dissolving Co in the acid used to treat rock phosphate, is widely used to increase the Co content of pasture forage. In the United States, Co is added to the mineral supplements, salt, or feed concentrates for dairy cattle in the northeastern states. The Co bullet technique promises to provide a convenient method of meeting the Co requirements of range livestock.

Selenium

The role of Se in plant and animal nutrition is still obscure. Although Se is not on the list of elements required by plants, certain species thrive where available Se is abundant in the soil, and accumulate sufficient quantities of this element to be toxic to animals. Although plants having as little as 4 or 5 p.p.m. of Se are considered likely to produce some toxic effects on animals, some species accumulate as much as several hundred parts per million of Se in their tissues. Soil areas known to produce vegetation containing toxic quantities of Se have been identified in several of the western states (*32*).

Of more recent interest are findings

indicative of an essential role for Se in animal health. The work of Schwarz and Foltz (*30*) and Patterson and coworkers (*24*) in 1957 showed that very small amounts of dietary Se would prevent liver necrosis in rats and exudative diathesis in chicks. The nutritive significance of Se is not easily evaluated, however. Nesheim and Scott (*22*) have shown that Se will not correct all symptoms of vitamin E deficiency in the chick, yet growth responses from Se have been obtained using diets adequate in vitamin E.

Later work in this country and in New Zealand (*5*, *21*, *27*) showed that as little as 0.1 p.p.m. of Se was effective in preventing white muscle disease in lambs and calves. Vitamin E has not been uniformly effective in preventing this myopathy.

White muscle disease in lambs and calves occurs in a geographic pattern strongly suggestive of a relationship to a soil and plant composition vector. As yet, it has not been established that the forages in areas where the "Se responsive diseases" are prevalent are lower in Se content than forage from areas where these problems are uncommon. This may be partly caused by the difficult analytical chemistry involved in measurement of very low concentrations of Se in plants. Furthermore, "Se responsive diseases" are quite possibly not the result of uncomplicated Se deficiency. Interference of unidentified dietary constituents with the functioning of Se or vitamin E is considered likely by many workers in this research area.

White muscle disease can be controlled by the injection of small amounts of Se or the addition of Se to feeds, but there is currently some uncertainty concerning restrictions on the use of Se in feeds. If it should be demonstrated that a low Se content of forage is a primary factor in the "Se responsive" animal diseases, soil scientists and fertilizer technologists will need to consider the problems of Se fertilization of soils. In meeting this problem, it should be kept in mind that the range between Se deficiency and toxicity is likely to be narrow, and relatively little is known of the chemical behavior of low amounts of Se in soils.

Iodine

Iodine was probably the first element to be used in the treatment of a nutritional disease, having found application in the treatment of goiter as early as 1820. Yet, there still exist several relatively unexplored phases of the I cycle in nature. In this case, transfer of I from the sea to the atmosphere to the land apparently is an important step.

Iodine has not been shown to be required by higher plants, although plants take up I in direct relation to its availability in soil. Species variation in the I content of plants is overshadowed by regional differences in plant composition.

Iodine is necessary for the prevention of goiter in animals and man. It has also been recognized for some time that the incidence of goiter varies in a geographic pattern related to the I content of plants. Plants from areas where goiter is common have much less I than those from areas where goiter is rare.

The I needs of man and of farm animals are normally met through the addition of I compounds to salt (NaCl). This method of supplementing diets with I has been so simple and effective that it may have discouraged research on the chemistry of I in nature.

Molybdenum

Interest in Mo in soil-plant-animal relationships centers around a deficiency of Mo for plants and a toxicity of Mo for animals.

Mo is required for plants and is often found to be deficient for legumes on acid soils, although some of the truck crops, particularly cauliflower, also exhibit the deficiency. The Mo concentration in plants may vary from less than 0.1 p.p.m. to more than 300 p.p.m. without any reported effect on plant growth (*13*, *25*).

Where plants contain more than 15 to 20 p.p.m. of Mo, the conditioned Cu deficiency, molybdenosis, discussed earlier, may affect livestock eating the plants. This raises the question of danger of developing molybdenosis by using Mo fertilizers on plants.

Inasmuch as Mo fertilizers are most likely to be used on acid soils where added Mo can be expected to revert to insoluble forms, there seems to be little danger to animals involved in proper use of Mo fertilizers for plants. There are, however, high Mo acid soils described (*17*) where excessively high concentration of Mo in legumes could follow high rates of liming, because of the increased plant availability of Mo in neutral or alkaline conditions.

At the present time, no economical system of soil treatment to decrease the availability of Mo in soils now producing forages of excessively high Mo content has been developed.

Although Mo has been shown to be a constituent of certain animal enzyme systems, attempts to produce Mo deficiency in laboratory animals have been unsuccessful (*11*).

Growth responses of chicks have resulted from Mo additions to the diet, but Leach and coworkers (*14*) have shown that this effect is contingent upon the presence in the diet of certain types of protein. With other protein sources containing considerably less Mo the response is not evident.

Boron

Boron is required by plants and an extensive literature concerned with its function in plants and its use in fertilizers has been developed. Although B is not required by animals, its use in fertilizers may result in plant composition changes important to animals. Several investigators (*10*) have shown that the use of B fertilizers on B-deficient alfalfa increases carotene or provitamin A in the forage. At times, changes in plant composition of potential importance to the animal have resulted from B applications, although no significant increase in plant growth or yield per acre was evident.

Micronutrient Fertilizers in Relation to Animal Nutrition

The foregoing discussion of several of the micronutrients involved in animal nutrition emphasizes the differences among the micronutrients in their pathways or functions in the soil-plant-animal chain. Because of these differences, the potential role of fertilizers in meeting animal requirements for micronutrients needs to be developed specifically for each element.

Agronomists and fertilizer technologists should, however, keep in mind that the livestock management system may be an important factor in determining whether the animal requirement for micronutrients can best be met by fertilizers or by feed supplements. Fertilizers are likely to be most useful where animals are fed entirely from pastures. Where animals are hand-fed grains or other feed concentrates, addition of micronutrients to the feed mixtures or mineral supplements is more common at present.

In many areas, micronutrient fertilization will likely become more common. Increased fertilization commonly places greater demands on the stores of elements in the soil that are not supplemented through the fertilizer practice. Furthermore, scientists are gaining greater insight into where micronutrient problems exist both for plants and animals and where soil amendments provide the most practical means of correcting micronutrient problems. But indiscriminate micronutrient fertilization is not likely to be effective in meeting the micronutrient needs of either plants or animals. The animal requirement for micronutrients and potential imbalances among the micronutrients in animal nutrition should be kept in mind, along with differences among soils in their ability to fix these elements, in developing the technological background of the increased use of micronutrient fertilizers.

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MICRONUTRIENT AVAILABILITY

Chemistry and Availability of Micronutrients in Soils

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Recent developments in the chemistry and availability of micronutrients are difficult to generalize because of the great diversity in their chemical properties, their reactions with soil, and the plant roots' ability to absorb them from the soil. Five chemical pools for each cation are postulated based on solubility, exchange reactions, and chemical form. The micronutrient anions cannot be separated into equally definite pools. These pools are discussed in relation to research on soil tests and significance to plant absorption.

PUBLIC INTEREST in the mineral micronutrients is at an all time high and will undoubtedly increase as more instances and kinds of deficiencies are brought to light. The correction of a micronutrient deficiency in vegetation or of a malady in livestock by the application of a microelement to soil or to foliage—often only a fraction of an ounce of the element to an acre—offers some of the most spectacular instances of man's domination of nature.

Since about 1860 when Fe was shown to be needed by green plants, the list of essential micro or trace elements has grown steadily as experimental techniques and methods for removal of trace element impurities from chemicals and water improved. Micronutrient cations required by higher plants now include Fe, Cu, Zn, and Mn. Cobalt is essential for legume bacteria in the fixation of nitrogen from air and, hence, is basic to our agricultural economy. Some species of plants require or are benefited by Na, also. The list of micronutrient anions now includes B, Mo, and Cl. Interest in micronutrients does not stop at what plants alone need, but includes those additional ones needed by animals and not supplied in adequate amounts by forage and grain. Additional ones are Co for microbial synthesis of vitamin B_{12} (which contains Co) in the gut of ruminants; I for the thyroid hormone, thyroxine; Se for prevention of white muscle disease; and possibly Ba, Sr, and Br (*1*).

The only property that the micronutrients have in common is that plant and animal requirements for them are small in contrast to their requirements for the macroelements. However, even within the trace group for plants, large differences in requirements occur (*25*).