THE EFFECT OF SOILS AND FERTILIZERS ON THE NUTRITIONAL QUALITY OF PLANTS

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The Effect of Soils and Fertilizers on the Nutritional Quality of Plants

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Do fertile soils produce crops that are more nutritious than those grown on poor soils? Has soil depletion endangered the quality of our food supply? Do the soils in certain areas produce crops lacking in some elements that are essential to animals and man, even though not required by plants? Are there potentially harmful minerals in the plants from certain areas? These are questions that have puzzled people for a long time. The search for answers to them will be increasingly important in meeting the world's future needs for food.

These questions can be answered only in respect to specific nutritional factors and specific crop plants, animals, and kinds of soil. Within these limits, science has provided answers for some of these questions and for some areas of the world, but there is still much to be learned. The U.S. Plant, Soil and Nutrition Laboratory (fig. 1) is conducting research on the factors influencing the nutritional quality of plants.

[1] Publications of many research workers, both in United States and in other countries, have been used in the compilation of this bulletin, and are gratefully acknowledged even though individual references are not included.

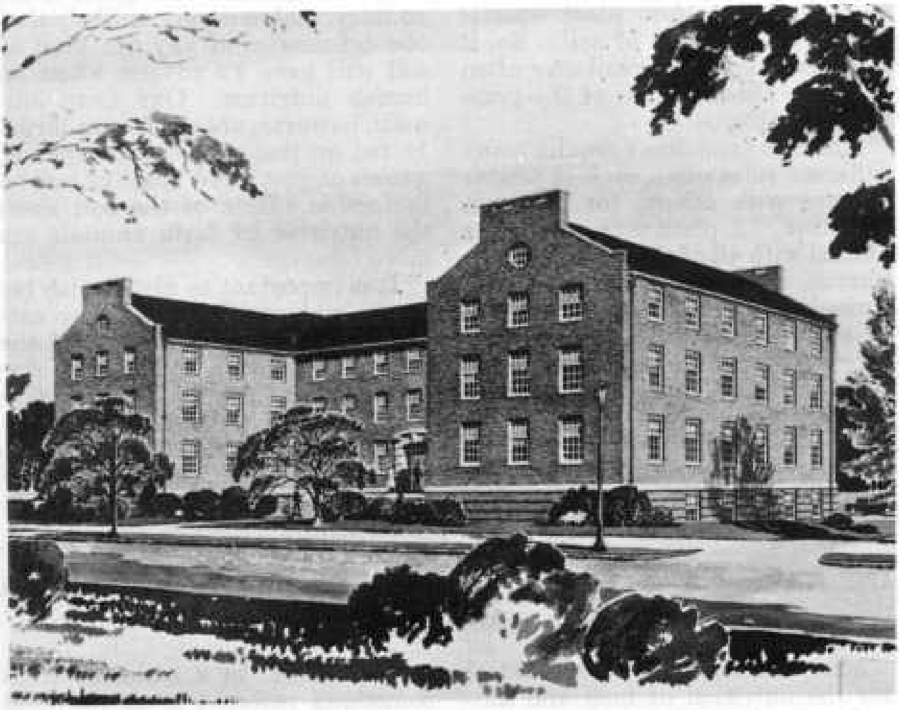

FIGURE 1.—The U.S. Plant, Soil and Nutrition Laboratory at Ithaca, N.Y.

The Nutritional Quality of Plants

The first step in considering the effect of the soil upon the nutritional quality of plants is to take a brief look at the meaning of "nutritional quality" of plants, and at some of the complexities of the food chain extending from soil to plant to animal.

Different plants serve different purposes in the diets of man and animals. Sugarcane, for example, is grown, processed, refined, and used in food to supply just one compound, sucrose. The sucrose isolated from sugarcane is the same compound and has the same nutritional value regardless of the soil upon which the cane grew.

In contrast to sugarcane, pasture plants are expected to furnish most, if not all, of the many substances required for the proper nutrition of the animal grazing the pasture. Furthermore, the animal usually is restricted by the pasture fence to a choice of a few plant species grown on one kind of soil. So, it is reasonable that the soil may often influence the nutrition of the grazing animal.

Animals (and man) require many different substances, each in proper balance with others, for optimum nutrition. A plant may supply the animal with all of the calcium, phosphorus, iron, zinc, and manganese it needs, yet at the same time be deficient in cobalt, or contain a toxic excess of selenium, or have an undesirable ratio of molybdenum to copper.

The entire diet or ration must be considered in any appraisal of the nutritional quality of plants. One component of the diet may supply all that is needed of one element, and little else, while other components of the diet supply all the other requirements. A man may obtain most of the iron he needs from meat, and most of the calcium he needs from green vegetables or milk. A plant may be seriously lacking in some element required by animals and still be a valuable part of a mixed diet or ration.

Different animals have different nutritional requirements. For example, ruminant animals, like cattle or sheep, can make effective use of simple inorganic salts of cobalt, but most of the other animals and human beings require their cobalt in a complex compound called vitamin B_{12}.

As far as the people of the United States are concerned, our varied diet, composed of animal products, fish, plants, and plant products, originating in different parts of the country, makes it very unlikely that the deficiencies of any one kind of soil will have an adverse effect on human nutrition. Our farm animals, however, are sometimes largely fed on just a few plant species, grown on just a few kinds of soil, so noticeable effects of the soil upon the nutrition of farm animals are more common.

It is important to distinguish between malnutrition caused by eating plants lacking in some of the required elements and hunger due to insufficient food. Unproductive soils have been the cause of widespread hunger, even though the sparse crops produced on them were not deficient in essential nutrient elements.

The Movement of Nutrient Elements From Soils to Plants to Animals

Many elements that are essential for the nutrition of man and animals move from the soil to the plant to the animal in a series of steps sometimes referred to as the food chain. Generally, this process works fairly well, and man and animals get many of the elements they need, without excessive amounts of those that may be detrimental, from soils by way of plants. There are some instances, however, where defective functioning of this food chain has resulted in malnutrition of animals. Cases of human malnutrition that are due to deficiencies or excesses of elements in the soil are very rare.

This section will describe the movement of several elements from soils to plants to animals, and the relation between the levels of these elements in the soil to the nutrition of animals and man. A separate section will discuss the problem of nitrogen in soils in relation to protein nutrition.

The soil supplies plants with magnesium, calcium, nitrogen, potassium, phosphorus, sulfur, copper, zinc, iron, manganese, cobalt, molybdenum, and chlorine. These elements are required by both plants and animals. Boron is also required by plants, but its essentiality to animals has not yet been established. On the other hand, sodium, iodine, and selenium are required by animals, but have not yet been shown to be essential for all plants. As research progresses, there probably will be some additions to the lists of elements required by plants and animals, but the amounts of them needed are almost certain to be very small.

In addition to the elements listed above, both plants and animals require carbon, hydrogen, and oxygen. However, plants get these elements from the air and water, so the fertility level of the soil is not a factor in their supply.

Many different kinds of soil are used for the production of food and feed crops, and each of these soils may have different combinations of characteristics insofar as its ability to supply plants with nutrients is concerned. Some older kinds of soils of humid, tropical areas are deficient in many of the elements required by plants. On the other hand, the younger soils of dry, temperate regions tend to be rich in whatever elements were present in the parent materials from which they were formed. Even in humid, tropical areas, there are some kinds of soil, such as those on steep slopes where erosion brings fresh rock to the surface and those in flood plains where new sediments are accumulating, where the levels of many essential elements are fairly high.

The different soils do not act as simple storehouses for nutrients to be used by the plant. Many elements are held within the soil in a chemical form that is not readily utilized by plants. The addition of an element to one kind of soil may result in a much higher level of this nutrient in the plants that are grown on the soil, but the same addition made to another kind of soil may have little or no effect upon the composition of the same species of plants.

Different species of plants also vary in their requirements for the different elements and in their ability to extract them from insoluble combinations within the soil.

The complex nature of the relations between soils, plants, and animals can best be understood by examining how some of the required elements move individually from soils to plants and thence to animals and man.

Calcium is always present in green plants. Usually the legumes, such as beans, clover, alfalfa, and peas, contain more calcium than do the grasses. But the grasses generally contain sufficient calcium to meet the requirements of grazing animals. Grain crops are generally lower in calcium than are forage crops, and it is often necessary to add a calcium supplement to the diets of hens or cattle that are being fed rations high in grain and low in forage.

In human diets, milk and vegetables are major sources of calcium. Cows will give milk of essentially the same calcium content, regardless of the level of calcium in the cow's diet. So, among people, calcium deficiency is usually due to failure to consume enough milk and green vegetables, and not due to a deficiency of calcium in the soil where the milk cows graze or food plants are grown.

A shortage of vitamin D may interfere with the utilization of calcium in the body and, thus, bring about a "conditioned" calcium deficiency. This may lead to rickets in children.

The calcium content of any one plant species does not change very much when calcium is added to the soil. So, the level of calcium in the soil has few direct effects on the nutritional quality of plants. But, the addition of calcium in the form of limestone to an acid soil frequently makes it easier to grow leguminous plants, like alfalfa, which are often high in protein and essential minerals. So, the addition of calcium to the soil may have an indirect effect upon nutrition by permitting the farmer to grow a different and possibly more nutritious kind of crop plant.

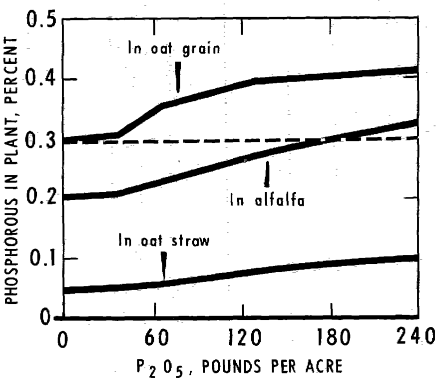

FIGURE 2.—The effect of rate of phosphorus fertilizer application upon the concentration of phosphorus in oats and alfalfa grown on Clarion loam. Many animals require about 0.3 percent phosphorus (indicated by dashed line) in their diets for normal growth.

Potassium is required in fairly large amounts by both plants and animals. The forage grasses and legumes require so much potassium that if they grow at all, they will provide the animal with sufficient potassium to meet its requirements. Potassium deficiency in animals is not common, and where it does occur it can rarely be traced back to a deficiency of potassium in the soil.

Phosphorus is of critical importance to many of the life processes of both plants and animals. When the soil is deficient in phosphorus, certain plant species may contain too little of this element to meet the requirement of the animal that eats the plant. But, this is not always true; the complexity of the problem is illustrated by figure 2.

The graph shows the concentration [2] of phosphorus in oats and alfalfa grown on Clarion loam in Iowa, which was fertilized with different rates of phosphorus fertilizers and seeded to a mixture of these crops. In this experiment the yield of both oats and alfalfa was markedly increased by the use of the phosphorus fertilizer. The phosphorus content of the crops was also increased, but to a lesser extent than the yield. In studying this graph, keep in mind that many animals require about 0.3 percent phosphorus in their diets for normal growth. The phosphorus content of the oat straw was very low in relation to the 0.3 percent needed by animals, even at the highest rate of application of phosphorus fertilizer. The phosphorus content of oat grain was above the animal requirement even without use of any

[2] The relative content of a component, commonly expressed in percentage by weight or by volume, in parts per million, or in grams per kilogram.

phosphorus fertilizer. The alfalfa, on the other hand, was changed from a crop containing an inadequate amount of phosphorus for animals to one containing an adequate amount through the use of phosphorus fertilizer.

The method of meeting the phosphorus requirements of plants and animals can best be selected on the basis of the responses to phosphorus shown by the plants. If the use of phosphorus fertilizer will result in a substantial increase in crop yield, this practice is a logical first point of attack upon the problem. If there is not an appreciable increase in yield, then phosphorus-rich mineral mixtures can be fed to the animal.

Cobalt is required, in very small amounts, by the micro-organisms that live on the roots of leguminous plants and convert nitrogen from the atmosphere into chemical forms that can be used by higher plants. It is not uncommon to find plants growing very well even though they contain too little cobalt to meet the needs of the cattle and sheep that eat these plants. In the United States, we have very few areas where addition of cobalt fertilizers will increase the growth of plants, but we have extensive areas where grazing sheep and cattle will suffer from cobalt deficiency unless this element is provided as a feed supplement.

Legumes generally contain more cobalt than do grasses, but even legumes are deficient in cobalt for grazing animals in some areas (see fig. 3).

The pathways and function of cobalt in the soil-plant-animal system are unique. Except for the requirement by the micro-organisms on the roots of legumes, no other requirement of cobalt by plants has been discovered. Animals require their cobalt to be in the form of a complex compound called vitamin B_{12}. Vitamin B_{12} is not generally found in plants, but when a cow or sheep eats a plant, micro-organisms in the rumen and in the digestive tract synthesize vitamin B_{12} from the cobalt and the other compounds in the plant. This vitamin then performs vital functions in the animal's body and, as a part of the milk and meat, provides for the vitamin B_{12} needs of other animals, including man. So, in supplementing the diets of animals and man with cobalt, the simple inorganic forms of this element are satisfactory for ruminant animals; monogastric animals such as man, however, must be provided with cobalt in the form of vitamin B_{12}.

The addition of the inorganic salts of cobalt to salt licks or feed supplements is the most common method of meeting the cobalt requirements of cattle and sheep in the United States. But the use of cobaltized fertilizers on the pasture soils is also an effective way of meeting the ruminant's requirement for this element, and is widely used for this purpose in other parts of the world. Still another method is to place heavy ceramic "bullets" containing cobalt in the animal's rumen. These bullets stay in the rumen and slowly release cobalt for the needs of the animal.

Iron, *manganese*, and *zinc* are required by both plants and animals. There are many places in the United States where plant growth is retarded by deficiencies of iron, manganese, or zinc, and can be greatly improved by the use, either in sprays or by soil treatment, of an available form of the deficient element. Most of the cases of a deficiency of iron, manganese, or zinc in plants are due to the insolubility of these elements rather than to a small total amount of these elements in the soil.

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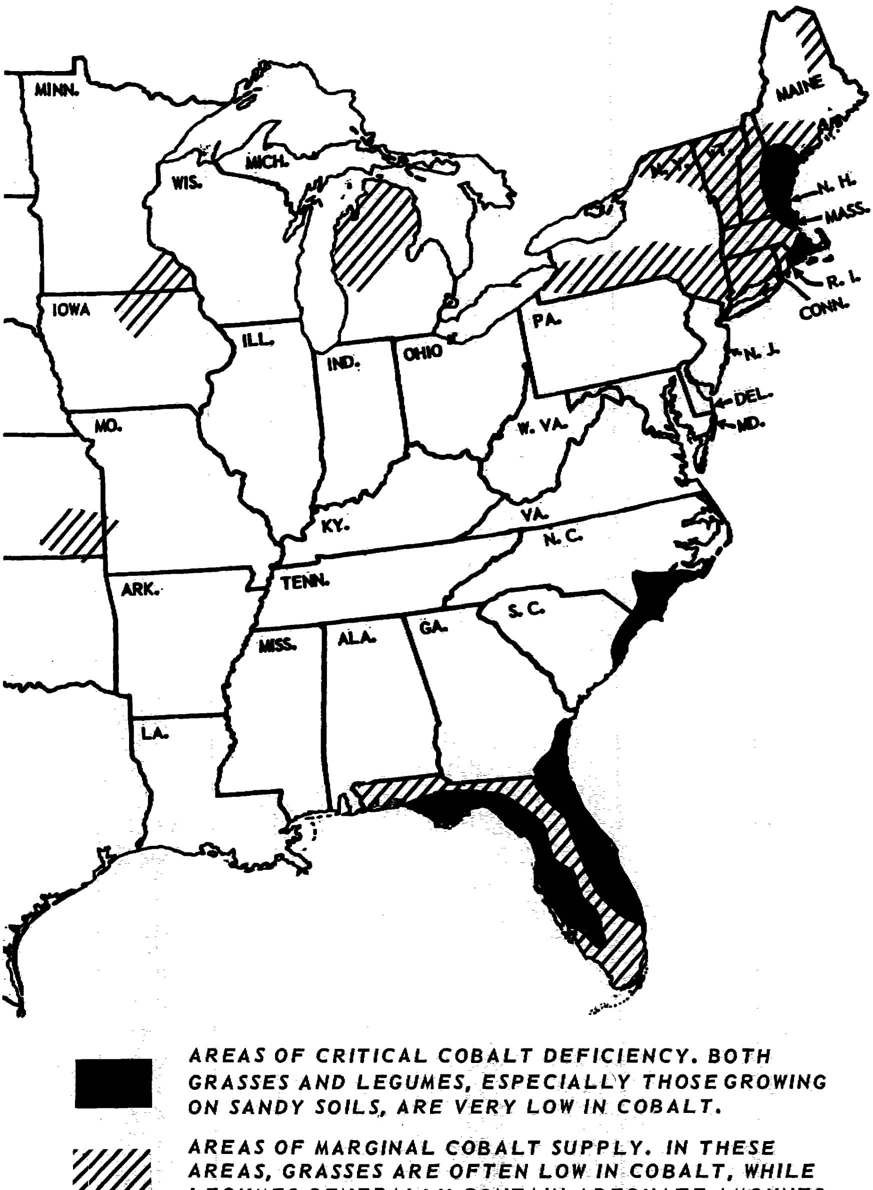


FIGURE 3.—Distribution of cobalt deficiency in Eastern United States. There are no large cobalt-deficient areas in the States not shown.

Although the sprays or soil treatments used to correct iron, manganese, and zinc deficiencies in plants usually result in some increase in the level of these elements in plant tissues, their value is primarily to the plant and not to the animal that eats the plant. A major cause of deficiencies of these elements for animals is that only a small part of the iron, manganese, or zinc contained in some plants is utilized by the animal. The zinc requirement of the animal has been shown to vary according to the kind of protein and the level of calcium in the diet.

Grazing animals rarely suffer from deficiencies of iron, manganese, or zinc. Anemia, which is due to a deficiency or poor utilization of dietary iron, is common in young pigs and calves kept in confinement and fed on a diet of milk. A poor utilization of zinc leads to parakeratosis in pigs. The diets of chicks are usually fortified with manganese to prevent a bone defect called perosis.

Anemia in humans is due to a deficiency of hemoglobin, an important iron compound in the blood. This disease is usually brought about by poor utilization of iron in the body or by chronic loss of blood. In one case, iron deficiency anemia in children has been related to circumstances where vegetables grown on iron-deficient soils were the primary source of dietary iron.

Deficiencies of zinc have been noted in young men in some of the Middle Eastern nations.

If they were all utilized, the amounts of iron, manganese, and zinc in plants would generally be adequate to meet the needs of man and animals. A change in diet or the correction of some condition hindering the utilization of these elements in the body, rather than the addition of these elements to the soil, is an effective means of preventing their deficiency in man and animals.

Copper is required by both plants and animals, and yet at high levels it may be toxic to both. Several other elements are similar to copper in exhibiting this dual role of essentiality and toxicity.

Copper deficiency in plants is most frequently encountered on acid soils high in organic matter and on very sandy soils. Large additions of copper to the soil are frequently required for successful crop production on newly reclaimed acid peat and muck soils.

Copper deficiency in animals is widespread and brings about a number of nutritional diseases in livestock. In parts of Australia, Southeastern United States, and certain other places, the use of copper supplements for animals is a requirement for a profitable livestock industry. Some forms of copper found in plants are not readily utilized by animals. This is especially probable for the copper in lush pastures. In other places, a conditioned copper deficiency in animals, brought about by an excess of molybdenum, is a serious problem in animals. This problem is examined in the discussion on molybdenum.

Copper deficiency in humans is rare, but some cases of anemia have responded better to treatment with iron plus copper than with iron alone. Liver and seafoods are important sources of copper in human diets.

Copper toxicity to animals is less common than copper deficiency. This toxicity has occurred where animals forage in vineyards and in other areas where copper fungicides are used, and some cases have been due to overdosage of the animals with copper as a therapy for copper deficiency or to control internal parasites. Copper toxicity to animals grazing under so-called "natural" conditions occurs in Australia, but has not been a problem in the United States.

In Australia and New Zealand the addition of copper fertilizer to soils has been effective in meeting the needs of both the plant and the grazing animal. On some of the copper-deficient soils of the United States applications of copper fertilizers have increased plant growth without producing a marked change in the copper content of the plants, and animals grazing these plants may still suffer from copper deficiency.

Molybdenum is required in very small amounts by plants. It plays an important role in the fixation of nitrogen by micro-organisms in the roots of leguminous plants, and applications of very small amounts of this element to some acid soils have resulted in increased growth and a higher protein content in legumes. In general, molybdenum deficiency in plants is found only on acid soils. Liming the soil sometimes markedly increases the availability of molybdenum to the plant.

Animals need so little molybdenum that there is some doubt as to whether or not they have a true requirement for this element. Some recent evidence from New Zealand suggests that a moderate level of molybdenum in human food may help to protect against dental decay. If additional research should confirm this suggestion, the molybdenum content of human foods everywhere should be closely studied.

An important factor in that portion of the food chain involving the movement of molybdenum is that plants can accumulate, without any evidence of damage, a concentration of molybdenum that will bring about serious nutritional disturbances in the animal that eats the plant. In the Western United States, there are a number of areas of poorly drained alkaline soils that produce plants containing such high concentrations of molybdenum that animals feeding on these plants suffer from critical nutritional disorders. The alkaline soils that produce plants high in molybdenum are frequently formed from granitic parent materials and are high in organic matter. High-molybdenum plants have also been found on some organic soils in Florida. In the Eastern United States, on a few acid soils developed from shales that are high in molybdenum, liming the soil increases the uptake of molybdenum by plants to the point where these plants may become toxic to animals.

High levels of molybdenum interfere with the utilization of copper by the animal. At low-to-moderate levels of copper intake, the bad effects of molybdenum upon copper metabolism are greatest where the sulfate level in the diet is high.

Cattle suffering from molybdenum-induced copper deficiency show rather characteristic symptoms, including weight loss, diarrhea, and fading of hair color. Extra copper received by the animal, either as a drench, a mineral supplement, or by injection, brings about a dramatic recovery and return to a thrifty condition. Cattle receiving injections of copper glycinate can graze forages very high in molybdenum with no ill effects. Figure 4 shows the effect of a diet excessively high in molybdenum on a heifer. Figure 5 shows a heifer fed the same diet as the heifer in figure 4, but protected from molybdenum-induced copper deficiency by copper injections.

The complexity of the soil-plant-animal relations involving molybdenum can best be illustrated by a list of the possible results of using a fertilizer containing molybdenum in different situations:

1. On a molybdenum-deficient acid soil, molybdenum additions may increase the growth and the protein content of plants, and if the suggestions of the New Zealand work are verified, may produce

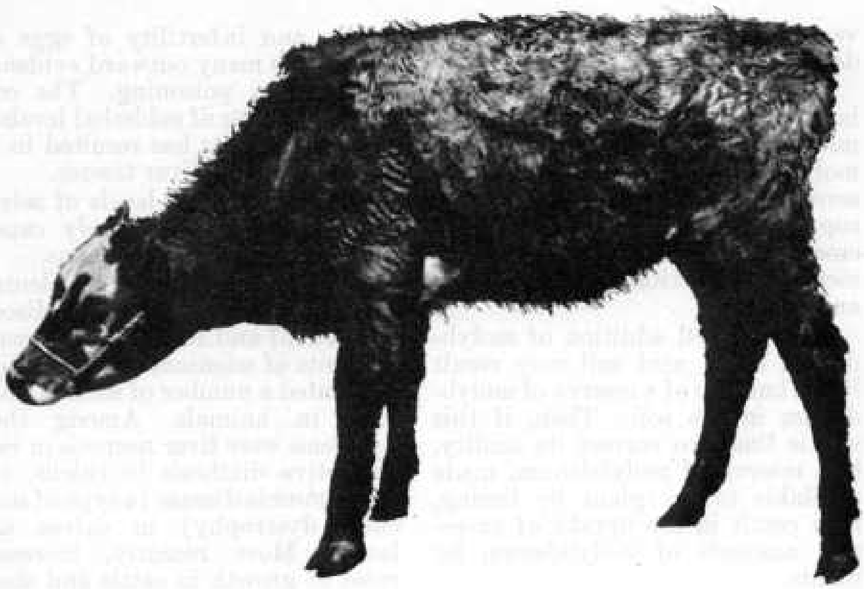


FIGURE 4.—Heifer suffering from a diet high in molybdenum. (Courtesy University of Nevada.)

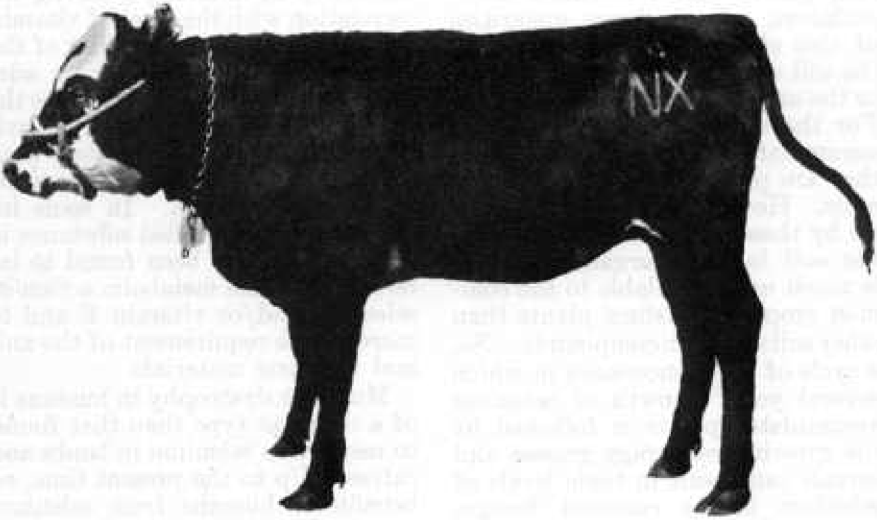


FIGURE 5.—Heifer fed the same high-molybdenum diet as heifer in figure 4, but protected from molybdenum toxicity by copper injection. (Courtesy University of Nevada.)

vegetables that help to prevent dental decay.

2. On a neutral or basic soil that is producing forages of low-to-moderate copper content, excessive molybdenum additions may lead to severe cases of molybdenum-induced copper deficiency in animals and create a need for copper supplements or injections to protect the animals.

3. Continued addition of molybdenum to an acid soil may result in the buildup of a reserve of molybdenum in the soil. Then, if this soil is limed to correct its acidity, this reserve of molybdenum, made available to the plant by liming, may result in the uptake of excessive amounts of molybdenum by plants.

Selenium is not generally required by plants, but its deficiency or excess in animal diets may be fatal.

A remarkable feature of the movement of selenium in the soil-plant-animal food chain is that certain plants, called selenium accumulators, take in large quantities of this element if it is present in the soil and become extremely toxic to the animals that eat these plants. For the most part, these selenium accumulator plants are not ones that are preferred by grazing animals. However, the selenium taken up by these plants and returned to the soil in their organic residues is much more available to the common crop and pasture plants than other soil selenium compounds. So, a cycle of plant succession in which several years' growth of selenium accumulator plants is followed by the growing of forage grasses and cereals can result in toxic levels of selenium in the common forages and cereals.

Farm animals suffer from both acute and chronic manifestations of selenium toxicity. In acute cases, death may occur. In chronic cases, defective hooves, loss of hair, lameness, malformations of newborn lambs, and infertility of eggs are among the many outward evidences of selenium poisoning. The continued feeding of sublethal levels of selenium to rats has resulted in serious damage to liver tissues.

Excessively high levels of selenium in plants have rarely caused selenium toxicity in humans.

A new aspect of the selenium problem appeared with the discovery in 1957 and 1958 that very small amounts of selenium in animal diets prevented a number of serious problems in animals. Among these problems were liver necrosis in rats, exudative diathesis in chicks, and white muscle disease (a type of muscular dystrophy) in calves and lambs. More recently, increased rates of growth in cattle and sheep and higher birth rates in sheep have been obtained when rations were supplemented or the animals injected with very small quantities of selenium.

In many instances of selenium deficiency in animals, a strong interrelation with the level of vitamin E or antioxidants in the diet of the animal has been found. An adequate level of vitamin E reduces the need for selenium, and there is evidence that an adequate, but nontoxic, level of selenium reduces the need for vitamin E. In some instances, an unidentified substance in certain feeds has been found to interfere with the metabolic action of selenium and/or vitamin E and to increase the requirement of the animal for these materials.

Muscular dystrophy in humans is of a different type than that found to respond to selenium in lambs and calves. Up to the present time, no benefits to humans from selenium supplementation of diets have been observed, but research on this is continuing. In view of the demonstrated value of very small amounts of selenium to rats, chickens, horses, cattle, and sheep, a need for this element in humans is possible, but since human diets come from so many different sources, it is less likely that humans would have a diet extremely low in selenium.

The distribution of some of the different selenium problems is shown on the map (fig. 6). From this map, one can see that there is a large area around the Great Lakes and extending on into the Northeastern States, and another in the Pacific Northwest, where selenium is apparently deficient in soils and plants and where white muscle disease is fairly common. There are other areas where plants may contain very high concentrations of selenium. These areas of selenium toxicity are localized and confined to the western part of the Great Plains and the Rocky Mountain footslopes. In still another large area, including parts of the Plains States, the western Cornbelt and the lower Mississippi Valley, the supply of selenium in soils and plants is apparently adequate to prevent white muscle disease, and yet there is no selenium toxicity.

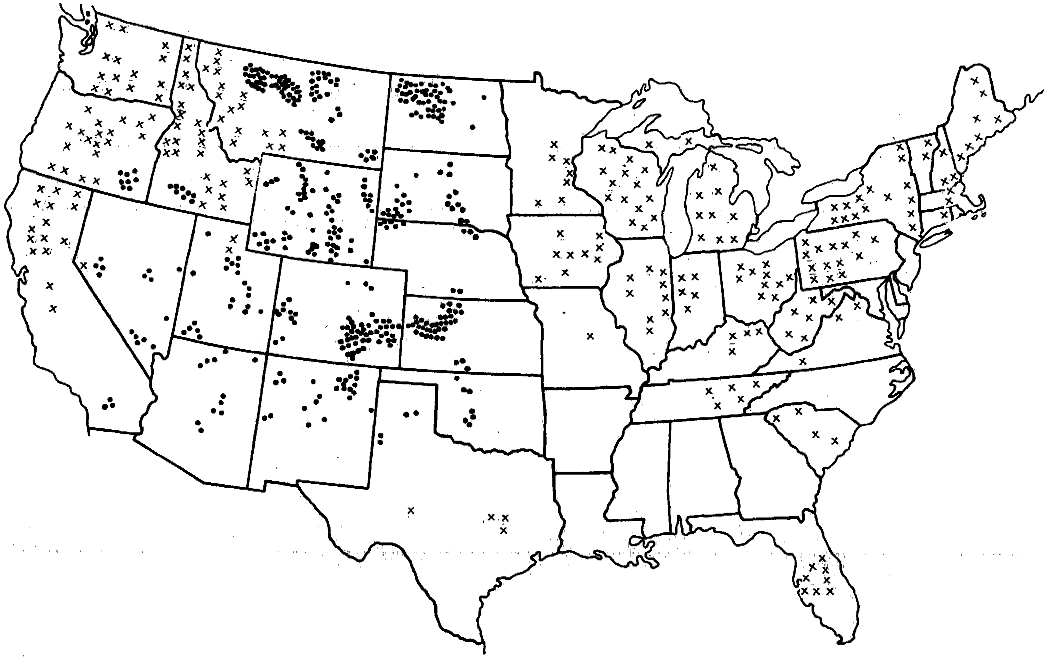
In regions where selenium toxicity has occurred, ranchers avoid grazing areas where high-selenium plants may be found, especially during dry seasons, when a shortage of feed may cause the animals to eat some of the selenium-accumulator plants. The addition of small amounts of certain arsenic compounds to the ration is also beneficial in preventing some cases of selenium toxicity. In the selenium-deficient areas, sheep and cattle are sometimes injected with very small amounts of selenium to prevent white muscle disease and to increase rates of growth. In New Zealand, selenium is included in the drenches used to control parasites.

The margin between selenium deficiency and toxicity is narrow. Only about one-third of an ounce of selenium in 100 tons of feed is all that is required to protect animals from white muscle disease, and about 1 pound of selenium in 100 tons of feed is probably enough to have some detrimental effect on animals. Because of the hazards involved in the addition of selenium to animal feeds, this practice is not permitted by current regulations. The addition of selenium to soil cannot be recommended until we learn a great deal more about the chemistry of selenium in soils and its uptake by crop plants and develop sure methods of preventing any hazard from excess selenium.

Sodium and chlorine are both essential for animals. Chlorine is required by plants, but it is so generally present in soils and fertilizers that no field cases of chlorine deficiency in plants or animals have been noted. Sodium is not an absolute requirement for plants, although in certain plant species, it may increase yields and partially substitute for the required potassium. Plants rarely contain sufficient sodium to meet the needs for this element in the animal or man that eats the plant. Common salt, sodium chloride, is the oldest and most widely used mineral supplement for human and animal diets.

It would be difficult to add sodium to soils in amounts sufficient to raise the sodium content of the common crops to the point of meeting the sodium requirements of animals and man from plant sources. This is due to the fact that soils high in sodium are very poor soils for plant growth. An excess of sodium is responsible for the low fertility and undesirable physical properties of the "alkali soils" of dry regions. So, an attempt to route the sodium that animals need through the soil and the plant might jeopardize the productivity of the soil. This danger is especially acute on the fine-textured soils of subhumid regions.

Iodine is required by animals but not by plants. Even so, plants will accumulate appreciable amounts of



• RECORDED OCCURRENCES OF PLANTS EXCESSIVELY HIGH IN SELENIUM.
× RECORDED OCCURRENCES OF WHITE MUSCLE DISEASE, A LIVESTOCK DISEASE RELATED TO SELENIUM DEFICIENCY.

FIGURE 6.—Areas where plant composition or nutritional problems indicate a deficiency or excess of selenium.

iodine in their tissues if it is present in an available form in the soil, and iodine from plants is one of the important sources of iodine in animal rations.

The relation of a lack of iodine in diets to a high incidence of goiter was one of the first instances to be discovered of a mineral deficiency that affected the health of man and animals. It now appears that a number of other factors, including the presence of goiter-inducing organic compounds in certain plants, are also related to the presence of goiter.

Plants low in iodine are most often found growing on geologically young soils and in areas of low rainfall. It appears that the cycle of iodine in nature involves the vaporization of iodine compounds from the sea, their transport inland by wind, and their deposition on land by rainfall.

The use of iodized salt to correct iodine deficiency in man and animals is one of the most strikingly successful examples of supplementation of diets with an essential element. Iodine supplied to humans and animals in iodized salt is just as effective in prevention of goiter as is the iodine naturally contained in the plants of high iodine areas. It would be possible to add iodine to soils and produce crops that contained sufficient iodine to meet human and animal needs, but since iodine leaches out of soils in the drainage waters, the application of iodine would need to be repeated rather frequently. The pronounced success of iodized salt in meeting the iodine requirements of man and animals has minimized interest in iodized fertilizers.

Magnesium is a required element for both plants and animals. In plants, it is an integral part of the molecule of chlorophyll, the compound that captures the sun's energy to set in motion the synthesis of most of the world's food supply. Magnesium is also essential to the operation of important energy transformations in living cells. Magnesium deficiencies in plants are common in many parts of the world. Dolomitic limestone, a mixture of calcium and magnesium carbonates, is often added to acid soils to supply magnesium to plants and to correct acidity.

Legumes nearly always contain more magnesium than do grasses. Although the magnesium levels in plants can be increased moderately by adding magnesium to the soil, the magnesium levels in grasses are still below those in most legumes, even when the grasses are grown on a soil high in available magnesium.

Lactating cows and ewes sometimes suffer from grass tetany, a disorder related in some complicated way to a deficiency of magnesium. It is not due to a simple lack of magnesium in the diet, but seems to be more prevalent when the diet is not only low in magnesium but also high in potassium and crude protein. Grass tetany has been a serious problem in Western United States and in some areas of the Southeast. It is most common when freshly lactating animals are grazing the first flush of growth of grasses in the early spring months, although some cases have occurred among cattle being wintered on grass hay. It is rarely found when legume forage makes up a major part of the animal diet.

In the British Isles, fertilization of the soil with dolomitic limestone or other magnesium compounds is used in an attempt to prevent grass tetany, and feed supplements high in magnesium are sometimes used during critical periods of the year.

Sulfur is an important constituent of proteins in both plants and animals and is an essential element for all living things. Sulfur deficiencies in plants are especially common on the gray wooded soils of cool, temperate regions. Many of the soils developed from volcanic materials in northern California and the Pacific Northwest are deficient in sulfur.

For many years, sulfur in the form of calcium sulfate was an accessory part of most commercial fertilizers and probably helped to prevent the development of widespread sulfur deficiency in the Eastern United States. Volatile sulfur compounds from smoke are an important source of sulfur for plants growing around industrial centers and may even cause some injury to plants close to smokestacks.

Animals require sulfur in the form of sulfur-containing amino acids. In ruminant animals, the micro-organisms in the rumen will synthesize these required amino acids, providing that the animal gets sufficient sulfur in inorganic forms. So, the sulfur requirement of a cow or sheep can be based upon the total amount of all forms of sulfur taken in by the animal; whereas, for the monogastric animals, including man, the sulfur requirement is expressed in terms of the sulfur amino acids, methionine and cystine. In this respect, the cycle of sulfur and sulfur amino acids resembles the cycle of cobalt and vitamin B_{12} in the route from soil to plant to animal. An important difference is due to the fact that certain plants contain fairly large amounts of the sulfur amino acids, whereas vitamin B_{12} is rarely present in plants.

If a legume forage crop has enough sulfur to make optimum growth, it will probably contain enough sulfur to meet the needs of cattle and sheep. In some instances, an increase in crop yield and an improvement in nutritional quality will be double benefits from sulfur fertilization.

The use of a sulfur fertilizer on a sulfur-deficient soil will not make much difference in the percentage of sulfur amino acids in the plant, but the total production of sulfur amino acids per acre will be higher due to increased plant growth. This is illustrated in figure 7, which shows some effects of adding sulfate to a culture solution in which alfalfa was grown. Large increases in growth followed the addition of sulfate to the culture solution. The total sulfur in the plants was also increased, but on a relative basis not so much as was the yield. The concentration of methionine in alfalfa was increased only slightly, and even at the highest level of sulfur addition, this concentration was well below that commonly found in soybeans. Thus, the concentration of the essential sulfur amino acids in plants depends primarily upon the kind of plant, and much less upon the level of available sulfur in the soil.

Many other elements such as vanadium, tungsten, silicon, chromium, and bromine follow the pathway from soil to plant to animal. Some of these will undoubtedly be found to perform an essential function in either plants or animals as research on them progresses. Recent evidence suggests that some plants contain sufficient cadmium to be potentially detrimental, at least to laboratory animals. High levels of certain of the other elements found in plants will probably prove to be detrimental to animals.

The soil-plant system, however, often operates to protect animals from toxic concentrations of certain elements. Certain potentially toxic elements, such as arsenic, are tightly held by the soil and not readily taken up by plants.

The nature of the movement of many elements from rocks and soils to plants and animals is only partially known. Improvements in our knowledge of these processes will very likely result in ways of assuring the nutritional quality of plants.

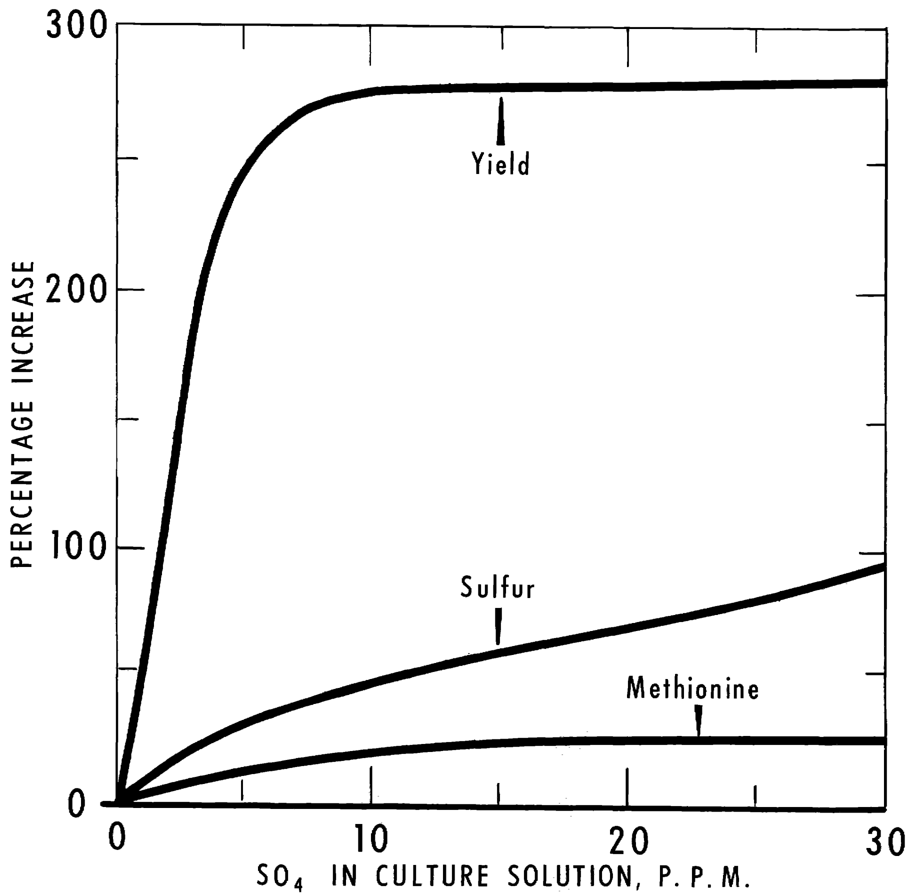


FIGURE 7.—The effect of adding sulfate to the culture solution upon the yield of alfalfa and the concentration of sulfur and methionine in plants.

Soil Nitrogen and Protein Nutrition

A shortage of available nitrogen in the soil is a critical factor in limiting food production in humid areas. Over 10 million tons of nitrogen in fertilizers is being used in the world annually and much more will be needed in the future.

The nitrogen contained in plants is present primarily in proteins. A deficiency of protein, both in kind and amount, is the most critical human nutrition problem in the world; but increased additions of nitrogen to the soil, with the resulting production of bigger crops with higher protein content, will not automatically provide a direct solution to this pressing problem. Proteins are large molecules built up through the linking together of smaller compounds called amino acids. Human beings require specific amino acids from the protein molecule. The amounts of these amino acids in food are governed by a whole series of forces acting at varied points along the food chain.

First of all, most of the nitrogen from the soil is taken into the plant in the form of inorganic ammonium and nitrate ions. Sometimes these inorganic forms of nitrogen in the soil are formed from the breakdown of soil organic matter, crop residues, or manures; at other times they are added to the soil in the form of nitrogen fertilizers. Special groups of micro-organisms can take inert gaseous nitrogen from the air and convert it to forms available to all plants. One of these groups of micro-organisms is found in the nodules or roots of leguminous plants such as clover, peas, and beans.

After the inorganic compounds of nitrogen are taken into the plant, the nitrogen in them is normally combined with carbon and other atoms to form the molecules of amino acids. This synthesis of amino acids is in itself a complex process, involving many steps, and following a different pathway for each of the 20-some amino acids found in proteins. The rate at which this synthesis takes place is governed by many factors, including the nutritional status of the plant in respect to all required elements and the supply of materials available to provide the metabolic energy needed to make the synthetic processes move forward.

Once formed in the plant, these amino acids constitute a "pool" of building blocks for use in the synthesis of protein. The process of protein synthesis is essentially one of linking different amino acids from this pool together to form long chainlike molecules, with the chains often folded, coiled, and cross-linked and each chain made up of possibly hundreds of molecules of 20 different amino acids.

This process of linking amino acids together to form proteins is controlled almost entirely by an inherited code of instructions, passed on genetically to each new cell. This inherited set of instructions for protein synthesis dictates the sequence in which molecules of the different amino acids are linked together. This sequence in turn determines the nature of the protein, its function within the cell and, indeed, the nature of the entire organism.

When a plant is growing well, the process of synthesizing proteins from amino acids proceeds at a fairly rapid rate, and normally 80 percent or more of all the nitrogen in the plant is combined into protein molecules. The pool of free amino acids usually contains less than 15 percent of all the nitrogen in the plant, although in young plants in which the supply of energy-rich compounds needed to power the process of protein synthesis is deficient, as much as 40 percent of the nitrogen in the plant may occur in the free amino acid pool. Certain mineral deficiencies may also lead to a "piling up" of free amino acids in the plant and reduced plant growth. However, the amino acids that are most critical in human nutrition are rarely found in significant amounts in this free pool.

Animals require specific amino acids. Of the 20 or so different amino acids that are linked together in protein molecules, 8 or 9 are required in the diet of most animals. An early step in the digestive processes of an animal is the cleavage of the protein chains in the food into the individual amino acids from which they were made up. Then in the animal, these amino acids may be recombined into new sequences or kinds of protein. The requirements of animals for different amino acids are quite specific, and there is only a limited substitution or sparing one for another. Diets deficient in specific amino acids can be made adequate by supplementation with these amino acids in "free" form. It is not necessary that they be combined into protein. Plant proteins are often deficient in one or more of the essential amino acids required by man, and the serious nutritional disease called kwashiorkor is widespread among young children in areas where plant products are the primary source of dietary protein.

Ruminant animals, such as cattle, sheep, goats, and water buffalo, seem at first to form a notable exception to the rule that animals require specific amino acids. In these animals, the micro-organisms in the rumen break up the amino acids or other nitrogen compounds that are contained in the plants they eat and recombine the elements released by this breakdown into new molecules of amino acids—those that are required by the animal. So, it might be more accurate to state that ruminant animals require specific amino acids but they have in their rumen a means of producing the ones they need, provided the raw materials are contained in the animals' food. These animals have a wide tolerance as far as these raw materials are concerned. Some of the simple nitrogen compounds such as urea can be used by ruminants as an initial source of nitrogen for the synthesis of amino acids. Similarly, they can build inorganic forms of sulfur into the essential sulfur-bearing amino acids.

The amino acid requirements of animals are similar to those of man, and so protein foods of animal origin such as meat and milk usually represent a higher quality or better balanced protein for humans than do plant proteins. However, human diets that will have the necessary amounts and ratios of the essential amino acids can be prepared from plant sources if the proper plant proteins, carefully selected so that all of the essential amino acids are contained in some one or the other, are blended together. The ruminant animal performs the special function in the food chain of converting low quality nitrogenous compounds into high quality protein for human consumption.

The role of soil fertility, including the level of available nitrogen in the soil, in meeting the world nutritional requirements for amino acids and protein is, thus, essentially one of determining the magnitude of protein synthesis per acre.

An adequate level of soil fertility operates primarily to give the plant a chance to form protein, and is only one of many factors such as light and water that are also required to give the plant this chance. Given this chance, the plant will build into protein those sequences of amino acids that are directed by its genetic makeup. So, in meeting the world needs for amino acids, adequate levels of soil fertility must be combined with the breeding and selection of plants that form proteins rich in those amino acids required by man. These plants must also be protected from insects and diseases. There should be appropriate use of animals, especially ruminants, to convert low-quality proteins to high-quality proteins, and a food technology that includes the proper blending of proteins from different sources to provide and distribute attractive diets balanced in the amino acids that are essential for humans.

Nitrate in Plants and Animals

Sometimes nitrogen compounds from the soil move into the plant more rapidly than the nitrogen is utilized in the formation of amino acids and proteins. When this happens, nitrogen accumulates in the plant tissues in the form of nitrate. High concentrations of nitrate in plants are toxic to the animals that eat the plants and can cause very toxic gases to be given off in silos where these plants are ensiled.

The accumulation of toxic levels of nitrates in plants may occur when a high level of available nitrogen in the soil occurs at a time when plant growth is slowed by cloudy weather, low temperature, or lack of moisture. The high level of available soil nitrogen may be the result of a rapid breakdown of soil organic matter or crop residues, the use of heavy applications of animal manures, or the use of high rates of nitrogen fertilizers. Nitrate accumulation frequently occurs when the leaves are wilted due to drought and yet the soil is still sufficiently moist to permit nitrates to enter the plant roots.

Different plant species show different tendencies to accumulate toxic concentrations of nitrates in their tissues. The cereal grain crops when cut at an immature stage for hay or silage, some annual grasses, and certain weeds such as pigweed are most likely to contain toxic concentrations of nitrates when conditions are right for nitrate accumulation. Toxic concentrations of nitrate are less often found in perennial grasses and legumes. Within any one plant species, the nitrate concentration in the stems and leaves exceeds that in the seed.

When an animal eats plants containing nitrate, some of this nitrate is converted in the digestive tract to nitrite, a less oxidized chemical form of nitrogen. This nitrite then enters the bloodstream and interferes with the ability of the blood to carry oxygen throughout the body. So, the nitrite that is formed from nitrate is the true toxic factor in nitrate poisoning. In ruminant animals, there is additional opportunity for nitrate to be reduced to nitrite, and thus ruminant animals are more likely to be affected by nitrate toxicity than are other animals and man. Nitrite does not occur in plants in significant amounts.

Nitrate toxicity is frequently fatal to ruminant animals, and abortions of unborn calves may also occur in acute cases. The prime diagnostic symptom for cases of nitrate poisoning is chocolate-brown blood, coupled with a darkening of exposed membranes and a discoloration of white skin areas. Methylene blue is widely used by veterinarians in the treatment of nitrate toxicity, and most acute cases will respond to proper treatment if prompt action is taken.

Sublethal or chronic effects of nitrate toxicity have also been suspected. These sublethal effects include a disturbance of the functioning of the thyroid gland and interference with the utilization of vitamin A by the animal. The exact implication of nitrate toxicity in these chronic cases is difficult to establish, however, and other nutritional disturbances in addition to nitrate toxicity are possibly responsible for some effects that have been attributed to nitrates.

The exact amount or concentration of nitrate in an animal feed that will result in nitrate poisoning depends upon the rate of feed consumption and upon other components in the diet. An animal that is slowly eating upon a pasture or hay that is high in nitrate can consume, without damaging effects, an amount of nitrate that would be fatal if applied all at once in a drench.

There have been no authenticated cases of nitrate poisoning of humans due to eating plants high in nitrates. Very young babies have been poisoned when water high in nitrates was used to make up the baby formula, but even in these cases, bacteria in the water may have contributed to the injury. There have been several cases of death in humans due to the inhalation of toxic gases accumulated in silos where high-nitrate plants were stored.

Nitrate toxicity represents a serious problem that can be brought about by a malfunction of the soil-to-plant-to-animal food chain. Although the total loss of livestock in any one year from this cause is not great, these losses are usually concentrated on a few farms, and can be very damaging to those particular farms. There are, however, certain precautions that can minimize the danger of nitrate toxicity. For one thing, the conditions that may lead to nitrate accumulation in plants can be recognized and farmers can be alerted to the danger in areas where these conditions have occurred. Feeds known or suspected to be high in nitrates can be diluted with feeds low in nitrate. Prompt therapeutic action can be taken when acute nitrate poisoning is diagnosed. The weeds that are known to be nitrate accumulators can be eliminated from the pastures by proper weed control measures.

Highly toxic silo gases have a sharp odor, and a silo where these gases may be present should always be thoroughly force-draft ventilated before anyone enters.

It should be especially noted that a high level of available nitrogen in the soil is only one of the factors involved in the accumulation of excess nitrate in plants, and that these high levels of available nitrate have sometimes occurred in soils that have never received applications of manures, composts, or nitrogen fertilizers. An attempt to restrict the use of manures, composts, or nitrogen fertilizers to a level that would prevent high levels of available nitrogen in soils would not eliminate all instances of nitrate toxicity and would critically reduce yields and food production.

The Effect of Soil Fertility on the Vitamin Content of Plants

Man and animals require a large number of different vitamins, and these vitamins must generally be present in the food, since most of them are not synthesized within the body to any significant extent. The total amount of any one vitamin needed each day is very small.

The vitamins are fairly complex organic compounds. Plants serve as an important source of some of these vitamins in human diets. The vitamins contained in plants are generally synthesized within the plant; in only rare cases has any uptake of a vitamin from the soil been noted.

Vitamin A is a complex alcohol containing 20 atoms of carbon in each molecule. Although this vitamin is not found as such in plants, plants do contain a series of colored compounds called carotenes that are readily converted to vitamin A in the animal body. Carrots and alfalfa are important plant sources of carotenes, sometimes called provitamin A.

The carotene content of green plants is generally related to the depth of the green color. When normally green plants become yellow, or chlorotic, due to a deficiency of iron, the correction of this iron deficiency in the plant will result in an increase in carotene content, as well as an increase in yield. Boron deficiency in alfalfa sometimes results in a yellow or reddish discoloration of the plant. The fertilization of boron-deficient alfalfa with boron has resulted in a higher carotene content in the alfalfa. Thus, in this case, the fertilization of the plant with an element that is not required by the animal results in an improvement in the nutritional quality of the plant for the animal.

The vitamin B complex consists of at least 11 different organic compounds, each one essential to some facet of good health. Some of these compounds are found in plants, and for some of them, plant sources make a major contribution to the dietary requirements. Generally, however, animal products such as meat, milk, and eggs are major sources of these vitamins. Animal products are especially important in supplying vitamin B_{12} to humans.

The B vitamins that are found in plants are essential to the normal metabolism of the plant cell, and the plant will not grow at all unless it forms these vitamins. In studies of the effects of plant nutrition upon the amount of B vitamins in plants, the levels of the different nutrients available to the plant have not made consistent differences in the concentration of these B vitamins in the plant unless there was also a marked difference in the growth of the plant.

Vitamin C, or ascorbic acid, is essential for the prevention of scurvy in humans. Citrus fruits and tomatoes are very important sources of vitamin C in human diets. Other fresh fruits and vegetables, including potatoes, also make important contributions of this vitamin. The vitamin C content of tomatoes depends primarily upon the intensity of sunlight striking the fruits of the tomato in the immediate preharvest period. Variations in the level of available nutrients in the soil result in very little change in the vitamin C content of the tomatoes, unless a particular soil fertility treatment results in vigorous vegetative growth and large leaves that tend to shade the fruit. These shaded fruits will be lower in vitamin C than fruits more exposed to the sun.

Although there is much still to be learned about the many factors that affect the concentration of the different vitamins in plants, it appears that the fertility level of the soil influences this concentration primarily by providing the proper nutrients to insure normal growth of the plant. When the plant is growing normally and producing a satisfactory yield, the vitamin content of its tissues will depend primarily upon the kind of plant and upon the weather.

The Effect of Fertilizers on the Nutritional Quality of Plants

The high levels of food production common in the developed countries at the present time have required the use of substantial applications of commercial fertilizers, along with many other good practices. These fertilizers are primarily compounds of nitrogen, phosphorus, and potassium with accessory amounts of sulfur, calcium, magnesium, and chlorine. The trace elements, such as boron, zinc, iron, manganese, molybdenum, and copper are generally included only when they produce profitable increases in crop yield.

Because some fertilizers do not contain all of the elements necessary to man and animals, some people have speculated that the bumper crops produced with these fertilizers might be of inferior nutritional quality. Direct evidence on this question is difficult to obtain, especially for humans, whose diets in the developed countries usually come from many kinds of soil and from both plant and animal products. The existing evidence on this question does not indicate any general inferiority in the nutritional quality of foods produced at high yield levels and with the use of fertilizers.

Animal feeding experiments have been conducted in which a diet of a crop grown at a high level of fertilization has been compared with a diet of the same crop grown without fertilization. Quite often, the fertilized crop has been of superior feeding value to the unfertilized crop, but the differences in favor of either one have generally been slight, except for cases where the fertilizer contained some element like cobalt which was very deficient in the unfertilized soil. When the two crops are compared as components of mixed rations, including the feed supplements normally used, differences are rare.

Those countries where the per acre use of fertilizers is high have a greater average national life expectancy than do countries where fertilizer use is low. However, the countries with high rates of fertilizer use also have high standards of sanitation, varied diets, and many other factors that might contribute to long life expectancy. So, a simple correlation between fertilizer use and life expectancy is not necessarily proof that the fertilizers contribute to longevity.

From a broad point of view, however, it is certain that fertilizers have been a factor in the improvement of human diets. Fertilizers are used primarily for two purposes— to enable the farmer to produce the kinds of crops that would not grow satisfactorily on his unfertilized soils and to obtain higher yields. Thus, they contribute to the variety and abundance of the human diet in countries where they are extensively used. High yields of food crops make it possible to use more land for the production of animal feeds and, thus, permit the use of more milk, meat, and eggs in human diets. There is no evidence that this variety and abundance in the diets of developed countries has been purchased at the cost of decreased nutritional quality.

Whenever a naturally infertile soil is made more productive through the use of fertilizers, there exists a possibility of emphasizing, at least temporarily, a deficit or imbalance of elements essential to man and animals through the inadvertent omission of some of these essential elements from the fertilizer and, thus, from the plant. The recognition and correction of these deficiencies or imbalances represents a continuing, but not impossible, challenge to research workers. When the decision whether or not to use commercial fertilizers to increase and maintain food production is being made, the possibility of these deficiencies or imbalances must often be weighed against the certainty of hunger if fertilizers are not used.

Organic Versus Inorganic Fertilizers

Soils that have a high content of organic matter usually have many desirable physical properties. For example, they are easy to till, absorb rain readily, and tend to be drought-resistant. Because soils high in organic matter have these desirable properties, some people have speculated that they might also produce plants of superior nutritional quality and that the use of organic composts or manures would result in plants of superior quality to those produced with inorganic fertilizers.

A number of experiments have been conducted to check on this speculation. The nutritional quality of plants grown in soils that have received large amounts of organic manures has been compared with that of plants grown on soils that have received only inorganic fertilizers or, in some cases, with plants grown in culture solutions containing only inorganic salts of the essential elements. Any differences in their content of essential elements or vitamins that have been noted have been too small to be of any nutritional significance, and have been in favor of the inorganic fertilized plants as often as in favor of those grown with organic materials.

This result is to be expected when one considers the relationship between the plant and the soil. For the most part, the elements essential to plant growth enter the plant in the inorganic form. If an element is originally present in the soil in some organic combination, this organic combination is broken down to an inorganic form by the mirco-organisms in the soil before the element enters the plant. Once converted to inorganic forms, the atoms of this element are indistinguishable from other atoms of the same inorganic forms that have never been a part of an organic combination.

The organic matter in the soil does serve as an important reserve source of certain nutrients for plants and, in many cases, it helps to keep important nutrients available to the plant. But within the plant and the animal that eats the plant, the nutrients that have been released from soil organic matter have the same effect as nutrients freshly applied in inorganic fertilizers.

It is possible for certain organic compounds, if they are present in the soil, to enter the plant. In one case, vitamin B_{12}, a compound not normally found in plants, was found in turnip greens that had been produced on a soil containing organic matter. But the amount of vitamin B_{12} that could be moved into plants through this route would not be sufficient to meet human needs and we would still have to depend upon animal products to meet our needs for this vitamin. For those vitamins normally found in plants, synthesis of the vitamin within the plant is much more important than any possible uptake of the vitamin from the soil in meeting dietary vitamin requirements.

Special types of organic compounds called chelates make some elements more available to plants and are especially useful in maintaining a supply of available iron in the soil. In other instances, however, organic materials tend to tie up certain elements in forms unavailable to plants. "Corral disease" of trees is due to a zinc deficiency brought about by heavy applications of animal manures and soils high in organic matter are often deficient in available manganese and copper.

It is evident, therefore, that although soil-organic matter benefits agriculture in many ways, it does not automatically impart to the soil an ability to produce plants of superior nutritional quality compared with those produced by inorganic fertilization. Farmers should use all practical means to conserve and increase the organic content of their soils, but they should do this to improve the tilth, the water intake and retention, and the resistance to crusting and erosion of their soils, and not in expectation of some effect upon the nutritional quality of the crops produced.

Soil Depletion and the Nutritional Quality of Plants

Many of the important food producing areas in the world have been in cultivation for a long time and the total withdrawal of certain essential elements from the soil in these areas has been appreciable. In some areas, much of the original surface soil has washed or blown from the fields.

It is very difficult to make an accurate appraisal of the effects of soil depletion or erosion upon the nutritional quality of crops because so little is known of the exact nutritional quality of crops produced on soils when they first began to be tilled. Nearly all the soils of the developed countries produce more now than they did when they were first used for crops. In the case of certain elements required by animals but not by plants, a level within the soil that results in a satisfactory concentration of this element in crops when yields are low may not be enough to provide adequate levels when yields are high.

In the areas where selenium is very deficient in soils and white muscle disease is prevalent, the removal of many large crops of hay has probably intensified this selenium deficiency. On the other hand, the nutritional quality of plants now growing in certain areas has been improved, especially for grazing animals, through the use of elements like copper, cobalt, phosphorus, and sulfur in fertilizers.

Some soils were deficient in cobalt, copper, phosphorus, iodine, and certain other elements at the time they were first brought into cultivation. The problem we now recognize as cobalt deficiency was present, although not recognized as such, in Colonial times in New England, and selenium toxicity was described by Marco Polo in his accounts of his travels in Asia.

Even though it is probably impossible to know accurately just what effect any past treatment of the soil may have upon the nutritional quality of the crops now being produced, we must, nevertheless, recognize that the composition of plants does change, for better or for worse, with the changes that take place in soils as a result of continuing soil use. The changes in the chemical properties of the soil that may result in crops of low yield or poor nutritional quality can probably be recognized and corrected, providing strong research programs are directed toward these questions. Processes of soil depletion that result in a destruction of the favorable physical properties of soil—the ability of the soil to provide a deep, moist, well aerated rooting zone for plants—represent a more serious problem that do changes in chemical properties.

Some Continuing Problems

A marked increase in food production will be needed in some parts of the world in order to meet human food requirements. Much of this increase must take place in regions like the tropics, where the natural supply of many essential elements in the soil is very low. Furthermore, the press of population upon food supply in these areas is so great that human diets will be made up largely of plant products, with limited amounts of food from animal sources. In order to meet these needs for food, it will be necessary to develop measures that will assure the production of high yields of food plants of high nutritional quality from soils that are not currently producing such crops.

Success in the development of the needed measures will require additional knowledge of the chemistry of the essential elements in these soils and the pathways of movement of the various elements through plants to animals and humans.

In some of the more highly developed regions, current trends in soil, crop, and animal management practices are based upon the use of just a few plant species for the bulk of the livestock ration. In places where animals once grazed over large areas covered by numerous native plant species, they now graze limited areas of lush pasture made up of just a few plant species. This trend results in a greater and more efficient production of animal products for human diets. But, it may inadvertently eliminate from the animal's ration some plant that has served as a particularly effective means of transferring some essential trace element from the soil to the animal. For example, the black gum tree of Southeastern United States is noted for its tendency to accumulate cobalt in its leaves. Animals that occasionally browse black gum trees or shrubs are likely to get an adequate supply of cobalt, even though the grasses that make up most of their diet are critically deficient in this element. When these animals are confined to a smaller, even though more productive, pasture with no black gums in it, the use of cobaltized fertilizers or feed supplements is required. So, as we move toward more intensified systems of animal production, based upon high yields of a limited number of plant species, special attention to insure that the ration still includes all of the essential elements is required.

New problems involving the interrelations of soils, plants, and animals will undoubtedly become critical in the future. The solution to these problems may require the application of new scientific information about soil chemistry, plant nutrition, animal nutrition, medicine, and other sciences. Some of the information that will be needed probably has not been developed at the present time. But, it appears very probable that this information can be discovered, the needed practices for crop production can be developed, and the future nutritional problems involving the soil-plant-animal chain can be solved, if adequate research programs are carried out.

Summary

Man and animals require a large number of different substances, each in proper balance with the others, for adequate nutrition and health. Many essential elements move along a food chain extending from the soil to the plant to the animal. Each of them moves along this chain in its own pathway.

The inherent characteristics of the soil and those acquired through use and management affect the composition and, at times, the nutritional quality of the plants that grow upon it. The effects of the soil upon the nutritional quality of plants cannot be explained through broad generalizations; they must be given for specific nutrients, soils, plants, animals, and diets.

Plants may grow normally and yet contain amounts of certain elements that represent critical deficiencies or toxic excesses for the animals that eat these plants. Some of these problems can be effectively countered by the addition of certain elements to the soil. In other cases, the direct supplementation of the animal's ration or injection of the animal with the proper material is more effective.

Fertilizers have played an important role in improving the nutrition of man. This role has been primarily one of helping to provide varied and abundant foods.

There is much about soil-plant-animal relations that is still unknown. A continuing search for new knowledge in this field can be an important factor in preventing malnutrition.

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