ONE BY ONE, new elements have been added to the list of those known to be necessary for plant growth and health. Some of these elements are needed in only a few parts per million of soil; yet without this trace, plants—and animals also—suffer from serious diseases. This is one of the most interesting fields of modern research in plant and animal nutrition. It is dealt with in this article, which closes with a reference list of so-called secondary elements and what is known about each of them in relation to the health of plants and animals.

Neglected Soil Constituents That Affect Plant and Animal Development

By J. E. McMurtrey, Jr., and W. O. Robinson

BECAUSE of its complex nature, the soil commonly contains small quantities of numerous chemical elements certain of which, in suitable compounds, are necessary in small amounts for plant and animal development. Frequently, however, elements that are essential at low concentration become toxic if they are available in slightly higher concentrations. Unusual soil constituents frequently occur naturally, or they may be added by man accidentally—and sometimes intentionally in controlling insects, rodents, weeds, or plant diseases—in amounts that are deleterious to plant development and to the animals feeding upon the plants.

The response of the plant or animal to a deficiency or excess of an element in the diet can most accurately be recognized and measured by the symptoms produced. The actual quantities involved are frequently so minute that routine chemical procedures are not sufficiently delicate to measure amounts that produce striking effects on the plant or animal organism. Recent careful study of the effects of these elements on growth has supplied the explanation of failures in plant and animal development previously attributed to unknown causes or, in some instances, erroneously to other conditions.

It is now generally admitted that for normal development plants require the following chemical elements in suitable compounds: Carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, boron, copper, and zinc. Animals may require all of these and in addition sodium, chlorine,

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1 J. E. McMurtrey, Jr., is Senior Physiologist in the Division of Tobacco and Plant Nutrition, Bureau of Plant Industry; and W. O. Robinson is Chemist in the Soil Chemistry and Physics Research Division, Bureau of Chemistry and Soils.
iodine, and cobalt. The quantities necessary for the normal development of plants or animals vary considerably. Those required in small quantities include iron, manganese, boron, copper, zinc, iodine, and cobalt. The members of this last group are the ones that commonly become toxic in slightly larger quantities than those required. Another group of elements that are toxic at relatively low concentrations includes aluminum, arsenic, barium, chromium, fluorine, lead, selenium, and thallium.

The elements present in plants and animals in very small quantities are commonly referred to as "rare," "trace," or "minor" elements. None of these terms is entirely suitable; most of the elements are in no sense rare, they do not occur in traces in all plants or soils, nor are the effects they produce on plant or animal development of a minor nature. There appears to be no completely satisfactory term that can be used to refer to this group of elements. The term "secondary elements" is used frequently in the following discussion to contrast this group with the primary group that includes nitrogen, phosphorus, potassium, and calcium. However, this use of the term is merely for convenience and is not to be construed to mean that they are of any less importance for normal plant and animal development.

The importance of the secondary elements to plant growth was not generally realized till early in the present century. The method used to demonstrate the necessity for them was to grow plants in media from which the elements under investigation were withheld. In such tests, however, the few parts per million of boron, zinc, manganese, etc., necessary for plant growth were frequently present as impurities in the water supplied, in the chemicals ordinarily used in preparing the nutrient solutions, in the sands, or in the containers. It was only by exercising the strictest chemical control in excluding traces of the elements under study that proof of the plants' requirements could be established.

Every few years a new chemical element has been added to the list of those that plant physiologists consider essential to plant growth. Early in the present century Gabriel Bertrand and coworkers announced that manganese, boron, and zinc are necessary for plant development. More than 20 years elapsed before this was generally accepted. A few years ago the same chemist announced that nickel and cobalt were present in all soils and plants, and that in plants these elements were concentrated in the leaves. He raised the question whether they are not really essential plant constituents. Nickel and cobalt occur in plants in the order of only a few parts per million.

The quantities of many of the secondary elements in plants are equivalent to only a few pounds per acre. This in terms of the soil is but a few parts per million, and since the soil is such a complex mixture of a great number of different minerals, many of which are of complex composition, it is only natural to suppose that the average soil would contain enough of the secondary elements to produce normal plant growth.

1 A general idea of the quantities of the secondary elements involved in plant growth is given by the following facts: An acre of soil to the depth of a foot weighs roughly 4,000,000 pounds. One pound of boron per acre has been recommended as a field application for tobacco. This is one-fourth part per million on the soil weight basis. If we assume an optimum moisture content of 20 percent and no absorption of boron by the soil, then there are 1\(\frac{1}{4}\) parts per million in the soil solution. Fifty pounds of nitrogen per acre often is a liberal application. This would result in a concentration of 62\(\frac{1}{4}\) parts per million of nitrogen in the soil solution.
However, even before the agricultural workers of this country devoted much attention to the presence of the elements required in small amounts in relation to plant growth, they began to notice that in many places certain crops gave poor yields and were affected by what are now known as deficiency diseases. Familiar examples of these are the sand drown of tobacco, the magnesium deficiency disease of potatoes in the highly fertilized soils of Maine and in the sandy soils of the Coastal Plains, the chlorosis of tomatoes on certain Florida marl soils, pecan rosette, and citrus mottle leaf.

The sand drown of tobacco has been found to be due to a deficiency of magnesium. If the soil contains less than 0.2 percent of magnesium oxide (MgO) the tobacco plant is liable to suffer from sand drown. The chlorosis of tomatoes on certain Florida soils can be cured by the application of a few pounds per acre of manganese; in fact, a light application of stable manure furnishes enough manganese to remedy the chlorosis. Pecan rosette and citrus mottle leaf yield to the application of relatively infinitesimal quantities of zinc.

Yellows of tea has been corrected by use of sulphur compounds. It has recently been shown that internal cork of apples, top rot of tobacco, cracked stem of celery, internal browning of cauliflower, and heart rot and dry rot of sugar beets can be controlled by the use of small applications of boron to the soil on which these crops are grown. Copper compounds have produced remarkable results, especially on peat soils and in correcting the permanent wilting of the upper leaves of the tobacco plant caused by copper deficiency.

In some cases soil deficiencies are not revealed by any effect on plant growth yet the plant is not being supplied with a sufficient quantity of some elements to produce a normal healthy growth of animals feeding on it. Among examples of this is the failure of cattle to develop normally when feeding on the products of the sandy soils of Florida, which do not supply enough iron and copper, or possibly cobalt, to the plant. In New Zealand, the lack of enough cobalt in certain soils causes the "bush sickness" of sheep. The abnormal occurrence of human goiter in parts of Switzerland and of Wisconsin, Minnesota, and Washington is due primarily to a deficiency of iodine in the soil.

History furnishes one very pertinent example that appears to give a sound precedent in the application of elements that are not necessary for plant growth but the lack of which causes deficiency diseases in animals. Nearly all vegetative growth is so deficient in both chlorine and sodium that both these elements must be taken with the food to create the hydrochloric acid of the gastric juice and to counterbalance the large excess of potassium ingested with the plant. This problem was unconsciously solved by the physiological craving for salt, and the deficiency is easily made up by merely supplying salt to the animal. In some cases where a particular secondary element is not directly needed for plant growth, it appears that the soil deficiency might best be corrected in the same way.

Sometimes a certain element may be present in the soil in abundance, but because it is not in available form plants or animals may suffer from the lack of that element. The unavailability may be due to the insoluble nature of the soil minerals containing the element in question.
In other soils the reaction, acid or alkaline, may be such that the element is not sufficiently soluble in the soil solution. For instance, the liming of the soil to the neutral point and beyond may cause chlorosis due to lack of iron or manganese. A very small quantity of zinc in an acid soil may be sufficient to prevent pecan rosette, whereas in a neutral soil many times more would be quite ineffective.

Deficiencies of the secondary elements, except of iodine in special cases, are not likely to occur in soils formed from the decomposition of granite and other igneous rocks. These soils contain a great variety of minerals in the sands and silts, and also generally contain a relatively large amount of fine clay—the soil-absorption complex, which has the property of retaining many of the elements in a form not readily washed out by percolating water but still available to plants.

Many soils, such as the very sandy soils of the Coastal Plain, contain very little of the absorption complex, and the sands and silts contain very few minerals other than quartz. These soils are likely to show deficiencies of secondary elements necessary for the normal development of plants and animals. Soils of volcanic origin such as those of the Hawaiian Islands and New Zealand may show deficiencies in a number of elements. Soils high in calcium carbonate may produce deficiency diseases owing to the fact that boron, iron, manganese, and perhaps other elements are rendered relatively insoluble by that compound.

It is evident that in the future more attention must be paid to soil deficiencies of all elements essential for normal development of plants and animals. Larger crops grown on highly cultivated soils are exhausting the reserves in all cases where the crops are removed from the soil. There is also another potent factor operating in the same direction. The commercial fertilizers applied to obtain larger yields are for the most part comparatively pure salts, which through the phenomenon of base exchange tend to displace the secondary elements in the soil and cause them to be used by growing crops or carried away in the drainage water. These commercial fertilizers are different from farm manure in that they do not ordinarily contain enough of the secondary elements to be of any significance. It is not unreasonable to believe that some small part of the increased yield following the application of commercial fertilizers is due to the increased availability of the secondary elements rather than entirely to the nitrogen, phosphorus, and potassium applied.

There is a tendency at present to use very concentrated salts as fertilizers to reduce carriage and application costs. With the use of these concentrated fertilizers the depletion of the elements not supplied may be more rapid. Most pronounced in this direction will be the depletion of the sulphur, magnesium, and calcium reserves in the soil. Heretofore very little attention has been paid, in the fertilization of lands, to sulphur and magnesium. The reason for this is that potash salts and superphosphate, which are the principal constituents of most commercial fertilizers, frequently contain magnesia and commonly calcium with more sulphate than phosphate. Thus a deficiency of calcium, sulphur, and magnesium has not occurred as generally as would otherwise have been the case. American soils contain, on the whole, less sulphur than phosphorus, but if other sulphates such as
ammonium sulphate and potassium sulphate are used in the newer concentrated fertilizers, no sulphur deficiency should occur.

While the continuous use of chemical fertilizers tends to deplete the essential elements not supplied to the soil, the use of stable manure, leafmold, wood ashes, and peat tends to conserve them. On dairy farms, a large part of all elements is returned to the soil, and the secondary elements contained in such concentrates as are purchased from the outside are therefore actually added to it. Leaf litter, leafmold, and wood ashes contain many of the elements taken from the forest soil in proportions desirable for the nourishment of the trees. The undesirable ones have been largely eliminated. Furthermore, the secondary elements in leafmold, particularly manganese, are in a very available form. In long-continued experiments at Woburn and Rothamsted in England it has been found that stable manure has maintained the fertility of the soil over much longer periods than has the use of chemical fertilizers containing nitrogen, potash, phosphorus, and sulphur. The numerous chemical elements contained in the manure are undoubtedly an important factor in this observed maintenance of fertility.

Many of the elements naturally occurring in soils are as undesirable as some of them are necessary. Our present information leads us to believe that selenium, thallium, fluorine, chromium, lead, and probably arsenic, are undesirable soil constituents even at the lowest concentrations.

In some instances elements are added to the soil in the form of spray residue or by direct treatment as, for example, the relatively heavy applications of lead arsenate to the soil of nurseries for the control of the Japanese beetle. The addition of lead and arsenic appears to be unqualifiedly undesirable from the standpoints of the maintenance of soil fertility and of safeguarding animal health. Variations in soil composition and reaction cause great differences in the toxicity produced by these elements, which will be explained later under the descriptions of the effects of the two elements in question. Copper and sulphur are frequently added to the soil in the form of spray residues. The quantities of both these elements added per acre are comparatively small and except in extreme cases would be beneficial rather than harmful. The long-continued use of sulphur without liming would, however, cause a considerable rise in soil acidity and result in the depletion of the soil bases.

The problem of the addition of secondary elements to commercial fertilizer is a complicated one and must be conservatively handled. The compatibility of carriers of secondary elements with other ingredients of the fertilizer mixture is to be considered. It will frequently be difficult to obtain a uniform mixture of the small amounts required. In many cases the chemical reaction of the clay or absorption complex, as well as the question of economy, will be a determining factor. Thus the addition of a pure manganese salt to a clay saturated with calcium will very soon result in the precipitation of insoluble manganese dioxide. A similar reversion to an insoluble form apparently occurs with zinc. Molybdenum and copper and other elements with similar properties have relatively insoluble sulphides. The presence of the sulphide ion in the soil may render these elements too insoluble to be of practical use.
Some of the secondary elements have very narrow ranges of concentration in which they are of use to plants. Boron is one of these. For many plants in water-solution cultures a few parts of boron per million are absolutely necessary for plant growth, while 20 or more parts per million are fatal to many plants. A familiar example of boron toxicity occurred during the World War when potash sources containing considerable borax were used in potato and tobacco fertilizers. In some cases as little as 30 pounds per acre resulted in greatly diminished yields, and applications in excess of 50 pounds killed the plants.

Although the search for unusual plant constituents is still in its infancy, it has developed that certain plants when grown in some environments concentrate one or another of these elements. Thus it has been found that the Australian silky oak, members of the *Symphlocos* genus (sweetleaf), the clubmosses, and hickory are notable aluminum-absorbing plants. According to spectroscopic determinations some mushrooms have been found to contain 0.01 percent of silver. In the Danube region in Europe the scouring-rush (*Equisetum palustre*) is reported to be a "gold digger." A certain violet absorbs so much zinc it has been named *Viola calaminaria* from the zinc-bearing mineral calamine. The woody aster and various species of *Astragalus* take up so much selenium that a few ounces of the dry plant are a lethal dose for sheep. Other instances might be cited. As the study progresses, doubtless many other plants with voracious appetites for unusual elements will be discovered.

It has been reported, but is as yet unconfirmed, that barium is concentrated in the eyeballs of animals, zinc in the reproductive glands, bromine in the pituitary body, and cobalt and nickel in the pancreas. The same authority reports that boron is concentrated in the pistils of flowering plants.

The lack of accurate information on the content of secondary elements in soils and plants and the effect of small quantities of these elements on animal and human health constitutes an important problem for further research.

A REFERENCE LIST OF THE SECONDARY ELEMENTS AND THEIR RELATION TO PLANT DEVELOPMENT

In the following pages the importance of individual chemical elements will be discussed from the viewpoint of their effects on plant and animal development. For convenience of reference they will be treated in alphabetical order.

**Aluminum**

Aluminum oxide, in combination with silica and water, forms the clay of the soil. Next to silicon it is the most abundant of the soil mineral constituents. Aluminum in combination in the soil is the least soluble of the major soil elements and is one of the main constituents of lateritic soils, which represent the end product of the soil-leaching processes. The solubility of aluminum in the soil is profoundly affected by the presence of other ions. Of these the hydrogen ion is of the most importance and the phosphate ion probably ranks next. Only the very acid soils have a sufficient concentration of hydrogen ions to dissolve

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3 See *Formation of Soil*, p. 948.
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significant quantities of aluminum hydroxide, but the reactions occurring in the soil are not so simple as those studied in the laboratory, and in the presence of the complex forms of organic matter in the soil much alumina is probably held in solution at hydrogen-ion concentrations that would completely precipitate pure aluminum hydroxide.

There is some doubt as to whether aluminum is essential to plant growth. Plants vary greatly in alumina content. In general the greatest concentrations are found in the roots. In the leaves the element is generally present as a few hundredths of 1 percent of the dry weight, and will average somewhat higher than iron. Like iron, zinc, and manganese, aluminum in the leaves follows the concentration of the chlorophyll, being much greater in green than in blanched or chlorotic leaves.

Some plants appear to be specifically aluminum-loving. A sample of sweetleaf (Symplocos tinctoria) contained 4.54 percent of alumina. Hickory and tea leaves growing on acid soils contain nearly 2 percent, and on limestone soils that are alkaline in reaction hickory leaves have been found to contain 0.25 percent. Parts of other plants, such as barley hulls and barley grains, contain as much as 0.5 percent.

Plants growing on acid soils have more alumina than the same kind of plant on neutral or alkaline soils. In fact, the toxicity of very acid soils has been ascribed to the soluble or active aluminum present. The element is toxic at low concentrations in water cultures.

The addition of acid calcium phosphate, or superphosphate, has a beneficial effect on soils that are already acid. Although the acidity of the soil is increased, the beneficial action may be due in part to the precipitation of the soluble and toxic aluminum and manganese as phosphates of low solubility.

Although some workers have reported that aluminum is essential for normal growth and development of plants, there do not appear to be any deficiency diseases reported as due to the lack of this element. On the other hand, some root rots are ascribed to the presence of excessive quantities. Aluminum sulphate has found some use in France as a catalytic fertilizer for over 20 years, and limited use has been made of it in the growing of such acid-loving plants as rhododendrons, azaleas, and blueberries. It has also been used to change the color of hydrangea flowers, which are normally pink on neutral soils but turn blue when sufficient aluminum sulphate or other acid-producing material has been added to the soil.

Antimony

Antimony has not been reported as occurring in plants or soils. It has been found less toxic to plants than arsenic. The use of considerable antimony potassium tartrate to control certain insect pests on citrus trees may possibly bring up a spray-residue problem similar to that of lead and arsenic.

 Arsenic

Arsenic is present in all soils, varying from a few tenths of 1 part to over 500 parts per million. Most soils contain less than 10 parts. It is widely distributed in plants, from a barely detectable quantity to as much as 10 parts per million. Barley grown on western orchard soils that have accumulated considerable arsenic from sprays has been found to contain as much as 13 parts per million in the leaves and over 1,200 in the roots.

The addition of large quantities of arsenates to the soil directly or indirectly in the control of insect pests has caused a distinct arsenic problem in the Cotton Belt, in areas infested with the Japanese beetle, and in some commercial fruit orchards.

In soils in general there is no relation between the quantities of total and water-soluble arsenic. The quantity of water-soluble arsenic in natural soils and in soils to which arsenates have been added is dependent upon two things—the reaction of the soil and the quantity and nature of the clay or colloidal matter. The addition of small quantities of arsenates to acid sandy soils will give rise to such a high concentration of water-soluble arsenic that legumes will not grow. Very much larger applications fail to inhibit the growth of legumes on soils of heavier texture, especially if the clay contains an abundance of iron. In some of the western orchards it has been found that arsenic has not been leached below the depth of plowing in some 20 years. On the acid New Jersey Podzols, however,
considerable arsenic leaches or is carried from the surface to the subsoil in 1 year. In the latter soils it would appear that arsenic would be leached out by natural processes covering a period of years, while in the former it would continue to accumulate in the surface soil.

Some nitrifying bacteria are stimulated by the presence of small quantities of soluble arsenic in the soil. In higher concentrations it is poisonous to nearly all plants.

It is doubtful if it would ever be desirable to apply arsenic as a soil amendment. The problem is rather to get rid of the arsenic that has been applied as sprays or insecticides, or to render it noninjurious. For the latter purpose the addition of lime to decrease the acidity or the application of hydrated ferric oxides appear to be the only practical remedies.

**Barium**

In small amounts barium is present in all soils and in all plants. Quantities present in soils vary from a few thousandths of 1 percent to as much as 3.68 percent of barium oxide (BaO) (in a special soil in the vicinity of a barite mine). Only small quantities find their way into plants; tobacco has been found to contain as high as 0.15 percent and alfalfa 0.14 percent.

Barium is poisonous to plants at low concentrations. In the presence of calcium carbonate, however, considerable concentrations may occur in the soil solution without rendering the soil markedly infertile. Barium replaces other bases in soil colloids very energetically. For this reason nearly all soils contain small quantities of exchangeable barium notwithstanding the fact that there is a low concentration of barium in the earth's crust. In some soils there is so much exchangeable barium that it would seem to interfere with the absorption of sulphate by the plants through the formation of insoluble barium sulphate.

The quantities of barium taken up by the plant even from a soil high in barium are so low that there is little likelihood of animals being poisoned by eating the plant. The cattle poisoning in certain Colorado pastures that was once thought to be due to barium has been found to be due to alkaloids or to selenium.

**Beryllium**

Beryllium has been found in small quantities in plants growing on the island of Elbe in soils containing beryl. It has also been found in spectroscopic traces in the ash of hickory leaves growing on ordinary soils.

The characteristic beryllium mineral is beryl. That this mineral is very resistant to decomposition by the soil-forming processes is proved by the high content of beryl in soils formed from pegmatite veins. Small quantities of beryl are widely distributed in granites and it is probable that granite also contains small quantities of beryllium in other forms. It would seem that clay from granite soils should generally contain some beryllium, but this has not been demonstrated. Beryllium so much resembles aluminum that it is most difficult to determine small quantities of one in the presence of large quantities of the other.

Beryllium in very low concentrations is toxic to citrus cuttings in solution cultures.

**Boron**

Boron, from the standpoint of agriculture, is unique among the chemical elements in that very small quantities are necessary for the normal growth of many, if not all, plants and only slightly higher concentrations cause injury. With a number of plants the range between these two levels in water culture is only a few parts per million.

Boron is present in quantities up to 200 parts per million in all normal, healthy plants. Orchard-grown citrus leaves suffering from boron injury may contain in excess of five times as much. There are very few reliable data on the boron content of soils for the reason that the analysis of soils for the very small quantities of boron they contain is a very difficult matter. Tourmalines, which normally contain about 10 percent of boron, are universally present in soils, though commonly in very small quantity, and judging from their permanence they must be nearly insoluble.

It has recently been shown that internal cork of apples, top rot of tobacco, cracked stem of celery, heart and dry rots of sugar beets (fig. 1), and similar physiological diseases of plants are due to a deficiency of boron. These names
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indicate the dominant symptoms that characterize the disturbance to growth of the crop in question. The actual quantity of boron that must be supplied on soils where the element is deficient in order to produce normal growth varies with the method of application, the season, the soil, the source of the boron, and the crop. However, the quantity should be small—in the case of tobacco, for example, about 1 pound per acre in soluble compounds with applications immediately adjacent to the plant. With celery and beets the quantity necessary may be greater. It has been reported that boron will sometimes correct injuries to alfalfa and other field crops due to overliming.

Certain European workers have pointed out that heart rot and dry rot of sugar beets are more prevalent on alkaline soils, possibly owing to the fact that certain borates are relatively insoluble, especially those of magnesium.

![Figure 1](image1.png)

**Figure 1.**—Effects of boron deficiency on beet roots: *A*, Normal root; *B*, root showing heart and dry rots due to boron deficiency; *C*, section of beet root showing early stage of heart rot due to boron deficiency. (Photos by J. E. Kotila and G. E. Coons, Bureau of Plant Industry.)

It is also important to keep in mind the fact that relatively small quantities of boron become toxic under certain conditions. A few years ago, potash salts containing boron in amounts harmful to plant growth were used as fertilizer and caused damage to crops. Irrigation water occasionally contains boron in amounts toxic to plants. Considerable damage to citrus crops in California was caused by irrigation water containing more than one-half part per million of boron.

The specific effects of boron on the growth of tobacco plants are shown in figure 2. The symptom characteristic of boron deficiency may be best understood when considered as developing in progressive stages. First, the young leaves composing the terminal bud exhibit a light-green color, the bases of the individual leaves being of a lighter green than the tips. When this condition develops, the bud leaves cease to grow and manifest a drawn appearance. Following this, the tissue at the base of the young leaves breaks down and becomes brownish to black. The final result of this stage is the death of the terminal bud, but sometimes the disturbance does not progress so far and the young leaves make later growth, in which case they may be distorted or notched by twisting to one side because of the growth around the injured tissue. The stalk toward the top of the plant
also may show a one-sided or twisted growth. If the boron deficiency is not too extreme, the lateral buds (suckers) may develop in the axils of the leaves or at the base of the stalk, but they generally break down as described above. The automatic topping of the plant produced by death of the terminal bud results in a thickening and increase in area of the leaves. The upper leaves tend to roll in a half circle downward from the tip toward the base, becoming glabrous, stiff, and brittle, and when the midrib is broken the vascular tissue shows discoloration. The element boron appears to function in terminal growth or meristematic tissue development, since those are the parts of the plants that first manifest abnormalities resulting from a shortage.

The occurrence of boron in irrigation waters and the deposits of borax occurring in the evaporated residues of surface soil water in some arid regions indicates that boron is not absorbed and held by the soil colloids. Additional evidence of this is the fact that a very slight application of borax over that needed by the plant causes injury. In this respect boron is quite different from copper and zinc, which are absorbed by soil colloids.

The inclusion of small amounts of boron in fertilizer mixtures would appear to be a desirable practice in many areas where field and orchard crops have been found to manifest symptoms of shortage of the element. Compounds of this element are compatible with the salts that are commonly used in fertilizer mixtures. Sodium tetraborate (borax) has been found by test to be a suitable source of the element. For some experimental work boric acid and borosilicates, finely ground, have been found to be good boron sources.

The application of such a small quantity as 1 pound per acre requires careful grinding and mixing with the regular fertilizer to insure even distribution.
Bromine

Bromine appears to be generally present in quantities of the order of a few parts per million in plants and soils. Raw German potash salts contain considerable bromine. This element supplied to plants in the form of sodium bromide shows no immediate ill effects, but later in the life of the plant the effect is quite serious. The clay of ordinary soils does not retain bromine and it would be quickly leached from the soil.

Cadmium

Very little is known of the effect of cadmium on plants or of its occurrence in soils. It is one of the very few elements that have not been reported in plant ash. Possibly the attention that is being given zinc agriculturally may result in increasing our knowledge of cadmium, which resembles zinc in many ways.

Caesium

This rare alkali has been reported in a few plants and soils in spectroscopic traces. Beyond these facts there is very little known about caesium in relation to plant growth. The caesium mineral pollucite occurs occasionally in pegmatite veins and there is a possibility that in rare cases soil masses contain notable quantities of caesium. It behaves much like potassium, and like that element it is probably absorbed and retained in the soil clay. Although this element resembles potassium it cannot be substituted for potassium to produce normal plant growth.

Chlorine

Chlorine is found in all soils and plants. A few plants, such as buckwheat, seem to require chlorine for complete development, but it is not considered essential to plant growth in general. The quantities found in soils of humid regions are generally small. In the so-called alkali soils of semiarid and arid regions crusts of various chlorides may accumulate. Chlorine is not retained by soil colloids and is easily leached out by rain water.

Plants vary a great deal in chlorine content. This element seems to act as a vehicle to carry various bases in solution into the plant. Complications resulting from this action are probably responsible for the differences of opinion as to the fertilizing value of chlorine. Plants fertilized with chlorine salts may contain several percent of chlorine, though in general plants are so deficient in sodium chloride that it is necessary for herbivorous animals and man to take considerable salt. The animal needs the chlorine of common salt as the source of hydrochloric acid in the gastric juices. Excesses of chlorine are harmful to plant growth, but small amounts have been found to protect the plant from excessive drying during drought periods. The relationship of the chlorine content of cured tobacco to the fire-holding capacity of the leaf is well recognized. When the cured leaf contains any considerable quantity of chlorine the fire-holding capacity is lowered.

Chromium

Chromium is present in all soils and in all plants. Except in some soils formed from serpentine and other ferromagnesian rocks, the quantities are very small, of the order of a few thousandths or a few hundredths of 1 percent. However, in some of the serpentine soils of Puerto Rico more than 5 percent of chromic oxide has been found, and many of the “poison spots” in Josephine County, Oreg., contain as much as 2 and 3 percent of chromic oxide.

The quantities found in plants are very small, generally at most only a few parts per million.

Chromium salts, in very small concentrations, have been found toxic to plant growth, and chromium in the form of chromates is particularly toxic. Attempts to use the spent liquors resulting from chrome tanning of leather showed these products to be very toxic. When applied to high lime soils or used in conjunction with much lime the toxic effect was largely nullified.

At least two forms of chromium occur in the soil. One form is the mineral chromite, a very insoluble ferrous chromite. This is very inactive and except in
the very acid soils should have little deleterious effect. The other form, which appears in the colloidal matter or clay, probably is isomorphous with the oxides of aluminum and iron, and becomes soluble in the same soil conditions that dissolve alumina and iron oxide.

Agriculturally, chromium must be considered a deleterious element. No plant or animal diseases due to lack of chromium have been reported, and except for the universal occurrence of minute quantities in plants there is no evidence that even small quantities of chromium are of use to plants.

Several instances of industrial chromium poisoning have been reported and some Canadian investigators have found human tumors that contained chromium.

The relatively high percentage of chromium in the soils of the Conowingo barrens and in other soils formed from high ferromagnesian rocks is at least a prominent cause of the infertility of such soils.

**Cobalt**

Cobalt occurs in most soils in quantities ranging up to 10 and 15 parts per million. In various plant leaves the cobalt content may be as high as 2 or 3 parts per million.

Plants do not seem to suffer from the lack of even very small quantities of cobalt. In water cultures small quantities have been found to be stimulating, but in larger concentration the element is toxic, producing effects resembling manganese deficiency.

In New Zealand it has been found that sheep suffer from a lack of cobalt in the natural vegetation in soils having less than 2 to 3 parts per million of the element. When cobalt in the soil exceeds 5 to 10 parts per million the plants take up enough to produce normal growth in the sheep. It is probable that cobalt may be a factor in certain cattle deficiency diseases in Florida that are now thought to be due to lack of iron.

**Copper**

Copper apparently occurs in all soils, ranging from about 1 to over 50 parts per million in normal agricultural soils. It is found in plants up to about 100 parts per million. It is especially high in some seeds and, according to spectroscopic determinations, in some mushrooms.

Copper is absorbed with considerable avidity by the clay acids, but this absorbed copper is easily replaced by some of the other bases. In fact, the use of copper salts has been proposed to determine the base-exchange capacity of soils. The relatively large applications of copper sulphate, 30 to 200 pounds per acre, that have been used to produce normal plant growth on marsh soils is a practical illustration of the absorptive capacity of the soil for copper. The presence of copper in sea water and in oysters and other sea food indicates that it is leached from the soil. On the other hand if the sulphide ion be present in soils, copper will tend to be retained as a nearly insoluble sulphide. It is not impossible that the observed beneficial use of copper salts is due in some cases to the precipitation of the sulphide ion.

Copper compounds function in plant nutrition. It has been recently found that the dieback of citrus can be remedied by applications of copper salts. The yellow tip, or reclamation disease, on the marshy soils of Europe has been corrected by copper, and in Florida and New York it has been found necessary to apply 25 to 50 pounds of copper sulphate per acre to soils high in organic matter before lettuce and other plants can be grown successfully. Abnormalities in the growth of many plants produced on peat soils have been corrected by the use of copper compounds.

It is possible to demonstrate the effect of copper on growth of plants by using the solution-culture method. For this, pure chemicals containing little or no copper are necessary, and the water used in the preparation of nutrient solutions must be redistilled to free it from traces of copper. Special containers for growing plants must be used to avoid contamination by copper compounds. Tobacco grown under these conditions with and without copper shows striking effects (fig. 3, A and B).

The plants grown without copper have a characteristic appearance. The upper leaves are unable to maintain their turgor and consequently wilt badly. These plants are permanently wilted and do not regain moisture during the night or in cloudy weather as does a plant that has wilted during a hot day. Growth
is reduced in proportion to the degree of shortage of the element and the stage of growth at which the element is withdrawn. When copper was the limiting growth factor during the flowering stage, it was observed that the amount of seed set was reduced and the seed stalk was unable to stand erect.

The copper necessary to correct the effect in nutrient solutions varied from one-sixteenth to one-eighth part per million. Amounts much in excess of these produced a decided stunting of plants. The quantities of copper that have been used on soils to correct the above-described conditions are relatively large—from 30 to 200 pounds of copper sulphate per acre. These soils have a high fixing power for copper compounds so that heavy applications are necessary to produce the desired effect, although small applications of copper as dust or spray have also produced striking results. So far as available experimental evidence indicates, the action of copper compounds is not beneficial on soils other than peats or mucks.

It has been reported that copper sulphate will cure a curious form of soil infertility caused by overliming. The action of the copper in this case is obscure.

In animal metabolism copper is necessary in addition to iron to form the hemoglobin of the blood. Certain counties in Florida produce pasture grass so deficient in both iron and copper that cattle fed on it will not mature normally.

The inclusion of copper compounds in all standard fertilizer mixtures would not appear to be justified until further experimental evidence is available indicating that this element is deficient in a wider variety of soils. Soluble copper compounds would not appear to be compatible with soluble phosphates since cupric phosphate is relatively insoluble.

Figure 3.—Effects of mineral deficiencies on growth of tobacco: A, Normal tobacco plant grown in nutrient solution with copper added; B, tobacco plant grown in nutrient solution without copper; C, in sand culture without manganese; D, in sand culture without iron; E, normal tobacco plant grown in sand culture with complete nutrient solution added; F, in sand culture without zinc.
Fluorine

Small quantities of fluorine are found in plants, but the element is not generally considered essential to plant growth. In soils fluorine has been found in quantities ranging from traces up to 0.15 percent. Mica and tourmalines, both of which may contain up to 1 percent of fluorine, are present in practically all soils.

In some cases small quantities of fluorides have proved stimulating to plant growth.

Fluorine probably does not act like chlorine in the soil. The predominating basic ion in the soil is calcium, and since the solubility of calcium fluoride is but 16 parts per million in water, it is doubtful if the fluorine in its maximum concentration in the soil would exceed 8 parts per million, which is the amount of fluorine in a saturated solution of this salt.

Florida and Tennessee phosphate rocks contain from 3 to 4 percent of fluorine, and about three-quarters of this is retained in fertilizers made from these sources. Considerable fluorine is therefore added to soils fertilized with commercial fertilizers.

Fluorine in drinking water in excess of 1 to 3 parts per million, according to different authorities, causes mottled teeth and other physiological disturbances in animals. The effect of higher concentrations of fluorine in plants used as food for animals and man is not known. Experimental work with rats has shown that 14 parts per million of fluorine in the diet interferes with the normal development of teeth. It would appear best to reduce to a minimum the quantity of fluorine applied with commercial fertilizers. The use of fluorine compounds as insecticides is growing, and in years to come the quantity of fluorine added to soils through this source may be considerable.

Germanium

Very little information on germanium is available. Spectroscopic traces occur in the ash of marine plants, and it has been found that barley plants will take up this element. Germanium occurs in spectroscopic traces in a number of minerals. Topaz is practically never without some small quantity of germanium. The element also occurs in many zine blends.

Gold

Gold is widely distributed in nature, mostly in very minute quantities. It has been reported that sands from the banks of the river Danube in south Slovakia contain about 0.1 gram of gold per ton, and plants growing on this sand are able to accumulate gold. The ash of corn grains contained 0.0002 percent, and the ash of Clematis contained 0.06 percent gold. The whole plant of scouring-rush accumulated gold to the extent of 610 grams per ton of ash. The metal is said to be concentrated in the seeds of the flowering plants.

Iodine

Iodine is unique among the elements occurring in the soil in small quantities in that a deficiency has been discovered to be of importance not by its effect on plant yields but by its effect on man and domestic animals.

The recognition of the importance of iodine in the diet for the control of certain types of human goiter has been one of the outstanding developments in recent medical science. There is a high incidence of goiter in certain regions of the world; notable among these are parts of Switzerland and of the States of Wisconsin, Minnesota, and Washington. This high incidence of goiter is associated with a very low iodine content of the soil. Soils of such regions are generally quite acid, and the highly leached clay they contain does not possess the power of anion retention, so that even the small quantities of iodine that were present in the geological strata are leached out by the percolating water. These soils may contain only a few parts per billion of iodine—not enough to grow plants with sufficient iodine to prevent goiter.

The birth of hairless pigs has been caused experimentally by feeding brood sows diets low in iodine and prevented by supplying iodine compounds. Goitrous conditions have been induced in calves experimentally by feeding rations low in iodine.
Soils developed from limestone in humid regions and those near the seacoast usually contain sufficient iodine to prevent goiter.

In some cases the application of small quantities of iodine to the soil has resulted in a slight increase in crop yield, but the main value of such additions would seem to be the increase of iodine in the leafy parts of plants that may supply the element to man directly or through meat, poultry, and dairy products.

Since iodine is so easily leached from the soil, large, infrequent applications are not as desirable as small applications made to a particular crop. Iodine is contained in many commercial soil amendments in considerable quantity. Among these are dried fish and Chilean nitrate. Seaweed contains much iodine as well as other desirable elements.

Iron

Iron has long been recognized as essential to normal plant development. In fact, it was the first of the secondary elements under discussion to be recognized as indispensable to plant growth under field conditions. Iron is directly connected with the functioning of the chlorophyll. In the leaves of healthy plants iron will average a few hundredths of 1 percent, the amount never varying greatly. The iron content of plants is relatively constant compared to that of manganese and aluminum.

Although there is an abundance of iron in nearly all soils, the exchangeable iron in calcareous and other soils around the neutral point may be so low that the plants are unable to absorb enough for healthy growth. Besides the iron of the undecomposed silicate minerals in the soil, there are two other general forms, the iron of the colloidal clay or absorption complex, and iron in the form of oxide, both hydrated and anhydrous. The iron in the colloidal clay behaves much the same as aluminum.

The solubility of iron in the soil is governed by the reaction of the soil, the element being comparatively soluble in very acid soils, and also by the prevalence of oxidizing and reducing conditions. Iron in the form of hydrated iron oxide, particularly, is easily reduced under some soil conditions and remains in solution as ferrous bicarbonate. The submerged soil conditions that occur during very wet weather are favorable for the solution and transportation of iron in the soil solution, and in extreme cases the concentration of iron may exceed the toxic limit. Deep-rooted plants would appear to have considerable soluble iron at their command, for the zone of submergence is above the permanent water table many times during the year.

The addition of any reducing organic matter such as crop residues and stable manure increases the supply of available iron in the soil. The iron is temporarily reduced and made soluble, and the complex ions formed with the organic matter hold the iron, even after oxidation, in solution at pH concentrations that would otherwise precipitate ferric hydroxide.

The distinctive chlorosis (fig. 3, D) resulting from a shortage of iron was early recognized and was for a long time considered to be the only type of chlorosis in plants.

It has been reported from Hawaii that soils of high manganese content do not furnish sufficient available iron for normal plant development. The most effective method found for correcting this condition is the application of iron as a spray. With pineapples the quantity to control chlorosis may be four applications a year of an 8-percent solution of ferrous sulphate.

The crops grown on some Florida soils are so deficient in iron that cattle fed only on these crops show marked iron-deficiency diseases.

Soluble iron compounds are not compatible with soluble phosphates in fertilizer mixtures since they form insoluble compounds that are largely unavailable to plants. Soils having considerable iron in an unavailable form could be treated with acid-forming fertilizers such as ammonium sulphate or elemental sulphur to increase the acidity. Liberal applications of organic matter also increase the availability of the iron. Overliming is productive of chlorosis, and with plants susceptible to iron chlorosis lime should be sparingly used.

Lead

Lead in very small quantities is of general occurrence in plants and soils. Normally the quantities in edible plants or parts thereof are so small as to have no effect on the health of the animal eating the plant. However, the accumulation
of lead in the soil from spray residues may be of sufficient magnitude in some soils to raise the lead content of food plants to a dangerous point. Lead is a cumulative poison, and small quantities that by themselves cause no harm become dangerous when taken constantly.

Lead is "fixed" by the clay of the soil, and it would appear that the sulphate, sulphide, phosphate, and carbonate ions should render lead added to a normal soil so insoluble as to be inactive. Very acid soils, however, would increase the solubility of the lead. In some Oregon orchard soils it has been found that lead has not been carried down below the plow depth after the orchards had been sprayed for 20 years with lead arsenate.

Soluble lead compounds are toxic to plants except in very low concentrations, at which in some cases they seem to have stimulated growth. In some commercial apple orchards the residues from lead arsenate sprays have accumulated to such an extent that green manuring crops can no longer be grown. It is supposed that arsenic is chiefly responsible for this condition, though lead may be a contributing cause.

**Lithium**

Lithium occurs in plant ash almost universally but in very small quantities. In soils the quantities present have been found to vary from a spectroscopic trace to over 100 parts per million in ordinary agricultural soils.

Some field experiments show that very small applications of lithium salts are frequently stimulative; larger concentrations have proved toxic. Tobacco and potatoes are less susceptible to injury by lithium than many other crops. Lithium when applied in any considerable quantity to the soil in the form of soluble salts produces toxic effects on tobacco resulting in well-defined spotting of the lower leaves.

Many lithium minerals occur in pegmatite veins. Since these characteristic lithium minerals appear to alter or weather easily, it is doubtful whether many soils will contain more than a trace of this element. Tourmaline, however, which may contain as high as 1.5 percent of lithia, is quite resistant. Lithium appears to act in the same manner as sodium toward the soil colloids and is not absorbed like potassium.

**Magnesium**

Magnesium is essential to plant growth. It is a part of the chlorophyll molecule. Chlorophyll contains slightly less than 4 percent of magnesia. As a rule healthy plant leaves contain about 0.5 percent of magnesia.

Surface soils generally contain less than 1 percent of magnesia, though special soils derived from serpentinite have been found to contain more than 30 percent. A large part of the magnesia of soils is found in the colloidal fraction, and only about one-fourth or one-fifth of this is in the exchangeable or soluble form. A variable quantity of magnesia is in the hornblendes, micas, etc., of the sands and silts. A very few soils contain fragments of dolomite, a double carbonate of magnesium and calcium. One very unique soil from California contained magnesium carbonate.

One of the first deficiency diseases noticed in the field was the sand drown of tobacco. Sand drown was first recognized and reported in 1922 by Garner and coworkers. This is definitely a magnesium deficiency and generally occurs on the sandy Coastal Plain tobacco soils, which contain less than 0.2 percent of magnesia. A magnesium-deficiency disease of potatoes has also been found on the sandy Coastal Plain soils and on the highly fertilized potato soils of Maine where the fertilizer used contains much lime and little or no magnesia.

Plants develop a characteristic chlorosis when the magnesium supply is insufficient. The lower leaves of the plant are the first affected. The grasses, represented by the corn plant, manifest a streaking due to the loss of chlorophyll between the veins at the leaf tip and margins. Tobacco and other plants also manifest a loss of green color between the veins beginning at the leaf tip and margins. With cotton, this loss of green is followed by the development of a red color.

Soils containing a large excess of magnesium over lime have been found to be infertile. This has been explained as the result of an unfavorable ratio of lime to magnesia where the magnesia is in excess. The explanation is not entirely satisfactory, however, for a paucity of potash and phosphoric acid and a relatively great concentration of toxic elements, such as chromium, nickel, and cobalt, apparently always accompany an excess of magnesia.
Kainite and other potash-bearing salts contain considerable magnesia, and when these salts are used in fertilizers in sufficient amounts, no magnesium deficiency should occur. Magnesium limestones are commonly used as a soil amendment to supply magnesia. Water-soluble magnesium compounds that furnish 10 to 40 pounds of magnesium oxide per acre have been found to be adequate on soils deficient in magnesium, but larger quantities of magnesium limestone are necessary.

**Manganese**

Manganese is a common constituent of soils and plants, the quantities present in both varying greatly. In many soils and plants, manganese is a major element. Certain Hawaiian soils contain as much as 15 percent of manganous oxide, and some soils in the United States contain several percent. Some plant leaves contain as little as a few thousandths of 1 percent, and a number of tree leaves growing on very acid soils contain nearly 0.5 percent.

Defects in analytical methods are responsible for many misconceptions concerning the agricultural role of manganese. The old bromide method is not reliable, for it permits considerable manganese to escape detection, but the colorimetric method now almost universally used is quite accurate.*

Some soils contain only a very small quantity of manganese; others containing much manganese may have it in an unavailable form such as the very insoluble dioxide. The latter condition obtains in alkaline soils such as marls and calcareous soils, and in any soils immediately after heavy liming.

There is no correlation between the total manganese in soils and in the plants growing on the soils. The availability of the manganese is governed rather by the acidity and the reducing action in the soil than by the quantity present. White oak leaves growing on an acid podzolized soil of 0.004 percent of manganese oxide content took up 0.308 percent of manganese oxide, while the same kind of leaves on a limestone soil with 0.23 percent of manganese oxide took up but 0.020 percent. The exchangeable manganese of forest leafmold commonly equals and sometimes exceeds the exchangeable calcium.

The manganese in soils containing organic matter becomes very soluble when these soils are submerged for relatively short periods. Under these conditions the concentration of soluble manganese greatly exceeds the limits that have been found toxic to plants.

The recognition that manganese is an essential element for normal plant development has been confirmed by numerous investigators in the past few years. The gray speck of oats has been attributed to a shortage of this element in some soils. It has been found possible to cure the chlorosis of tomatoes and produce a normal growth on the calcareous soils of Florida by applications of manganese. Pahala blight of sugarcane in Hawaii appears to be correlated with a manganese deficiency. The characteristic effects of manganese shortage on the growth of tobacco plants are shown in figure 3, C. Considerable dwarfing is usually evident, and associated with this is a chlorosis of the upper leaves on the plant followed by a necrotic spotting, the tissue of the spots frequently dropping out. Essentially these same symptoms have been reported on tomatoes, beans, and oats.

The quantity of manganese that must be supplied on soils to correct the effects of shortage may vary, but additions of 25 to 50 pounds of manganous sulphate per acre have resulted in remarkable increases in crop yield on certain soils. Some of the variations are undoubtedly due to differences in the reaction of the soil. On acid soils, injury to tobacco by excessive quantities of manganese has been noted. It appears desirable that soluble compounds of manganese be applied separately and not in fertilizer mixtures containing soluble phosphates, since phosphates of this element are only slightly soluble.

Rations carefully freed from manganese produce a condition in test animals that seriously interferes with normal lactation. Bone deformities, resulting in a

* Unfortunately the bromine method is now seldom used, but the literature, particularly on the ash composition of plants, contains considerable data obtained by this method. In this old method the manganese is precipitated by boiling the slightly alkaline filtrate from the iron group precipitation with bromine water. The entire quantity of manganese in the plant may escape precipitation, and if the iron group is not carefully precipitated some manganese is lost with it. No plant has yet been analyzed by the colorimetric method that has not shown the presence of some manganese. With this method no group separations are made and the determination is made on a separate sample or aliquot part of the solution of the whole sample. All the manganese is oxidized by powerful oxidizing agents, such as sodium bismuthate, ammonium persulphate, or potassium periodate, to purple permanganic acid. The quantity of manganese present is determined by comparing the depth of color with a known quantity of manganese in the form of permanganic acid.
condition known as "slip tendon," have been produced in chickens by feeding rations low in manganese. Bones of chickens on this ration have been found to contain only about one-third as much manganese as normal chicken bones.

Molybdenum

Molybdenum has been found in very small quantities in a number of plants. In chickpea seeds as much as 9 parts per million has been found; in other legume seeds it ranges from this amount down to 1 part per million. In other plants, molybdenum appears to be present in quantities of less than 1 part per million. A few soils have been reported to contain a trace of molybdenum.

Small quantities of sodium molybdate greatly stimulate the nitrogen-fixing power of soils, and in an experiment recently carried out at Ithaca, N. Y., molybdenum gave the greatest increase in growth of some 35 trace elements tested. Molybdenum has been found to be toxic to some higher plants when present in any considerable concentration.

In Wyoming it has been found that wheat takes up molybdenum when sodium molybdate is added to the soil in which it is grown and that the wheat grains so grown are poisonous to cattle.

Nickel

Nickel is present, generally in minute quantities, in all soils and probably in all plants. The comparatively recent discovery of a specific organic precipitant for very small quantities of nickel, dimethylglyoxine, has made it possible to determine minute quantities of this element with accuracy.

Several soils derived from ferromagnesian rocks have been found to contain nearly 0.5 percent of nickel oxide. The quantities found in normal soils, however, will range from a few parts per million to a few thousandths of 1 percent. Plants seldom contain more than 2 or 3 parts per million.

In all but the most minute concentrations, nickel is toxic to plant growth, and the waste waters from mines where nickel ores are crushed have been the cause of serious complaints from neighboring farmers.

Nickel would appear to be one of the causes of infertility observed in soils formed from high ferromagnesian rocks.

From an agricultural standpoint, nickel may be considered a deleterious element. No deficiency diseases are now known to be due to a lack of nickel, and if future research should show that very minute quantities are necessary to plant growth, all soils, with the possible exception of very sandy leached soils, should contain enough of the element to supply plant needs.

Radium

Considerable work has been done on the effect of radium on plant growth. While some stimulation in growth has been reported as resulting from the application of radioactive wastes to soils, the consensus of opinion is that such applications are without desirable effect. These applications of radioactive residues increase the radioactivity of the soil to an inconsequential degree compared to the natural radioactivity, so that no increase in yield could be expected.

Exposure of seed to radium emanations, if not continued too long, hastens the maturity of the plant after germination. Some commercial success has been obtained by treating sweet corn seed with similar emanations from electrical sources for regions in which the growing season is short.

Rubidium

Rubidium closely resembles potassium and probably enters into much the same reactions in soils and plants as that element.

Rubidium can be detected spectroscopically in all soils and in all plants. The quantities present range from spectroscopic traces to several hundredths of 1 percent. Soils developed from pegmatite veins may contain relatively large amounts of rubidium, and on such soils plants will contain considerable quantities of this element.

Rubidium is probably absorbed by the colloidal matter of the soil and held against leaching even more tenaciously than potassium. Thus, it is probable that even the small quantities of rubidium that may be present in the original rock will persist in the clay or colloidal matter formed from the rock.

In small quantities, rubidium has been found to be stimulating to plant growth, but it does not seem to be able to replace potassium.
Selenium

Selenium closely resembles sulphur, but unlike this sister element, it is very poisonous to animals—even more so than arsenic. Selenium is toxic to most plants, also, though some species are tolerant of or possibly under some conditions even partially dependent upon it for normal development.

The cause of the alkali disease of cattle prevalent in the grazing sections of some of our Western States has now been shown to be selenium. Selenium is present in detectable quantities in all soils, but it reaches toxic concentrations only in those derived from the Cretaceous shales in semiarid climates. On a seleniferous soil, one species of *Astragalus* has taken up as much as 1.49 percent of selenium. Field-grown wheat has been found to contain as high as 30 parts per million, and cabbage raised in the greenhouse on soils to which sodium selenate had been added contained 758 parts per million in the leaves. It has been observed that plants normally high in sulphur absorb much more selenium than those low in sulphur. This suggests a functional relationship between the two elements.

Selenium appears to have a rather definite reaction with some components of the soil. With ferric oxides it forms a basic ferric selenite so insoluble that plants grown on ferruginous soils containing several parts per million of selenium may be essentially free from this element.

In the form of potassium sulphoselenide, selenium is very effective in the control of the red spider. In semiarid and possibly in humid climates, however, this use of selenium is not recommended when there is any possibility of using the soil thus contaminated for growing food crops.

In greenhouse experiments, sulphates inhibit the intake of selenium by plants, but in field experiments the application of various forms of sulphur has not been successful in materially decreasing the intake of selenium by some grains. The sulphate content of seleniferous soils is generally high. However, it is of interest that certain plants manifest some symptoms produced by selenium toxicity that are also characteristic of sulphur deficiency.

Silicon

Silicon occurs in the largest quantities in the various grasses. In the scouring-rush it is the major ash constituent.

Silicon in the forms of quartz, undecomposed silicates, and various hydrated silicates or clays is commonly the major soil constituent. In some lateritic soils of the Tropics the silica content may be less than 5 percent. Silica is always present in plant ash, but in varying quantities.

Normally, silica is quite insoluble. Its solubility is increased by the presence of alkalies and by high temperatures. Silicon, in its more active forms in the soil, increases the availability of phosphorus. With alumina, ferric oxide, and water it makes up the main bulk of the soil colloids or clay. The properties of the soil colloids are largely dependent upon the ratio of silica to alumina.

Plants, particularly the grasses, grown in the absence of silica are especially susceptible to fungous diseases, and from this it is supposed that the normal plant is able to ward off such diseases because of the mechanical protection afforded by the silica in the outside walls of the plant.

While silica is not poisonous, cases have been reported where cattle have died as a result of lacerations of the walls of the digestive tract from the sharp siliceous spikes of rice hulls. *Silica* in the form of sand ingested by horses and cattle eating grain directly on sandy ground or drinking from shallow streams causes sand colie, which is frequently fatal.

The silicosis that occasionally causes death of miners and industrial workers is caused by silica dust in the air and not by silica in food plants.

Silver

Mushrooms have been reported to contain as much as 100 parts per million of silver, as determined by the spectroscope, and it has been reported in other plants. Little is known about the occurrence of silver in agricultural soils.

Silver salts seem to be toxic to plant growth.

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*For a more detailed discussion of this subject see Selenium In Soils, p. 830.*
Sodium

Sodium is a common constituent of plants, but in most cases the quantities present do not exceed a few tenths of 1 percent. In soils there is seldom more than this quantity except where undecomposed sodium minerals are present in the sands and silts or where the clay has been saturated by sodium.

Sodium is not retained by soil colloids where there is much opportunity for leaching. The sodium released by the decomposition of the various sodium minerals is washed away in the drainage water and appears in the form of salt in the sea. In semiarid regions where alkali crusts are formed, the soils are profoundly altered in their properties by the reaction of the sodium salts with the clay acids, which renders the clay very impervious to water.

Some experiments show that the addition of salt has increased the growth of crops. The phenomenon of base exchange enters here, and the salt addition may have released other elements of more direct use to the plant. In the plant potassium greatly exceeds sodium, while in the blood of the animal the reverse is true. From the standpoint of herbivorous animals, practically all agricultural crops are deficient in sodium, and for ages this deficiency has been supplied by the addition of salt directly to the diet.

Strontium

Strontium is closely related to calcium and barium. In the 10-mile depth of the earth's crust there is about 0.018 percent of strontium compared with 3.65 percent of calcium. Strontium is widely distributed in soils, but in small quantities of the order of 0.05 percent. Plants contain roughly one-fifth as much.

Strontium probably reacts like barium with the colloidal matter of soils. One would expect it to be absorbed rather energetically and to displace some of the other bases present in greater quantities. Such a reaction would account for the persistence of small quantities of strontium in the soil.

Strontium does not seem to be essential to plant growth. In water-culture experiments it can only partially replace calcium in the plant. Strontium salts are toxic to plant growth in all but relatively small concentrations, but not so toxic as barium salts.

Sulphur

Sulphur is present in all plants in considerable quantity and is necessary for their growth. In high-protein grains like wheat it runs generally over 0.3 percent, and in cabbage and broccoli it reaches a concentration of several percent. The sulphur content of soils is comparatively low, generally running between 0.1 and 0.3 percent.

A large part of the sulphur in the soil appears to be contained in the organic matter. The part present as sulphate ion is not strongly held by the ordinary clay of the soil but is easily leached out and appears as sulphates in the sea. In semiarid and arid regions, calcium sulphate (gypsum) and even the more soluble sodium sulphate frequently occur as soil components. When soils are submerged under water for some time, sulphates are reduced to sulphides, hydrogen sulphide is given off, imparting a characteristic odor, and the soil becomes very toxic owing to this component and others.

A general survey of the sulphur and phosphorus content of crop plants and soils reveals the fact that soils in general are more deficient in sulphur than in phosphorus. It seems strange, then, that so little attention has been given to sulphur as a fertilizer constituent. The fact is that sulphur has been applied more or less unconsciously with phosphorus in the forms of superphosphate and acid-treated bone. In superphosphate, the sulphates commonly exceed the phosphates. Largely because of this, sulphur deficiencies in soil have not appeared. The use of highly concentrated fertilizers in which the phosphates carry no sulphates will create a sulphur deficiency unless sulphates are added.

The atmosphere contains considerable quantities of sulphur compounds, which are brought down by rains and function in the nutrition of plants. It is possibly for this reason that a sulphur shortage has not become generally acute. In the arid regions of the West, sulphur deficiency has been found in alfalfa and other crops and corrected by the use of sulphur compounds. Effects of sulphur deficiency in plants are characterized by loss of green color in the younger leaves of the plant, including the veins. In extreme cases all the leaves may be light green.
Neglected Soil Constituents

Thallium

Thallium is of interest largely because of its use in poisoning grain and other bait for rodent control. When this poisoned bait is scattered on the soil, the effects persist for several years. Thallium is poisonous to both plants and animals, and it should be used only under expert supervision. Little is known of its natural occurrence in plants and soils. When artificially applied, it is probably taken up by the plant, and as little as 35 parts per million in sandy soils has practically prevented the growth of plants. Whether this element is stored in the edible parts of plants in quantities sufficient to be toxic to man and animals is a question for further research to determine. Thallium compounds have been used as depilatories with disastrous effects.

Titanium

Small quantities of titanium, of the order of a few parts per million, are found in plants. It is almost a major constituent of soils; few soils contain less than 0.5 percent of titanium dioxide, and some Hawaiian soils contain as much as 10 percent. The major part of the titanium in soils seems to be of an inert nature resembling silica.

The leaves of plants contain a few parts per million of titanium, and like iron, aluminum, and zinc, titanium follows the concentration of the chlorophyll when the composition of the blanched and green leaves of cabbage and lettuce are compared.

Vanadium

Considering the resemblance of this element to phosphorus, there is surprisingly little vanadium in plants. There is some geological evidence that in the past plants or animals have concentrated vanadium. Some Peruvian shales contain up to 0.5 percent of vanadium pentoxide. Analysts have found that the ash of several peculiar samples of cannel coal have yielded values of vanadium pentoxide ranging from 35 to 38 percent. Asphaltic substances in many localities contain considerable vanadium. The same may be said of petroleum products, and there is considerable evidence that, in past geological ages at least, vanadium has been concentrated by biochemical processes.

Vanadium is present in agricultural soils in quantities ranging from 0.01 to 0.1 percent. In the analysis of a series of 48 plants, only 4 showed the presence of more than 10 parts per million of vanadium. These were pine needles, beets, and bean and clover plants.

Vanadium is concentrated in sandstones and other sedimentary rocks and in clays. With the soil colloids, it would be expected to behave much like phosphorus. Vanadium is reported to be absorbed by some invertebrates as a substitute for copper and phosphorus in their blood.

Zinc

Zinc is widely distributed in plants and other biological material. In the general run of vegetables, quantities present range from 1 to 10 parts per million. In cereals and legumes, 10 to 50 parts are commonly found. Ordinarily forest tree leaves have been found to contain from 2 to 240 parts per million of zinc. A certain variety of European wild violet (Viola calaminaria) tops the list of zinc imbiber. Liver and oysters are especially high in zinc, and maxima of 339 and 341 parts per million, respectively, have been noted.

This metal seems to be present in all soils in minute quantities. Various analyses show from 2 to 50 parts per million. The lowest quantities are found in sandy soils.

It has been proved that zinc is essential to the normal development of wheat, barley, beans, and buckwheat, and it is probably necessary for the normal development of other plants. It has been found possible to produce distinctive effects on the growth of the tobacco plant in sand or solution cultures by withholding zinc.
The effects are characterized by a spotting of the lower leaves of the plant, which in extreme cases has resulted in almost total collapse of the leaf tissue (fig. 3, F). The lower leaves of the plant first develop a faint chlorosis. The break-down of leaf tissue typically follows and proceeds rapidly after it has begun, developing more rapidly during cloudy periods than when the weather is normal. These characteristics correspond to a break-down that occurs very extensively under field conditions during wet periods when a large proportion of the crop frequently succumbs to a leaf spot that has commonly been attributed to bacterial invasion. It is not possible to say at the present time whether zinc deficiency enters into the complex, but research is in progress to determine this.

The necrotic areas that develop on leaves of tobacco plants when zinc has been withheld commonly begin at the leaf tips and on the lower leaves of the plant, although there are instances where the bottom leaves of the plant may not be the first involved, nor have the lesions always been localized at the leaf tips. The lesions usually involve a very small area at first and in some instances are surrounded by a halo. These areas characteristically soon develop a brown color. Frequently the small veins, which at first are not involved, soon break down, as does the entire leaf tissue.
While it is recognized that small amounts of zinc are essential to plant growth, larger quantities are toxic to most plants.

Zinc resembles copper so far as reactions with the soil colloidal matter are concerned. Zinc is absorbed by the soil colloid and a part is held in the exchangeable condition. Zinc phosphate is so nearly insoluble at hydrogen-ion concentrations generally found in the soil that the phosphate ion will reduce the availability of zinc salts. In neutral or alkaline soils, zinc phosphate is so very nearly insoluble as to account for observed unavailability of zinc in such soils.

Pecan rosette, shown in figure 4, citrus little leaf and similar troubles of deciduous trees, the bronzing of the leaf of tung trees, and white bud of corn are ascribed to zinc deficiencies. Very marked effects on growth and correction of the troubles mentioned have been reported from the use of zinc compounds. The exact significance of these compounds in this connection does not appear to be clear, since large applications are required to correct the condition. If the element were functioning as a nutrient, relatively small applications should be sufficient, provided precipitation did not render unavailable the zinc compounds added. However, it has been shown in work with citrus and pecans that injections into the trunk of the tree and dipping and spray applications to the leaves are effective, indicating that the element does act as a plant nutrient.