Mammals and birds sometimes seek shelter or nesting sites in the ground. Many of them scarcely affect the soil as a medium for plant growth.

A notable exception is the soil-dwelling rodents. Although their acre-weight is usually only about a few pounds even in the uncultivated land, their soil transporting activities sometimes are considerable. In building their tunnels and nests, they transport large quantities of subsoil to the surface. The open burrows in turn catch dry or waterborne surface debris and humus-rich surface soil. Water movement into the subsoil may be facilitated by the presence of rodent burrows. In some circumstances this is desirable; in others it is not. The farmer applying irrigation water does not always express himself in temperate language when he finds gopher holes.

Toxic Elements in Soils

Firman E. Bear

We got the word “toxin” from the Greek word for huntsman’s bow. “Toxic” came to refer to the effects of the poisons that man applied to the tips of arrows he used for hunting.

A toxic element is one that brings injury and sometimes death to the living organism that absorbs it.

Plants may suffer injury and die from high concentrations of salts, even salts that carry essential elements. Water of a high content of salt may be toxic to animals. Plants may be harmed by relatively small amounts of a particular element in the soil; animals may be injured by eating the plants in which that element has accumulated.

Selenium probably is the most troublesome. It is a serious hazard to livestock and probably to people in a wide semiarid belt that extends from inside Canada southward across the United States into Mexico.

Selenium (Se), a nonmetal, resembles sulfur in its chemical properties. The so-called metallic selenium is a silvery-gray, crystalline solid. Selenium tends to be present in largest amounts in areas where the soils have been derived from Cretaceous rocks. Such soils average about 5 parts per million of total selenium, but some contain as much as 80 p.p.m. Lack of rainfall has prevented the solution of the selenium minerals and the removal of their salts in drainage waters.

Cultivated crops and native grasses seldom contain enough selenium to be dangerous to animal life. The selenium content of wheat from such areas is usually only a few parts per million. When such wheat is mixed with wheat from other regions and with other foods, no trouble is likely, at least among people outside these areas.

The primary problem is selenium-accumulating forage plants, in which the concentration of selenium may reach 15,000 p.p.m. Even at much smaller concentrations, selenium may harm animals that eat considerable amounts of the forage.

The major selenium-accumulating forage plants are certain species of Astragalus (vetch), Xylorhiza (woody aster), Onopopsis (related to goldenrod), and Stanleya (of the mustard family). Astragalus is the most widely distributed. About 24 of its more than 200 species are selenium accumulators.

The accumulator plants seem to need selenium to grow well. The element
tends to be toxic to nonaccumulating plants. It apparently replaces sulfur in the sulfur-containing amino acids.

Accumulator plants not only are troublesome in themselves as forage for livestock—they increase the concentration of selenium in the soil in which they grow. They leave the accumulated selenium behind in soluble form in their dead tissues for more ready absorption by the next accumulator.

Two types of livestock injury are recognized. Alkali disease causes malformation and sloughing off of hoofs. Blind staggers, a more advanced form, leads to death within a short time. Eggs of hens fed seleniferous grain have low hatchability. Concentrations of 5 p.p.m. of selenium in food or 0.5 p.p.m. in milk or water are considered dangerous for people.

The degree of injury to livestock is related to the condition of the range, notably in very dry years. Selenium-accumulating plants tend to be deeper rooted than the grasses. They survive more severe aridity. They may remain as the principal forage for grazing in time of drought.

Selenium toxicity to livestock can be overcome partly by feeding linseed oil meal as a supplement. Sodium arsenite has been found useful as a remedy, but it is too poisonous to have around the ranch. Considerable experimental work has been done with the less toxic arsanilic acid and related compounds, but they are less effective than the arsenite. Sulfates are a partial antidote for selenium toxicity but they are not effective in overcoming the toxicity of selenites or of the organic compounds of selenium.

To solve the selenium problem, a multiple approach has been suggested—a careful survey and mapping of the soil of the seleniferous areas, development of a more complete list of accumulator plants, and more exact descriptions of the symptoms of injury to livestock that have eaten selenium-containing forage and grains. The worst areas should be fenced off and posted with warnings to stockmen. Everyone should be aware of using selenium-containing water.

Arsenical sprays, when used repeatedly, have brought about accumulations of arsenic to the point of toxicity in orchard soils, notably in Washington. Many orchards have had 15 lead-arsenate cover sprays of 100 gallons a tree yearly for a long time.

Arsenic (As) is a gray, brittle, crystalline substance. It occurs combined with sulfur, oxygen, and other elements, and as the element. The arsenates are fixed by soils in a relatively insoluble state and are not lost by leaching. They tend therefore to accumulate. Nevertheless, as much as 12 p.p.m. of water-soluble arsenic has been found in the top 6 inches of soil in orchards.

Barley and alfalfa seedlings are injured at concentrations of 2 p.p.m. of water-soluble arsenic. The tips of their leaves turn yellow a few days after they emerge.

Arsenic toxicity is particularly troublesome where old orchards have been removed and attempts are being made to replace them or to grow grass, grain, or vegetables on the sites.

Plants vary in their tolerance for arsenic. Apples, pears, grapes, and raspberries are among the most tolerant fruits. Rye, asparagus, cabbage, potatoes, and tomatoes are among the most tolerant field crops. Bluegrass, orchardgrass, and ryegrass are among the most tolerant forage plants.

Least tolerant plants include peaches and apricots among the fruits; barley, wheat, peas, and beans among the field crops; and alfalfa, clovers, vetch, and Sudangrass among the forages.

Other fruit, field, and forage crops are intermediate in tolerance.

Most plants, wherever grown, contain traces (normally less than 0.5 p.p.m. dry weight) of arsenic. Plants growing on soils in which arsenates have accumulated have been found to contain as much as 14 p.p.m.

Arsenic toxicity is evidenced by slow, stunted growth and late maturity of
plants. Shot-hole and marginal scorch occur on the leaves of the more sensitive fruits, notably peach and apricot and sometimes cherries. The leaves drop prematurely. Legumes tend to die in the seedling stage, following the appearance of small spots of dead tissue scattered over the leaves. Grain crops turn yellow and die back from the tips of the leaves. Arsenic-poisoned corn seems to suffer from too little moisture. Injury is most pronounced during warm, dry months.

Treatment for arsenic toxicity consists in the use of 1 to 2 tons of iron sulfate to the acre, or triple-superphosphate at about the same rate, or, for peach trees, zinc sulfate at the rate of 5 to 10 pounds a tree. At pH values above 6, a chelated form of zinc, about 1 pound to a tree, is preferred.

Other methods of dealing with this problem include growing only the most tolerant types of trees and crop plants and deep plowing to bury the surface soil to a depth of 1 to 2 feet. The plowing does not suffice for peaches. The most important period is when the trees or crops are being established. The best method in replanting orchards is to set the young trees in 2 to 4 cubic feet of uncontaminated soil. Arsenites seem to be more troublesome than arsenates.

The ferric forms (or oxidized compounds) of iron therefore are more useful than the ferrous forms (or reduced compounds) as correctives.

Plants on soils treated with ferric compounds contain much less soluble arsenic than those growing on soils not so treated. Aluminum sulfate is not a satisfactory substitute for the corresponding iron salt.

**Molybdenum** serves in plants as a catalyst in enzyme systems that function in reducing nitrate to ammonium in preparation for the synthesis of amino acids and proteins. It has a similar part in nitrogen fixation by the nodule bacteria of legumes and by the nonsymbiotic bacteria.

As far as is now known, toxicity of molybdenum enters the agricultural picture only in relation to livestock production. The element appears to be essential as a respiratory catalyst, but trouble is experienced at concentrations above 10 p.p.m., dry weight, in green forage.

Areas of serious molybdenum toxicity to livestock have been found in California and Florida. The indications are that the element may also be present in toxic amounts in the forage of widely scattered places in the semiarid regions of the West.

The total molybdenum content of soils usually is about 1 to 3 p.p.m. Soils containing 75 p.p.m. of molybdenum have been found in Hawaii. The molybdenum content of soils in the localities of California where cattle are injuriously affected usually do not exceed 10 p.p.m. Molybdenum differs from most of the essential trace elements in that its availability is highest at soil pH values that approach neutrality. Most of the other trace elements are most available in acid soils.

One remedy for molybdenum deficiency for plants growing on acid soils is to lime the land liberally. Applications of superphosphate tend to have similar but less pronounced effects. Conversely, the available molybdenum in the soil can be reduced by acidulation with sulfuric acid, partly because the pH value of the soil is lowered and partly because it provides a competitive ion for absorption by the plant.

One of the best methods of overcoming molybdenum toxicity is to grow forage crops on the land for harvesting as hay until the more readily available supplies of molybdenum have been removed from the soil and hauled away with the hay.

**Fluorine** usually is present in plants within a range of 2 to 20 p.p.m. dry weight. We have no evidence that it is useful as a plant nutrient. Tea is the best known accumulator of fluorine; its dried leaves may contain as much as 400 p.p.m.

In acid soil and following applica-
tions of soluble fluorides, the fluorine content of some plants can be raised to levels of 500 p.p.m. or higher. Injury usually results before the fluorine content has been raised to 50 p.p.m. At higher levels the plants may die.

Soils normally contain 100 to 300 p.p.m. of total fluorine, with increasing concentrations in the subsoil. Soils derived from rocks high in phosphate may contain as much as 8,000 p.p.m. Fluorine is often added to soils in fertilizers and insecticides. It is brought down in the rain, notably in areas around factories where fluorine-containing ores are processed. Yet, as far as we know, fluorine toxicity to plants seldom or never occurs in open fields away from such factories.

A possibility exists that plants on strongly acid soils are poisoned by fluorine accumulations from applications of fluorine-containing insecticides. Any such toxicity can be overcome by liming materials and soluble phosphates, which immobilize the soluble fluorides and tend to produce the highly insoluble, fluorine-containing mineral apatite.

Most of the toxicity of fluorine to plants has been by way of the atmosphere, particularly near factories that process phosphate and aluminum. Atmospheric fluorine may also cause trouble in cities where large amounts of soft coal are burned and around ore refineries. Active volcanoes discharge large amounts of fluorine, which have caused serious injury to livestock grazing nearby.

Instances of injury from volatilized fluorine have occurred in Tennessee. In Maury County the fluorine was emitted in the thermal processing of phosphate rock, which normally contains about 4 percent of fluorine. During the high-temperature operations, as much as 90 percent of the fluorine is given off as silicofluoride. On coming in contact with moist air, silicofluoride yields hydrofluoric acid, a gas that is highly toxic to the leaves of plants. Only about one-third as much fluorine is liberated in the sulfuric acid method as in the thermal process of manufacturing available phosphates.

In Blount County, Tenn., the source of the fluorine was the cryolite that was being used in the production of aluminum. About 7 pounds of fluorine per acre were being brought down annually in that area. Somewhat larger amounts were found in the rain around the phosphate rock-processing factories in Maury County. Still larger amounts fell on the city of Knoxville. Less than a pound of fluorine falls on an acre in rain in nonindustrial areas.

Animals are subject to injury from high fluorine intake by way of feed and water. Serious injury to livestock occurred in the places mentioned.

We have limited evidence as to the need of animals for fluorine. But fluorine seems to be useful because it is a constituent of teeth and bones. It helps reduce the tendency to tooth decay if taken in proper amounts. Excess amounts lead to disintegration of the teeth and bones. Such troubles are experienced in areas near deposits of phosphate rock where the water tends to contain more than normal amounts of fluorine.

Equally serious problems arise when pulverized phosphate rock is fed to livestock as a substitute for bonemeal—but that danger can be avoided by roasting the rock at high temperatures to drive off the fluorine.

A person takes in about 0.5 to 1.0 milligrams of fluorine daily. If larger amounts are consumed, the excess is excreted in the urine. The only known injury from moderate excess is to the teeth and bones. Evidence of deficiency, indicated by excessive tooth decay, appears to be much greater than that of toxicity from too high consumption.

In some cities enough fluoride is added to the drinking water to raise its fluorine level to 1 p.p.m. We have indications that the incidence of caries is reduced when that is done.

BORON TOXICITY came into prominence during the First World War, when the United States was forced to develop its own supplies of potash salts.
to replace those formerly purchased from German producers. The most easily developed source was that at Searles Lake in California. When mixed fertilizers containing potash from that source were first used for crops, widespread damage resulted, notably to potatoes and vegetables.

Investigations disclosed that boron was present in these fertilizers in toxic concentrations. Some shipments of Searles Lake potash salts contained as much as 20 percent of borax, of which more than 11 percent is boron. Steps were taken immediately to refine the salts, and the problem was solved.

Plants need boron, but the amount required is about 25 to 75 p.p.m. Many plants absorb much larger amounts if the boron is available, often to the point of readily apparent injury. Some plants will accumulate up to 200 p.p.m. Soybeans, sweetpotatoes, and sunflowers are among these accumulator plants.

Boron differs from the other essential trace elements in that the tolerance of the plant for more than the amount required is limited. Any excess results in the development of yellowish-brown spots around the edges of the leaves, particularly the oldest ones. The brown spots may be distributed over the entire leaf in severe cases.

The boron problem is not confined to the manufacture and use of fertilizers. It enters also in the development and use of irrigation waters in arid regions. Boron often is present in arid soils and in the irrigation water used on them as water-soluble sodium borate. Some water carries so much that it cannot be used for irrigation.

In rating irrigation waters for crop production, the boron limit for sensitive crops is usually set at about 0.66 p.p.m. For semitolerant crops, the limit is set at about 1.33 p.p.m., and for tolerant crops at 2 p.p.m.

Most of the beans and all of the nut and fruit trees are classed with the sensitive crops. Alfalfa, sugar beets, onions, carrots, and cabbages are among the most tolerant crops. The remaining crops are mostly semitolerant.

The water-soluble forms of boron in humid regions have long since been carried off in drainage waters. The boron that remains is in the form of highly insoluble minerals, notably tourmaline. The total boron in the soils of humid areas normally is 25 to 100 p.p.m., of which about 1 percent is soluble in hot water.

About 0.35 p.p.m. of hot-water-soluble boron in soil is adequate for most crops, although some require considerably higher soluble-boron levels. The difficulty lies in knowing the point at which toxicity may develop for a particular crop.

It has become standard practice in the more intensively farmed parts of the humid regions to add 5 pounds of borax to each ton of mixed fertilizer. For topdressing established alfalfa, as much as 100 pounds of borax may be added to each ton of fertilizer.

A broadcast application of 10 pounds of borax to the acre can be made in most cases without hurting the crop. If that amount is placed only along the row, however, plants may be injured. Applications of 50 to 100 pounds of borax to the acre have been broadcast successfully for cauliflower and beets in deficient heavy soils. Great care is needed in using borax for crops on very sandy soils; on them the less soluble mineral colemanite is preferred.

Manganese and iron are a pair of trace elements that may interfere with each other as catalysts in enzyme systems that perform necessary functions in living organisms. One that is present in excess may substitute for the other to the extent that plants are injured.

Studies with culture solutions have shown that a deficiency of iron—evidenced by a characteristic yellowing of the leaves—can be induced by limiting the supply of iron available to the plant and by raising the supply of manganese to abnormally high levels in relation to those of iron. Catalase, peroxidase, and cytochrome oxidase activities are depressed then.

That is proof that a balance is in-
The problem is to determine for each plant—in its environment—what constitutes the best ratio of available iron to manganese in the nutrient solution or soil. That may apply to the many other pairs of essential and non-essential trace elements and to the secondary and major elements.

The important point is that a deficiency of one element and an excess of another may produce virtually identical effects on a plant: The element in excess has a toxic effect on the plant.

Often or always we can define toxicity, in relation to mineral nutrition of plants and animals, in terms of balance. On that basis, any element may be toxic in excess, and deficiency and toxicity are opposites.

Most soils in humid regions are naturally acid or may become acid soon after they are put to agricultural use. The reaction of such soils tends to fall to about pH 5 unless lime is applied to them. The pH values may fall to 4 or lower in some places, or they may remain well above 5—depending on the nature of the rock material from which the soil was formed and the nature of any rock material that lies immediately beneath the soil.

The purpose of liming soil is to raise its pH value usually to around 6, such a value having been found to be favorable for best growth of most crops, notably the legumes. One of the reasons is that availability of manganese in acid soils is often so high as to result in toxicity. Liming the soil causes a lowering in the solubility of manganese and presumably brings the iron and manganese into better balance in relation to plant needs.

We have evidence that traces of aluminum may be essential to some plants. But there is little likelihood of any deficiency, for most soils contain relatively large amounts of total aluminum. The range in humid temperate climates is 1 to 8 percent. Tropical soils may contain somewhat higher percentages, along with much higher percentages of iron. The combined amounts of these two elements, calculated as the oxides, may total as much as 80 percent in a Latosol.

To be troublesome to crop plants, aluminum must be present in soluble form in concentrations of 10 to 20 p.p.m. or more. Such concentrations are not likely to occur even in acid soils unless use is made of some highly soluble, acidifying fertilizer salt, such as ammonium sulfate. The sulfuric acid resulting from oxidation of sulfides in some swampy locations may have a similar effect. In either instance, unless lime is applied, the concentration of soluble aluminum tends to increase beyond the tolerance of many crop plants.

Yet some plants grow well on acid soils, indicating a high degree of tolerance for soluble aluminum or for any other element of similar character that may be present in excess under such conditions. Thus blueberries, cranberries, oats, peanuts, potatoes, rye, redtop, watermelon, rhododendron, and azalea are plants that tolerate acid soil. Corn, cotton, strawberry, tomato, timothy, and vetch are fairly tolerant.

The greatest difficulty is experienced with alfalfa, asparagus, beets, and celery. Lettuce, onions, and spinach are especially sensitive to soluble aluminum.

Some plants are noted for their capacity to accumulate aluminum. An Australian oak was found to contain a jellylike deposit of aluminum succinate. The ash of a part of the trunk of that tree was nearly 50 percent aluminum. Analyses of leaves of *Symplaca tinctoria* (sweetleaf) showed aluminum concentrations of 3 to 4.5 percent.
Other toxic elements exist in soils from place to place, usually near ore deposits and around ore refineries and in places where they have been applied as constituents of fungicides or insecticides. Among them are barium, nickel, copper, zinc, and lead.

Barium is toxic to plants only in extreme conditions, such as those around barite mines, where soil concentrations as high as 33,500 p.p.m. of total barium have been reported. Brazil nuts are noted for their high content of barium—up to 4,000 p.p.m. Barium carbonate has been used as a rat poison and is toxic to plants.

Nickel is toxic to plants at relatively low concentrations. Soils derived from serpentine rocks are notably high in nickel—a fact that may explain the lack of productiveness of such soils, although there is evidence that excess manganese and a deficiency of molybdenum also may be involved.

Total nickel in soils ranges usually between 10 and 40 p.p.m., but values as high as 140 p.p.m. have been reported. The nickel content of plants is usually between 0.5 and 2 p.p.m. Toxicity in tomatoes developed at 40 p.p.m. of nickel in the plants. Growth stopped at 150 p.p.m.

Copper is more likely to be deficient than excessive in soils, both in relation to the needs of plants and of the animals that consume them. Nevertheless, copper is under suspicion as a toxic element after continued use of copper sulfate as a fertilizer and as a fungicide, particularly for plants growing on sandy soils. Notable cases of bad effects from copper have been reported in citrus groves in Florida.

The copper content of soils usually ranges between 10 and 40 p.p.m. and that of plants between 2 and 20 p.p.m. Much higher values are known for certain soils, and more than 500 p.p.m. of copper have been found in celery. Applications of as little as 10 pounds of copper sulfate per acre has been applied to copper-deficient peats without crop damage. Copper sulfate is an antidote for molybdenum toxicity.

Excessive concentrations of zinc exist in some acid soils as a result of the presence of nearby deposits of zinc ores. The zinc content of soils usually is 20 to 200 p.p.m. and that of plants between 30 and 50 p.p.m. Ragweed (Ambrosia) is noted as a zinc accumulator, nearly 4,000 p.p.m. of zinc having been found in one specimen growing near a zinc-mineral outcrop. Zinc toxicity has been troublesome around zinc smelters. The toxicity to plants is readily overcome by liming the soil.

Lead poisoning of livestock has been experienced from time to time around lead mines, where concentrations as high as 45,000 p.p.m. of total lead have been reported in soils, and in places where animals have had access to lead-containing paints.

Considerable controversy has been aroused on the subject of residues of lead arsenate sprays on fruits. There is little evidence of injury to plants from lead poisoning except where lead arsenite has been used as a spray. Lead arsenate is usually preferred for spraying because it is less soluble and more stable than the arsenite.

Almost any soil element is toxic to plants when it is present in abnormally high concentrations. Such abnormalities may be natural to the soil, or they may be the result of applications of salts of the several elements in fertilizers, insecticides, or fungicides. Sewage sludges often have abnormally high amounts of some of the trace elements. Often one or more species of plants thrive under such conditions and may serve as indicator plants. Often they accumulate the elements to relatively high concentrations. Livestock grazing on them may be poisoned.

But the question still remains as to whether such toxicity is a direct result of the presence of the element in excess or an indirect result of its replacement of some similar element that is essential to the living organism.