Sulfur and Soil Fertility

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Plants get sulfur from the soil, rain and irrigation water, fertilizers, insecticides, fungicides, and the atmosphere.

Sulfur is essential to life. Many plants use about as much sulfur as they do phosphorus.

Sulfur (S) is a nonmetallic element that occurs in several forms. The stable form under ordinary conditions is a pale-yellow, brittle, crystalline solid, which burns with a blue flame to give sulfur dioxide and combines with many metals to form sulfides. Large amounts are extracted in Texas and Louisiana.

Soil supplies of sulfur are so meager in some places that deficiencies exist; in other places supplies are very low.

Considerable sulfur—upwards of 40 pounds an acre, which is enough for crops—is released in industrial areas in the smoke of burning coal and carried to the soil in rainwater.

Atmospheric sulfur, which is utilized by plants, also is present in large amounts in industrial areas.

Sulfur accretion from rainwater in nonindustrial localities may be only about 4 pounds an acre a year, and atmospheric sulfur is of little importance there.

All water used for irrigation in the Western States contains dissolved sulfur in a form usable by plants, but the amount depends on how much water is applied and its sulfur content.

Crop production has been maintained in some areas of potential sulfur deficiency by the application of fertilizers, in which sulfur may be only an incidental component. The trend in the preparation of commercial fertilizers is toward higher concentrations of the major nutrients, and some or all of the sulfur is being eliminated—a development that may intensify the problem of supplying sulfur.

Some plants of the crucifer, or mustard, family (cabbage, cauliflower, kale, turnip, radish) and the lily family (onions, asparagus, and many flowering plants) have particularly high requirements of sulfur. A 15-ton crop of cabbage and a 20-ton crop of turnips absorb on the order of 40 pounds of sulfur an acre. A 15-ton crop of onions takes up about 19 pounds.

Legumes, cotton, and tobacco utilize relatively large amounts, ranging from 20 pounds an acre for 4 tons of alfalfa to about 15 pounds an acre for good yields of the other crops.

Small grains, grasses, and corn are less sensitive to sulfur. They require 10 pounds an acre or less.

The sulfur generally is well distributed through the plant.

It usually is absorbed from the soil as the sulfate ion, in which form it is readily mobile within the plant. The sulfate form is converted in plant metabolism to a reduced form, mainly the sulphydryl group.

Sulfur in plant compounds may be reconverted to the sulfate form and reutilized in the formation of other sulfur-containing compounds in a different part of the plant. Relatively large amounts may be moved in this way—from older tissues to newer tissues in sulfur-deficient plants and into the seed and fruit of maturing plants.

Sulfur may also enter the leaves as sulfur dioxide from the atmosphere.

Sulfur is a constituent of all plant proteins, some plant hormones, the mustard-oil glycosides, and glutathione.

The sulfur content of plant proteins (in which sulfur occurs as the amino acids, cystine and methionine) never exceeds 2 percent. The amino acids are important in animal nutrition and may improve the quality of protein in flour for bread making.

The plant hormones that contain
sulfur—thiamin and biotin—act as plant growth regulators and also are important in animal nutrition.

The mustard-oil glycosides impart flavor to plants. Glutathione supposedly is involved in plant respiration.

Sulfur appears to influence several plant processes. Protein synthesis is retarded in the sulfur-deficient plants, and as a result amino acids and other nitrogen-containing compounds may accumulate in the tissues. Sulfur may favor the development of nodules and the subsequent nitrogen fixation by legumes. Sulfur seems to be associated with the formation of chlorophyll, as shown by the yellow color of sulfur-deficient plants. Anthocyanin pigments develop in some plants that lack sulfur, an indication that sulfur affects carbohydrate metabolism.

**Symptoms of Sulfur Deficiency** in plants generally are like those of nitrogen deficiency. The plants are stunted and are pale green to yellow in color. Such chlorosis often is severe on the older leaves, but on some plants, notably citrus, tobacco, and cotton, it is worst on new growth. In contrast to the pattern for nitrogen deficiency, the severely chlorotic leaves of sulfur-deficient plants do not die back in early stages of the deficiency and do not show a characteristic pattern.

On some plants, like turnips, a marked redness develops in the lower leaves. It starts in the leaf veins and gradually spreads to the interveinal tissue as the deficiency gets worse.

Sulfur deficiencies in nonlegume crops occur most commonly at high levels of nitrogen fertilization. As the organic matter of the surface soil declines with continued cultivation, nitrogen deficiencies may develop in crops; the responses to nitrogen fertilization are readily demonstrated.

Because the soil organic matter is the main store of both sulfur and nitrogen, however, sulfur released by the decomposition of organic matter declines in proportion to the decrease in release of nitrogen. When all of the nitrogen available for use by a non-legume crop is supplied from decomposition of the soil organic matter, the sulfur released at the same time is adequate for crop needs. But if the supply of soil nitrogen is supplemented with heavy applications of sulfur-free nitrogenous fertilizer, the amount of nitrogen available for crop use may be excessive in relation to the sulfur.

Under such high-nitrogen and low-sulfur conditions, plant-growth processes are disrupted, and plants develop symptoms of sulfur deficiency. Sometimes total growth has been reduced by fertilization with nitrogen alone, whereas combined applications of nitrogen and sulfur have given the normal yield increases expected from the nitrogen application.

Deficiencies of sulfur may result from combined additions of nitrogen fertilizers and high-energy, low-sulfur organic materials. Then the available sulfur is tied up by the resulting large increase in the microbes in the soil. This effect has been noted more commonly in greenhouses than in experiments in the field.

Sulfur may be toxic to plants.

Sulfur dioxide in the atmosphere in any sizable concentration kills plants. The countryside near smelters sometimes is nearly denuded of vegetation. Most species are injured by exposure for only an hour to air containing one part in a million of sulfur dioxide. This sort of atmospheric contamination has been controlled somewhat in modern
installations that discharge the gases from high stacks or recover the sulfur at the point of discharge.

Plants also may suffer from high concentrations of soluble sulfates in the soil profile. Such conditions normally develop only in arid or semiarid regions and in poorly drained soils. Very likely this sensitivity comes about because high concentrations of sulfate tend to limit the uptake of calcium.

Most of the sulfur in soils of humid regions is in the organic fraction and is high in the soils that accumulate organic matter.

The supply is much less plentiful in weathered soils. Thirteen Chernozems described in the Atlas of American Agriculture, Part III contain a mean of 1,080 pounds of sulfur an acre in their A horizon. Twelve Prairie (Brunizem) soils contain a mean of 792 pounds, and 43 Red-Yellow Podzolic soils contain a mean of 420 pounds.

Total sulfur is more abundant in the surface than in lower soil horizons. In a number of soils in Ohio, the depths at 0-6 inches, 6-12 inches, 12-18 inches, and 18-24 inches contained 1,056, 830, 686, and 528 pounds of total sulfur an acre, respectively.

The transformation of sulfur in the soil organic matter into forms available for plant use is largely a microbial process. If the soil is well aerated, the organic sulfur is oxidized to sulfates, which plants can use directly.

An interesting application is the use of a commercial product that is fortified with an efficient sulfur-oxidizing microflora and sold as inoculated sulfur. Inoculation hastens the oxidation process. Inoculated sulfur sometimes is more effective than the elemental sulfur.

If the soil is waterlogged or if for other reasons anaerobic conditions prevail, the oxidation is retarded, and even added sulfates may be reduced to elemental sulfur, hydrogen sulfide, or related products.

Sulfates are usable by plants and are mobile within the soil profile.

A study of sulfur supplies and requirements for crops in the Southeastern States was begun in 1953 by the Department of Agriculture in cooperation with 12 experiment stations in the South and the Tennessee Valley Authority. Sulfur extracted from soils with sodium acetate-acetic acid solution is taken as a measure of available sulfur. In the Southeast, particularly in the light-textured soils of the Coastal Plain, the distribution of this extractable sulfur is almost the reverse of that of total sulfur.

These Southeastern soils have a unique pattern in distribution of extractable sulfur. Surface horizons typically contain 3 parts per million (6 pounds an acre) or less. A definite accumulation occurs in some lower horizons. This zone of accumulation may occur at a depth of 6 inches or it may be as much as 30 inches beneath the surface. Concentrations as great as 280 parts per million (560 pounds an acre) have been found in the zones. The contrast with the distribution of total sulfur is evident. The accumulation zones are correlated with horizons having an increase in clay content, a reduction of pH, or both.

Extractable sulfur, accumulated in the lower horizons, may be unavailable to shallow-rooted crops but may be available to deep-rooted plants, except in early stages of growth. Thus cotton responded to sulfur in certain soils in Alabama, but alfalfa and sericea lespedeza did not. Seedling plants often are deficient in sulfur throughout the Southeast; as their roots extend into deeper horizons, however, the deficiencies may disappear and yields may be normal or nearly normal.

Deficiencies of sulfur may persist throughout the growing season in the Northwest—an indication that subsoil accumulations of extractable sulfur do not occur there. Sufficient research has not been completed to determine how widely the pattern extends beyond the Red-Yellow Podzolic group, however.

Additions of sulfur in rainwater may be adequate for crop production in
areas away from industry, rainwater has added only 5.4 pounds of sulfur an acre a year. In six rural areas in Nebraska, a 2-year study gave a corresponding value of 6.2 pounds an acre a year. An estimated 6 pounds of sulfur an acre a year are added in precipitation in Washington. Sulfur accretions of this amount alleviate, but do not end, deficiencies of sulfur if other supplies are inadequate.

Additions of sulfur in the irrigation water may be enough to supply the total crop requirements. Western river waters contain 6 pounds to 2 thousand pounds of sulfur an acre-foot of water. The average is 50 pounds. The sulfur content of most rivers is lowest near their source and increases as the flow is supplemented with drainage water from irrigation projects. In only a very few areas in the West is sulfur fertilization of irrigated crops required for the maximum yields.

The sulfur content of well waters, though highly variable, generally is lower than that of river waters.

As to fertilizers, normal superphosphate contains about 11 percent of sulfur in the form of gypsum. Ammonium sulfate contains about 24 percent, and potassium sulfate about 16.5 percent. The average mixed fertilizer sold in the United States has about 7.5 percent.

In the Northwest, increases in yields of alfalfa from applications of superphosphate and potassium sulfate, formerly attributed to the primary constituents of those fertilizers, were found later to be largely responses to sulfur.

The equivalent of about 1.4 million tons of sulfur was applied in primary fertilizers in the United States in 1955. Additions in secondary nutrient fertilizers, liming materials, manures, and miscellaneous items (including insecticides and fungicides) brought the total close to 2 million tons that year.

That total is large, but the additions of sulfur from those sources were not uniformly distributed and perhaps were inadequate in some areas where soils were deficient and rainfall and irrigation water added little sulfur.
Fertilizers that are essentially sulfur-free have been used increasingly. Ammonium nitrate, anhydrous ammonia, urea, and ammonia solutions are examples among the nitrogen carriers.

The use of concentrated superphosphate and other phosphorus carriers with little sulfur has been expanding.

We recommend that farmers in areas of potential deficiency should have a planned program of adding sulfur instead of depending on incidental applications in ordinary fertilizer materials.

Losses of sulfur from soils are due mainly to leaching, erosion, and removal by crops.

Some sulfur is lost from soils of humid regions in drainage water. Measured losses from eight soil types in Illinois maintained in fallow ranged from 1.5 to 57 pounds of sulfur an acre a year; the average was 30 pounds. The larger losses occurred from the more permeable and more fertile soils. Annual losses from a Fayette silt loam with 10 percent slope in Wisconsin were approximately 1 pound an acre when crops were grown and 3 pounds an acre from uncropped soil.

The measurements in both States were made in lysimeters that permitted runoff and probably are fairly applicable to sloping upland soils. Earlier measurements, made in lysimeters that did not permit runoff, were considerably higher.

Sulfur losses from erosion have been estimated to average about 6 pounds an acre.

The losses may deplete soil supplies of sulfur, except perhaps in industrial and irrigated areas where accretions may exceed losses.

A balance sheet of the sulfur economy of soils and crops in the United States would appraise these additions and losses. It would be expected that soils well supplied with organic matter and occurring near industrial areas would not at present need sulfur fertilization. Requirements in such areas may change, particularly if sulfur-free fertilizers come into wide use or coal is replaced as fuel.

Iron and Soil Fertility

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Most soils contain an abundance of total iron, which all plants need, but many interacting factors affect and limit the iron that plants can use.

An accumulation of the heavy metals—copper, manganese, zinc, and nickel—in relation to available iron may induce iron deficiency in plants in acid soils.

Lime-containing soils, however, are most apt to contain too little iron; plants on such calcareous soils may have an abnormal growth, which is called lime-induced chlorosis. Its symptoms are yellow foliage, lack of vigor, and unproductiveness. It is common in the arid Intermountain and Southwestern States.

A deficiency of iron exists in almost every major fruit-growing area.

It is difficult to supply iron in a form available to plants. Such soil amendments as ammonium sulfate have been used to furnish plant nutrients and at the same time increase the soil acidity, which affects iron solubility. Some new compounds, called iron chelates, have been found to correct many deficiencies of iron.

One of the functions of iron is to be a catalyst in the production of chlorophyll, the green pigment in plants.

You can recognize iron deficiency by looking at the new, growing leaves. The tissue between the veins becomes lighter in color than the veins. The areas between the veins become yellow as the deficiency advances. Only a branch of a tree may be affected, or