THE IMPORTANCE OF SULPHUR IN PLANT NUTRITION

Sulphur has been recognized as one of the many elements required for plant growth for nearly 130 years. Deficiencies of this plant nutrient were identified as early as 1900 on certain soils in the Pacific Northwestern states (2, 28, 29). In Canada, this deficiency was first discovered in 1927 on some soils in Alberta (1, 41). In spite of these early records of the need for sulphur, it has received only limited attention until quite recently.

Interest in sulphur as a plant nutrient has increased greatly in the past few years, partly because reports of sulphur deficiency throughout the world are becoming more frequent and extensive (2, 7, 38). The main reasons for greater occurrence of sulphur deficiencies are:

1. Increased use of high analysis, essentially sulphur-free fertilizers
2. Decreased use of sulphur as a fungicide and insecticide
3. Increased crop yields which require larger amounts of all of the essential plant nutrients
4. Increased consumption of low sulphur fuels and increased emphasis on control of air pollution
5. Increased ability to identify soils low in sulphur

Role in the Plant

Sulphur is required by the plant for:

1. the synthesis of the amino acids cystine, cysteine, methionine and hence for protein elaboration
2. the activation of certain proteolytic enzymes such as the papainases
3. the synthesis of certain vitamins (biotin and thiamin or vitamin B1), glutathione and of coenzyme A
4. the formation of the glucoside oils found in onions, garlic and cruciferous plants
5. the formation of certain disulphide linkages which are associated with the structural characteristics of protoplasm. The concentration of sulphydril (-SH) groups in plant tissues has also been shown to be related to increased cold resistance in some species.

Sulphur was recently shown to be present in the nitrogenase enzyme system which is involved in the fixation of nitrogen by microorganisms (11). In certain situations free living nitrogen-fixing organisms in the soil and the nodule bacteria in legumes will make significant contributions to the nitrogen supply in soils.

Nitrogen and sulphur requirements are closely linked because both are required for protein synthesis. Plant protein contains about 1% S and 17% N. The need for sulphur fertilization often depends upon the supply of N and other nutrients and fertilization at high rates of these elements may induce a sulphur deficiency.

Requirement by Crops

Crops differ in their requirements for sulphur. The sulphur requirements of certain crops along with their requirements for nitrogen, phosphorus and potassium are shown in Table 1.

Some vegetable crops such as cabbage, turnips and onions have high requirements for sulphur. A supply of readily available sulphur is especially important for these crops because they have a relatively short growing season.

Legumes have an intermediate sulphur requirement. Cotton and tobacco require as much sulphur as some of the leguminous crops. Small grains, grasses and corn are less sensitive to sulphur.

Table 1 also shows that the sulphur requirements of some crops are quite similar to their phosphorus requirements.

Crop requirements for sulphur increase greatly as higher yields are obtained. Although record-yielding crops represent only a small fraction of all crops grown, they do indicate what can be done with good management practices. Some recent record yields and resulting nutrient uptake which might be quite common in the near future are shown in Table 2.

North America Deficiencies

Listed below are the states in which crop responses to sulphur have been reported.

So. Atl. States	**So. Cent. States**
N. and So. Carolina	Alabama
Georgia	Mississippi
Florida	
E.N. Cent. States	**Mt. States**
Ohio-possibly	Montana
Wisconsin	Idaho
	Colorado
W. So. Cent States	**Pacific States**
Louisiana	Washington
Oklahoma	Oregon
Texas-East and West	California
W. No. Cent. States	**Other States**
Minnesota	Hawaii
Nebraska	
Kansas	
Iowa-possibly	

Crop responses to sulphur have also occurred in the Canadian provinces of British Columbia, Alberta, Saskatchewan and Manitoba (7).

Recent Beneficial Effects

Cereals

Wheat has shown good response to sulphur in Texas (10). A sulphate fertilizer greatly increased the yield of NPK-fertilized oats in field tests on four Gray Wooded soils of the Peace River region (27).

Corn

The first reported occurrence of sulphur deficiency in corn in California was made in 1968 (20). The deficiency was observed north of Davis in the Sacramento Valley. Other sulphur deficient corn fields were found in Butte County in the Nord area (21).

Forage Crops

Sulphur deficiencies occurred in the Puyallup area of western Washington

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when repeated heavy dosages of non-sulphur bearing nitrogen fertilizers were applied to orchardgrass (24). Responses to this element were not expected in this area because it is near a large industrial area and significant amounts of incidental sulphur in rainwater and atmosphere were anticipated.

Sulphur responses were reported in 1968 in east Texas on coastal bermuda grass at Overton and on a mixed stand of ryegrass and clover at Flynn (36, 37).

The 1968 yield results from eight strip trials on established alfalfa in northwestern Wisconsin indicated that lack of sulphur may be limiting yield of this crop at some locations (19). Experiments started in 1966 in western Montana showed that applications of sulphur increased yields and longevity of stands of alfalfa (31).

Yield of Reed canarygrass-Alsike clover seeded on an organic soil in the Quesnel area of B.C. was increased ten-fold by using sulphur in combination with nitrogen, phosphorus and potassium (40). The nitrogen, phosphorus and potassium treatment yielded only 0.3 ton/acre.

Rape

Large responses have been obtained in the Peace River Region where NPK-fertilized rape was treated with from 20-40 lb. of sulphur per acre (26). Applications of sulphur containing fertilizer to certain soils in the province of Manitoba also increased yields of this crop (33).

Sorghum

Sulphur deficiency was observed several years ago in sorghum growing near the Sacramento River in Tehama County, California (22). The deficiency was very prominent early in the growing season but tended to diminish as the crop matured.

Soybean

Recent trials in Arkansas showed that sulphur fertilization improved soybean yields.

Sugarcane

Responses by sugarcane to sulphur fertilization have been found in Louisiana (15) and Hawaii (18).

Annual Range

Sulphur applied in combination with either nitrogen and phosphorus has produced more feed and animal gains on annual ranges in California and southern Oregon (3).

Timber Range

The beneficial effects of 200 lb. of nitrogen/acre upon the yield, nutritive value and palatability of pinegrass were accentuated by the addition of 100 lb. of sulphur/acre (14). This grass is an important understory species present on about 15 million acres of timber range in B.C.

Conifers

There have been recent indications that S may be beneficial to the growth of conifers in the Pacific Northwest (6, 32, 35). The color and growth of Christmas trees grown on glacial moraine soils in the state of Washington was improved more by nitrogen plus sulphur than by nitrogen alone (39). Growth of loblolly and slash pine seedlings in Southeastern U.S. was improved more by dressings of ammonium sulphate than by either ammonium nitrate or urea (23).

Turfgrass

Studies conducted at Puyallup, Washington, have shown that sulphur is beneficial for cool season turfgrass (16). Applications of sulphur have improved the appearance and vigor of bentgrass, have minimized the damage from Fusarium and Ophiobolus Patch diseases, and have prevented invasion of good turf by Poa annua. Sulphur is now included in the fertilizer recommendations for turf in western Washington e.g. 12-4-8-3.45 lb. of nitrogen, phosphorus, potassium and sulphur per 1,000 sq. ft., respectively.

In Florida, the growth of warm season grasses and their resistance to dollarspot have been improved considerably when sulphur is included in the fertilizer program (17).

Table 1

Sulphur Contained in Various Crops as Compared With Their Content of Nitrogen, Phosphorus and Potassium [1]

Crop	Yield per Acre	Sulphur	Nitrogen	Phosphorus	Potassium
Corn	100 bu.	8-10	160	26	100
Cotton	1.5 bales	12-15	105	20	55
Wheat	40 bu.	9-12	70	13	41
Alfalfa	5 tons	20-24	225	21	187
Clovers	4 tons	15-20	160	18	133
Grasses	4 tons	8-10	120	18	100
Cabbage	15 tons	19-38	97	11	81
Turnips	20 tons	25-35	90	18	150
Onions	15 tons	18-20	90	18	66

1 Expressed as elemental sulphur, nitrogen, phosphorus and potassium. Source: "Sulphur—the Essential Plant Food Element," The Sulphur Institute, 1962. Original data derived from Ensminger and Jordan, "The Role of Sulphur in Soil Fertility," Advances in Agronomy, Vol. 10 (1958), and "Our Land and its Care," National Plant Food Institute.

Table 2
Estimated Sulphur Content of Record-Yielding Crops in U.S.A. in 1966

Crop	Location	Yield/Acre	S-content pounds/acre
Alfalfa	California	16.2 tons	97
Corn	Missouri	305 bu.	31
Soybeans	Iowa	93 bu.	26
Wheat	Washington	209 bu.	44

Crop Residues

Sulphur plays an important role in the management of crop residues. Growth of winter wheat in the greenhouse was depressed by the addition of straws containing less than 0.15 percent sulphur (34). Straws with a higher sulphur content did not reduce wheat yields.

The use of ammonium thiosulphate and ammonium bisulphite fertilizers is believed to be effective in reducing the incidence of Foot Rot on winter wheat in eastern Washington (4). Two separate effects are thought to be involved: (1) effective removal of a ready source of fungus infection by speeding up the decomposition of the wheat stubble, and (2) the fungicidal effect of ammonium thiosulphate and ammonium bisulphite when sprayed on the growing crop in late fall or early spring.

Supplying Sulphur

The most common dry sulphur-containing fertilizers are ammonium sulphate (21-0-0-24S), ammonium phosphate-sulphate (16-20-0-14S), normal superphosphate (0-20-0-12S), potassium sulphate (0-0-53-18S), potassium-magnesium sulphate (0-0-22-15S), elemental sulphur, and gypsum (20%S).

Ammonium bisulphite (8.5-0-0-17S), ammonium thiosulphate (12-0-0-26S),

Made of potassium magnesium sulphate

and ammonium polysulphide (20.6-0-0-40 to 45S) are the most popular liquid fertilizer sources of sulphur.

Solid or Dry Fertilizers

A number of new solid sulphur-bearing fertilizers have been developed. Some of these are discussed below.

a) **Granular Triple Superphosphate-Elemental Sulphur (0-46-0-20S)**

This product prepared by TVA has been tested in Nebraska, California, Montana, Oregon and perhaps other states. It is a satisfactory source of both phosphorus and sulphur. One fertilizer manufacturer in the Western U. S. is now producing a granular triple superphosphate-elemental sulphur product with an analysis of 0-38-0-20(S).

b) **Ammonium Phosphates-Elemental Sulphur**

Solid and liquid sulphur have both been incorporated into ammonium phosphates and complete N-P-K granular materials produced by the ammoniator-granulator technique. Usually 12-15 percent sulphur has been introduced into the ammonium phosphates. Two complete fertilizers, 10-20-30-3(S) and 12-24-24-3(S), used for the fertilization of cotton were produced in the Southeastern U.S. by this process. Experimental fertilizers composed of 11-48-0 plus elemental sulphur and 16-48-0 plus elemental sulphur have been produced and tested in British Columbia. They proved to be good sources of sulphur for alfalfa (9).

c) **Ammonium Polyphosphate-Elemental Sulphur**

TVA has produced substantial amounts of a 12-51-0-15(S) for testing by bulk blenders in the Willamette Valley of Oregon (25).

d) **Ammonium Phosphate-Ammonium Sulphate-Urea**

One manufacturer in Western Canada has introduced recently a homogeneous 23-23-0-6(S) containing ammonium phosphate, ammonium sulphate and urea. The 23-23-0 marketed in this region is usually a heterogeneous or mechanical mix of ammonium phosphate and ammonium nitrate.

e) **Ammonium Phosphate-Urea Phosphate-Elemental Sulphur**

A fertilizer based on ammonium phosphate, urea phosphate and elemental sulphur is described as particularly suitable for alkaline soils (12). A typical grade is 15-45-0-5(S).

f) **Urea-Sulphur**

A relatively new nitrogen fertilizer containing urea and elemental sulphur was marketed on a limited scale in the Western United States. It was a prilled material composed of a uniform mixture of the two components and contained 40% N and about 10% S. When placed in moist soil, urea dissolves and moves out of the fertilizer particle, leaving a honeycombed skeleton of sulphur which is oxidized to sulphate. Crop responses to urea-sulphur were erratic. In some cases satisfactory results were obtained while in other instances unfavorable results occurred. These differences can probably be traced to differences in rate of oxidation, placement and distribution of the particles in the soil.

Coating of urea granules with sulphur may provide an effective controlled-release nitrogen fertilizer at relatively low cost (30). The coated product has about 10-16 percent sulphur and the nitrogen content varies from 35-40 percent. Although improved nitrogen utilization is the main consideration with this new fertilizer, the sulphur present in the coating will eventually be oxidized and become available for plants.

g) **Urea-Ammonium Sulphate**

A mechanical mixture of urea and ammonium sulphate with a grade of 34-0-0-11(S) was offered for sale in Western Canada in 1967. There are indications that this fertilizer, which gained ready acceptance, may be replaced partly by a homogeneous product containing the same two components.

h) **Ammonium Nitrate-Ammonium Sulphate**

A fertilizer made from ammonium nitrate and ammonium sulphate with an analysis of approximately 24-0-0-12(S) was available in California. The TVA and a British fertilizer manufacturer have developed methods for producing a granular homogeneous ammonium nitrate-sulphate. TVA products have grades of 30-0-0-5(S) and 27-0-0-11(S).

i) **Nitrophosphates Containing Sulphur**

Nitrophosphates made in Norway are now being distributed in the Western United States (5). Two grades, 15-15-15 and 21-7-14, containing sulphur are being marketed.

j) **Granular Sulphur Assemblages**

The last of the newer solid materials is prilled or pan-granulated elemental sulphur. Finely divided elemental sulphur is an effective fertilizer but is unpleasant to handle. Consequently there has been considerable interest in developing granular elemental sulphur fertilizers which will disintegrate at a reasonably rapid rate after application to soil. High analysis granular sulphur assemblages have been prepared by suspending sodium bentonite in molten sulphur and either prilling or pan-granulating the molten material. Binding agents such as gypsum, goulac (calcium lignosulphonate), and ammonium sulphate have been used either alone or in various combinations. Soluble salts such as sodium sulphate and ammonium sulphate have been included to supply an immediately available source of sulphur and in some methods of preparation to also assist in the formation of hard durable granules. However, ammonium sulphate should be avoided in certain assemblages because it appears to impair their disintegration properties. A surfactant can be added to facilitate the entrance of water into the prills. The quantities of the various components in these assemblages can vary widely but it is important to have as high a total sulphur content as possible and still retain the properties imparted by the binders and additives.

Bentonite is a swelling type clay and when sulphur assemblages containing it are placed in soil there is sufficient mechanical disintegration of the granule, caused by swelling of this clay, to produce smaller particles. This is extremely important for sulphur must be in a fairly finely divided state (for early response at least 30-40% of the sulphur should be -80 mesh) to be rapidly converted to the sulphate form.

Porous granules with considerable internal surface area are probably formed following dissolution of soluble binding agents or additives such as gypsum, sodium sulphate, ammonium sulphate and goulac. The resulting condition of greater exposure of elemental sulphur within the granule should favor the oxidation of sulphur to sulphate.

Early this year a high-analysis granular sulphur product became available commercially. This product contains 88 percent sulphur and the remaining portion is believed to be mainly bentonite. It has good physical properties making it suitable for bulk blending or for direct application. Upon contact with water it will degrade into smaller particles which facilitate the

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oxidation of sulphur to sulphate. This new fertilizer replaces a granular sulphur product which contained over 99 percent sulphur and had excellent physical properties but was unsuitable agronomically.

Various experimental assemblages have been investigated in greenhouse, growth chamber and field trials in California, Georgia, Minnesota, Nebraska and British Columbia. In several of these trials the new sulphur fertilizers were as effective as finely divided sulphur or gypsum (8, 13).

New Fluid Sulphur Fertilizers

Anhydrous ammonia-sulphur and sulphur dioxide are the only new liquid sulphur fertilizers. Some suspensions containing sulphur have been made by TVA.

a) **Anhydrous Ammonia-Sulphur**

A comparatively new preparation being considered is a solution of elemental sulphur dissolved in anhydrous ammonia. The experimental solutions usually contain 10-12% sulphur. Test programs with a TVA product have been conducted by nine companies in seven states. Laboratory and field trials have shown preplant applications to be effective on wheat and barley in the Pacific Northwest. However, acceptance of this fertilizer material has been slow because of corrosion of tanks on applicator rigs and clogging of nozzles and supply lines.

b) **Sulphur Dioxide**

Investigations at Washington State University showed that liquified sulphur dioxide (50% sulphur) injected directly into the soil was as effective as gypsum as a source of plant nutrient sulphur. Rates of application of up to 64 lb. of sulphur per acre were used without harm to crop plants. Fertilizer dealers have not readily accepted the introduction of this sulphur source because, (1) separate pump and storage tank on applicator rigs are needed and, (2) present pumps are not designed for accurately metering small amounts of liquid sulphur dioxide.

c) **Suspensions**

Suspensions with grades such as 9-18-18-10(S) and 12-12-12-20(S) have been prepared by TVA by mixing finely ground sulphur with 12-24-0 base suspensions, urea-ammonium nitrate solution and potassium chloride.

Use of Sulphur as a Soil Amendment

Sulphur and its compounds are also applied to the soil for (a) lowering the pH of naturally alkaline or overlimed soils and (b) reclaiming alkali and saline-alkali soils.

Predicting the Need for Sulphur Fertilizers

Several soil testing laboratories in the United States and Canada measure available sulphur in soils either routinely or upon request. These laboratories will recommend the amount of sulphur to be applied to soils containing less than adequate amounts of this nutrient for good crop production. Certain laboratories may also use crop analysis for determining the need for sulphur fertilizers.

Summary

Crop yields are increasing because of more adequate fertilization, better plant varieties and other improved farming practices. Higher crop yields bring about greater withdrawal of sulphur, and other nutrients, from the soil. There is an increasing need for the inclusion of sulphur in fertilizers to produce good crop yields and to replenish the amount of this nutrient removed by crops. Through the efforts of research organizations such as TVA and the fertilizer industry a number of sulphur containing fertilizers are now available to meet the needs of most cropping situations.

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