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FACT SHEET

SULFUR FERTILIZATION IN TEXAS

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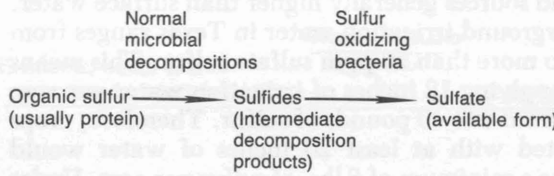
Since sulfur (S) is found in some amino acids which combine to form proteins, it is essential that plants have an adequate supply of available sulfur in the soil. Research studies show that plants absorb the sulfate ion ($SO_4=$) from the soil. Sulfates originate from natural constituents in the soil such as sulfides, gypsum and organic matter. Sulfates are also added in fertilizers, rainfall and irrigation water. Sulfates are leached from sandy soils in the higher rainfall regions of Texas. Due to the chemical nature of the sulfate ion, it moves relatively freely in the soil water, and high concentrations generally are not found. Some soils contain gypsum and others may contain sulfides, if poorly drained.

Concern has been expressed about possible sulfur deficiencies in Texas soils and the need for sulfur fertilization. For the past 10 to 20 years, less sulfur has been added to soils in fertilizers because of changes in production from super-phosphates to ammonium phosphates. A shift toward liquid fertilizers during the past decade also has resulted in less sulfur being applied. The trend toward low sulfur fuels resulted in less sulfur getting into the soil through rainfall, but this trend may be reversed with the increased use of coal and lignite (7). There is also an indication that fertilizers in current use contain more sulfur compounds as impurities than was common a few years ago.

The purpose of this publication is to provide a better understanding of the availability of sulfur in Texas soils, to indicate research data available and to suggest where sulfur fertilization is desirable.

Sulfur in Soils

It has been estimated that about 95% of the sulfur in soils is found in the organic matter. The amount varies from less than 100 lbs. per acre in low organic matter soils to more than 500 lbs. in soils high in organic matter. Microbial decomposition is necessary to convert this sulfur to forms available to plants. The conversion to the sulfate form takes place as follows:



The release of sulfur from organic matter is brought about by microbial action. Incubation studies reveal that from one to two percent of the total sulfur in the soils studied was mineralized during a 10 week incubation period (1). Therefore, soils containing as much as 500 ppm organic sulfur may release between 10 and 20 lbs. per acre during a growing season.

Sulfates can be converted to sulfides under reducing conditions. Golden (4) demonstrated a better reponse to applied S on poorly drained soils, and attributed this to lower levels of available S under reducing conditions.

Elemental sulfur causes acidification of an alkaline soil as a result of the microbial conversion of sulfur to form sulfuric acid, which combines with calcium to form calcium sulfate or gypsum, thereby negating the soil's alkaline effect. Sulfur containing compounds, such as calcium sulfate, ammonium sulfate and others, do not react to neutralize carbonates and, hence, do not acidify a soil.

Sulfur from the Air

Sulfur gases such as sulfur dioxide (SO_2) are important sources of this essential nutrient. These gases dissolve in rain water to form sulfurous acid, which enters the soil and provides a source of sulfur for

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plants. These gases generally originate from the burning of fossil fuels such as coal, lignite and natural gas that contain sulfur compounds. There has been concern in some regions about the possibility of "acid rain", but the amount of sulfur gases currently escaping into the atmosphere does not appear to be a problem in Texas.

The amount of sulfur entering the soil from rainfall varies, but measured amounts range from 5 to 20 lbs. per acre per year. In many areas, this amount is enough to meet crop requirements. When this sulfur is added to that released from soil organic matter, plant residue decomposition and native soil S, the need for S fertilization is confined to non-irrigated crops grown on deep sandy soils low in organic matter. In Texas, most of the potentially sulfur-deficient areas are in the eastern part of the state. Even here, not all soils are expected to respond to sulfur fertilization.

Sulfur in Ground Water

Most waters contain some sulfates, with underground sources generally higher than surface water. Underground irrigation water in Texas ranges from two to more than 20 ppm sulfate sulfur. This means that applying 12 inches of irrigation water per acre adds from 4 to 40 pounds of sulfur. Therefore, crops irrigated with at least 20 inches of water would receive a minimum of 6 lbs. of sulfur per acre. Under these conditions, a response from sulfur fertilization of irrigated crops is not expected, and seldom has been reported.

Irrigation water analyses, including sulfate levels, can be obtained from several sources, including the Texas Agricultural Extension Service laboratories at College Station. For more information, contact the County Extension Office.

Sulfur in Plants

Because sulfur is part of the protein molecule found in every plant cell, it is essential for new growth. Sulfur is also present in several organic compounds which have characteristic odors and flavors in plants, such as mustard, onions and garlic.

The sulfur content of major Texas crops is shown in Table 1. However, crop removal of sulfur varies, depending upon the portion of the plant harvested. For example, harvesting the vegetative portion or whole plant removes more sulfur than only seed harvests. Legumes generally contain more sulfur than grasses.

The sulfur content of plants is important, since the residue from harvested crops adds to the organic reserves in soils. There is concern about the nitrogen to sulfur ratio in animal rations, especially forages (6). An N/S ratio of 17 or less is considered favorable for animal requirements.

Table 1
Sulfur content of harvested crops (3)

Crop	Yield	lbs sulfur(S)
Corn grain	100 bu	8-10
Grain sorghum	5000 lbs	6-8
Corn silage	15 tons	25-30
Soybeans	40 bu	5-8
Alfalfa	8 tons	30-40
Coastal bermudagrass	8 tons	25-30
Oats	80 bu	5
Wheat	50 bu	10-12
Rice	5000 lbs	4-6
Cotton	1500 lbs*	8-10

*Seed Cotton

Results from Sulfur Studies

In evaluating results from sulfur applications, it is important to distinguish between the acidifying effects on soils and the nutritional benefits to plants.

Acidifying effects. There is considerable misunderstanding about the acidifying effects of sulfur compounds. The primary acid production originates from the oxidation of elemental sulfur.

$$S + O_2 \xrightarrow{\text{Sulfur oxidizing bacteria}} SO_2 + H_2O \longrightarrow H_2SO_3$$

elemental	oxygen	Sulfur gases	Water	Sulfurous acid

In soils containing free calcium carbonate, the sulfurous acid can react to produce gypsum through the following reaction.

$$CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + H_2O + CO_2$$

Calcium Carbonate	Sulfuric acid	Gypsum	Water	Carbon dioxide

This reaction reduces the alkalinity of the soil. However, the addition of too much sulfur can produce enough salts to be a problem for growing plants. It is generally preferable to apply 400 to 600 lbs. of finely divided elemental sulfur per acre (10 to 15 lbs. per 1000 sq. ft.), let it react six to 12 months, then make another application if additional acidification is desired. One pound of sulfur can neutralize approximately three pounds of calcium carbonate.

Nutritional benefits. The nutritional benefits are from the sulfate ion, since this is the form absorbed by plants. A summary of results from experimental studies in Texas is presented in Table 2. The only variable between treatments was sulfate fertilization. Results for Coastal bermudagrass hay production at Overton show a consistent response to sulfur fertiliza-

Table 2
Research results from sulfur studies in Texas

Location	Soil type	Crop	yield, lbs/acre No S	yield, lbs/acre + S
Overton	Darco	Coastal bermuda-grass	14,105*	15,549*
Overton	Troup	Coastal bermuda-grass	14,236	16,271
Beeville	Clareville	Coastal bermuda-grass	8,638	8,500
Beaumont	Lake Charles	Ryegrass	4,600	4,500
Malakoff**	-----	Clover	4,490	4,246
Thrall	Houston	Grain Sorghum	3,687	3,436
Temple	Houston	Grain Sorghum	3,748	3,454
Beaumont	Lake Charles	Rice	4,550	4,523
Beaumont	Lake Charles	Rice	4,705	4,583
Bushland	-----	Wheat	3,060***	3,060***
Lubbock	Amarillo	Cotton (lint)	453	438

*5 year average
**From Texas Power and Light Company report by Dr. Aaron Baxter; other results from Texas Agricultural Experiment Station reports.
***51 bu

tion. This was confirmed by a greenhouse study with ryegrass, which showed that dry matter production increased from 690 to 908 lbs/acre while the N/S ratio decreased from 30 to 11 with sulfur fertilization. Other crops and locations have not shown a consistent yield response from sulfur fertilization.

In addition, numerous nitrogen source studies have been conducted during the past 20 years, with little difference demonstrated between the sources containing sulfur and those without.

Based on data available, the following recommendations are made for sulfur fertilization on deep sandy soils used for Coastal bermudagrass production in east Texas under nitrogen fertilization of more than 200 lbs/acre annually.

Source	Annual rate lbs/acre
Ammonium sulfate*	150
Calcium sulfate (gypsum)	200
Elemental sulfur (very fine)	30**

*Will also supply 31 pounds of N.
**Enough can be applied in a single application to last two to three years. However, high rates produce more acidity. One pound of elemental sulfur neutralizes 3 pounds of calcium carbonate.

Fertilizer Sources of S

Materials containing sulfur that can be used as fertilizer are listed in Table 3. Sources, such as elemental sulfur and sulfides, that must be oxidized to sulfates before the sulfur is available to crops may show delayed responses. This is most often expected for cool-season crops. Hard prilled sulfur has shown a delayed availability for Coastal bermudagrass.

Table 3.
Sources of sulfur that can be used as fertilizers

Name of fertilizer	Chemical formula	Percent sulfur(S)
	Highly water soluble	
Ammonium sulfate	$(NH_4)_2SO_4$	24
Potassium sulfate	K_2SO_4	18
Potassium-magnesium sulfate	$K_2SO_4 \bullet MgSO_4$	23
Magnesium sulfate	$MgSO_4 \bullet 7H_2O$	13
Ordinary superphosphate	$Ca(H_2PO_4)_2 + CaSO_4$	14
Ammonium thiosulfate solution	$(NH_4)_2SO_3 + H_2O$	26
Ammonium bisulfite solution	$NH_4HSO_3 + H_2O$	17
	Low water solubility	
Calcium sulfate (gypsum)	$CaSO_4 \bullet 2H_2O$	17
	Water insoluble	
Elemental sulfur and processed materials	S	88-100

Diagnostic Techniques

Profitable returns from fertilization are dependent upon the level of available sulfur in the soil, crop, yield potential, N fertilization, irrigation and other production practices.

Identifying deficient conditions. Observation of deficiency symptoms, plant analysis and soil tests all provide useful information.

Visual symptoms. Sulfur deficient plants appear light green and often resemble the early stages of nitrogen deficiency. However, the lower leaves do not turn yellow as with nitrogen deficiency. Sulfur deficient legumes develop symptoms similar to nonlegumes.

Plant analysis. The total sulfur content of plants, as expressed as a percentage of a dry weight, varies between plants (Table 4). Some researchers have attempted to establish "critical" levels, with .1 percent for nonlegumes and .2 percent for legumes being common. However, the age of the plant and plant part analyzed will affect these values.

A nitrogen/sulfur ratio of 16 to 17 has been used to evaluate the feeding quality of forages. This generally means that grasses fertilized with high rates of nitrogen may need sulfur fertilization and supports research data for Coastal bermudagrass reported by Matocha (2) and others.

Measuring sulfur content of plants is a valuable diagnostic method for confirming deficiency symptoms, evaluating experimental and demonstration

Table 4
Interpretation of plant analysis values*

Crop	Plant Part	State of growth	Deficient	Low	Sufficient
				Percent S	
Corn	Ear leaf	Silking	<.10	.10-.15	>.15
Alfalfa	Top 6 inches	Early bud	<.20	.20-.30	>.30
Oats	Top leaves	Boot	<.15	.15-.20	>.20

*From Voss (7).

results and for use in general surveys to locate potentially deficient soil regions. When used to confirm deficiency symptoms, paired samples should be collected, one from normal and one from deficient areas.

Soil Analysis. Total sulfur is not correlated with available sulfur; therefore, it generally does not predict responses. A limited amount of work has been devoted to the development of suitable soil test methods for available sulfur. Water or salt solution extractions of sulfate sulfur ($SO_4=$) have been used with some degree of success. However, the sulfate ion moves freely in soils since it remains in solution and moves with the soil water and has shown only a fair correlation with yield responses.

As sulfur deficiencies and responses to fertilization become more common, it is probable that more effort will be devoted to soil test methods and soil sulfur tests will become more common.

Summary

1. Sulfur is an essential plant nutrient. Deficiencies result in a general light green color of plants. Legumes and grasses under high N fertilization have the highest S requirements.
2. Plants absorb the sulfate ion. Most of the reserve sulfur in soils is in the organic or mineral form. Sulfates in solution can be leached from the soil.
3. The most consistent evidence of crop yield responses from sulfur as a plant nutrient is on deep, highly leached sandy soils in East Texas.
4. Sulfur deficiency in arid regions and under irrigation is unusual. Underground water contains more sulfates than surface water.
5. In regions where gas, coal or lignite containing sulfur is used for fuel, significant amounts of sulfate are added to soils.
6. Sources of sulfur include ammonium sulfate, calcium sulfate (gypsum), ordinary superphosphate, ammonium phosphate-sulfate, ammonium thiosulfite and elemental sulfur.

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