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Research and Extension
Department of Agronomy MF2264 Soil Fertility

Sulphur in Kansas
Plant, Soil, and Fertilizer Considerations

Sulphur (S) is one of 16 elements essential for crop growth. Although sulphur is considered a secondary nutrient, it is often called the fourth major nutrient ranking just below nitrogen, phosphorus, and potassium. Deficiencies of sulphur in crop production are increasing, in Kansas and worldwide. The purpose of this publication is to discuss sulphur in terms of plant, soil, and fertilizer considerations.

Plant Considerations

Sulphur is taken up by plants as the sulphate ion (SO_4) and may be retained in this form in plant tissues and cell sap. Much of the sulphate is reduced and used in the formation of amino acids, proteins, and oils; in nitrogen fixation (root nodules); in structural components of protoplasm; and in activation of certain vitamins and enzymes. Sulphur is essential as a structural component of some amino acids found in both plants and animals, thus it is a part of the makeup of every living organism. Chlorophyll formation also is dependent on proper sulphur nutrition.

The amount of sulphur in plants is similar to phosphorus in many cases, thus removal by crops can be sizeable especially when the entire above ground portion of the crop is harvested. Sulphur removal by various crops is summarized in Table 1.

Sulphur deficiency on growing crops is often mistaken for nitrogen deficiency. With sulphur deficiency, many crops become uniformly chlorotic. The pale yellow symptom of sulphur deficiency often appears first on the younger or uppermost leaves, while nitrogen deficiency initially appears on the older lower leaves. Deficiencies of sulphur are often difficult to identify because the paling in crop color is not always obvious. Crops lacking sulphur also may be stunted, thin-stemmed and spindly. In the case of cereal grains, maturity is delayed. On legume crops, nodulation may be reduced. In some crops, a reddish color may first appear on the underside of leaves and on stems.

The need for sulphur is associated with amounts of nitrogen available to crop plants. This relationship is not surprising since both are components of protein and are associated with chlorophyll formation. Nitrogen and sulphur also are linked because sulphur plays a key role in the activation of the enzyme nitrate reductase, which facilitates conversion of nitrates to amino acids. Low activity of this enzyme due to sulphur deficiency depresses soluble protein concentrations in plant tissues.

Significant economic forage and grain yield losses can occur with sulphur deficiency, even when deficiency symptoms are not obvious. This can be particularly true when high levels of nitrogen nutrition are not balanced with adequate sulphur. Nitrogen use efficiency can be significantly reduced when sulphur is deficient.

Soil Considerations

Sulphur is usually present in relatively small amounts in soils and a majority is in organic forms. Sulphur deficient soils are often low in organic matter, coarse-textured, well-drained, and subject to leaching. In recent years, an increasing number of finer textured soils have shown sulphur deficiency, however.

Much like nitrogen, sulphur tends to cycle in the soil environment. The soil sulphur cycle is illustrated in Figure 1.

Soil organic matter is an excellent source of sulphur. Since organic sulphur is not plant available, sulphate must be released from reserves of organic matter. This is done through biological transformations that are similar to those affecting nitrogen. Nitrogen and sulphur mirror each other closely in terms of the transformations and reactions that occur in the soil. Mineralization of sulphate from soil organic matter is controlled by organic matter levels, temperature, and moisture. Generally, environmental factors that favor plant growth enhance sulphur release from organic matter.

Sulphate (SO_4), is an anion (negatively charged ion) and as such is mobile in the soil though not as free moving as nitrate (NO_3) or chloride (Cl). In well-drained, coarse-textured soils, sulphate can be leached below the root zone especially in high rainfall areas or under irrigation. Supply of sulphate in soils can vary greatly from year to year, based on crop removal, environmental conditions, and the amount of sulphur deposition from the atmosphere.

The total sulphur concentration of soil varies widely from about 50 to 50,000 parts per million (ppm). As is the case with many other nutrients, however, total

Table 1*. Sulphur Removal by Various Crops*

Crop	Yield	N	P_2O_5	S
			lbs	
Corn	200 bu grain	150	85	15
	Stover	116	25	18
Grain Sorghum	150 bu grain	120	60	22
	Stover	130	30	16
Wheat	80 bu grain	92	44	7
	Straw	42	10	15
Canola (rapeseed)	35 bu grain	66	32	12
	Straw	39	14	9
Soybeans	60 bu grain	240*	48	12
	Stover	84	16	13
Alfalfa	6 ton	225*	60	30
Cool-season grass	4 ton	140	46	16
Sunflower	3,500 lb seed	125	60	6
	Stover	51	10	10

**Legumes can get most of their nitrogen from the air.*

sulphur is not necessarily a good predictor of a soils ability to supply this nutrient. Most soil testing laboratories are measuring extractable sulphate sulphur (SO_4-S) and using this value to make recommendations. Due to the importance of organic matter and soil texture in predicting fertilizer sulphur needs, however, most labs will also factor these into recommendations. Organic sulphur is often estimated as the difference between total sulphur and sulphate sulphur (SO_4-S).

The Kansas State University Soil Testing Laboratory now offers a sulphate sulphur (SO_4-S) soil test. For best interpretation of this test, soil organic matter and texture also need to be known. Therefore, the organic matter test needs to be requested and soil texture reported on the information sheet. This information coupled with crop and yield goal allow for the best possible sulphur recommendations.

Like profile nitrogen samples, soil samples to be analyzed for sulphur should be sampled deeper than normal soil samples and air-dried before mailing. Since sulphate sulphur (SO_4-S) is mobile, sampling to a 24-inch depth is suggested for best results. When sampling for routine analyses (pH, phosphorus, potassium) and organic matter and zinc a 0 to 6 inch and 6 to 24 inch sample is suggested.

Significant amounts of sulphur can be added to the soil via irrigation water. In Kansas, sulphur content of irrigation water varies, but in some cases enough sulphur could be added through irrigation to meet crop needs. The sulphur content of irrigation water should be determined by testing and factored into sulphur recommendations.

Fertilizer Considerations

Deficiencies of sulphur have become common over most of North America. The incidence of sulphur deficient soils has increased in recent years likely due to one or more of the following:

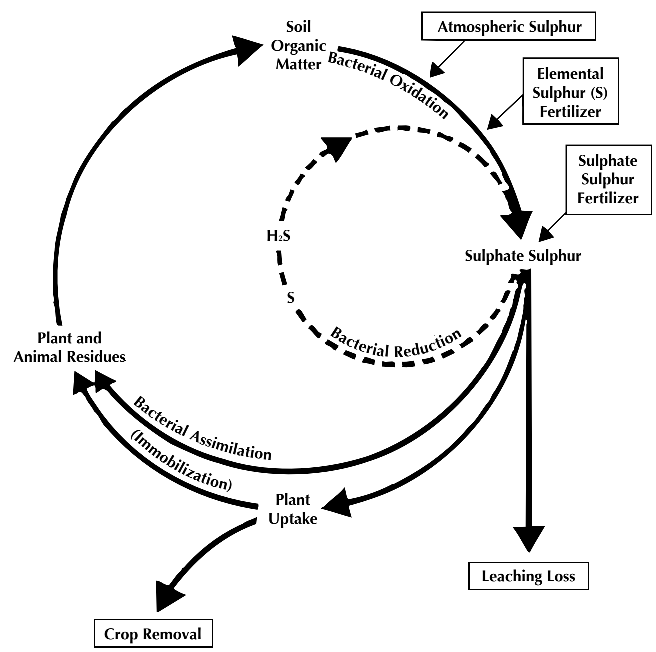
- higher analysis fertilizers that contain little or no sulphur
- more intensive cropping systems (doublecropping, less use of fallow, more use of crop residue) that result in more sulphur removal
- higher yielding varieties and hybrids
- less sulphur deposition from the atmosphere
- declining levels of organic matter

Due to these factors, the use of sulphur fertilizers is increasing. Liquid and dry sulphur-containing fertilizer materials are plentiful. In fact, more sulphur-containing fertilizer materials are available to the industry than any other major or secondary plant nutrient. A recent industry survey lists 16 dry and five fluid sources of sulphur products. Table 2 shows the more commonly used dry and fluid sources of plant nutrient sulphur.

Ammonium Sulfate

This is one of the oldest sources of ammoniacal nitrogen, manufactured as a by-product of the coking of coal from the steel industry. Ammonium sulfate is also manufactured as a by-product from metallurgical and chemical operations. Nearly one-fourth of world production comes from caprolactam manufacture, a raw material for the production of synthetic fibers. Three to four pounds of by-product ammonium sulfate are formed for each pound of caprolactam produced. Ammonium sulfate accounts for 4 million tons of plant nutrient sulphur worldwide. This product can be blended with most other dry fertilizers or can be made into a liquid. Ammonium sulfate is a good source of both nitrogen and sulphur, has low hygroscopicity, and is chemically stable. Its use may be undesirable on acidic soils, due to the acid-forming potential.

Figure 1. *The Soil Sulphur Cycle*



Ammonium Thiosulfate

This is a clear liquid material with no appreciable vapor pressure containing 12 percent nitrogen and 26 percent sulphur. Ammonium thiosulfate is the most popular sulphur-containing product used in the fluid fertilizer industry, as it is compatible with nitrogen solutions and complete (N-P-K) liquid mixes or can be used in suspensions. When ammonium thiosulfate is applied to the soil,

Table 2. *Common Sulphur Fertilizer Sources*

	Plant Nutrient Content			
	N	P_2O_5	K_2O	S
Source		%		
Ammonium Sulfate	21	0	0	24
Ammonium Thiosulfate	12	0	0	26
Gypsum (hydrated)	0	0	0	18.6
Potassium Sulfate	0	0	50	17.6
Potassium Thiosulfate	0	0	20	17
Ammonium Polysulphide	20	0	0	40-45
Potassium Magnesium Sulfate	0	0	22	22
Elemental Sulphur (various forms)	0	0	0	90-100

it decomposes to form colloidal elemental sulphur and ammonium sulfate. Ammonium thiosulfate should not be used in starter fertilizers placed in direct seed contact, because of toxicity to seed.

Gypsum

Gypsum is calcium sulfate and is commonly available in a hydrated form containing 18.6 percent sulphur. This material is generally applied in a dry form and is available in a granulated form that can be blended with other materials.

Potassium Sulfate

This material, usually applied in a dry granular form, is often referred to as sulfate of potash. It contains 50 to 52 percent K_2O and 17 to 18 percent sulphur. Potassium sulfate is widely used as a K and sulphur source in potato and tobacco production since these crops are sensitive to large applications of chloride.

Potassium Thiosulfate

This is a relatively new product that is a clear liquid containing about 20 percent K_2O and 17 percent sulphur. Potassium thiosulfate can be mixed with other liquid fertilizers and has potential for use in starter fertilizer mixes where both K and S are needed. This material should not be placed in direct seed contact.

Ammonium Polysulphide

This material is often a dark red to brown solution containing 20 percent nitrogen and 40 to 45 percent sulphur. Besides supplying nitrogen and sulphur, this material also is used for reclaiming high pH soils and for treating irrigation water. It is compatible with nitrogen solutions but is incompatible with phosphate-containing liquids. Ammonium polysulfide is a good source of sulphur, but is not as convenient or pleasant to handle as ammonium thiosulfate due to a strong hydrogen sulfide (rotten egg) odor.

Potassium Magnesium Sulfate

This material, sometimes called Sul-Po-Mag or K-Mag, is marketed as a dry material that is 22 percent K_2O, 22 percent sulphur, and 11 percent Mg. It is used in mixed fertilizers or sometimes applied alone to supply sulphur and magnesium on soils deficient in these two elements.

Elemental Sulphur

Several manufacturers have an elemental sulphur product available. These products are usually 90 percent or higher sulphur content with a small amount of binding material or bentonite to facilitate blending and application. Concern exists about availability of elemental sulphur during the year of application. Before it becomes available for plant uptake, elemental sulphur must first be oxidized to sulphate and this can be a slow process when surface applied. Many factors affect the rate of oxidation of elemental sulphur to sulphate. Particle size, rate, method, and time of application are important. Soil temperature and moisture are critical. Generally, anything that favors oxidation, fine particle size, incorporation, warm temperatures, and adequate moisture, favors quicker conversion to sulphate. Topdressing elemental sulphur on wheat or cool-season grasses is not recommended as conditions would not be favorable for conversion of elemental sulphur to sulphate in time to help the crop that year.

Sulphur Research in Kansas

Over the past 15 to 20 years, considerable research with sulphur fertilization has been conducted in Kansas. Positive yield responses have been noted on corn, wheat, grain sorghum, alfalfa, and cool-season grasses (bromegrass and tall fescue). Yield responses on irrigated crops have been limited to cases where the irrigation water was low in sulphur. In dryland situations, responses to sulphur fertilization have been most consistent on coarse-textured, low organic matter soils. Consistent responses, however, have been obtained on bromegrass and many of these sites had organic matter levels of 3.0 percent or higher.

Sulphur Recommendations

Fertilizer sulphur requirements depend on the difference between soil additions of this nutrient from precipitation, irrigation water, crop residues, and fertilizers and soil losses through crop removal, leaching of sulphate sulphur (SO_4-S), erosion, and volatilization. At average or lower yield levels in Kansas, much of the sulphur needs are met by additions through precipitation or irrigation water and from mineralization of soil organic matter. Optimum yields of crops in Kansas may require addition of supplemental sulphur fertilizer.

The following equation may be used to help develop sulphur fertilization recommendations.

$$\text{S Rec} = (\text{YG} \times \text{CF}) - \text{OM S} - \text{H}_2\text{O S} - \text{Man S} - \text{ST S}$$

where:

YG is yield goal
CF is crop factor
OM S is organic matter sulphur (2.5 lb S per % O.M.)
H_2O S is sulphur contribution from irrigation water
Man S is sulphur from manure application
ST S is soil test sulphur

Crop factors for commonly grown Kansas crops include:
Corn and grain sorghum: 0.2 lb S per bu
Wheat: 0.60 lb S per bu
Soybean: 0.40 lb S per bu
Canola: 0.60 lb S per bu
Sunflower: 0.005 lb S per pound or 5 lb S per 1,000 lb
Alfalfa: 6.0 lb S per ton
Cool season grasses: 5.0 lb S per ton

Example 1:

Crop :	Irrigated Corn
Yield Goal:	200 bu/a
Irrigation Data:	15" H_2O applied, H_2O has 3 ppm S
Manure:	None
Soil Test S:	0-24" = 2 ppm
Soil Organic Matter:	1.0%
S Rec =	$(200 \times 0.2) - 2.5 - 10.2 - 0 - 14.4$
S Rec =	13.0 lb/a

In this example, irrigation water sulphur can be calculated by taking 15 (inches of water applied) times 27,150 (gallons per acre inch) times 8.33 (pounds per gallon) to get the pounds of water applied. In this case 3.4 million pounds were applied. Since the water has 3 parts per million sulphur, 10.2 pounds (3.4 × 3) of sulphur was applied in the water. A condensed formula to use is: sulphur in irrigation water = .226 × inches of water applied × ppm sulphate sulphur (SO_4-S) in water.

Soil test sulphur can be calculated by taking soil sulphur result (2 ppm) × 0.3 × sample depth in inches (24) to get 14.4 pounds per acre sulphur from the soil. If samples less than 24 inches are taken, adjust for sulphur found in the sampled depth.

Example 2:

Crop:	Dryland Wheat
Yield Goal:	60 bu/a
Manure:	None
Soil Tests: 0 to 24" =	3 ppm
Soil Organic Matter:	0.5%
S Rec = (60 × 0.6) - 1.25 - 0 - 0 - 21.6	
S Rec =	13 lb/a

In the above examples, manure was not applied, but Table 3 gives estimates of available sulphur in manures.

These values are for the first year following manure application. Approximately one-half of the first years' values can be used the second year following application.

Soil test sulphur can represent a significant part of the sulphur requirement. Ideally, a sampling depth of 24 inches is recommended since sulphate sulphur (SO_4-S) moves with soil water. Just as is the case with other nutrients, a good representative soil sample is vital. The Kansas State University Soil Testing Laboratory now offers a sulphur soil test. The sulphur test is not part of the general package (pH, lime requirement, phosphorus (P), and potassium (K)) and must be specifically requested.

This sulphur recommendation equation should provide a good starting point for most Kansas crops. The exception is cool-season grass forages. Recent work in Kansas has shown consistent forage yield responses to sulphur fertilization even when soil organic matter levels are in the 3 to 5 percent range. Accordingly, the recommendation is to apply 15 pounds per acre sulphur to cool-season grasses for optimum forage production under high level management systems.

Summary

Sulphur, often called the fourth major nutrient, is essential for plant growth and sulphur deficiencies are becoming more widespread in Kansas and other states. Sulphur is essential for the formation of certain amino acids, proteins, and oils; is a structural component of protoplasm; and is necessary for activation of certain vitamins and enzymes. Sulphur cycles in the soil environment, much like nitrogen. Soil organic matter is an excellent source of sulphur. Plants take up sulphur as the sulphate (SO_4) ion. Sulphate in the soil is leachable.

If supplemental sulphur is needed, several sulphur fertilizers are available. Recent Kansas research has verified a need for sulphur fertilization in some instances.

Sulphur recommendations can be determined based on several considerations. Crop grown, yield goal, soil organic matter levels, level of sulphur in irrigation water, manure application, and soil test sulphur levels are all important factors to consider when developing sulphur recommendations.

Table 3. *Estimate of available sulphur from various manures*

	Sulphur Content			
	Solid		Liquid	
Manure	Total	Available	Total	Available
	lb/ton		lb/1,000 gal	
Beef	1.8	1.0	4.8	2.6
Dairy	1.5	0.8	4.2	2.3
Swine	2.7	1.4	7.6	4.0
Poultry	3.3	1.8	9.0	5.0

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MF2264 July 1997