A2525

Understanding Plant Nutrients

Soil and Applied Sulfur

E.E. Schulte and K.A. Kelling

Although sulfur is described as a secondary plant nutrient, largely because it is not deficient as often as are nitrogen, phosphorus, and potassium, it is as important as any of the major nutrients. In fact, many crops contain approximately equal amounts of sulfur and phosphorus.

SULFUR REACTIONS IN SOILS

Sulfur transformations are very similar to those of nitrogen. Most sulfur in the soil is unavailable as a part of the soil organic matter. As shown in Figure 1, organic sulfur and reduced sulfide sulfur ($S^{=}$) combine with oxygen to form available sulfate sulfur ($SO_4^{=}$) in warm, well-aerated soils. This process is very similar to the conversion of organic nitrogen into available ammonium (NH_4^+) and nitrate nitrogen (NO_3^-).

Available sulfate sulfur is tied up by bacteria during the decomposition of crop residues rich in carbon. Available sulfur can also be changed into unavailable sulfide sulfur in water-logged soils. Fortunately, this immobilized or reduced sulfur is usually only temporarily unavailable. As the soil warms or as aeration improves, this unavailable sulfide sulfur combines with oxygen to re-form available sulfate sulfur.

Harvesting and leaching remove sulfur from the sulfur cycle. Crop removal varies from less than 10 lb/a of sulfur for grain crops to more than 20 lb/a for legumes and corn silage (Table 1). Sulfate sulfur is not readily held by soil particles, except for acid clays, so in most soils it can be leached below the root zone. However, sulfate sulfur does not leach as readily as nitrate nitrogen, and some acid, clayey subsoils contain sizeable reserves of available sulfate.

Figure 1. The sulfur cycle.

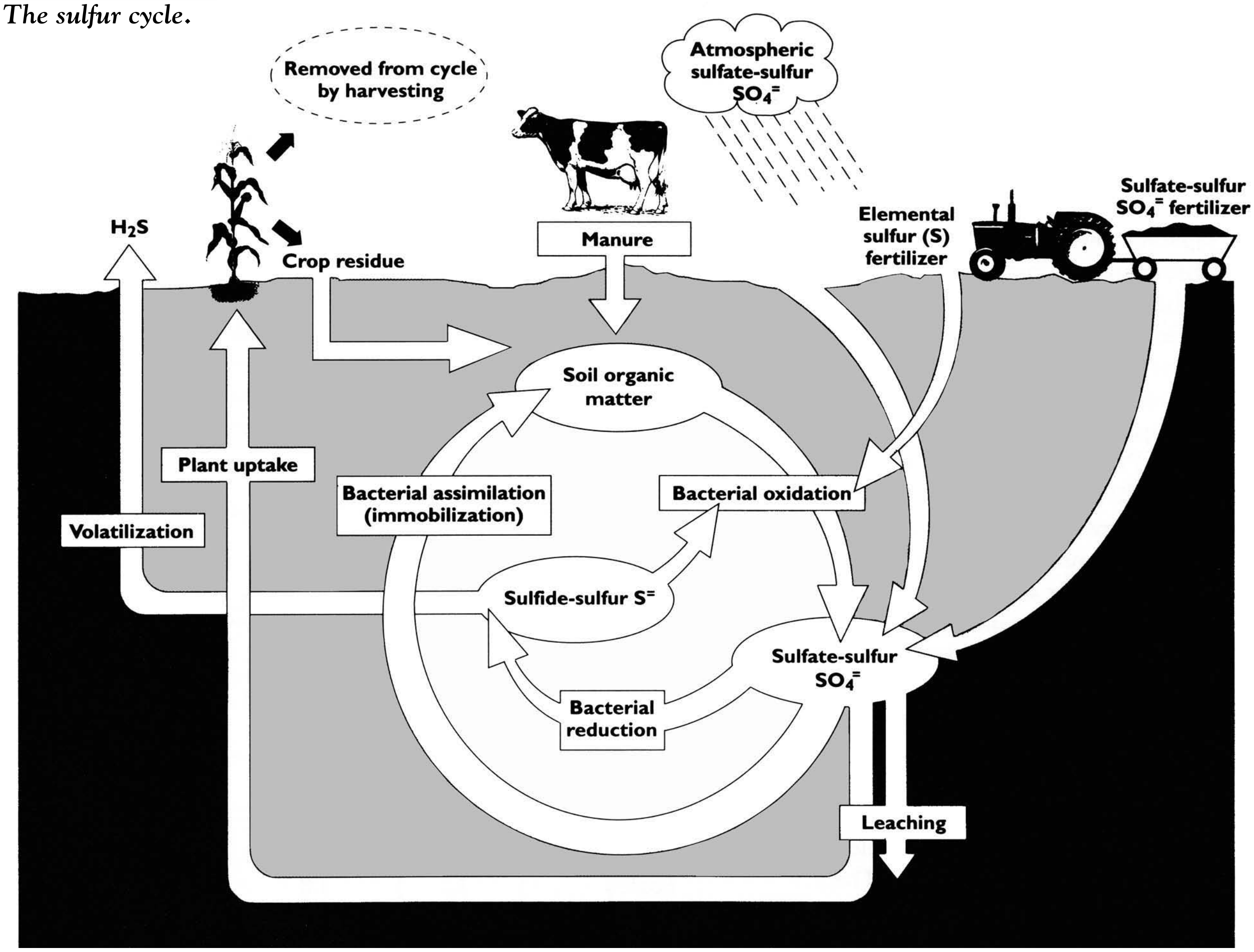

Table 1. Sulfur removed in the harvested portion of crops.

CROP	PORTION HARVESTED	YIELD PER ACRE	SULFUR REMOVED
			lb/a
Alfalfa	Hay	4 tons	23
Corn	Grain	150 bu	10
	Silage	15 tons	25
Oat	Grain	80 bu	5
	Straw	2 tons	9
Potato	Tubers	400 cwt	10

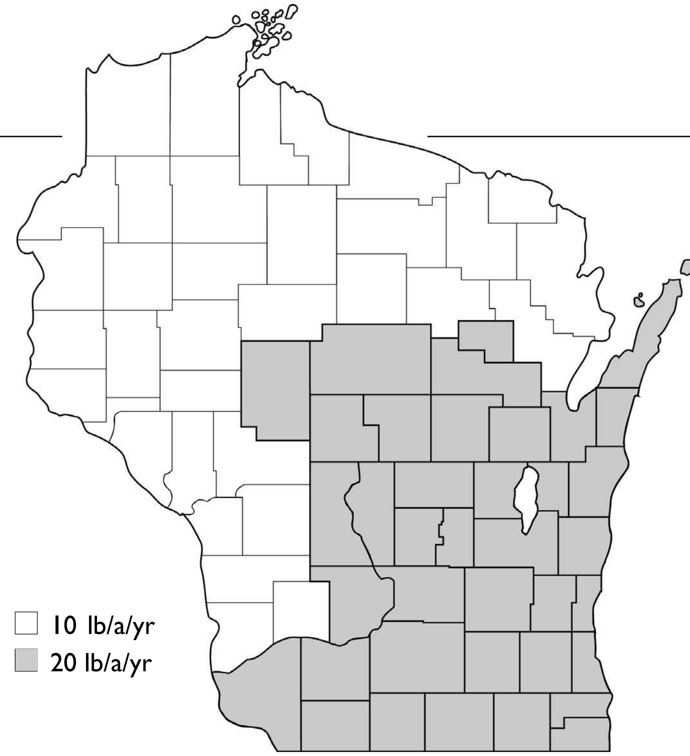

Figure 2. Sulfate sulfur in precipitation.

Sources of Sulfur

Soils commonly contain 200–600 lb/a of total sulfur. Nearly all is in the unavailable organic form. As organic matter decomposes, a small portion of this sulfur is converted into available sulfate sulfur. Approximately 2.8 lb/a of sulfur are released annually from each 1% organic matter in Wisconsin soils. Another source of un-applied sulfur is atmospheric contamination, which results from burning coal and, to a lesser extent, oil and gas. This atmospheric sulfur is washed from the air and deposited on the land in rainwater. Precipitation typically deposits 5–30 lb/a of sulfate-sulfur per year in Wisconsin. Western and northern Wisconsin receive about 10 lb/a of sulfate sulfur annually in precipitation. The remainder of the state gets twice as much (Figure 2).

Many Wisconsin farmers use manure to apply sulfur. The sulfur contribution from manure varies among animal species and with the rate of application (Table 2). About 55% of total manure sulfur becomes available to crops in the year of application. The final source of sulfur is the subsoil. Clayey, acidic subsoils may contain substantial amounts of plant-available sulfate sulfur. Annual sulfur-supplying capacities of subsoils are considered low at 10 lb/a, medium at 20 lb/a, or high at 40 lb/a.

Sandy soils may require annual applications of sulfate forms of sulfur because the sulfate leaches through these soils relatively rapidly. Irrigation water, however, may contain sufficient sulfate-sulfur for the crop. In these cases, response to fertilizer sulfur is likely only in years with above-average rainfall, when little irrigation water is applied.

All sulfate forms of sulfur fertilizer are equally effective when surface-applied or incorporated (see Table 3). Elemental sulfur, however, is insoluble and must be transformed into sulfate-sulfur by soil bacteria before plants can use it. The rate of this transformation depends on particle size and degree of mixing with the soil. To be effective, elemental sulfur should be worked into the soil well in advance of the time the crop needs it. Without mechanical incorporation, elemental sulfur is incorporated to some extent by falling into cracks when the soil dries or by the

Table 2. Estimates of available sulfur from manure as affected by animal and manure type.

	SULFUR CONTENT			
	SOLID (lb/ton)		LIQUID (lb/1000 gal)	
KIND OF ANIMAL	TOTAL	AVAILABLE	TOTAL	AVAILABLE
Beef	1.7	0.9	4.8	2.6
Dairy	1.5	0.8	4.2	2.3
Poultry	3.2	1.8	9.0	5.0
Swine	2.7	1.5	7.6	4.2

activity of earthworms and burrowing insects. If the soil is known to be deficient in sulfur, include some sulfate sulfur in topdress applications for immediate sulfur availability.

Row crops and small grains require about 10 lb/a of sulfur in sulfur-deficient areas. Alfalfa requires 25–50 lb/a if applied during the seeding year or 15–25 lb/a when topdressed on established alfalfa. These treatments generally will supply enough sulfur to last 2–3 years. Sulfur may be applied as row fertilizer, but thiosulfate should not be seed-placed.

DIAGNOSTIC TECHNIQUES

Deficiency Symptoms

Sulfur is a component of the amino acids cysteine, cystine, and methionine. These amino acids are among the "building blocks" of protein, and shortage of sulfur retards protein synthesis.

Sulfur, as a constituent of nitrate reductase, is involved in the conversion of nitrate into organic nitrogen. Sulfur deficiency consequently interferes with nitrogen metabolism, which explains why sulfur deficiency resembles nitrogen deficiency in many crops. However, the symptoms usually are not as dramatic and are not localized on the older leaves. Lack of sulfur appears as a light green coloring of the whole plant. Legumes, especially alfalfa, have a high sulfur requirement, so deficiencies usually appear on these crops first. Corn, small grains, and other grasses show sulfur deficiencies less frequently. Sulfur deficiency in corn sometimes mimics other deficiencies such as manganese or magnesium in that it causes interveinal chlorosis: the upper leaves tend to be striped, with the veins remaining a darker green than the area between the veins.

Soil Analysis

Soil tests for available sulfur are helpful but in general are not as precise as tests for phosphorus and potassium. Sources of sulfur not directly measured by the soil test may contribute significantly to crop requirements. The Wisconsin soil-testing labs calculate a sulfur availability index (SAI) by estimating sulfur released from organic matter, sulfur in precipitation, subsoil sulfur, and sulfur in manure if applied, which they add to the soil-test sulfur-sulfate to determine the total available sulfur. If these contributions add up to 40 units or more, response to added sulfur is unlikely. If the index is between 30 and 40, the sulfur need should be confirmed by plant analysis, and if the index is less than 30 sulfur should be added. See Extension publication A2809, *Soil Test Recommendations for Field, Vegetable and Fruit Crops*, for additional information on the sulfur availability index.

Table 3. Fertilizer sources of sulfur.

NAME OF FERTILIZER	CHEMICAL FORMULA	ANALYSIS ($N\text{-}P_2O_5\text{-}K_2O$)	PERCENT SULFUR
VERY SOLUBLE			
Ammonium sulfate	$(NH_4)_2SO_4$	21-0-0	24
Ammonium thiosulfate (60% aqueous solution)	$(NH_4)_2S_2O_3 + H_2O$	12-0-0	26
Magnesium sulfate	$MgSO_4 \cdot 7H_2O$ (Epsom salts)	0-0-0	14
Ordinary superphosphate	$Ca(H_2PO_4)_2 + CaSO_4$	0-20-0	14
Potassium magnesium sulfate (Sulpomag)	$K_2SO_4 \cdot 2MgSO_4$	0-0-22	23
Potassium sulfate	K_2SO_4	0-0-50	18
SLIGHTLY SOLUBLE			
Calcium sulfate (gypsum)	$CaSO_4 \cdot 2H_2O$	0-0-0	17
INSOLUBLE			
Elemental sulfur	S	0-0-0	88–98

Plant Analysis

Some laboratories analyze sulfur routinely as part of their plant analysis program, while others analyze this element only upon request. When a soil tests low or moderate in available sulfur (SAI less than 40), it is a good idea to verify the suspected deficiency through plant analysis. Instructions for sampling various crops and directions for sending samples to the laboratory are available from county Extension offices and the Soil & Plant Analysis Laboratory, 5711 Mineral Point Road, Madison, WI 53705.

Guidelines for the required levels of sulfur in plant tissue for some of the major agronomic crops are given in Table 4.

ADDITIONAL INFORMATION

These publications in the *Understanding Plant Nutrients* series are available from your county Extension office:

Soil and Applied Boron	(A2522)
Soil and Applied Calcium	(A2523)
Soil and Applied Chlorine	(A3556)
Soil and Applied Copper	(A2527)
Soil and Applied Iron	(A3554)
Soil and Applied Magnesium	(A2524)
Soil and Applied Manganese	(A2526)
Soil and Applied Molybdenum	(A3555)
Soil and Applied Nitrogen	(A2519)
Soil and Applied Phosphorus	(A2520)
Soil and Applied Potassium	(A2521)
Soil and Applied Sulfur	(A2525)
Soil and Applied Zinc	(A2528)

Table 4. Sulfur plant-analysis interpretations for common Wisconsin field crops.

			INTERPRETATION			
CROP	**PLANT PART SAMPLED**	**TIME OF SAMPLING**	**DEFICIENT**	**LOW**	**SUFFICIENT**	**HIGH**
			%			
Alfalfa	Top 6 inches	Early bud	<0.20	0.20–0.25	0.26–0.50	>0.50
Corn	Earleaf	Silking	<0.10	0.10–0.20	0.21–0.50	>0.50
Oat	Top leaves	Boot stage	<0.15	0.15–0.20	0.21–0.40	>0.40
Soybean	First trifoliate	Early flower	<0.15	0.15–0.20	0.21–0.40	>0.40

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R-09-92