Secondary Mineral Nutrients—Sulfur

With this section, we will complete our three-part discussion of the so-called secondary macronutrients. We looked at calcium in the January, 1996 issue of FNN, magnesium in July of that year, and will conclude with sulfur in this issue. As in past issues, Eric van Steenis of the British Columbia Ministry of Forests helped with the writing of this section.

Sulfur has been known to be an essential plant nutrient for over 100 years, and is considered a macronutrient because it is required by plants in approximately the same concentration as phosphorus and magnesium. It is rarely applied as a fertilizer in traditional agriculture, however, because sulfur is commonly found in soils and is also supplied in rain and irrigation water. The other fascinating aspect of this mineral nutrient is that it cycles through nature in both organic and inorganic forms and under both aerobic and anaerobic conditions **(Figure** 5).

Role in Plant Nutrition

Although plants can absorb a small amount of gaseous sulfur dioxide (SO_2) through their foliage, the most common method of uptake is by the roots as sulfate ions ($SO_4^{=}$). These sulfate ions are transported throughout the plant in the xylem and also are stored in this form. In some ways, the assimilation of sulfur is similar to nitrogen because sulfate ions must be reduced in the chloroplasts of the leaves before they can be incorporated into amino acids and proteins. Proteins are

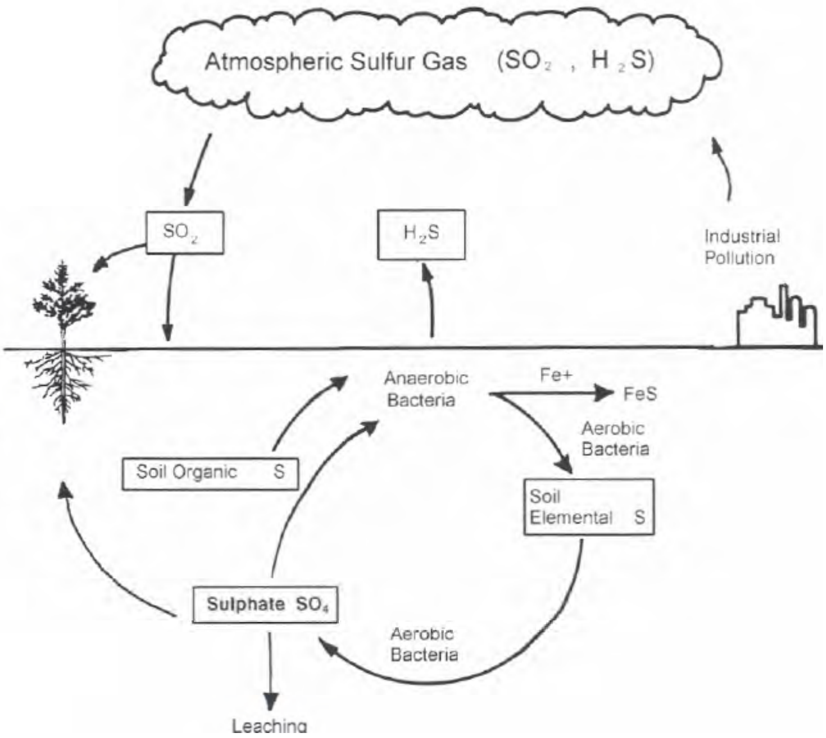

Figure 5. The sulfur cycle in nature. Although plants can absorb minute amounts of sulfur dioxide (SO_2) from the air, the) obtain most of this essential mineral nutrient as sulfate ions ($SO_4^{=}$)from the soil (modified from Mengel and Kirkby 1979)

constructed from combinations of 22 different amino acids. Sulfur is critical to the structure of the 2 keys amino acids, cysteine and methionine, which is reflected in the approximate 10:1 nitrogen:sulfur ratio of all proteins. Disulfide bonds or bridges help maintain the 3-dimensional structure of proteins, and need to be maintained to prevent denaturation as can happen during dehydration or frost injury **(Figure 6).** This essential nutrient also is a component of several vitamins, such as thiamine and biotin, as well as coenzyme A which is involved in the Krebs cycle. Non-reduced sulfate is used structurally in sulfolipids in cell membranes and polysaccharides, and there is evidence that sulfolipids also are involved in the regulation of ion transport across membranes.

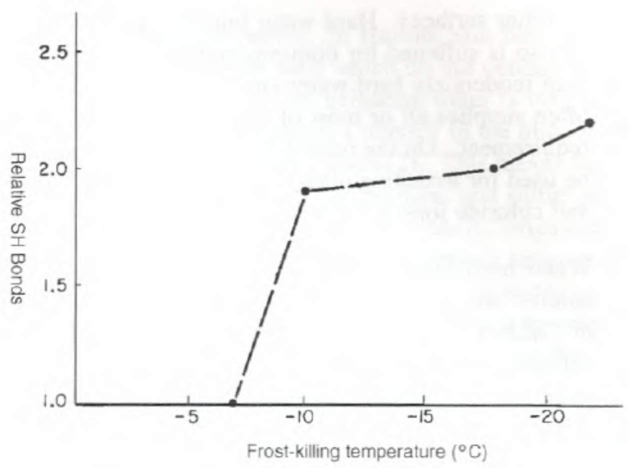

Figure 6. Sulfhydryl (SH) bonds in plant proteins are thought to be related to cold hardiness, as shown in this example for Pinus sylvestris *(modified from Levitt and others 1961)*

Availability and Uptake

Bareroot nursery soils contain sulfur in both organic and inorganic forms **(Figure 5)** but only the inorganic fraction is normally available for plant uptake. When organic matter decomposes under aerobic conditions, sulfur is released in the sulfate form but this happens too slowly to be of practical significance. The sulfur in soil minerals, such as gypsum ($CaSO_4 \cdot 2 H_70$), is only available for plant uptake after it has been oxidized into sulfate ions. Because sulfur is found in both available and unavailable forms in the soil and the concentrations of these form varies over time, bareroot nurseries should have their soils tested for S on an annual basis to determine if fertilization is warranted. Artificial growing media components like peat moss, vermiculite and perlite contain essentially no available sulfur.

Small amounts of sulfur dioxide are found in the atmosphere due to the burning of fossil fuels and decomposition of organic matter **(Figure 5).** Because sulfur dioxide is very soluble, it can be deposited in rainfall and therefore supplied to crops in ground water. In industrialized areas, this source is considered to be sufficient to meet crop needs. The amount of sulfur in irrigation water varies widely, however: a recent survey from across the US found that 4% of the water samples contained no S, and another 65% contained less than 10 ppm. Compared to a target level of around 60 ppm, this is too low to supply the needs of rapidly growing seedlings. Even within a state like Texas, however, the S content of irrigation water varied from 0 to 510 ppm so the only way to know how much your water contains is to have it chemically analyzed. (See The Nutritive Value of Water in this section for more information)

The fact that sulfate is an anion affects its availability in two ways: first, elemental sulfur must be oxidized before it can become absorbed, and second, sulfate anions are not strongly held in the soil or growing medium. So, unlike calcium and magnesium which can accumulate on the cation exchange sites in the soil, sulfur must be regularly supplied to a growing crop.

Diagnosis of Deficiencies and Toxicities

Healthy seedlings should contain from 0.10 to 0.20 % sulfur on a dry weight basis **(Table 3).** The symptoms of sulfur deficiency are often difficult to distinguish from those of nitrogen because deficiencies of both nutrients result in a shortage of proteins. Sulfur is not as mobile in the plant as nitrogen so chlorosis due to sulfur deficiency is most severe on the younger foliage whereas nitrogen chlorosis shows up first in older leaves.

Conifers: In general, sulfur deficient crops are chlorotic and slightly stunted but the severity can vary considerably by species. In a controlled experiment with container seedlings, the needles of sulfur deficient Douglas-fir seedlings were chlorotic and severely twisted. With white spruce, the symptoms were much less severe and only the ends of the needles became golden towards the end of the growing season.

Broadleaves: Sulfur deficiency causes a moderate reduction in height growth compared to nitrogen deficiency. The first signs of sulfur deficiency show on the younger leaves which are initially light green but eventually develop scorched and curled margins. Necrotic areas can form along the margins and then spread inward to the leaf midrib. In some species, sulfur deficiency also affected root growth.

Table 3. The three "secondary nutrients": Calcium, Magnesium, and Sulfur

Element	Symbol	Average Concentration in Plant Tissue (%)	Adequate Range in Seedling Tissue (%) Container	Bareroot
Nitrogen	N	1.5	1.20 to 2.00	1.30 to 3.50
Potassium	K	1.0	0.30 to 0.80	0.70 to 2.50
Calcium	Ca	0.5	0.20 to 0.50	0.30 to 1.00
Magnesium	Mg	0.2	0.10 to 0.15	0.10 to 0.30
Phosphorus	P	0.2	0.10 to 0.20	0.20 to 0.60
Sulfur	**S**	**0.1**	**0.10 to 0.20**	**0.10 to 0.20**

Toxicity: Sulfur toxicity is rare in soils but two types of plant injury are common under conditions of acid rain in heavily industrialized regions. The symptoms of acute SO_2 injury include marginal and interveinal chlorosis and necrosis. Chronic injury is diagnosed as leaf chlorosis and bleaching which may continue until the chlorophyll is destroyed and the interveinal portions of the leaf are nearly white.

Monitoring

Most good agricultural soils contain adequate S in organic and inorganic forms although the amount in the available sulfate form can vary considerably. Soil tests can only measure the inorganic fraction and so give only a partial picture of total available sulfur. Tests can be used to determine whether fertilization is required, and should be done annually especially in high rainfall areas where leaching is severe. Container growers should assume that their media does not contain any sulfur and that the only possible source is the irrigation water. The most appropriate way to monitor mineral nutrients is to collect the applied solution while fertigating and have it chemically analyzed. It also is possible to collect the saturated media extract and leachate but the results of these tests are more difficult to interpret.

Plant tissue analysis can be helpful in diagnosing sulfur deficiencies, especially when paired tests with healthy seedlings are run. Because considerable variation can exist, establishing base nutrient standards for your own species is highly recommended.

Sulfur Management

- Analyze your irrigation water. Since sulfur is often carried in water, both bareroot and container nurseries should have their irrigation water analyzed.

- In container nurseries, formulate and apply well-balanced fertigation solutions. Because growing media contains no sulfur and container crops are often grown in enclosed structures, nursery managers must supplement the amount of sulfur that is found in their irrigation water. Gypsum or slow-release fertilizers like Osmocote® can be incorporated into the growing media although the heavy irrigation rates in container nurseries can cause the sulfate to be quickly leached. Magnesium sulfate and potassium sulfate are inexpensive soluble fertilizers for fertigation **(Table 4),** and a target concentration of around 60 ppm SO,-S should be adequate for all forest and conservation crops. Remember that sulfate is not adsorbed on the cation exchange sites and therefore regular fertigation is necessary to maintain a good supply during periods of rapid growth.

- In bareroot nurseries, apply sulfur fertilizers if warranted. When a need for supplemental sulfur has been confirmed, then the next step is to select the most appropriate fertilizer. There are many options when it comes to selecting a sulfur fertilizer **(Table 4).** Gypsum and superphoshate can be easily and cheaply applied to the soil and incorporated prior to sowing, and so the best choice will depend on what other nutrients are also needed. Other more soluble sources of sulfur like ammonium sulfate and Epsom salts can be applied during the growing season as a top dressing.

In conclusion, sulfur is an essential mineral nutrient that is often overlooked because small amounts are found in the soil and water. Less than optimal seedling growth rate ("hidden hunger") may be the most common symptom of a minor sulfur deficiency because background levels can be just high enough to avoid severe nutrient deficiencies from becoming apparent. Analyzing your irrigation water and soil is the only way to know if you have a problem.

Table 4. Some common fertilizers containing sulfur

Fertilizer	Sulfur Content	Other Nutrients	Use in Nurseries
Ammonium sulfate	24%	21 %N	Top dressing in bareroot beds; available as a soluble for container crops; lowers soil pH
Ammonium sulfate nitrate	15%	26% N	Top dressing in bareroot beds
Gypsum	18%	22 % Ca	Relatively insoluble soil amendment that should be incorporated prior to sowing
Magnesium sulfate (Epsom salts)	13%	10 % Mg	An excellent fertilizer for container crops - very soluble, and contains no inert materials.
Osmocote® 18-10-10	3.4%	18% N 4.8 % P 8.3% K + Others	Slow-release fertilizer with an 8 to 9 month release rate. Incorporate into growing media.
Potassium sulfate	18%	44%K	Good soluble fertilizer for container crops.
Sul-Po-Mag®	18%	25 % K 8 % Mg	Good multinutrient fertilizer which can be top-dressed
Superphosphate	16%	8 % P 14 % Ca	Good multinutrient fertilizer but insoluble so incorporate prior to sowing.

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