

Crop plants need at least seventeen elements for normal growth. Three of these elements come from air and water and the other fourteen come from the soil (see Table 1:1). Of the fourteen essential elements obtained from the soil, six are used in relatively large quantities and are thus referred to as macronutrients. They are nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. Crop plants utilize large amounts of these elements and most fertilizer programs are designed to supply them in adequate amounts.

Sulfur has long been recognized as essential for plant and animal growth. Although much is yet to be learned about the functions of this element, it is known to be indispensable for many reactions in every living cell. Sulfur is a constituent of the amino acids methionine and cystine, deficiencies of which result in serious human malnutrition. The vitamins biotin and thiamine contain sulfur, and the structure of proteins is determined to a considerable extent by sulfur groups. As with the other essential elements, sulfur plays a unique role in plant and animal metabolism. Many crop plants contain as much sulfur as phosphorus, and it ranks in importance with nitrogen and phosphorus in the formation of protein. In short, sulfur is an element without which plant and animal life, as we know it would soon cease. Unlike Ca and Mg, which are taken up by plants as cations, sulfur is absorbed primarily as the sulphate ($\text{SO}_4^{=}$) anion. It can also enter plant leaves from the air as sulfur dioxide (SO_2) gas. Sulfur as stated in the introduction is a part of every living cell and is a constituent of two of the 21 amino acids, which form proteins. Other functions of sulfur in the plant:

- Helps develop enzymes and vitamins
- Aids in seed production
- Is necessary in chlorophyll formation although it is not a constituent of chlorophyll
- Is present in several organic compounds which give the characteristic odors to
- Garlic, mustard and onion.

Plants deficient in sulfur show a pale green coloring of the younger leaves, although the entire plant can be pale green and stunted in severe cases. Leaves tend to shrivel as the deficiency progresses.

Sulfur, like nitrogen, is a constituent of proteins, so deficiency symptoms are similar to those of nitrogen. Nitrogen deficiency symptoms are more severe on older leaves, however, because nitrogen is a mobile plant nutrient and moves to new growth. Sulfur, on the other hand, is immobile in the plant, so new growth suffers first when sulfur levels are not adequate to meet crop need. This difference is important in distinguishing between the two, particularly in the early stages of a deficiency.

Plants deficient in sulfur can be thin-stemmed and spindly. Crops such as cabbage and canola may develop a reddish color, first appearing on the undersides of leaves and on stems. On alfalfa, leaves are long and slender and branching is reduced.

Inorganic soil sulfur, that form available to plants, occurs as the $\text{SO}_4^{=}$ is not attracted to soil clay and organic matter surfaces except under certain conditions. It remains in the soil solution and moves with soil water, so it is readily leached. Certain soils accumulate $\text{SO}_4^{=}$ in the subsoil, which would be available to deep-rooted crops. In arid regions, sulfates of Ca, Mg, potassium (K) and sodium (Na) are the predominant inorganic sulfur forms.

Much of the soil sulfur in humid regions is associated with organic matter. Through biological transformations, similar to those of Nitrogen, sulfate compounds are produced that are available to the plant.

The Sulfur Cycle, shows the relationship among atmospheric, fertilizer and soil sources of sulfur. Proper management insures efficient use of sulfur, with minimal loss by leaching or erosion. There is not net gain or loss of sulfur in nature.

The number of soils deficient in sulfur is increasing. There are several contributing factors, including:

- Increased crop yields that remove large amounts of sulfur

- Increased use of high analysis fertilizers containing little or no incidental sulfur
- Decreased use of high sulfur fuels and improved sulfur removal techniques from stack gases
- Less use of sulfur containing pesticides
- Immobilization of sulfur in organic matter which accumulates because of conservation tillage practices

The need for sulfur is closely related to the amounts of nitrogen available to crop plants. This close relationship should not be surprising, since both are constituents of proteins and are associated with chlorophyll formation.

Nitrogen and sulfur are further linked by the role of sulfur in the activation of the enzyme nitrate reductase, which is necessary for the conversion of nitrate to amino acids in plants. Low activity of this enzyme depresses soluble protein levels, while raising nitrate concentrations in plant tissue.

High levels of nitrate, which accumulate when sulfur is deficient, drastically inhibit seed formation in sensitive crops such as canola. Nitrate can also be toxic to animals consuming forages deficient in sulfur. Adequate levels of sulfur improve manganese utilization by ruminants by reducing non-protein nitrogen levels (nitrate).

Scientists have often suggested that the N:S ratio (total N to total S) in plants is a good diagnostic guide for determining a sulfur deficiency. Ratios of 10:1, 15:1, 7:1, 11:1 and others have been considered. There is a strong relationship between nitrogen and sulfur, on that cannot be ignored when nitrogen fertilizer use efficiency is evaluated. Table 1:4 illustrates the point. Coastal Bermuda grass responded to sulfur fertilization. Sulfur also increased nitrogen use efficiency, improving profit potential and reducing the chance of nitrate leaching into groundwater.

Soil organic matter has already been mentioned as the primary soil sulfur source. More than 95 percent of the sulfur found in the soil is tied up in organic matter. Other natural sources include animal manures, irrigation water, and the atmosphere.

Most fertilizer sulfur sources are sulfates and are moderately to highly water-soluble. The most important water insoluble sulfur fertilizer is elemental sulfur, which must be oxidized to the sulfate sulfur form before plants can use it. Bacterial oxidation of sulfur in the soil is favored by

- Warm soil temperatures
- Adequate soil moisture
- Soil aeration
- Fine particle sizes

Degradable elemental sulfur fertilizers, like Disper-sul® 90%, are granular or Pastille (split-pea) that can be easily broadcast, blended or banded. These fertilizers differ from traditional forms of elemental sulfur which do not degrade very rapidly.

Degradable elemental sulfur can not be used directly by the plants. Soil microorganisms must first oxidize elemental sulfur and convert it into soluble sulfate (SO₄-S). Oxidation of degradable sulfur occurs through the growing season. This process slowly releases the sulfate sulfur so it will be available to the plant over a longer period of time.

Particle Size

Degradable sulfur is made from molten elemental sulfur and bentonite clay. These clay particles aid in dispersing the tiny particles of elemental sulfur after it comes in contact with soil moisture. The soil microbes then feed on the small particles and oxidize the elemental sulfur into sulfates that can be used by the plant.

Factor That Influence Conversion

Conversion of elemental sulfur into a sulfate form is influenced by:

- Soil Temperature— the rate of conversion increases as soil temperature increases.
- Soil Moisture— Dry conditions can reduce the conversion process.
- Microbial Activity— Thiobacillus Bacteria are essential for converting sulfur to sulfate. While most soils contain sufficient populations, Thiobacillus activity has been shown to increase after successive applications of elemental sulfur.
- Soil contact— is essential so that soil micro-organisms can interact with the elemental sulfur.

Advantages of a Degradable Sulfur

- Degradable sulfur act as a “slow release” fertilizer to feed the plant all year long. Most crops consume the most sulfur at bloom stage.
- Fall or spring broadcast applications help broaden the work load
- Can be banded when used in a long term maintenance program
- Easily blends with other fertilizer components when bulk blending
- High analysis reduces the volume of sulfur needed
- Doesn't leach until conversion “Slow Release”
- Safe handling
- Low salt index, can be seed-placed at higher rates

Elemental Sulfur Powder (99.5% S) is a fine, ground sulfur powder high in analysis, elemental sulfur powder is dangerous to handle. This product does not lend itself to easy application and is difficult to store and handle. The fine particles of this product in a closed environment could easily cause a fire or explosion. The advantages of this product is that it converts quickly to the sulfate form that the plant can use. It will also blend with the soil correcting a high pH of the soil quicker.

Fertilizers containing the soluble sulfate form (SO₄-S) are most commonly sold in the granular form as ammonium sulfate. This form of sulfur is highly leachable and can be washed from the root zone in the event of a high rainfall. This source of sulfur should not be used in a soil rebuilding program and should be used as a in the season solution to sulfur problems. The use of ammonium sulfate has several advantages:

- Available to the crop immediately
- Can be used as rescue treatment from severely deficient soils during growing season
- Can be top-dressed or banded
- In a form that lends itself to bulk blending

Thiosulfate fertilizers (ammonium thiosulfate 12-0-0-26) are in a solution and has a portion of the sulfur that must be oxidized into the sulfate form to allow plant uptake. This is a low analysis fertilizer and will increase labor, handling and trucking cost. It also, has the same problems that ammonium sulfate in that it can be leached from the root zone with a high rainfall event. It also should not be used in a long term soil sulfur rebuilding program. The advantages of this product is it is suitable for liquid fertilizer operations

and due to the interface with the soil particles the sulfur is quickly oxidized to the sulfate form.

Calcium Sulfate (Gypsum) has been used as a source of sulfur fertilizer for many years. The sulfur content in Gypsum is 18.6% and studies show that conversion takes place very slowly, therefore making it unsuitable product for rebuilding sulfur in the soil .

- Plants are small and spindly with short, slender stalks.
- Growth rate is retarded and maturity is often delayed, particularly with cereal grains
- Young leaves are light green to yellowish color, with even lighter colored veins. Yellowing of the leaves is often confused with N deficiency.
- On legumes you will have reduced nodulation
- Spotting of leaves
- Crop like canola, lentils, and alfalfa may flower but have reduced seed set