c. Sulfur

Sulfur is essential for selective amino acid production. It is used for building blocks of proteins and also reduces disease incidence. Sulfur content in leaf tissue ranges from 0.15% to 0.50% of the dry weight.

The sulfate anion (SO_4^{-2}) is the primary form available in soil solution. Like nitrate, the sulfate ion can leach from the soil. Deficiencies may occur where grass clippings are removed, excessive watering occurs, and sandy soils predominate. Initial deficiency symptoms include a light yellow-green color, with yellowing most pronounced in younger leaves, since sulfur is mobile in plants. Older leaves become pale, then turn yellowish green in interveinal areas. Leaf tips are scorched along the margins. Roots tend to be longer than normal and stems become woody. Bermudagrass grown in sandy soils has been shown to respond to applications of sulfur.

More than 90% of available sulfur is found in organic matter, which has a nitrogen to sulfur ratio of approximately 10:1. Deficiencies may occur when the nitrogen to sulfur ratio is greater than 20:1 or at high soil pH levels (>7.0). Sulfur may be precipitated as calcium sulfate ($CaSO_4$), while at lower pH levels (<4.0) the sulfate anion may be adsorbed by aluminum and/or iron oxides. Turf clippings with a high nitrogen to sulfur ratio ($\geq$20:1) decompose slowly; this may slow thatch biodegradation, since microorganisms require sulfur to decompose plant residues. Sulfur is supplied as a contaminant in some fertilizer sources, such as superphosphate. However, many new high-analysis fertilizers frequently do not contain appreciable sulfur.

In poorly drained, waterlogged soils where soil oxygen is exhausted, SO_4^{-2} and organic matter containing sulfur can be reduced to toxic hydrogen sulfide (H_2S) by sulfate-reducing bacteria. Excessive application of elemental sulfur to golf greens also may encourage hydrogen sulfide buildup. Insoluble sulfides also may form when sulfur reacts with soil iron.

Fe^{+2}	+	S^{-2}	---------->	FeS
		sulfide		iron sulfide

Turf soils containing toxic levels of hydrogen sulfide or iron sulfate are acidic and commonly form a "black layer" several inches below the soil surface. They are characterized by the distinct hydrogen sulfide (i.e., sewer or rotten egg) smell. Low soil oxygen also can cause reductions in manganese, copper, and iron and produce gray- and blue-colored subsoils. This phenomenon often occurs in poorly drained soils.

IV. Micronutrients

As previously discussed, micronutrients are essential elements needed in relatively small amounts (e.g., <50 ppm). Many soils in the United States supply micronutrients in large enough quantities that there is no need for supplements. Other sources of micronutrients occur as impurities in fertilizers. In Florida, however, soils composed of sand and peat or muck, pockets of soil with high pH levels and high phosphorus content, poor drainage, and periods of extended, heavy rainfall contribute to micronutrient deficiencies (Fig. 1). For example, as soil pH is increased, iron changes from its available (soluble) ionic form to hydroxy ions and, finally, to insoluble or unusable hydroxide, or oxide forms.