Mosaic
AgriSight®
TRUSTED CROP NUTRITION EXPERTISE℠

ISSUE 13: 2017

Oxidation of Elemental Sulfur in Soils

Sulfur (S) is one of the 17 elements essential for plant growth, and the fourth most important after nitrogen (N), phosphorus (P) and potassium (K) in terms of amount required by crops. When considering nutrient sources, elemental S (ES) is the most concentrated form of S, making it appealing due to lower transportation costs (per lb of nutrient) when compared to sulfate-based fertilizers. Elemental S is not taken up by crops in the applied form, and must be converted in the soil to sulfate S before uptake by plants or microorganisms. This article describes how elemental S is oxidized in soil, and the factors that affect the rate of oxidation. Results from a model predicting rates of S oxidation in granulated fertilizers containing elemental S are provided to illustrate the key factors affecting oxidation in soil.

Key Factors Affecting Elemental S Oxidation

Oxidation of elemental S in soil is a microbial process requiring the presence of both water and oxygen (Fig. 1). The converted sulfate can be taken up by crops, taken up by microorganisms in the soil, or leached below the root zone in coarse-textured soils or high-rainfall areas. There is a wide variety of microorganisms in soil that are capable of oxidizing elemental S, including both bacteria and fungi; oxidation is not solely dependent on the presence of specific S-oxidizing organisms. The primary factors affecting elemental S oxidation are as follows:

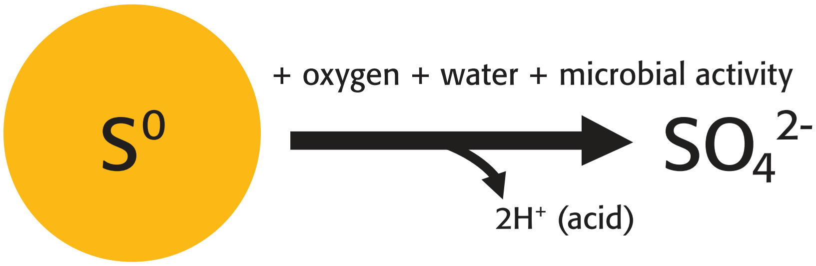

Fig. 1: The reaction of elemental S (S^0) oxidation to sulfate (SO_4^{2-}).

Soil and environmental factors affecting elemental S oxidation:

Oxidation is more rapid in warm, moist soils with high organic matter (OM) contents. Oxidation reactions of elemental S are also faster in alkaline soils than in acidic soils (Fig. 2).

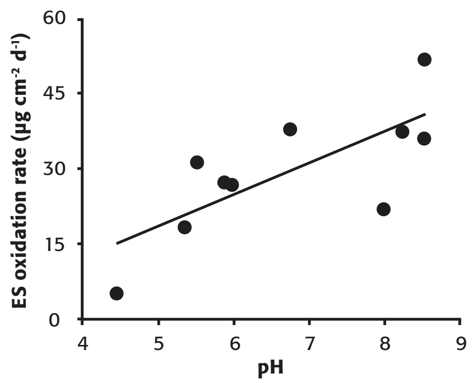

Fig. 2: Effect of soil pH on oxidation of elemental S (ES) across 10 soils (Zhao, et al. 2015).

Of the soil and environmental factors affecting oxidation rate, temperature and soil pH have the greatest effect.

Fertilizer attributes affecting elemental S oxidation:

Oxidation of elemental S is also affected by the characteristics of the fertilizer, including the particle size of elemental S and/or its concentration in the fertilizer.

- Elemental Sulfur must be oxidized into SO_4^{2-} for uptake by crops
- Oxidation rates increase in warm, moist soils and in alkaline soils
- Oxidation rates decrease with larger ES particle size and higher concentrations of ES within a fertilizer granule

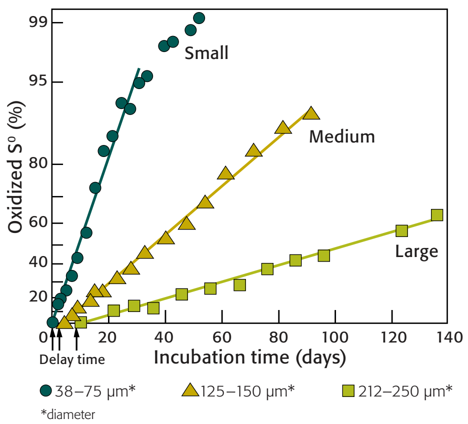

Fig. 3: Effect of elemental S (S^0) particle size on the rate of oxidation in soil where particles were dispersed throughout the soil (Watkinson and Blair 1993).

Oxidation is a surface-based process, and surface area increases dramatically as particle size decreases; therefore, particle size is one of the most important attributes affecting oxidation. When elemental S is dispersed throughout the soil, the oxidation of elemental S is faster as the particle size of the elemental S decreases (Fig. 3). In co-granulated elemental S fertilizers (i.e., in which elemental S particles are co-granulated with macronutrients [N, P, K]), the oxidation is reduced compared to the elemental S particles of the same size dispersed through soil. This is not because the macronutrients reduce the oxidation rate, but because of the reduction in surface area of elemental S available for oxidation when dispersed in soil. Therefore, the lower oxidation rate of co-granulated elemental S can be explained by a reduction in the surface area of S in contact with the soil.

Additionally, the ES concentration within a fertilizer granule affects the surface area and oxidation rate. Fertilizer granules with a high concentration of ES (Fig. 4A at 90%) have much smaller surface area than a co-granulated fertilizer with a low concentration of ES (Fig. 4B at 5%). An Excel-based model has been produced by the Fertilizer Technology Research Centre, University of Adelaide, that integrates all soil, environmental and fertilizer-granule factors that affect the oxidation of elemental S in soils, thus allowing predictions of oxidation rates in various locations with defined fertilizer types. An example of the model's output is shown in Fig. 5. The oxidation of the S pastilles is predicted to be much slower than for the S in the MicroEssentials® granules. This is due to the much higher concentration of the S pastilles, resulting in less surface area exposed to the soil.

Fig 4A: Example of fertilizer granule with 90% ES.

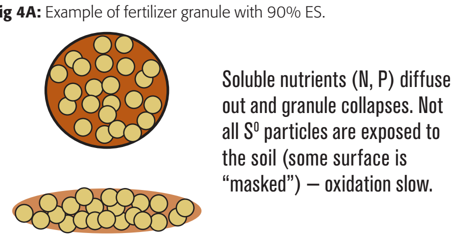

Fig 4B: Example of fertilizer granule with 5% ES.

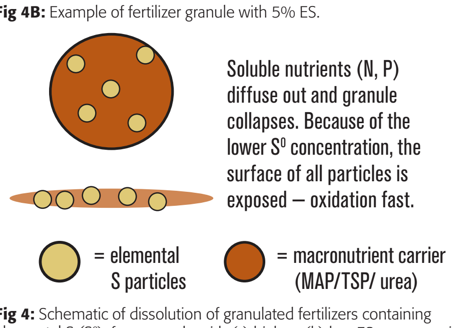

Fig 4: Schematic of dissolution of granulated fertilizers containing elemental S (S^0), for a granule with (a) high or (b) low ES concentration (McLaughlin, et al. 2015).

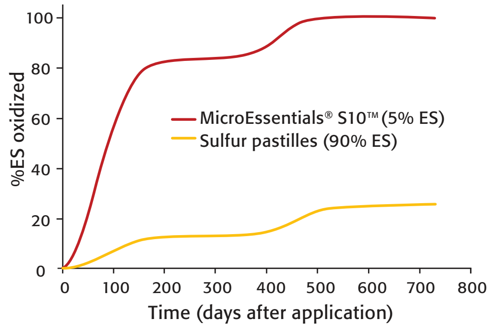

Fig 5: Effect of elemental S concentration of granule on oxidation for co-granulated products over two years. The model simulation integrates climatic data for Kansas and a soil having a pH of 7.5 and an organic matter content of 4 percent (Fertilizer Technology Research Centre, University of Adelaide).

In conclusion, elemental S must be oxidized into the plant-available form of SO_4^{2-} for uptake and is affected by soil, environmental and fertilizer factors. Elemental S oxidation is a microbial process that is largely driven by temperature and soil pH. Warmer climates and/or higher soil pH increase oxidation rate. Additionally, the fertilizer source and characteristics have a significant effect on oxidation rate. The individual particle size of ES distributed throughout the granule and the total ES concentration of the fertilizer granule are major contributors. Oxidation rate decreases as particle size increases and ES concentration within the fertilizer granule increases.

References

Degryse F, Ajiboye B, Baird R, da Silva RC, McLaughlin MJ (2016a) Oxidation of elemental sulfur in granular fertilizers depends on the soil-exposed surface area. Soil Sci Soc Am J 80: 294–305. doi: 10.2136/sssaj2015.06.0237.

Degryse F, da Silva RC, Baird R, McLaughlin MJ (2016b) Effect of co-granulation on oxidation of elemental sulfur: theoretical model and experimental validation. Soil Sci Soc Am J 80: 1244–1253. doi: 10.2136/sssaj2016.02.0054.

Friesen DK (1996) Influence of co-granulated nutrients and granule size on plant responses to elemental sulfur in compound fertilizers. Nutr Cycl Agroecosys 46: 81–90.

Germida JJ, Janzen HH (1993) Factors affecting the oxidation of elemental sulfur in soils. Fert Res 35: 101–114. doi: 10.1007/bf00750224.

Janzen HH, Bettany JR (1987) The effect of temperature and water potential on sulfur oxidation in soils. Soil Sci 144: 81–89. doi: 10.1097/00010694-198708000-00001.

Lawrence JR, Germida JJ (1988) Relationship between microbial biomass and elemental sulfur oxidation in agricultural soils. Soil Sci Soc Am J 52: 672–677.

McLaughlin MJ, Degryse F, da Silva RC, Baird R (2015) Co-granulated elemental sulfur/sulfate fertilizers and their role in crop nutrition. Better Crops with Plant Food 99: 7–10.

Tourna M, Maclean P, Condron L, O'Callaghan M, Wakelin SA (2014) Links between sulphur oxidation and sulphur-oxidising bacteria abundance and diversity in soil microcosms based on soxB functional gene analysis. FEMS Microbiol Ecol 88: 538–549. doi: 10.1111/1574-6941.12323.

Watkinson JH, Blair GJ (1993) Modelling the oxidation of elemental sulfur in soils. Fert Res 35: 115–126.

Zhao C, Degryse F, Gupta V, McLaughlin MJ (2015) Elemental sulfur oxidation in Australian cropping soils. Soil Sci Soc Am J 79: 89–96. doi: 10.2136/sssaj2014.08.0314.

Acknowledgment: Fertilizer Technology Research Centre, University of Adelaide

The Mosaic Company
3033 Campus Drive
Suite E490
Plymouth, Minnesota 55441
800-918-8270
www.CropNutrition.com