FACTORS INFLUENCING EFFICACY OF ELEMENTAL SULFUR FERTILIZERS

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ABSTRACT

Elemental S is produced in large quantities in both the US and Canada as a byproduct of fossil fuel production. This form of S must be oxidized to sulfate by soil microorganisms before crops can utilize it and thus may not reliably meet crop requirements in the year of application. Rapid oxidation may be attainable with fine particle size (large surface area), effective dispersion, and favorable environmental conditions. Based on published results from four field experiments, elemental S can be an effective source of S if appropriately formulated and applied.

INTRODUCTION

The demand for S fertilizers has increased due to reduced S deposition and increased use of S-demanding crops such as canola. Most fertilizers applied to alleviate S deficiencies have S in the form of sulfate that can be directly taken up by plant roots, e.g., ammonium sulfate (21-0-0-24).

Although approximately 15 million tons of elemental S recovered annually from petroleum refineries, natural-gas-processing plants, and coking plants in North America, only a small fraction of this S is utilized directly as fertilizer for crops because this form must be oxidized by soil microorganisms before it is available to plants. The major factors influencing the efficacy of elemental S fertilizers and several examples of effective use are reviewed here. If effective, elemental S fertilizers have potential advantages of high S content and low manufacturing cost.

Factors influencing efficacy of elemental S fertilizers

Many different microorganisms capable of oxidizing elemental S are present in agricultural soils (Germida and Janzen, 1993). Most oxidation in agricultural soils is catalyzed by a mixed population of heterotrophs rather than autotrophic oxidizers such as *Thiobacillus oxidans*. The overall process is: $S^0 + O_2 + H_2O \Rightarrow H_2SO_4$ (i.e., acidifying). A lag before maximum oxidation rates may occur due to time required for microbes to colonize the surface of introduced elemental S.

As oxidation is a surface process, the rate of oxidation depends on the area, not quantity, of elemental S applied (Degryse et al., 2016; Fox et al., 1964). As particle diameter increases from 2 um to 2 mm, the time required for 50% oxidation increases from 1 day to more than 3 years under lab conditions (Table 1). Thus, it can be clearly seen that particles should be less than ≤ ≈20 µm to significantly contribute to crop S requirements in the year of application.

Table 1. Impact of particle size on surface area and oxidation rate.

	Per g of elemental S		
Diameter (mm)	# Particles	Surface area (cm^2)	Days to oxidize 50%†
0.002	10^{11}	14,000	1
0.02	10^{8}	1,400	10
0.2	10^{5}	140	100
2	10^{2}	14	1000

†Based on Janzen and Bettany 1987a and Janzen 1990.

Elemental S oxidation is suppressed when particles are in close proximity to each other. This suppression may be due to water limitation caused by hydrophobicity and/or the accumulation of acidic or toxic oxidation products. Janzen (1990) found that oxidation was negligible when the soil to S ratio was less than 100:1 and increased rapidly as this ratio increased to 1000:1. For this reason, banded application of elemental S fertilizer is less effective than broadcast application.

Elemental S is often co-granulated with bentonite or other fertilizers to improve handling. Oxidation is suppressed compared to a uniform mixing of fine particles, but can be considerably enhanced by reducing the proportion of elemental S and granule size in the final product. Compared to uniformly-mixed particles, oxidation was 30-fold slower for bentonite products (90% elemental S), but only 4-fold slower for products co-granulated with monoammonium phosphate (MAP) (5 to 7.5% elemental S) (Degryse et al., 2016).

The rate of elemental S oxidation also depends on environmental conditions. The process is more sensitive to temperature than most soil biological processes: oxidation was reduced by 50% at 73 °F (23 °C) and 90% at 59 °F (15 °C), compared to oxidation at 86 °F (30 °C) (Janzen and Bettany, 1987). The process is less sensitive to soil moisture, but as with many biological processes, the process is optimum at field capacity and reduced by dry or anaerobic conditions.

The efficacy of elemental S to meet crop requirements also depends on factors influencing the degree of S deficiency. Annual crops with a high and early S requirement (e.g., canola) will be more sensitive to delayed S supply than crops with a lower and later S requirement (e.g., corn). Crops grown on soils that are extremely deficient in S will be more sensitive to delayed S supply than crops grown on soils that are only moderately deficient in S.

Examples

Three elemental S fertilizers were compared in central Alberta: a finely-divided aqueous suspension (Micro-S) and two bentonite products (Karamanos and Janzen, 1991). The products were applied at 0, 27, 54 and 108 lb S/ac. In the year of application, extractable soil SO4-S, canola S uptake and canola seed yield were substantially increased by application of Micro-S, at an efficacy equivalent to about 50% of ammonium sulfate. Benefits of bentonite products in the year of application were small to non-existent, as were residual benefits of all products in two subsequent years.

A co-granulated elemental S product (particles <10 µm, Sulvaris Inc. Calgary, AB) was compared to potassium sulfate on a S-deficient site in Saskatchewan (Malhi et al., 2014). Both products were broadcast (fall and spring) and banded at 18 lb S/ac/yr in the same plots over a period of three years. The efficacy to increase S uptake of the co-granulated product relative to potassium sulfate was 49% when broadcast and 21% when banded. Similarly, the relative efficacy to increase seed yield of hybrid canola was 84% when broadcast and 61% when banded. The relative efficacy was similar in all years. Subsequent testing in nine trials in the mid-west showed equal efficacy for corn yield and tissue S concentration for granular and liquid products manufactured with the same technology (MST®), relative to ammonium sulfate (M. Howell, personal communication).

Crop use efficiency of elemental S and sulfate from the same co-granulated product (MES®; The Mosaic Company, Tampa, FL) was determined by enriching each form independently with ^{34}S (Degryse et al. 2020). Crop recovery in aboveground biomass was determined over a two year period in Canada, Argentina and Brazil (Table 2). Crop recoveries of elemental S were considerably lower than of SO_4-S in both Canada and Argentina, which was attributed primarily to low temperatures limiting oxidation of elemental S (median diameter of 40 µm). In contrast, crop recoveries of elemental S and SO_4-S were similar but low in Brazil, which was attributed to warm and wet conditions that supported rapid oxidation and subsequent losses by leaching. Crop recovery of elemental S was higher than SO_4-S in the second year, but remained lower overall in Canada and Argentina.

Table 2. The percentage of elemental S and SO_4-S recovered in aboveground plant material (derived from Degryse et al. 2020).

	1st year			2nd year		
Trial location	**Crop**	**SO_4-S**	**ES†**	**Crop**	**SO_4-S**	**ES**
Canada	Canola	59	6	Wheat	7	13
Argentina	Corn	78	12	Soybean	8	13
Brazil	Soybean/Corn	7	8	Soybean/Corn	3	8

†ES, elemental S, median diameter of 40 µm.

The efficacy of a micronized elemental S fertilizer (Sulgro 70, manufactured by Sultech, Calgary, AB) sprayed on the soil surface without incorporation was compared to sprayed ammonium sulfate in eight field trials in southern and central Alberta over a two-year period (Bremer et al., 2021). The supply of S to PRS® probes (ion-exchange membranes) in soil was consistently increased by application of Sulgro 70 relative to the unamended control, but less than that obtained with ammonium sulfate. On average, the increase in soil S supply of Sulgro 70 was 75% of that of ammonium sulfate between 4 and 8 weeks after seeding for trials that received a minimum of 5 inches of rainfall. Based on increases in biomass S concentration in three trials where the unfertilized control had low S concentration (<3 g S kg 1), the relative efficacy of Sulgro 70 was 34%. Canola seed yield was not increased by application of ammonium sulfate nor Sulgro 70 in any of the trials.

CONCLUSIONS

These examples demonstrate that micronized elemental S that is well dispersed in soil under favorable moisture and temperature conditions can be rapidly oxidized and an effective source of S in the year of application. Small particle size and effective dispersal is critical for the supply of S to crops that have a high demand for S early in the growing season. These crops may require adjustment in timing or rates of elemental S application or co-application of sulfate S.

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