EVALUATION OF ELEMENTAL SULFUR AND SULFATE-ENRICHED TRIPLE SUPERPHOSPHATES IN A SOYBEAN-CORN ROTATION GROWN IN A BRAZILIAN CERRADO OXISOL

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Introduction

The Cerrado (savannas) biome comprises an area of 204.7 million ha in central Brazil, with 80 million ha (39.5%) under different agricultural uses. Cultivated pastures and crops occupy, respectively, 26.5% and 10.5% of the biome (Sano et al., 2008). Incorporation of the acid low-fertility Cerrado soils into the agricultural production process since the mid 1970s can be considered as one the greatest achievements of the Brazilian agricultural research associated to targeted government programs (Resck et al., 2008). Fertilization and soil acidity correction guidelines are among the main agricultural technologies for the region (Sousa and Lobato, 2004).

Rein and Sousa (2004) reported that since the 1950s, when the research on the fertility of Cerrado soils began, sulfur (S) deficiency have been frequently observed, with significant increases in crops and forage yields in response to S fertilization. The high annual rainfall, large distances from the oceans, the small industrial activity in the region and the frequent natural and human-made firing of the savanna vegetation most likely explain the widespread S deficiency of these soils.

Calcium and ammonium sulfates, including phophogypsum ($CaSO_4.2H_2O$) and gypsum contained in single superphosphate, are the main sources of S used in Brazil, with concentrations ranging between 15 and 24% of S. Another S source, much less used in Brazil, is the elemental sulfur (S°), with S content close to 100%. In this context, fertilizers enriched with S° can be promising sources supplying this nutrient (Santos Junior et al., 2010), reducing transportation costs per unit of S as well as the primary macronutrients N, P and K in more concentrated formulations.

There is a need, however, of scientific studies evaluating the agronomic efficiency of fertilizers enriched with S°, since its availability to plants depends upon the rate of oxidation in the soil with conversion to sulfate, which is the available form of S for plants. Thus, it is likely that the fertilizer placement method providing different levels of contact with the soil influences the ability to supply S to plants, while the part of the fertilizer S in the form of sulfate would attend the initial crop demand until S° is oxidized. The objective of this study was to evaluate the effect of triple superphosphates enriched with elemental sulfur and sulfate on the yield of soybean and corn in a Cerrado Oxisol.

Methods

An experiment was conducted in the experimental area of Embrapa Cerrados in Brasilia, in a very clayey pristine Oxisol. The experimental design is a randomized complete block with eight treatments (S fertilizers and placement methods) and three replications. Dolomitic limestone aiming to increase the soil base saturation to 50% was applied as well as corrective fertilization (350 kg/ha P_2O_5 as powdered magnesium termophosphate; 150 kg/ha of K_2O as potassium chloride; micronutrients as 50 kg/ha of powdered FTE BR-10), broadcasted and incorporated with disc harrow in May 2011.

Millet as a cover crop was sown in May 2011 (12 kg/ha of seeds, row spacing of 0.5 m), fertilized with KCl (150 kg/ha K_2O) and urea (100 kg/ha N) broadcasted on the soil surface and irrigated for proper crop development. The aboveground biomass and sulfur were evaluated and removed from the area in August 2011 to increase the chance of response to this nutrient by the soybean and corn crops. The millet regrowth was also fertilized with KCl (100 kg/ha K_2O) and urea (100 kg/ha N), with irrigation. In October 2011 the millet was cut and left on the soil as a mulch, with the following millet regrowth killed with glyphosate. Seed furrows were open with a planter at the no-tilled experimental area, with row spacing of 0.45 m for soybeans (1st and 3rd years) and 0.75 m for corn (2nd year). Plot dimensions were 4.5 m wide and 8 m long.

The treatments consist of three S sources (Table 1) broadcasted on the soil surface or banded in the seed furrow at planting at the dose of 15 kg/ha/year S, and a control (no S) treatment. Gypsum powder (calcium sulfate) as phosphogypsum was the reference S source. The two tested fertilizers were developed by Shell Sulphur Solutions, consisting of granular triple superphosphates enriched with micronized S° and a mixture of S° and sulfate ("Shell Thiogro TSP-S").

The phosphorus dose was the same for all treatments, 80 kg/ha/year P_2O_5, balanced with the regular TSP. Band treatments in the seed furrow were applied with a manual equipment whereas broadcast treatments were applied manually after sowing, in October 2011 (soybeans cultivar MGBR 46), October 2012 (corn single hybrid 30F53H) and October 2013 (soybeans cultivar BRS 8681). Potassium chloride was broadcasted after sowing at 80 kg/ha K_2O for every crop. Soybean seeds were inoculated with recommended *Bradyrhizobium japonicum* strains, and corn was fertilized with 30 kg/ha N as urea in the seed furrow at sowing and 120 kg/ha N side-dressed as ammonium nitrate. The crops were grown with supplemental irrigation, and harvested by hand after excluding 1.0 m at each end of the plots and two or one row at each side for soybeans and corn, respectively, with harvested areas of 16.2 m^2 and 18 m^2. Millet was sown every year after harvesting as a winter cover crop, providing mulch for the no-till system.

Results and discussion

Soybean and corn grain yields (13% moisture) in response to the fertilizer treatments are in Table 2. Significant responses to S nutrient were found for the three crops. Considering the first (2011/2012) soybean crop, yield gains due to the application of S reached 27.5%. Considering the TSP (no S) and the TSP + gypsum treatments, both at 80 kg/ha/year P_2O_5, the phosphorus fertilizer placement did not affect the yields, which was expected at the high level of soil phosphorus availability provided by the corrective phosphate fertilization before establishing the experiment. No significant differences were observed in the first year between the S sources for each fertilizer placement method, although there was a tendency for lower grain yields with the S° products (TSP-S1 and TSP-S2) compared to gypsum when banded in the seed furrow, but not when broadcasted. These results show that the tested S° products exhibited good ability to supply S to the crop already in the year of application. The fertilizer placement method affected the soybean (2011/20120) crop response to S contained in TSP-S1 and TSP-S2, which did not occur with gypsum. Soybean yields were higher for broadcast than band placement, particularly for TSP-S1 with nearly 100% S as S°. These results are possibly explained by the greater distance between fertilizer granules and larger contact area with the soil/mulch in the case of surface broadcast application, enhancing the oxidation process of S° when compared to band application in the seed furrow. The presence of the millet mulch prior to soybean planting, providing a better environment for microbes at the soil-mulch layer, likely favored the oxidation of S° for broadcasted TSP-S1 and TSP-S2.

With respect to the second crop (2012/2013), corn yield gains reached 36.0% due to the application of S. No significant differences were observed between the S sources for each placement method. However, an opposite tendency was found in relation to the first year, with grain yields slightly higher for the S° sources compared to gypsum when the fertilizers were banded in the seed furrow. This behavior can be explained by the higher residual effect of TSP-S1 and TSP-S1 applied for the previous soybean crop, which possibly had the S° fraction completely oxidized to sulfate, as well as the quick oxidation of the S° fertilizers freshly applied to corn.

Similar responses were observed with respect to the third crop (2013/2014), with soybean yield gains of 49.4% in response to S, no significant differences in relation to the S sources and placements but tendency of higher yields with TSP-S1 and TSP-S2 compared to gypsum, particularly when broadcasted.

Conclusions

1. Significant increases in grain yields in response to sulfur (S) fertilization were found for the soybean and corn crops growing in the no-till Cerrado Oxisol.

2. The tested triple superphosphates enriched exclusively with micronized elemental S or 2/3 elemental S and 1/3 sulfate-S were similar to gypsum as S sources for the soybean-corn rotation, regardless of the placement method of the fertilizers (banded in the seed furrow or surface broadcasted).

3. In the first year of the experiment soybean yield with the elemental S-enriched triple superphosphate was significantly higher when broadcasted than when banded in the seed furrow.

Keywords: Broadcast application; band application; no-tillage.

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Table 1. Phosphorus and sulfur contents of the fertilizers evaluated in the experiment.

Fertilizer	Total P_2O_5	Total S
	--------------%----------------	
Triple superphosphate TSP	48.7	0.89
Triple superphosphate TSP-S1 (100% S°)	44.5	10.2
Triple superphosphate TSP-S2 (2/3 S° and 1/3 sulfate)	39.3	11.6
Gypsum (calcium sulfate)	-	15.3 [1]

[1] Sulfur content in moist product.

Table 2. Grain yields of a soybean-corn rotation with three sulfur fertilizers and two placement methods in a Cerrado Oxisol under no-till management.

P_2O_5 dose	**S dose**	**Fertilizers**	**Placement method**	**Grain yields [1]** Soybeans 2011/2012	Corn 2012/2013	Soybeans 2013/2014
kg/ha/year				t/ha		
80	0	TSP	Banded	3.136 d	8.493 c	2.641 c
80	0	TSP	Broadcasted	3.194 d	8.866 c	2.786 c
80	15	TSP + gypsum	Banded	3.812 abc	10.370 b	3.794 ab
80	15	TSP + gypsum	Broadcasted	3.902 ab	11.347 ab	3.731 b
80	15	TSP-S1 (100% S°)	Banded	3.648 bc	11.008 ab	3.890 ab
80	15	TSP-S1 (100% S°)	Brodcasted	3.999 a	11.432 ab	3.946 ab
80	15	TSP-S2 (2/3 S° and 1/3 sulfate)	Banded	3.548 c	11.309 ab	3.904 ab
80	15	TSP-S2 (2/3 S° and 1/3 sulfate)	Broadcasted	3.814 abc	11.555 a	3.886 ab

[1] Means for each crop followed by the same letter are not different (*t* test, $p<0.05$). Coefficients of variation were 2.74%, 6.05% e 4.03%, respectively for 2011/2012, 2012/2013 and 2013/2014 crops.