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Sumário

Evaluation of Sulfur Enhanced Fertilizers in Soybean, Wheat and Sweet Sorghum Grown in a Brazilian Cerrado Oxisol

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Abstract

"Sulphur Enhanced Fertilizers" (SEF) have been experimentally developed by Shell, and consist of microfine particles of elemental sulphur with or without sulphate incorporated into phosphatic fertilizers. There is little information about the agronomic efficiency of SEF fertilizers in the Cerrado region. We compared SEF in terms of yields of soybean, wheat and sweet sorghum. Phosphogypsum was used as the reference S source. The effects of the sulfur treatments were evaluated for soybean and wheat during three years. Subsequently, the same treatments were evaluated for two consecutive sweet sorghum crops. Tested products with only elemental sulfur applied to the first soybean or wheat showed lower agronomic effectiveness compared to gypsum, whereas the product with one-third of sulfur as sulfate showed no significant differences. On the other hand, the residual effect of the tested products applied to the previous (wheat) crops were nearly equivalent to residual or freshly applied gypsum to soybeans. For wheat grown in the dry season and sweet sorghum grown in the rainy season, the residual effect of the tested products were better than residual gypsum at the same sulfur rate. These results indicate that all tested sulfur enhanced fertilizers could be used as sulfur sources.

Index terms: sulfur source; sulfur fertilization; savannah soil.

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Avaliação de Fertilizantes Enriquecidos com Enxofre Elementar em Soja, Trigo e Sorgo Sacarino em Latossolo do Cerrado

Resumo

Fertilizantes enriquecidos com enxofre elementar foram desenvolvidos experimentalmente pela Shell e consistem de micropartículas de enxofre elementar com ou sem sulfato incorporado em fertilizantes fosfatados. Foi comparada a eficiência dos fertilizantes em termos de produtividade de soja, trigo e sorgo sacarino. O gesso agrícola foi utilizado como referência. Os efeitos dos tratamentos com enxofre foram avaliados para soja e trigo durante três anos. Posteriormente, na mesma área experimental, os mesmos tratamentos foram avaliados para dois cultivos de sorgo sacarino. Os produtos testados com apenas enxofre elementar aplicado às primeiras culturas de soja ou de trigo apresentaram menor eficiência agronômica em relação ao gesso, enquanto que o produto com um terço de enxofre como sulfato apresentou a mesma eficiência do gesso. Por outro lado, o efeito residual dos produtos testados aplicado às culturas anteriores (trigo) foi equivalente ao gesso residual ou ao gesso fresco aplicado à soja. Para o trigo e sorgo sacarino, o efeito residual dos produtos testados foi melhor do que o gesso residual com a mesma dose de enxofre. Esses resultados indicam que todos os fertilizantes testados podem ser usados como fontes de enxofre.

Termos para indexação: fonte de enxofre; adubação com enxofre; solos de Cerrado.

Introduction

The Cerrado is a vast tropical savanna ecoregion of central Brazil, covering most of the states of Goiás, Mato Grosso do Sul, Mato Grosso, Tocantins and Minas Gerais, occupying 204 million ha, representing 23% of the area of the country. It is considered one of the last and largest agricultural frontiers in the planet, and yet, the most biodiverse among the world's savannas. Soil science has played an important role in the incorporation of the low-fertility and acid Cerrado soils into agricultural production systems (RESCK et al., 2008).

The high annual rainfall, long 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 explains the widespread sulfur deficiency of Cerrado soils. The world widespread utilization of low or non-sulfur containing fertilizers, such as triple superphosphate (TSP), diammonium phosphate (DAP), monoammonium phosphate (MAP) and urea has resulted in increasing sulfur deficiency in agriculture (BLAIR, 2009). Rein e Sousa (2004) reported that since the mid 1950's, when research on the fertility management of Cerrado soils began, significant responses to sulfur fertilization have been observed in yield and quality of crops.

In the Cerrado region, the main sources of sulfur are calcium and ammonium sulfates, including single superphosphate, phosphogypsum ($CaSO_4.2H_2O$) and gipsite. Phosphogypsum (15% S), applied at rates between 1 to 6 t ha^{-1} depending on soil texture, is widely used as a soil amendment in the Cerrado region to alleviate the subsoil acidity improving chemical conditions for deep rooting exploration. The high rates of sulfur applied as phosphogypsum have a very long nutrient residual effect, since sulfate is adsorbed in the subsurface layers of the root zone. However, phosphogypsum production is concentrated in few regions of the country and its transport cost per unit of sulfur is high, which is an important constraint to the use of this by-product as a sulfur fertilizer.

Elemental sulfur, with nearly 100% sulfur, is also used as a fertilizer, supplying sulfur to crops after its oxidation to sulfate in the soil. The oxidation rate of elemental sulfur is determined by the particle size, as well as soil factors (BOSWELL; FRIESEN, 1993; GERMIDA; JANSEN, 1993). However, the use of elemental sulfur is very limited in Brazil, despite of its high agronomic efficiency, as observed in Cerrado soils after applied as fine particles (VILELA et al., 1995; REIN; SOUSA, 2004).

Incorporation of fine particles of elemental sulfur into granules of NPK fertilizers offers an alternative to the use of this sulfur source in agriculture (BOSWELL; FRIESEN, 1993; YASMIN et al., 2007; BLAIR, 2009). The “Sulfur Enhanced Fertilizers” (SEF) have been experimentally developed by Shell, and consist of microfine particles of elemental sulfur with or without sulfate incorporated into phosphate fertilizers. The agronomic effectiveness and potential use of these sulfur enhanced fertilizer for crops cultivated in Cerrado soils deserve to be assessed.

Thus, the aim of this work was to quantify the fresh and residual effects of three sulfur enhanced fertilizer as sulfur sources in a three-year soybean-wheat rotation in a Cerrado Oxisol. Subsequently, the fresh and residual effects of these sulfur sources were evaluated for two crops of sweet sorghum in the same experiment.

Materials and Methods

Field study

A field experiment was performed at the experimental area of the Savannas Agricultural Research Center (Embrapa Cerrados) in municipality of Brasilia, DF, Brazil (15° 35′ 30″ S, 47° 42′ 30″ W, and 1.007 m above sea level) during 2008 to 2010. The climate of the region is Aw according to the Köppen climate classification, and the region is a tropical savanna with a well-defined dry season in the Autumn-Winter (may to september) and the rainfall season concentrated in the Spring-Summer (october to april). The average annual temperature and precipitation is approximately 22 °C and 1,500 mm, respectively.

The soil of the study site was classified as a clayey red Latosol (fine, mixed, isohyperthermic Rhodic Haplustox) with particle-size distribution consisting of 660 g kg^{-1} clay, 6 g kg^{-1} silt and 280 g kg^{-1} sand. In early of 2008, chemical properties were determined on soil samples collected prior to establishment of the experiment (Table 1). After that, the soil received dolomitic limestone to increase soil pH to 6.0, 240 kg ha^{-1} of P_2O_5 (thermalphosphate) and levels of others macro and micronutrients were adjusted to meet the requirements for soybean production as determined by soil analysis. Pearl millet was planted as a cover crop in June 2008 to deplete native soil sulfate, and the aboveground biomass was removed from the site at harvest in October 2008.

Table 1. Initial soil chemical properties.

Soil layer cm	pH	Al	Ca+Mg	P (Mehlich1)	K	H+Al	SOM#	S*
		cmol$_c$ dm^{-3}	cmol$_c$ dm^{-3}	mg dm^{-3}	mg dm^{-3}	cmol$_c$ dm^{-3}	g kg^{-1}	mg dm^{-3}
0-20	6,2	0,02	4,29	2.2	18	4.47	22.7	4.8
20-40	4,8	0,46	0,92	0.5	14	5.91	19.3	2.2

*Extracted with 0.01 mol L-1 Ca $(H_2PO_4)_2$ 1:2.5 (soil:solution ratio), analyzed by ICP-AES
#Soil organic matter (Walkley-Black)

Experimental design

The experiment was designed in randomized blocks, with three replications. There were eight treatments (Table 2). The SEF881 and SEF774 are sulfur enhanced monoammonium phosphate fertilizers. The SEF881 has 9.9, 48.9 and 12.1% of N, P_2O_5 and S (0.6% sulphate), respectively, while SEF 774 has 11.5, 43.6 and 12% of N, P_2O_5 and S (3.8% sulphate), respectively. The TSP-S1 and TSP-S2 are sulfur enhanced triple superphosphate. The TSP-S1 has 43.1% P_2O_5 and 9.4% S (0.6% sulphate), while TSP-S2 has 44% P_2O_5 and 8% S (2% sulphate). Due to differences in nutrient concentrations of the sulfur enhanced fertilizers, nitrogen (urea) and phosphorus (triple superphosphate) were balanced for all treatments. The sulfur rate of 20 kg ha^{-1} used was in the recommended range of 15-30 kg ha^{-1} for most crops in S-deficient Cerrado soils (REIN; SOUSA 2004).

Table 2. Sulfur fertilizer treatments applied to eight successive crops

Treatments	Crop 1 – Soybean (BRS Valiosa RR)		Crop 2 – Wheat (BRS 254)		Crop 3 – Soybean (BRS Valiosa RR)		Crop 4 – Wheat (BRS 254)	
	S rate	Fertilizers	S rate	Fertilizers	S rate	Fertilizers	S rate	Fertilizers
	kg ha^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
01*	0	MAP	0	MAP	0	MAP	0	MAP
02	0	MAP	20	SEF774	0	Residual + MAP	20	SEF774
03	0	MAP	20	Gypsum	0	Residual + MAP	20	Gypsum
04	20	SEF881	0	Residual + MAP	20	SEF881	0	Residual + MAP
05	20	SEF774	0	Residual + MAP	20	SEF774	0	Residual + MAP
06	20	Gypsum	0	Residual + MAP	20	Gypsum	0	Residual + MAP
07	40	Gypsum	0	Residual + MAP	40	Gypsum	0	Residual + MAP
08	0	MAP	20	TSP-S1	0	Residual + MAP	20	TSP-S2

Treatments	Crop 5 – Soybean- (BRS Valiosa RR)		Crop 6 – Wheat (BRS 264)		Crop 7 - Sweet Sorghum (BRS 506)		Crop 8 - Sweet Sorghum (BRS 506)	
	S rate	Fertilizers	S rate	Fertilizers	S rate	Fertilizers	S rate	Fertilizers
	kg ha^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
01*	0	MAP	0	MAP	0	MAP	0	MAP
02	0	Residual + MAP	20	SEF774	0	Residual + MAP	20	SEF774
03	0	Residual + MAP	20	Gypsum	0	Residual + MAP	20	Gypsum
04	20	SEF881	0	Residual + MAP	20	SEF881	0	Residual + MAP
05	20	SEF774	0	Residual + MAP	20	SEF774	0	Residual + MAP
06	20	Gypsum	0	Residual + MAP	20	Gypsum	0	Residual + MAP
07	40	Gypsum	0	Residual + MAP	40	Gypsum	0	Residual + MAP
08	0	Residual + MAP	20	TSP-S2	0	Residual + MAP	20	TSP-S2

* Control treatment (MAP only)

Fertilizing and seeding

The soybean, wheat and sweet sorghum cultivars grown each year are described in Table 2. Soybean was cultivated during december 2008 to may 2009 (first-crop), november 2009 to april 2010 (third-crop) and october 2010 to march 2011 (fifth-crop). wheat was cultivated during may to september 2009 (second-crop), may to september 2010 (fourth-crop) and may to september 2011 (sixth-crop), while sweet sorghum was cultivated during november 2011 to march 2012 (seventh-crop), and from november 2012 to april 2013 (eighth-crop).

The no-till system was adopted as soil management for all crops. Soil nutrient levels were adjusted to meet the requirements for soybean, wheat and sweet sorghum production (SOUSA; LOBATO, 2004). Soybean was sown in a plot of eight 6.0 m rows spaced 0.45 m between rows. The wheat was sown in a plot of eighteen 6.0 m rows spaced 0.20 m between rows. The sweet sorghum was sown in a plot of five 6.0 m rows spaced 0.70 m between rows (seventh-crop) and in a plot of seven 6.0 m rows spaced 0.50 m between rows (eighth-crop). The middle rows were used for data collection and the other rows served as borders. Weed control was performed manually, and disease and pest control were carried out as needed. For soybean and sweet sorghum growing in the rainy season there was a supplementary irrigation, while for wheat growing in the dry season there was full irrigation during the whole crop cycle. Irrigation was performed using a sprinkler system.

Harvesting

Plants (straw + grain) were harvested at maturity by cutting the stems at soil level. Fresh grain yields (corrected to 13% moisture) were weighted. Sub-samples of straw and grain were then dried at 60 ºC to constant weight. Stems of sweet sorghum were cut about 5 cm from the soil surface, leaves were then removed. The fresh stems were weighed in the field and expressed in tons ha^{-1}. Yield and juice quality (brix and total recoverable sugars) of sweet sorghum were measured.

Statistical analysis

Data were submitted to an analysis of variance (ANOVA) using PROC GLM procedure in Statistical Analysis System (SAS, 1999), followed by Tukey´s test (5% probability level) for mean comparison.

Results and Discussion

Visual observations

It was observed morphological symptoms of physiological sulfur deficiency in soybean, wheat and sweet sorghum plants for the treatment that received no initial S fertilizer (control treatment). The symptoms of sulfur deficiency were more evident for wheat crops. The plants with S deficiency showed yellowing between veins of young leaves, purpling on the underside of leaves and curling upwards of leaf margins. The treatment that received S fertilizer provided alleviation of S stress symptoms and acceleration of growth rates compared to control treatment.

Soybean

Soybean cultivated in 2008/2009

Yield differences in response to sulfur treatments were low for the first crop, ranging from 2,922 kg ha^{-1} to 3,035 kg ha^{-1} (Figure 1A). Grain yield with SEF881 (treatment 4) was lower than treatments 6 and 7 with gypsum at rates of 20 kg ha^{-1} and 40 kg ha^{-1}. However, SEF774 (treatment 5) was similar compared to gypsum treatments, showing that this sulfur enhanced fertilizer was effective in providing sulfur in sufficient quantity for soybean plants in the first year of growing. The better performance of SEF774 is probably related to the fact that nearly 1/3 of its S content is in the sulfate form, whereas in SEF881 the sulfate content is very low, restraining its fresh effect as S source.

Soybean cultivated in 2009/2010

In the third crop (soybean), the grain yield in the control treatment (MAP only) was significantly lower than the other sulfur treatments (Figure 1B). However, in contrast with the first crop, in the third crop there was not significant differences among sulfur sources, either freshly applied (plus residual from the 1st crop) or residual from previous 2nd (wheat) crop. These results indicate that in the third crop any of the sulfur sources was effective for normal soybean plant growth under the experimental conditions. Significantly lower (32%) grain yield was observed in S-deficient soybean plants of control treatment compared to other sulfur treatments (20 kg S ha^{-1}). Grain yields with SEF881 and SEF774 were higher by 18.5% and 17.2%, respectively, compared to control treatment, presumably due to the provided available SO_4-S through elemental sulfur oxidation during previous and present soybean-growing seasons.

Soybean cultivated in 2010/2011

In the fifth crop (soybean), yield was also the lowest for the control treatment (Figure 1C), increasing by 23.3% to 39.2% with sulfur fertilizer treatments freshly applied or residual from previous crops. When the tested fertilizers were freshly applied (treatments 4, 5, 6 and 7) in this third soybean crop there were no significant differences in yields comparing the SEF products with gypsum applied at the rate of 20 kg ha^{-1} year^{-1} of S.

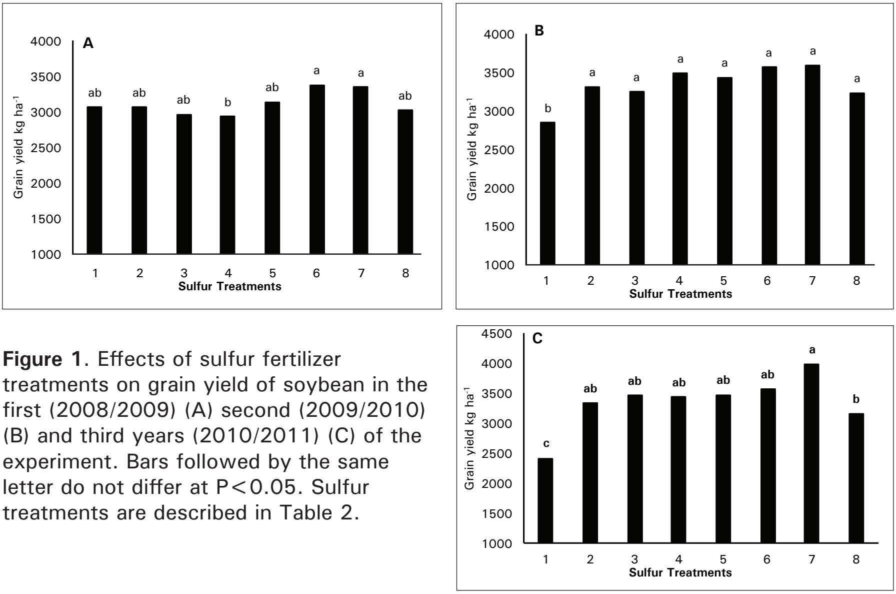

Figure 1. Effects of sulfur fertilizer treatments on grain yield of soybean in the first (2008/2009) (A) second (2009/2010) (B) and third years (2010/2011) (C) of the experiment. Bars followed by the same letter do not differ at $P<0.05$. Sulfur treatments are described in Table 2.

Evaluating the residual effect of the sulfur fertilizers, no yield differences were found in relation to freshly applied fertilizers in soybean cultivated in 2009/2010 and 2010/2011 (Figure 1B, 1C). Soybean yield responses to sulfur fertilization in 2010/2011 increased in relation to the previous crops, as an expected result of depletion of native soil sulfate, making this experimental site even more responsive to sulfur.

For annual maintenance sulfur fertilization all tested sulfur enhanced fertilizer could be used for soybean growing during the rainy season. The SEF88 and SEF774 (freshly applied or residual), and TSP-S1 and TSP-S2 (residual) fertilizers were as effective as gypsum in supplying sulfur to achieve adequate yields, suggesting that a relatively quick oxidation rate of the elemental sulfur in SEF and TSP fertilizers would explain the residual effect in supplying sulfur for the following crop. According to Sousa et al. (2014), recently developed sulfur enhanced fertilizers also based on micronized elemental sulfur incorporated into TSP exhibited fresh effect equivalent to gypsum when broadcast without incorporation, tested in the same Cerrado soil with soybean.

Wheat

Wheat cultivated in 2009

There was significant differences among sulfur treatments for grain yield of wheat cultivated in 2009 (second crop), varying from 2,197 kg ha^{-1} (control treatment) to 3,035 kg ha^{-1} (treatment 3, fresh gypsum at 20 kg ha^{-1}) (Figure 2A). Except for the control and TSP-S1 treatments (1 and 8), yields were not significantly different for the other treatments.

The performance of fresh TSP-S1 for wheat cultivated in 2009 was very similar to that observed for fresh SEF881 with soybean cultivated in 2009/2010. The TSP-S1 exhibited lower initial effect compared to gypsum but equivalent residual effect for the following soybean crop. Both SEF881 and TSP-S1 have only elemental sulfur incorporated into the granules, with small residual sulfate-S from phosphoric acid used in the production of MAP and TSP, whereas for SEF 774 and TSP-S2 around one-third of the incorporated sulfur is sulfate. Results from previous studies in the same site and soil showed that powdered elemental sulfur freshly applied was as effective as gypsum in supplying sulfur to grain crops (VILELA et al., 1995; REIN; SOUSA, 2004).

Wheat cultivated in 2010

Higher yields and response to sulfur fertilizers were found wheat grown in 2010 compared to the previous (2009) wheat crop (Figure 2B). Fresh or residual applications of sulfur had significant effects on wheat yield. Evaluating the cumulative residual effect to wheat of sulfur fertilizers applied to the previous soybean crops (2008/2009 and 2009/2010), SEF881 and SEF774 (treatments 4 and 5) were significantly superior to residual gypsum at 20 kg ha^{-1} year^{-1} (treatment 6) and nearly as effective as fresh gypsum at the same rate (treatment 3). It is likely that sulfate from previous gypsum applications has gone deep the soil subsurface layers, below the effective root zone, which has not happened at the same extent with the sulfur enhanced fertilizers.

Brennan et al. (2010) found the leaching removed 65% of sulfur from gypsum applied to canola in a sandy soil, and three leaching events caused loss of sulfate below 40 cm depth. This suggests that the lower wheat yield with residual gypsum treatment compared to residual sulfur enhanced fertilizers might be a consequence of leaching of sulfate below the root zone.

Wheat cultivated in 2011

There were significant differences among sulfur treatments in wheat cultivated in 2011 (Figure 2C). Freshly (cumulative) applied SEF774 was as effective as fresh gypsum, both at rate of 20 kg ha^{-1}. Yields with residual SEF881 and SEF774 treatments were lower than fresh gypsum, but higher than residual gypsum at 20 kg ha^{-1} year^{-1}, and about 6.3 and 5.4-fold higher than the control treatment Less pronounced residual effect of gypsum compared to SEF products was also observed in the previous wheat crop (2010). On the other hand, soybean yields in 2009/2010 and 2010/2011 (second and third soybean crops) were not significantly different in terms of fresh and residual gypsum and SEF products at 20 kg ha^{-1} S. These results are likely related to the quick dissolution and expected more pronounced leaching of sulfate from previous gypsum application, which does not happen at the same extent with SEF products. A relatively slow oxidation rate of elemental sulfur in these products would explain the better residual effect in supplying sulfur for the following crop. Differences in the root distribution pattern of wheat and soybean crops probably also play a role. Under irrigation during the dry season the wheat root system and nutrient uptake is largely confined to the moist layer of about 20 cm, which is not the case of soybeans growing during the rainy season with an expected better root distribution in the soil profile. Therefore, soybean is more able than wheat in taking up sulfate from subsurface layers in which sulfate is adsorbed in these soils (REIN; SOUSA, 2004).

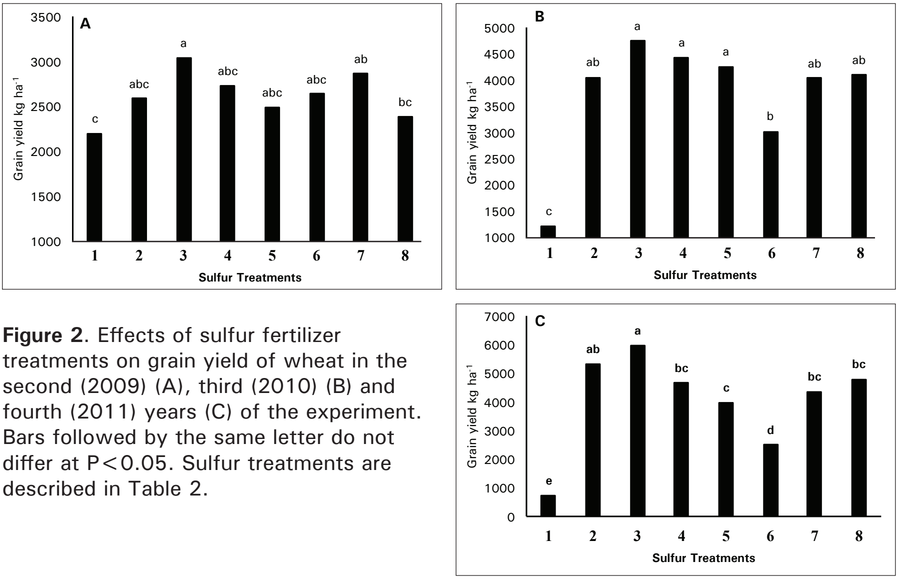

Figure 2. Effects of sulfur fertilizer treatments on grain yield of wheat in the second (2009) (A), third (2010) (B) and fourth (2011) years (C) of the experiment. Bars followed by the same letter do not differ at P<0.05. Sulfur treatments are described in Table 2.

Sweet sorghum

Sweet sorghum cultivated in 2011/2012

The stalk yields differed significantly among the sulfur treatments in the sweet sorghum cultivated in 2011/2012, when the lowest and highest yields were recorded for the control treatment (28.8 t ha^{-1}) and freshly applied gypsum at 40 kg ha^{-1} (42.6 t ha^{-1}), respectively (Table 3). Treatments with freshly applied gypsum and freshly or residual sulfur enhanced fertilizers had stalk yields nearly 40 t ha^{-1}. On the other hand, stalk yield with residual gypsum at 20 kg ha^{-1} S (treatment 3) was 33.7 t ha^{-1}. As found for the 2010 and 2011 wheat crops, higher sulfate leaching might explain the lower residual effect of gypsum to sweet sorghum compared to the elemental sulfur based SEF fertilizers.

Table 3. Effect of the sulfur fertilizer treatments on the stalk yield, juice quality (Brix) and total recoverable sugars (TRS) content of sweet sorghum. Sulfur treatments are described in Table 2.

Treatments	Sweet sorghum 2011/2012			Sweet sorghum 2012/2013		
	Stalk	Brix	TRS	Stalk	Brix	TRS
	t ha^{-1}	%	kg/t cane	t ha^{-1}	%	kg/t cane
01	28.8c	13.4	95.6	44.1bc	14.8	100.7
02	40.2ab	14.1	104.5	48.2abc	14.9	101.4
03	33.7bc	14.6	107.3	52.4a	15.0	108.9
04	41.3a	13.5	105.9	48.6abc	14.6	108.0
05	38.5ab	14.0	108.9	51.5ab	14.3	101.3
06	40.3ab	12.9	100.9	43.5c	15.7	110.8
07	42.6a	15.0	112.6	46.6abc	14.4	105.4
08	40.3ab	15.0	112.0	47.0abc	14,1	106.4
CV%	6.0	8.6	13.2	5.7	4.2	4.3

Ethanol conversion efficiency of sweet sorghum juice is related to contents of sucrose plus reducing sugars in the juice, which in turn is indicated by the brix reading (SAWARGAONKAR; WANI 2016). However, there was no significant effect of sulfur treatments on juice quality (brix) and cane content of total recoverable sugars (TRS) (Table 3). As the juice is extracted from the stalks, higher stalk yield means higher juice yield. Therefore, TRS yield (kg ha^{-1}) basically reflect the stalk yield, which was significantly lower for the control treatment (2,739 kg ha^{-1}) compared to the sulfur fertilizer treatments, 4,261 kg ha^{-1} on average (Figure 3A). Based on these results, sweet sorghum should be cultivated with applications of sulfur enhanced fertilizer freshly applied or residual from previous crop.

Sweet sorghum cultivated in 2012/2013

As found in the previous sweet sorghum crop (2011/2012), the lowest stalk yields were found for the control treatment and residual gypsum at 20 kg ha^{-1} (treatment 6), respectively 44.1 t ha^{-1} and 43.5 t ha^{-1} (Table 3). Other treatments, with stalk yields ranging from 46.6 t ha^{-1} to 52.4 t ha^{-1}, were not significantly different, with highest yields achieved with freshly applied gypsum freshly (treatment 3) and residual SEF774 (treatment 5).

As observed in the previous crop season, there was no significant difference among sulfur treatments for brix and TRS content of sweet sorghum cultivated in 2012/2013 (Table 3). Significantly lower TRS yield were found for the control treatment, 4,432 kg ha^{-1} (Figure 3B). No significant differences were found for the other treatments, with TRS yields ranging from 4,813 kg ha^{-1} (treatment 6, residual gypsum ate 20 kg ha^{-1} S) to 5,712 kg ha^{-1} (treatment 3, fresh gypsum at 20 kg ha^{-1} S).

Results of sweet sorghum suggest a limited capacity of this crop on taking up sulfate leached to subsurface layers after gypsum application in the previous crop, which might be related to a relatively shallow root distribution in the soil profile. Sweet sorghum, which has been cultivated in Brazil for ethanol production, needs to be further studied in relation to sulfur nutrition and fertilization management.

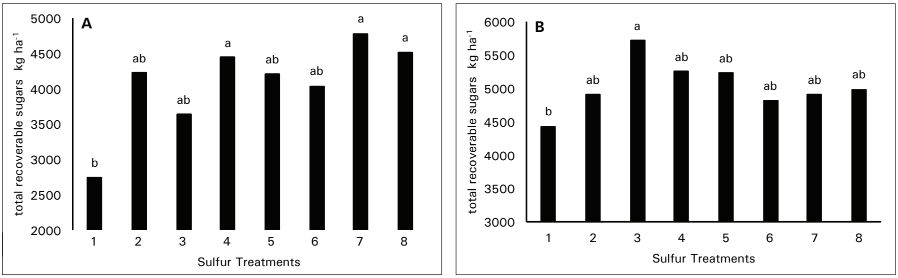

Figure 3. Effects of sulfur fertilizer treatments on total recoverable sugars (TRS) yield of sweet sorghum in the fourth (2011/12) (A) and fifth (2012/13) years (B) of the experiment. Bars followed by the same letter do not differ at $P<0.05$. Sulfur treatments are described in Table 2.

Conclusion

Yield increases in responses to sulfur fertilizers were low for the first soybean crop. There was a significant response to freshly applied gypsum for the first wheat crop in relation to the control treatment. The SEF881 (soybean) and TSP-S1 (wheat), with nearly 100% elemental sulfur, performed worse than gypsum in terms of grain yield when freshly applied to this soil with low available sulfate-S cultivated for the first time. In terms of the residual effects of the sulfur fertilizers applied in the previous crop the effectiveness of gypsum, SEF774 and TSP-S were equivalent for soybean grown in the rainy season. For wheat grown in the dry season (irrigated) and sweet sorghum grown in the rainy season the residual effects of sulfur enhanced fertilizers (SEF774 and SEF881) were better than gypsum. For maintenance annual sulfur fertilization of soils with adequate sulfur availability, all tested sulfur enhanced fertilizers could be used.

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