Comunicação

Common bean grain yield as affected by sulfur fertilization and cultivars

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ABSTRACT

A better understanding of the differential growth of common bean cultivars with increasing soil sulfur (S) availability can indicate how to improve common bean grain yield in soils of Savannas. The objective of this study was to evaluate the response of sprinkler-irrigated common bean cultivars to sulfur fertilization in a no-tillage system. The experiment was designed as a randomized block in a split-plot scheme with sulfur rates (0, 10, 20, 40, and 60 kg ha^{-1}) as main plots and common bean cultivars (BRS Requinte, BRS Cometa, Diamante Negro, BRS Grafite, BRS Valente, and Corrente) as subplots, with three replications. Common bean cultivars did not differ regarding grain yield response to sulfur rates, which fitted to a quadratic equation. Among the cultivars tested, only BRS Requinte and BRS Valente differed in grain yield for S fertilization, the first being more productive. Moreover, S fertilization allows significant increases in common bean grain yield in average of six cultivars and must be considered in cropping systems aiming for high yields.

Key words: *Phaseolus vulgaris* L.; sulfated fertilization; savanna soils.

RESUMO

Produtividade de grãos do feijoeiro comum em função da adubação com enxofre e cultivares

A melhor compreensão do crescimento diferencial de cultivares de feijoeiro comum com o aumento da disponibilidade de enxofre (S) no solo pode indicar como melhorar a produtividade de grãos do feijoeiro comum em solos do Cerrado. O objetivo deste estudo foi avaliar a resposta de cultivares de feijoeiro comum, sob irrigação, ao enxofre, no sistema plantio direto. O delineamento experimental foi em blocos casualizados, em esquema de parcelas subdivididas, com doses de enxofre (0, 10, 20, 40 e 60 kg ha^{-1}) como parcelas e cultivares de feijoeiro comum (BRS Requinte, BRS Cometa, Diamante Negro, BRS Grafite, BRS Valente e Corrente) como subparcelas, com três repetições. As cultivares de feijoeiro não diferiram quanto à resposta da produtividade de grãos às doses de enxofre, a qual se ajustou a uma equação quadrática. Entre as cultivares testadas, somente a BRS Requinte e a BRS Valente diferiram quanto à produtividade de grãos para a adubação com S, sendo a primeira mais produtiva. A adubação com enxofre proporciona aumentos significativos na produtividade de grãos do feijoeiro comum na média de seis cultivares e deve ser considerada em sistemas de cultivo visando elevadas produtividades.

Palavras-chave: *Phaseolus vulgaris* L.; adubação sulfatada; solos de cerrado.

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INTRODUCTION

The common bean crop is of significant economic importance in many countries and is considered an important source of protein for human consumption. In the 2012 harvest, 23 million Mg of common bean grains were produced worldwide and the major producers were Myanmar (3.72 Mg), India (3.63 Mg), Brazil (2.82 Mg), China (1.45 Mg), the USA (1.44 Mg), and Mexico (1.08 Mg) (FAOSTAT, 2015). However, despite its importance, technology is seldom used for common bean crops, resulting in a global average grain yield of only 804 kg ha^{-1} (FAOSTAT, 2015). More specifically in Brazil, this crop represented 5.85% of the entire grain production area and 1.7% of the total grain production in the 2013/2014 growing season. The common bean crop is the 3rd largest agricultural crop in Brazil and occupies an area of 3.2 million hectares, behind only soybean (*Glycine max* L. Merrill) and corn (*Zea mays* L.) (CONAB, 2015). The Brazilian average yield of the common bean in the growing season of 2014/2015 was 1,044 kg ha^{-1}, but there are farmers reaching grain yields higher than 3,500 kg ha^{-1} (CONAB, 2015).

To achieve a higher grain yield, the plant fertilization management must be improved because a properly balanced supply of nutrients and the use of fertilizers can achieve significant increases in grain yield (Fageria *et al*., 2011). The common bean requires high amounts of sulfur (S) for its development, because of its high content of protein. This nutrient is also involved in the enzymatic processes and redox reactions and is a constituent of the amino acids cystine, cysteine, and methionine, which constitute about 90% of the plant S (Malavolta *et al*., 1997).

Sulfur is the third most exported nutrient by common beans and about 5.4 to 6.0 kg S in 1,000 kg of grain are exported, which represents about 20-25% of the amount absorbed. In sulfur-deficient plants, there is loss of plant grow strength; they become weak with thin stems and leaves with a pale yellowish green color, leading to a reduction in the formation of branches and the number of flowers and pods, resulting in low grain yield (Cusciol *et al*., 2006). Sulfur is found in the soil in both organic and inorganic forms. Although the first form represents more than 90% of total S in most soils (Fageria *et al*., 2011), it is the inorganic form (sulfate anion - SO_4^{-2}) that is absorbed by plants. Thus, the soil ability to meet the demand of the plant nutrient is closely related to the content of soil organic matter and the mineralization of organic S to inorganic forms, such as sulfate. In the soil solution, sulfate is easily leached because it is weakly retained by the coordination mechanism of adsorption (Ishiguro & Makino, 2011) and the sulfate adsorption is higher in clayey soils rich in iron and aluminum oxides (Jung *et al*., 2011).

Thus, the most likely responses to sulfated fertilization occur in soil with high pH and low clay and organic matter contents (Rheinheimer *et al*., 2007). In addition, the increased use of fertilizers with concentrated formulations without S or with low content, the reduction in the use of S as defensive, and the increased extraction and exportation of this nutrient due to the increase in grain yield have made S deficiency more frequent (Furtini Neto *et al*., 2000). When there is not a sufficient supply of S, the application of high rates of other nutrients (N, P, and K) may not result in increased yields (Crusciol *et al*., 2006).

Rosolem & Marubayashi (1994) suggested the application of 20 kg ha^{-1} S when its content in the soil is less than 2.0 mg kg^{-1}, while Rein & Sousa (2004) recommended the use of 15-30 kg ha^{-1} of S, even in soil with average content (5-9 mg dm^{-3} S), especially in areas well fertilized with other nutrients.

In common bean crop, Ambrosano *et al*. (1996) recommended the application of 30 kg ha^{-1} of S when aiming at grain yield exceeding 2000 kg ha^{-1}, regardless of the sulfur content in the soil. Corroborating this recommendation, Osório Filho *et al*. (2007) found, for common bean in no-till, a maximum estimated yield of 3,130 kg ha^{-1} with the application of 25 kg ha^{-1}. Crusciol *et al*. (2006), however, also for common bean in no-tillage, required a greater dose, 49 kg ha^{-1} S, to achieve maximum yield of 2,644 kg ha^{-1}.

These divergent data raise the hypothesis that, maybe, there is a difference among cultivars in the ability of plants to respond to sulfur application. Our hypothesis is that common bean cultivars have different responses to S fertilization. The objective of this study was to evaluate the response of sprinkler-irrigated common bean cultivars to sulfur fertilization in a no-tillage system.

MATERIAL AND METHODS

The experiment was conducted on Fazenda Capivara, Embrapa Arroz e Feijão, located in Santo Antônio de Goiás, GO, at 16° 29' 15" S and 49º 18' 45" W and 823 m of altitude. The climate is tropical savanna and considered Aw according to Köppen's classification. There are two well-defined seasons: dry season, from May to September (autumn/winter), and rainy season, from October to April (spring/summer). The average annual rainfall is 1485 mm and the average annual temperature is 22.7 °C, ranging annually from 14.2 °C to 34.8 °C.

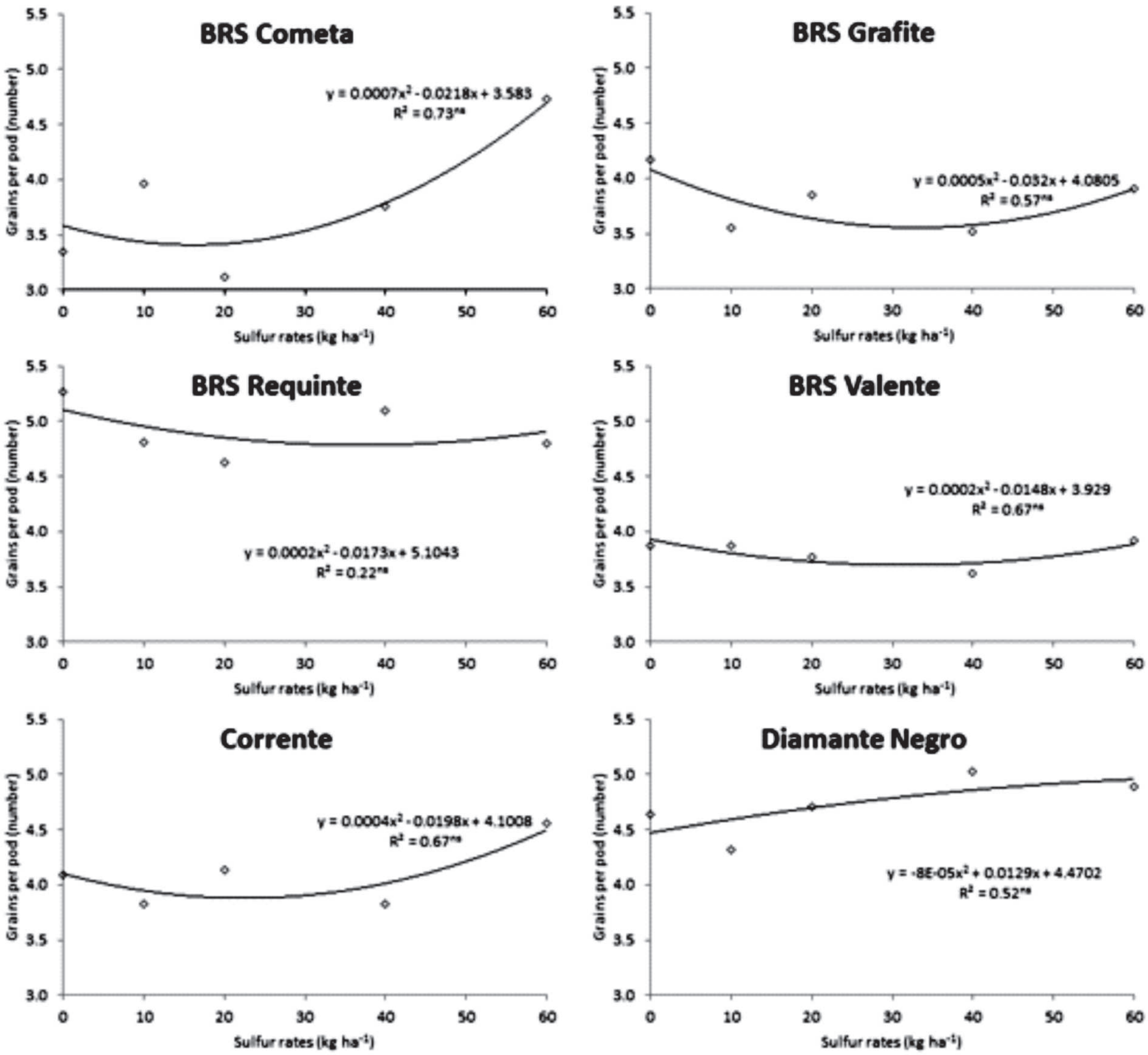
The soil is classified as a clayey (kaolinitic and thermic Typic Haplorthox) acidic soil. Initial soil chemical analyses were performed at a depth of 0-0.20 m to characterize the experimental area and presented pH (H_2O) = 5.7, Ca^{2+} = 18.0 $mmol_c$ dm^{-3}, Mg^{2+} = 10.0 $mmol_c$ dm^{-3}, Al^{3+} = 0.0 $mmol_c$ dm^{-3}, $H^+ + Al^{3+}$ = 28.0 $mmol_c$ dm^{-3}, P = 17.2 mg dm^{-3}, K^+ = 83.0

mg dm^{-3}, S = 5 mg dm^{-3}, Cu^{2+} = 2.3 mg dm^{-3}, Zn^{2+} = 5.9 mg dm^{-3}, Fe^{3+} = 80.7 mg dm^{-3}, Mn^{2+} = 16.2 mg dm^{-3}, and soil organic matter = 40.1 g kg^{-1}.

The experimental area was sprinkler-irrigated by central pivot and had been cultivated in a no-tillage system for five consecutive years. The last crop was soybean. Fifteen days before common bean sowing, glyphosate (1.6 kg ha^{-1} of acid equivalent) was applied.

The field experiment was arranged as a randomized block design in a split-plot scheme with three replications, having S rates (0, 10, 20, 40, and 60 kg ha^{-1}) with source ammonium sulphate (20% of N and 24% of S) in the main plots, and common beans cultivars (BRS Requinte, BRS Cometa, Diamante Negro, BRS Grafite, BRS Valente, and Corrente) in the subplots. The first two cultivars had grain type 'carioca' (grains with beige background with dark brown stripes), the following three had black grains, and the last one had grain type 'mulatinho' (grains with beige background without stripes). Each subplot consisted of four 5-m long lines and the two central lines without 1m at both ends were considered as useful area.

The sowing of the common bean cultivars was performed by hand on June 16th, 2014 in a 0.40 m row spacing and with 10 seeds per meter. Sowing fertilization was done with 60 kg of N ha^{-1} as urea, 100 kg of P_2O_5 ha^{-1} as triple superphosphate, and 100 kg of K_2O ha^{-1} as potassium chloride. At that time, we also broadcast the sulfur rates on the soil accordingly to each treatment. Seedling emergence occurred at eight days after sowing. In the V_4 vegetative stage of the common bean (three trifoliate leaves), a topdressing fertilization of 60 kg of N ha^{-1} as urea was performed for all plots. When the N dose was supplied as urea we deducted the N dose already applied as ammonium sulfate in the S fertilization. Other cultural



ns = no significance.

Figure 1: Number of grains per pod of common bean cultivars as a function of sulfur rates.

practices were performed according to the recommendations for the crop to keep the area free of weeds, disease, and pests.

The usable area of the plots was harvested by hand and was followed by mechanized thresher. The harvested common bean grains were weighed and the yield expressed as 130 g kg^{-1} of humidity. In addition, the following common bean characteristics were assessed: number of pods per plant and number of grains per pod (evaluated in 10 plants per plot that were chosen at random).

Data were subjected to an analysis of variance and the means were compared by Tukey's test at $p < 0.05$. If the quantitative data (sulfur rates) were significant, then the regression analysis was conducted. These analyses used the SAS statistical software. We also made the Pearson's correlation between yield and yield components considering sulfur rates.

RESULTS AND DISCUSSION

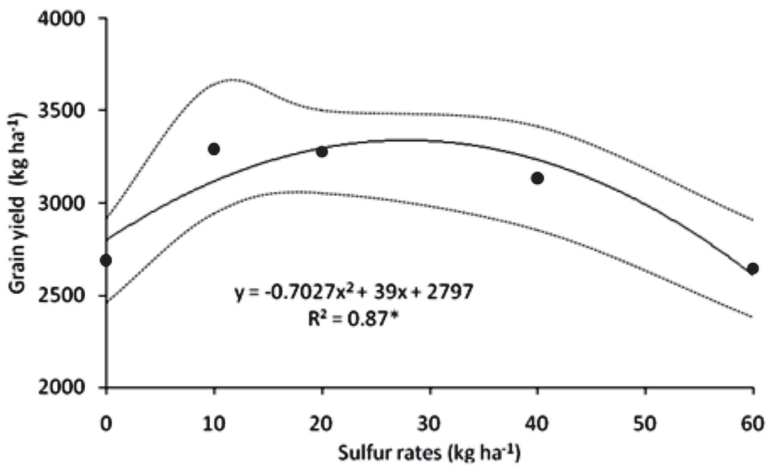
The interaction between the sulfur rates and cultivars was significant only for the number of grains per pod (Figure 1). The number of pods per plant was not affected either by the sulfur rates or by cultivars (Table 1) and the grain yield was significantly affected by single effect of these two factors (Table 1 and Figure 2).

The number of grains per pod is a characteristic of high genetic heritability, with little influence of the environment (Crusciol *et al*., 2006). However, we could see that there are differences among cultivars regarding sulfur rates and this fertilization caused significant differences in this characteristic. Cultivars BRS Requinte and Diamante Negro had the highest values of number of grains per pod and differed from the other cultivars (Table 1).

In the response of grain yield to cultivars, we could see that BRS Requinte had the highest grain yield and differed from the BRS Valente (Table 1). The response to sulfated fertilization was quadratic, with estimated maximum grain yield of 3,338 kg ha^{-1} in the rate of 27.8 kg ha^{-1} (Figure 2). This value is close to that obtained by Osório Filho *et al*. (2007) for common bean in no-till system and agrees with the recommendation of Ambrosano *et al*. (1996). This result of grain yield was probably due to the effect of sulfur rates in the number of pods per plant. The S deficiency causes a reduction in the formation of branches and in the number of flowers and pods, and consequently on common bean yield (Fageria *et al*., 2011).

Considering the means in each dose of sulfur, the number of pods per plant was positively correlated with grain yield ($r = 0.82$; $p < 0.05$) and negatively with the number of grains per pod ($r = -0.94$; $p < 0.05$) (Table 2). Negative correlations between the primary components of grain yield occur in most crops, particularly under conditions of environmental stress, which cannot allow maximum expression of the genes that control these components. It is believed that these correlations are due to the action of the environment on genetically independent components, which develop in a sequential manner, that is, first there is the number of pods per plant, then the number of grains per pod, and finally the mass of grains (Fageria *et al*., 2011). Productivity also showed a negative correlation with the number of grains per pod ($r = -0.90$; $p < 0.05$) (Table 2).

Our results showed that S fertilization was important to increase the grain yield of common beans. If farmers had made the fertilization without S, they would have reach only 2,797 kg ha^{-1}, according to the equation of Figure 2.



Dots represent means of grain yield of six cultivars in each sulfur rates.
Dashed lines represent confidence interval.
* Significant at $p < 0.05$.

Figure 2: Common bean grain yield as a function of sulfur rates.

Table 1: Number of pods per plant (NPP), number of grains per pod (NGP), and grain yield (YIELD) of common bean as a function of cultivars

Cultivar	NPP (no.)	NGP (no.)	YIELD (kg ha^{-1})
BRS Cometa	17.25 a	3.79 b	2,945 ab
BRS Grafite	15.39 a	3.80 b	2,914 ab
BRS Requinte	18.40 a	4.92 a	3,389 a
BRS Valente	19.22 a	3.81 b	2,636 b
Corrente	16.89 a	4.10 b	3,060 ab
Diamante Negro	17.59 a	4.71 a	3,114 ab
Coefficient of Variation (%)	20.74	9.96	18.88

[1]Means followed by the same letter in column do not differ by Tukey's test at $p < 0.05$.

Table 2: Pearson's correlation among number of pods per plant (NPP), number of grains per pod (NGP), and grain yield (YIELD) of common bean considering the means in each dose of sulfur

	NPP	NGP	YIELD
NPP	1		
NGP	-0,94*	1	
YIELD	0,82*	-0,90*	1

*Significant at 5% of probability.

On the other hand, if they put around 30 kg ha^{-1} of S, the grain yield would increase to 3,338 kg ha^{-1}. Therefore, this nutrient has importance in the yield of common beans and should be included in recommendations of common bean fertilization. Typically, in common bean cultivation, farmers apply lime and fertilizers such as N, P, and K, but S is seldom applied (Bona & Monteiro, 2010), which also may limit the crop yield.

CONCLUSIONS

Common bean cultivars do not differ regarding grain yield response to sulfur rates, which fit a quadratic equation.

Among the cultivars tested, only BRS Requinte and BRS Valente differ in grain yield for S fertilization, the first being more productive.

Sulfur fertilization allows significant increases in common bean grain yield in the average of six cultivars and must be considered in cropping systems aiming at high yields.

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