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DOSES OF APPLICATION SULFUR FOLIAR FERTILIZATION IN DIFFERENT STAGES OF DEVELOPMENT OF THE CORN OFF SEASON

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ABSTRACT

The sulfur has received little attention by the farmers and researchers, mainly in lower investment systems as the off season maize, the crop most sowed after soybean on the Mato Grosso state. The objective of the work was to evaluate in field conditions the agronomic performance and yield by off season maize submitted to the foliar sulfur application, combining different doses and times of supply (stages of corn). A randomized blocks experiment was carried out with four replications, in a factorial scheme 3x4. The treatments consisted of combination of 3 times of sulfur application (stages of corn): V4, V8 and V12, and 4 doses of sulfur: 0, 1000, 1500, 2000 mL ha^{-1}. The plant height and the number of plants per plot were not affected by the times of sulfur application. Applications on the V8 stage benefited the number of grain rows, number of grains per row, number of grains per ear, a thousand grain mass and grain yield. The doses of sulfur studied here did not influence the most of the characteristics evaluated, except the number of grains per ear, a thousand grain mass and grain yield. The number of grains per ear increased on the proportion of 0.0343 for each 1 mL ha^{-1} of increase in the sulfur applied. The behavior of the maize in grain yield, within each time of sulfur application, is linear with the increase of the doses studied here. For a mass of a thousand grains the behavior is linear or quadratic, according to the time of sulfur application considered.
Key-words: *Zea mays*, yield components, soybean-maize succession, mineral nutrition

1 Introduction

One of the factors that have influenced the crop's productivity is the deficiency of some essential nutrients. Sulfur is the fourth main element demanded by culture with recognized importance in mineral nutrition, mainly due to its participation in enzymes and proteins. In general, soils cultivated for many years with continuous use of concentrated fertilizers, with low sulfur levels (S <1% content), end up manifesting deficiency of the element in agricultural crops [1].

Sulfur is demanded by grain-productivity agricultural crops in quantities similar to those of phosphorus, that is, 10 to 30 kg ha^{-1} [2, 3], however it does not receive the same attention in fertilization yearly. There is no specific condition that determines the response of crops to the addition of sulfur, but there are circumstances in which soils may have less availability and show favorable results for fertilization with sulfur [4].

Sulfur has been gaining emphasis in the agricultural scenario, since the low content of the nutrient in tropical soils, the increase in productivity, the use of low sulfur fertilizers, the reduction of atmospheric sulfur and the lower consumption of sulfur pesticides are the main ones. Causes for the increased need for the use of this macronutrient in fertilization [5].

Von Pinho et al. (2009) [6] found a linear behavior for the accumulation of sulfur in the aerial part of the corn during the whole cycle, which indicates that the element must be available to the plants continuously. These authors report differentiated sulfur accumulation among corn cultivars, with cultivars with higher dry matter production accumulating an average of 30 kg ha^{-1}, while cultivars with high potential for grain production accumulated about 24 kg ha^{-1} of sulfur.

The importance of nitrogen in the corn crop is well known, being used in large doses and showing high response by the crop. It is also known that nitrogen and sulfur metabolism are closely linked and play a fundamental role in protein synthesis [7, 8] and the assimilation of both is correlated [9] .

Carchiochi et al. (2020) [10] studied the relationship between nitrogen and sulfur in corn

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nutrition in a series of five field experiments. The authors found a reduction in the efficiency of nitrogen use under sulfur deficiency and also the opposite, a reduction in the efficiency of sulfur use under nitrogen deficiency. The average response to sulfur fertilization in grain production was 11% (ranging from 6 to 18%) and the response to the combined use of the two nutrients was 59% (ranging from 11 to 93%), compared to the control treatment. Phosphorus can also be benefited by adding sulfur to corn planting fertilizers, as observed by [11]. These authors report an increase in the index and agronomic efficiency of phosphate fertilizer in the presence of 30 kg ha^{-1} of sulfur.

In most soils, sulfur in its organic form represents more than 90% of the total sulfur. The efficiency of the sulfur transformation processes in the soil depends on several factors such as soil temperature, pH, humidity, iron and aluminum oxides, carbon and nitrogen content and quantity and type of clay minerals [12]. Assessing the supply of sulfur in alkaline soil for two years, [7] reported responses of corn at plant height and harvest index using doses of up to 35 kg ha^{-1} of sulfur.

The different sources of sulfur, when applied via soil, do not seem to be determinants in the efficiency of fertilization, as confirmed by [13] when verifying an equal response to sulfate and elemental sulfur in the contents of leaf sulfur, chlorophyll index and root dry matter in corn. Even in cover fertilization, the corn crop is able to respond positively to the sulfur supply, as verified by [14]. The authors found an answer in grain yield when sulfur was supplied together with nitrogen in top dressing in a soil with low levels of the element.

Tiecher et al. (2012) [15] studied several crops in four different types of soil with varying doses of sulfur applied before planting and found interaction for the production of dry matter between crops and type of soil in response to the nutrient. In Brazil, little is known about the use of sulfur applied via leaf. Results of research with sulfur are not frequent in Brazil and in most cases the applications occur through compound products, not pure and isolated products with only the element. In addition, some technicians, agronomists and rural producers still consider the element as secondary, disregarding its importance [9].

As a result, it is necessary to carry out further research to assess the efficiency of fertilizers containing sulfur and the actual sulfur gains in crops, as well as the exact doses of the best response for each crop. In view of the above, the objective of the work was to evaluate, under field conditions, the agronomic performance and productivity of second crop corn submitted to the application of sulfur via leaf, combining different doses and stages of supply.

2 Materials and Methods

The experiment was conducted in a commercial area located on Av. Alexandre Ferronato, next to UFMT, Campus de Sinop-MT, cultivated under no-tillage system, between the months of February to June 2019. The location of the experiment is located at latitude 11º86'32 " S, longitude 55º 47'89 " O and altitude of approximately 380m with flat topography. The climate according to Koppen-Geiger is classified as Aw (tropical with dry winter), having two well-defined seasons, one rainy between October and April, and the other dry from May to September, with low annual thermal amplitude, varying between 24 to 27 ° C and average annual rainfall of 2100 mm [16].

Meteorological data were obtained from the Instituto Nacional de Meteorologia-INMET, Sinop station, in the period between February 8 and June 7, during which the hybrids remained in the field. Data related to precipitation, average temperature, maximum temperature and minimum temperature are shown in Figure 1.

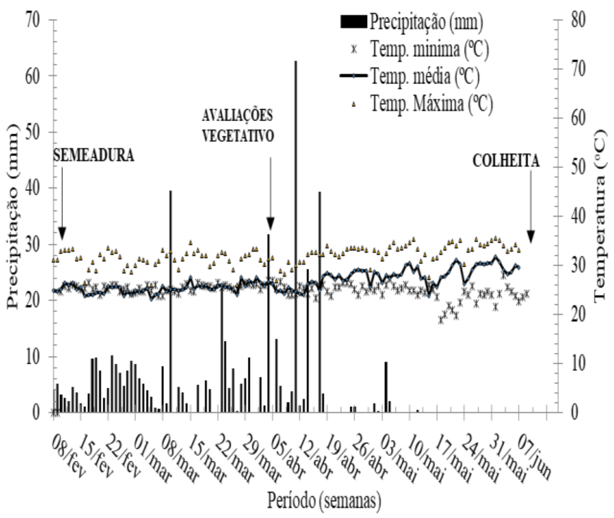

Figure 1. Temperature and precipitation data during the experiment period from February 8 to June 7, 2019.

The region's soil is classified as dystrophic Red Latosol (LVAd) [17]. Sampling was carried out on this soil in the 0 to 20 cm depth layer and subsequent chemical analysis in the laboratory. The chemical analysis of the soil provided the following results: pH (CaCL2) 5.4, M.O. 18.55 g dm^{-3}, P (Melich) 6.07 mg dm^{-3}, K 52.00 mg dm^{-3}, Ca 2.84 mg dm^{-3}, Mg 0.93 mg

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dm^{-3}, S 4.0 mg dm^{-3}, V = 57.2%, Ca/Mg ratio, 3.05, Ca/K ratio, 21.85, Mg/K ratio, et al. (in mg dm^{-3} were: Zn 5.51, Cu 0.44, Fe 199.16, Mn 11.25 and B 0.15. The physical analysis of the soil revealed sand, silt and clay contents of 497, 125 and 378 g dm^{-3}, respectively. With the result of the soil analysis, it was observed that the base saturation was in accordance with the crop requirement, not requiring liming.

The corn hybrid used was Land®, sown on February 1, 2019, with a stand of 60,000 plants ha^{-1}. For sowing fertilization, a dose of 40 kg of N, 98.4 kg of P_2O_5 and 52.5 kg K_2O ha^{-1} was used according to the expectation of good corn crop yield, according to [18]. The application of nitrogen in cover was made by haul and the source used was urea (45% N) at a dose of 30 kg ha^{-1}, the seeds came with TSI (industrial seed treatment) Basf®.

Before sowing, weed desiccation was carried out using 1.5 kg ha^{-1} of glyphosate (granulated) and in post-emergence, at 30 DAE, another 1.5 kg ha^{-1} of glyphosate was applied, with syrup volume of 100 L ha^{-1}. Cultivations were carried out according to the requirements of the corn crop. The control of weeds in post-emergence occurred within the recommended period, from germination to forty days after planting.

The experimental design adopted was randomized blocks (DBC) with four replications, in a 3x4 factorial scheme. The treatments consisted of a combination of 3 times of foliar sulfur application: 4 expanded leaves (V4 phenological stage), 8 expanded leaves (V8 phenological stage) and 12 expanded leaves (V12 phenological stage), and 4 doses of sulfur: 0, 1000, 1500 and 2000 mL ha^{-1}. The sulfur was purchased ready, in the form of a commercial product (S-MAX®), containing 50% of the element sulfur. The experimental plots consisted of five lines four meters long. The useful area of the plot consisted of the three central lines with three meters in length, because as a border, half a meter was discarded at each end of the lines.

The evaluations of plant height and number of plants in the useful plot were carried out at the stage of full flowering (R2). The height of plants was measured from the ground until the last leaf of the apex (flag leaf), taking the average of four plants per plot. The harvest was carried out manually on 06/04/2019. Afterwards, the number of rows of grains, number of grains per row and the average number of grains in the ears of four individual plants of the useful plot were counted. At harvest, the grains were threshed mechanically in a manual thresher from the Bottini® brand. After threshing, the beans were cleaned and sieved by hand, placed in properly identified paper bags. The grain moisture was then corrected to 130 g kg^{-1} water, in an oven with forced air circulation at 60°C. After moisture correction, the mass of a thousand grains (g) and grain yield (kg ha^{-1}) were determined with a Fillizola® balance of precision scale.

The data obtained were subjected to analysis of variance, at the level of 5% probability by the F test, with the aid of the SISVAR statistical program [19]. The treatment means were compared by the Skott-Knott test at 5% probability.

3 Results and Discussion

For plant height and number of plants in the plot, there were no differences depending on the time of application (phenological stages) of sulfur via the leaves. As for the number of rows of grains in ear, number of grains per row, number of grains per ear, mass of a thousand grains and grain yield, there were statistical differences in the periods of application. The V8 stage provided the best results for these components of corn production (Table 1).

For the number of grain rows, the application in V8 stage provided an increase of 11.8% in relation to the V4 season and 5.8% in relation to the application in the V12 stage. For the number of grains per row, the superiority of the application in V8 stage in relation to the average of the other stages, which did not differ among themselves, was 9.1%. This superiority of the V8 stage was maintained for the variables number of grains per ear (18.1%), mass of a thousand grains (3.6%) and grain yield (20.6%).

Andrade et al. (2019) [11] studied the sulfur supply in the initial development of corn, combining applications via soil and foliar with a product containing 50% sulfur content, as used in the present work. The authors also report a lack of effect for the plant height variable in the early evaluation they did, at 32 days after emergence, either with soil, leaf or combination of these.

There were no statistical differences as a function of sulfur doses in foliar application for most of the variables analyzed, except for the number of grains per ear and mass of a thousand grains (Table 2). For these variables, the dose of 2000 mL ha^{-1} showed the best responses.

Corroborating the results found here, using a soil with low sulfur contents (below 10 mg dm^{-3}), cultivated with different crops in two successions of crops, [5] also did not verify the response of soybean, black oats, canola and wheat to fertilizers with up to 60 kg ha^{-1} of sulfur. The authors attribute this to the sulfur supply via rainwater, which presented an average of 3.2 kg ha^{-1} $year^{-1}$ in the conditions of Rio Grande do Sul

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state and, even though it is small, may have contributed to the lack of response.

A different result was reported by [8] evaluated the response of corn to sulfur supplementation in nine environments with varying levels of organic matter in the soil (2.1% to 6.2%), an important source of sulfur for crops. The authors report an average increase of 8% in grain yield comparing the control treatment with the treatments that received doses equal or greater than 16 kg ha^{-1} of sulfur via soil.

Adjusting a regression model for the number of grains per ear, it appears that the response was linear in relation to the sulfur doses studied in this work. With each increase of 1 mL ha^{-1} in the sulfur dose, there was an increase of 0.0343 grains per ear (Figure 2).

There was an interaction between the factors of application of sulfur and dose for a thousand grains mass and grain yield. In the unfolding of the interaction between the sulfur application doses and application times for the mass of a thousand grains, it appears that for the V12 stage the first degree linear regression model adjusted well showing that for each 1 ml increase ha^{-1} in the sulfur dose the mass of a thousand grains is increased by 0.01 g (Figure 3).

For grain yield, there was a first-degree linear response to sulfur doses for all application stages. The V8 stage was the most responsive to the application of sulfur with an increase of 1.693 kg ha^{-1} of corn grains for each increase of 1 ml ha^{-1} in the applied sulfur dose. The V12 stage was the least suitable for the supply of leaf sulfur to corn, as it was the one with the lowest response in grain yield (Figure 4).

In turn, [2] found a quadratic response in grain yield and mass of a thousand grains in corn for sulfur doses applied via soil. The best dose found by these authors, 60 kg ha^{-1} of sulfur, promoted a 42.8% increase in grain yield, a value much greater than the 1.02% increase found in this study for the highest dose in relation to the control treatment.

An important result of foliar application of sulfur in corn was reported by [20] with doses much higher than those studied in this work. The authors found an answer for grain yield, mass of a thousand grains and weight of ear for all treatments that received sulfur fertilization, both via soil and foliar. For grain yield, dose of 16 or 20 kg ha^{-1} of sulfur via leaf did not differ statistically from doses of up to 100 kg ha^{-1} via soil. It can be assumed that the low response to sulfur at certain times of application is related to the lower production potential of off-season corn crop.

However, [3] found a generalized response to the supply of sulfur at the level of 20 small rural properties in Africa, cultivated with low production potential maize, which shows the relevance of the nutrient in the crop yield.

4 Conclusions

The application of 10 kg ha^{-1} of N at V2 by leaf spraying increases the plant height, the weight of a thousand seeds and the grain yield of soybean.

The application of N at V2 and R1 stages by leaf spraying, as a complement to BFN, promotes increase on grain yield.

The highest grain yield of soybean is obtained with N applied at V2 by leaf spraying.

Doses de aplicação de enxofre em adubação foliar em estádios na cultura do milho segunda safra

RESUMO – O enxofre (S) tem recebido pouca atenção por produtores, principalmente em sistemas produtivos de menor investimento como o milho segunda safra, a cultura mais semeada após soja, no estado do Mato Grosso. O objetivo foi avaliar em condições de campo o desempenho agronômico e a produtividade do milho segunda safra submetido à aplicação de enxofre via foliar, combinando diferentes doses e estádios de fornecimento no milho. Instalou-se o experimento em blocos casualizados com quatro repetições, num esquema fatorial 3x4. Os tratamentos consistiram da combinação de 3 épocas de aplicação de enxofre (estádios): V4, V8 e V12, e 4 doses de enxofre: 0, 1000, 1500 e 2000 mL ha^{-1}. A altura de plantas e o número de plantas não foram afetados pelas épocas de aplicação de enxofre. Aplicações no estádio V8 beneficiaram o número de fileiras de grãos, número de grãos por fileira, número de grãos por espiga, massa de mil grãos e produtividade de grãos. As doses de enxofre aqui estudadas não influenciaram a maioria das características avaliadas, com exceção de número de grãos por espiga, massa de mil grãos e produtividade. O número de grãos por espiga aumenta na razão de 0,0343 para cada aumento de 1 mL ha^{-1} na dose de enxofre aplicada. O comportamento do milho em produtividade de grãos, em cada época de aplicação de enxofre, é linear com o aumento das doses estudadas nesse trabalho. Para massa de mil grãos o comportamento é linear ou quadrático, conforme a época de aplicação considerada.

Palavras-Chave: Zea mays, componentes da produção, sucessão soja-milho, nutrição mineral.

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Table 1. Means of the plant height (PH), number of plants in the plot (NPP), number of rows grains per ear (NRG), number of grains per row (NGR), number of grains per ear (NGE), mass of a thousand grains (MTG) and grain yield (GY) in corn as a function of sulfur foliar application times.

Sulfur foliar application times:	PH (m)	NPP	NRG	NGR	NGE	MTG (g)	GY (Kg ha^{-1})
V4 phenological stage	1.84 a	14.00 a	15.31 c	25.62 b	390.53 b	265.48 b	4549.42 b
V8 phenological stage	1.85 a	13.69 a	17.12 a	28.43 a	482.12 a	272.93 a	5614.95 a
V12 phenological stage	1.86 a	13.19 a	16.18 b	26.50 b	425.62 b	261.43 b	4763.28 b
Coefficient of Variation (%)	3.49	10.14	7.02	8.49	11.83	3.13	12.87
General Means	1.85	13.95	16.20	26.85	432.76	266.61	4975.89

**** The averages followed by the same letters in the columns do not differ at the 5% probability level by the Scott-Knott test.**

Table 2. Averages of plant height (PH), number of plants in the plot (NPP), number of rows of grains per ear (NRG), number of grains per row (NGR), number of grains per ear (NGE), mass of a thousand grains (MTG) and grain yield (GY) in corn as a function of sulfur application doses.

Sulfur application doses (mL ha^{-1}):	PH (m)	NPP	NRG	NGR	NGE	MTG (g)	GY (Kg ha^{-1})
0	1.85 a	13.80 a	15.83 a	25.42 a	400.79 b	270.20 a	5362.58 a
1000	1.85 a	13.17 a	16.42 a	27.50 a	449.04 a	259.51 b	4259.14a
1500	1.84 a	14.33 a	16.08 a	25.83 a	413.45 b	262.93 b	4864.51 a
2000	1.86 a	14.53 a	16.50 a	28.67 a	467.75 a	273.81 a	5417.33 a

**** The averages followed by the same letters in the columns do not differ at the 5% probability level by the Scott-Knott test.**

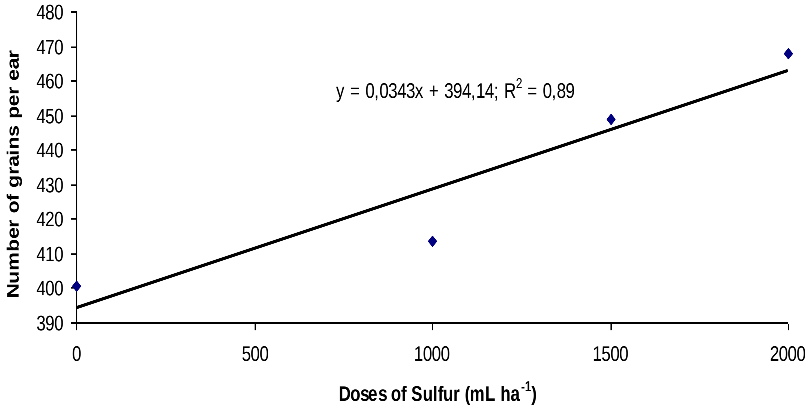

Figure 2. Number of grains per ear as a function of foliar sulfur doses.

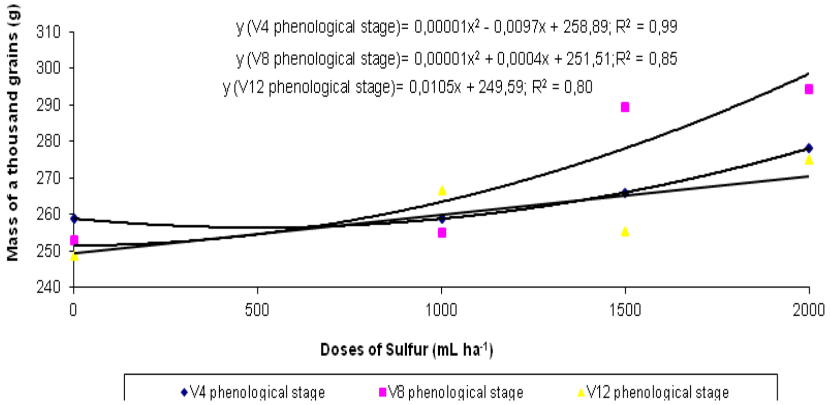

Figure 3. Mass of a thousand grains as a function of leaf sulfur doses for each application period.

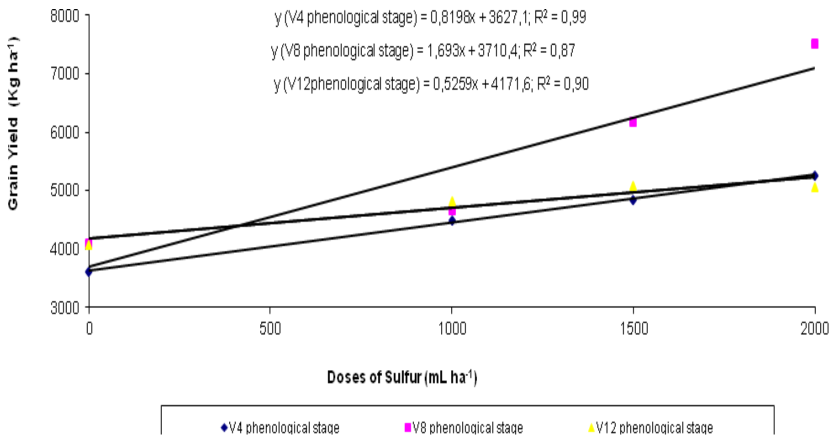

Figure 4. Grain yield as a function of leaf sulfur doses for each application periods.

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