Journal of Agricultural Science; Vol. 10, No. 8; 2018
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Increasing Levels of Sulfur on Lowland Rice in Different Soil Textures

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Received: May 7, 2018 Accepted: June 9, 2018 Online Published: July 15, 2018

doi:10.5539/jas.v10n8p372 URL: https://doi.org/10.5539/jas.v10n8p372

Abstract

A viable alternative to increase productivity in rice cultivation areas has been the investment in macronutrient fertilization. Sulfur (S) is an essential nutrient for plants, as it participates in the formation of several organic molecules, being essential to ensure high yields of rice. The aim of this paper is to analyze the rice crop performance in two types of irrigated floodplain soils under different doses of sulfur fertilization. The experiment was carried out on two lowland soils in Formoso do Araguaia-Tocantins, Brazil, under a randomized block design, in a 2 × 8 factorial arrangement, two soil types and eight sulfur doses, using ammonium sulfate as the source of S (0, 10, 20, 30, 40, 50, 60 and 70 kg ha^{-1} of S). The doses were applied when the plants were in the V3-V4 development stage in both soils. S provided plant a growth up to 40 kg ha^{-1}, which is the economical feasible dose for plant height in soil 1. With the increase of the dose of S over 60 kg ha^{-1} in soil 2, there was a decrease in the number of panicles per m^2. There was an increase in productivity in soil 2 and reduction in soil 1. The highest grain yield was obtained in soil with higher clay content. The dynamics of sulfur fertilization in floodplain soils requires further studies for a better understanding.

Keywords: fertilization, lowland soils, *Oryza sativa* L.

1. Introduction

The production of rice (*Oryza sativa* L.) in Brazil occurs under dry and irrigated cultivation. These different forms of production must be evidenced, since technological packages provide differentiated levels of production. In the State of Tocantins, rice cultivation occurs mainly under irrigated conditions, where the productive poles are in the Southwest of the State, with the largest producers being the cities of Lagoa da Confusão and Formoso do Araguaia, which adopt the irrigation system by flood during the season crop period.

The lowland soils are very heterogeneous, thus resulting in different behavior when compared to other soils submitted to the productive process (Bastos, Carvalho, Vieira, & Bertoni, 2005). When lowland soils are flooded, several reactions are affected, especially regarding nutrient uptake and availability (Taiz & Zeiger, 2004), which directly affects crop growth.

Among the nutrients that may undergo alterations in the rice production process by flooding, Sulfur (S) can be oxidized and occur in two chemical forms, Sulfides (H_2S_2) and elemental sulfur. However, the plants absorb the element in the aerobic solution of the soil in the inorganic form of anion sulfate ($S\text{-}SO_4^{2-}$) (Casagrande, Alleoni, Camargo, & Borges, 2003).

The available $S\text{-}SO_4^{2-}$ contents are directly related to soil pH and organic matter, clay and oxides, and the highest probability of responses to sulfate fertilization occurs in soils with high pH, low content of clay and organic matter that receive intensive cultivation associated with the use of concentrated fertilizers without S (Rheinheimer, Rasche, Osório Filho, & Silva, 2007). In addition, the ability of the soil to supply the nutrient demand of the plant is closely related to the organic matter content of the soil and the mineralization of organic S to inorganic forms (Tiecher et al., 2013). However, in the soil solution, sulfate is easily leached, and retained by the mechanisms of adsorption by coordination (Ishiguro & Makino, 2011).

Thus, assuming that the pH and amount of organic matter can influence the uptake of S in rice plants which are cultivated in lowland soils, interfering with productivity. Thus, the aim of the study was to analyze the rice crop performance in two soils of the lowland with characteristics different and doses crescent of sulfur fertilization.

2. Method

The experiment was carried out in the Formoso do Araguaia-TO, Brazil, located near the geodesic coordinates 11º47′ S and 49º31′ W and 240m altitude. The lowland rice cultivation was in two plots, and the different soils was classified as hydromorphic, but these soils presented different chemical characteristics and organic matter content (Table 1).

Table 1. Chemical and physical characteristics of the soils under study

	pH	Ca	Mg	Al	H+Al	CTC	K	P (Melich)	S	Texture			Organic Matter
										Clay	Slime	Sand	
		------------ cmolc/dm^3 (mE/100 ml) -----------						-- mg/dm^3 (ppm) --		----------- cmolc/dm^3 (mE/100 ml) ----------			
Soil 1	4.9	2.3	0.7	0.1	2.8	5.88	19.0	100.0	11.0	140	60	800	22.0
Soil 2	5.2	4.7	1.1	0.0	4.2	10.07	21.0	31.7	3.4	310	80	610	57.0

The experimental design was a split plot in 2 × 8 factorial scheme with three replications, two soils with different textures (Table 1), and eight doses of sulfur. Ammonium sulphate was used as the source of sulfur at doses of 0 (N and S, 0 of S and 54 of N, 10, 20, 30, 40, 50 and 60 kg ha^{-1} of S), totaling 16 treatments. The doses were applied at the V3-V4 development stage of the Irga 424 cultivar (three to four leaf fully developed plants).

Each experimental plot consisted of 4 lines of 5.0 m in length and spaced 0.4 m between rows. Only the two central lines were considered as useful plots for evaluations. The sowing was performed by a mechanized, tractor-seeder set in a conventional soil preparation system.

Planting fertilization was done in the sowing furrow with 250 kg ha^{-1} of N-P-K (6-20-20). Two applications of nitrogen in coverage were also performed, the first one being at 25 days after emergence at the dose of 54 kg ha^{-1} of N, and the second 40 days after emergence at the dose of 20 kg ha^{-1} of N, both the coverage applications were made using NPK formulation 20-0-20. As for the management of weeds, pests and diseases, these were done according to the schedule executed in the property, respecting the needs of the crop.

Based on the useful area of the plot, the evaluated agronomic characteristics were: plant height (AP), which was measured from the soil surface to the apex of the panicle of the central stem (cm); Number of panicles per m2, and grain yield, determined by the collection and weigth of grains of each useful plot, the results being transformed to kilograms per hectare (kg ha^{-1}) with grain moisture corrected to 12%.

The experimental data were submitted to individual and joint analysis of variance, with application of the F test. The joint analysis was performed under conditions of homogeneity of the residual variances. For the comparisons between means of treatments, the regression method was used, opting for the adjustment model with the highest value of R2. Both analyzes were performed using the computational application in genetics and statistics-GENES (Cruz, 2006).

3. Results and Discussion

According to results presented in Table 2, for the source of variation doses, significance was verified for the variables plant height, number of panicles and productivity ($p \leq 0.01$). The fact that the S doses are significant is mainly related to the rate of replacement of this nutrient to the soil, in the form of a concentrated fertilizer, in addition to the fact that it has a high content of organic matter, which reduces immobilization.

Thus, even if S is partially supplied by the atmosphere and soil organic matter, it can not be used as a concentrated fertilizer (Soares, Bardiviesso, Barbosa, & Barcelos, 2017), because symptoms of S deficiency in cultivated plants growing in the last decades due to factors such as the export of nutrients by intensive harvests, leaching, erosion, and mainly due to the absence of the macronutrient in the NPK formulations, ie, the use of only S-free concentrated fertilizers (Schimitt, Vendrusculo, Gatibonil, Santin, Wendling, Dall'Orsoletta, & Coldbella, 2018).

Concerning the effects of soil types, no significance ($p \leq 0.05$ and 0.01) was found for any of the characteristics evaluated, which indicates that the soil alone does not interfere on the analyzed variables. However, there was a significant interaction ($p \leq 0.05$) between the soil and the S doses applied for plant height and grain yield (Table 2).

Table 2. Summary of analysis of variance, characteristics; plant height; number of panicles and grain yield of rice in Formoso do Araguaia-TO

F.V.	D.O.F.	Mean square		
		Height of plants	Nº of panicles	Grain yield
Doses (D)	7	43.71**	5435.69**	655536.99**
Soils (S)	1	602.70^{ns}	5041.0^{ns}	10061584.0^{ns}
D × S	7	55.42*	5211.45^{ns}	1009565.07*
Residues	42	11.27	626.29	234416.38
Avarege		90.29	250.49	7972.40
C.V. (%)		3.71	9.99	6.07

Note. ** are significant ($P \leq 0.01$); * Significant ($P \leq 0.05$); ^{ns} Not significant by F test.

The effect of S on plant height (Figure 1) is best described by the quadratic regression model for soil 1. Increasing doses of S were observed to increase plant growth up to 40 kg ha^{-1}, with a maximum height of 89 cm. In contrast, at doses above 50 kg ha^{-1} of S, the plants did not have a good response to the growth stimulus of the apical part, with reduction in plant height.

This fact may have occurred because soil 1 has lower levels of organic matter; so that low levels of organic matter associated with compacted soil layers or sub-surface aluminum toxicity make the sulfur sulfate not accessible to the root system of plants and may even be deficient in the most demanding crops (Chao, Harward, & Fang, 1962).

The soil flooding for rice cultivation triggers a series of electrochemical changes that interfere with the availability of nutrients, causing the reduction of sulfate to sulfide in the nutritional dynamics of S (Assis, 2000), which may cause S deficiency, due to losses by H^2S volatilization, and consequently affecting plant growth (Carmona, Conte, & Fraga, 2009).

The volatilization losses are more accentuated in clayey soils, which when used for irrigated rice cultivation, even if superficially drained, can maintain a subsurface layer in the anaerobic state, causing volatilization and loss of S (Jordan & Ensminger, 1958). With lower nutrient contents in the deeper layers, can explain the lower growth of the plants in soil 1 compared in soil 2.

In addition, the sufficiency level of S currently considered is 10 mg dm^{-3} of S SO_4^{2-} for demanding crops, and of 5mg dm^{-3} of S-SO_4^{2-} for the other crop groups (CQFS, 2004). However, there are few reports of experiments with sulfated fertilization in the State of Tocantins, which requires studies that can establish a critical range for the soils of the region, directing the producers to increase their yields.

For soil 2, there was an increasing response at plant height with increasing S dose, with plants varying from 91 to 94 cm in height at 0 and 60 kg ha^{-1}, respectively. These results confirm that when the soil presents a higher content of clay and organic matter, sulfate fertilization tends to be adsorbed by the colloids of the clay, increasing the availability of the nutrient to the plants (Ensminger, 1954; Peak, Ford, & Sparks, 1999). It is expected that, heavy sulphate fertilizations on soils under these conditions will not cause a reduction in the height of rice plants grown in flooded soils. The non-reduction in plant height and the low amplitude of oscillation of the values found are interesting factors for the producers who perform the mechanized harvest, since the uniformity in the height of plants can reduce losses caused in the harvester's winch.

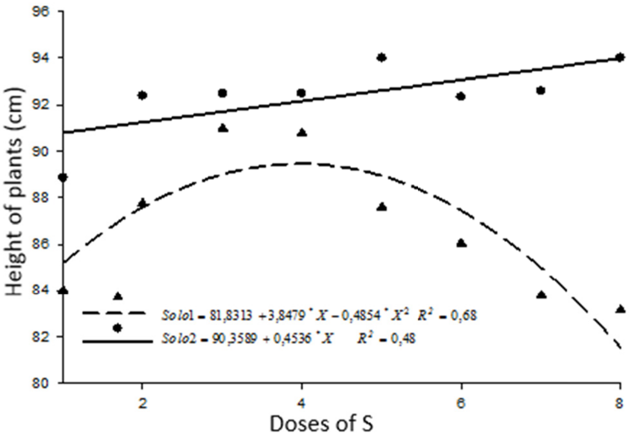

Figure 1. Plant height (cm) in two types of irrigated lowland soils under different doses of sulfur fertilization, in Formoso do Araguaia-Tocantins, Brazil

As for the number of panicles per square meter (Figure 2), it was observed that there was an increase in the number of panicles per square meter as the doses of S were increased, these doses are within what is indicated, that is soils with low organic matter or with generalized use of concentrated fertilizers, the application of 20 to 30 kg ha^{-1} of S. is suggested (Ribeiro, Guimarães, & Alvarez, 1999).

However, the number of panicles obtained when the culture was conducted in soil with higher clay content (soil 2) did not show the same behavior, generating a curve of better fit in the quadratic model. Thus, it is observed higher values in the number of panicles between the doses of 40 and 50 kg of S. However, with the increase of the dose of S over 60 kg ha^{-1} it can possibly intoxicate the plants diminishing their absorption and causing abortion of flowers in the flowering stage, reducing the number of panicles per square meter of 300 panicles m^2 at the dose of 50 kg ha^{-1} to 200 panicles m^2 at the maximum tested dose of 80 kg ha^{-1}.

The rice has a mechanism of protection of the rhizosphere to soften the effect of the toxicity of the elements in their reduced forms. It consists of the ability to oxidize the rhizosphere region, where during oxidative phosphorylation reactions, oxygen is enzymatically reduced, forming a water molecule in plant cells. The root supply can be made via soil or via the plant through air conducting tissues, called aerenquim, and oxidation of the elements in the reduced layer can occurs (Camargo, Santos, & Zonta, 1999).

However, the organic matter content in the soil directly influences the oxidation energy, because the increase of the organic matter favors the reduction, by the supply of electrons in the reactions, reducing the oxidation energy in the rhizosphere and facilitating the action of toxicity, which causes consequently, nutritional disorder (Camargo, Santos, & Zonta, 1999).

Thus, soil 2 containing a greater amount of organic matter facilitates the toxicity, causing a decrease in the number of panicles, but not significantly affecting the final yield of the rice.

These results disagree with those found by Mielniczuk, Rheinheimer, and Vezzani (2000) that studying the effect of nitrogen fertilization on rice cultivars in the irrigated floodplain, found a positive relationship between Nitrogen doses and number of panicles per square meter.

Therefore, M. L. S. Silva, M. A. D. Silva, and Trevizam (2017) emphasize the importance of the interaction of N and S in the fertilization recommendations, since N metabolism is strongly affected by the concentration of S in the plant. Much of the N in plants is in the form of proteins being the S constituent of two essential amino acids, cysteine and methionine. In the case of S deficiency, there will be a decrease in the production of these amino acids, inhibiting protein synthesis, consequently the plants have a lower content of chlorophyll and less developed roots.

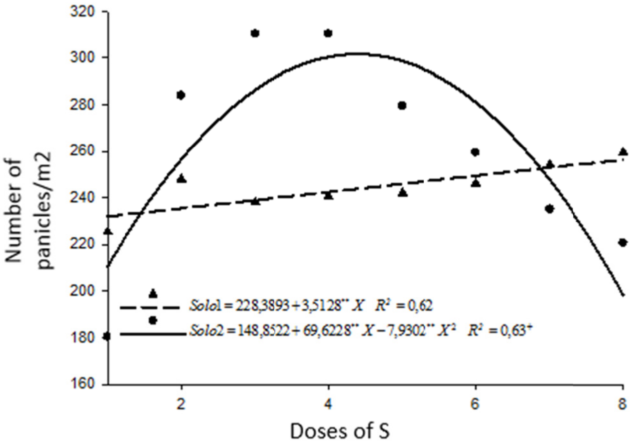

Figure 2. Number of panicles per square meter in two types of irrigated floodplain soils under different doses of sulfur fertilization, in Formoso do Araguaia- Tocantins, Brazil

The grain yield (Figure 3) was better expressed by the linear regression model in both soils. However, in soil 1, a reduction in grain yield was observed, as the S doses increased. The reduction in productivity is significant when compared to the application of S in the same dose in soil 2, about 15, 91% less. However, even with this reduction, it can be observed that the minimum productivity found in this experiment can be compared to the national average for irrigated rice cultivation, which is around 7,337 kg ha^{-1} (CONAB, 2018).

Based on these results, it can be inferred that sulfated fertilizers do not guarantee increase of rice yield in soils with low clay and organic matter, under floodplain conditions, since the control produced more than the other treatments tested. However, Osório Filho, Rheinheimer, Kaminski, and Dias (2007) point out that there is no specific condition that determines crop response to S additions, but there are circumstances where soils may be less available and have favorable results for S fertilization, and these should be considered.

In this context, several authors found a positive response between sulfate fertilization in different soil conditions, and in soils with low levels of organic matter and clay, the best responses of sulfated fertilization (Goepfert & Kussow, 1971; Anghinoni, Fiorese, & Moraes, 1976; Nascimento & Morelli, 1980; Wolffenbüttel & Tedesco, 1981; Bissani, 1985). However, the main difference and the possible attenuator for divergence of the results found in this work with those mentioned above may be related to the fact that the soil is in an anaerobic condition.

The results obtained in this work show that no positive responses were obtained with soybean fertilization for two years in the clay latosol. Alvarez (2004) also did not observe a response to the same crop vegetation and in the field under sandy Argissolo soil.

In soil 2 a positive correlation was obtained between grain yield and S doses, showing that the maximum nutrient absorption point has not yet been found by the plants, which can increase yields and obtain satisfactory results in terms of productivity. The averages varied from 8000 kg ha^{-1} to 8800 kg ha^{-1} between the 0-60 kg ha^{-1} doses of S, respectively. Neves, Buzetti, Arf, and Sá (2004) verified that the treatments that received nitrogen coverage produced more than 4,000 kg ha^{-1} of grains, which shows the importance of this practice in rice cultivation, to obtain high productivity.

It is again noted that the clay content of the soil influences the availability of S within the reach of the roots of rice plants. The clay soil has a higher retention capacity of S-SO_4^{2-}, since they have high levels of Fe oxides, making slower movement of the nutrient in the soil profile (Camargo, Santos, & Zonta, 1999), facilitating the production of a larger amount since under these conditions, plants can more easily resist the nutritional adversities of the irrigated rice production period.

Moreover, part of the S exported via the plant can be replaced naturally by the soil, through the mineralization of the organic matter, since about 90% of the S of the soil are present in this compound (Kliemann & Malavolta, 1993), which justifies that the soil 2 present higher production, since it has higher organic matter content in relation to soil 1.

Thus, it is evident that S is also a macronutrient that needs to be better studied to allow the necessary increments of irrigated rice productivity, mainly because S is an essential nutrient to plants, since it participates in the formation of several organic molecules, such as the amino acids cysteine, cystine and methionine, which make up most of the proteins, vitamins biotin and thiamine, coenzyme A, among others (Larbier & Leclercq, 1992).

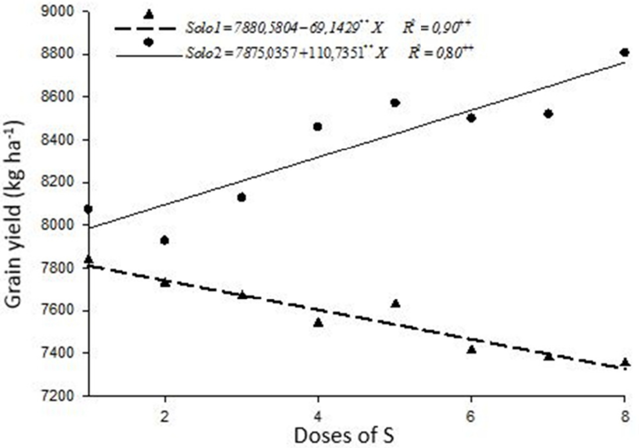

Figure 3. Grain productivity in two types of irrigated floodplain under different doses of sulfur fertilizer in Formoso Araguaia Tocantins, Brazil

4. Conclusion

Sulphated fertilizations on soils with higher clay content and organic matter tend to produce higher plants and increase productivity.

S fertilization in irrigated rice cultivation in soils with low organic matter and clay does not respond positively to plant productivity and height.

The dynamics of sulfur fertilization in lowlan soils requires further studies to direct rice producers to make efficient fertilization.

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