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3 Bolsista de Doutorado Sanduíche no Exterior do CNPq

4 Bolsista de Graduação Sanduíche no Exterior do CNPq

5 Bolsista de Doutorado da CAPES

6 Bolsista de Produtividade em Pesquisa do CNPq

Productivity and agronomic efficiency of cotton plants in response to nitrogen and sulfur supply

ABSTRACT

The Brazilian Savanna (Cerrado) ecosystem concentrates most of the area under cotton cultivation in the country, and is characterized, predominantly, by low fertility soils. Nitrogen (N) is the most extracted nutrient from the soil by most crops, while sulfur (S) fertilization has been little explored in studies with cotton plants. This study aimed to evaluate the effects of N and S fertilization on the N content of leaf, weight of 30 bolls, productivity, and agronomic efficiency of cotton plants grown in an Oxisol from the Brazilian Cerrado region. Two independent field experiments were carried out simultaneously in a completely randomized block design with four replications. The first experiment was composed of five levels of N (17, 100, 150, 200 and 250 kg ha⁻¹) and the second with five levels of S (24, 50, 75, 100 and 125 kg ha⁻¹). The leaf N content of the cotton plants increased linearly with the supply of up to 250 kg ha⁻¹ of N in the soil. The weight of 30 bolls and the seed-cotton productivity were considerably increased with the increase of the N and S levels in the soil. The maximum agronomic efficiency of the N and S fertilization was obtained with the application of 150 and 100 kg ha⁻¹ of N and S, respectively. Therefore, this study clearly showed the positive effects of the adequate fertilization of N and S on the productivity of cotton in soils from the Brazilian Cerrado region.

Key words: boll, fertilization, *Gossypium hirsutum*, leaf content, low fertility soil

Produtividade e eficiência agrônômica do algodoeiro em resposta ao suprimento de nitrogênio e enxofre

RESUMO

A região de Cerrado do Brasil, onde se concentra a maior parte da área de algodão plantada no País, possui, predominantemente, solos de baixa fertilidade. O nitrogênio (N) é o nutriente mais extraído do solo pela maioria das culturas enquanto a adubação com enxofre (S) tem sido pouco explorada em estudos com algodoeiro. O objetivo deste estudo foi avaliar os efeitos da adubação nitrogenada e sulfatada sobre o teor foliar de nitrogênio, peso de 30 capulhos, produtividade e eficiência agrônômica, em algodoeiro cultivado em um Latossolo da região de Cerrado Brasileiro. Dois experimentos de campo, independentes, foram conduzidos simultaneamente em delineamento em blocos completos casualizados, com quatro repetições, em que o primeiro experimento foi composto por cinco níveis de N (17, 100, 150, 200 e 250 kg ha⁻¹) e o segundo por cinco níveis de S (24, 50, 75, 100 e 125 kg ha⁻¹). O teor de N nas folhas do algodoeiro aumentou de forma linear com o fornecimento de até 250 kg ha⁻¹ de N no solo. O peso de 30 capulhos e a produtividade de algodão em caroço foram incrementados consideravelmente com o acréscimo dos níveis de N e S no solo. A máxima eficiência agrônômica das adubações nitrogenada e sulfatada foi obtida com a aplicação de 150 e 100 kg ha⁻¹ de N e S, respectivamente. Este estudo mostrou claramente os efeitos positivos da fertilização adequada de N e S sobre a produtividade do algodoeiro em solos da região de Cerrado do Brasil.

Palavras-chave: capulho, fertilização, *Gossypium hirsutum*, teor foliar, solo de baixa fertilidade

Introduction

The cotton (*Gossypium hirsutum* L.) is considered one of the main crops cultivated in the world, occupying a position of prominence from a social and economical point of view (Wilkins & Bulak Arpat, 2005; Benbouza et al., 2010). In Brazil, the harvested area of herbaceous cotton in 2009 was of 807,876 ha with an average production of 2,928.205 t ha⁻¹ of seed-cotton. Currently, cotton is the most profitable crop in Brazil, surpassing the soybean, with which it competes for planted area (Agrianual, 2011).

Among the factors that influence the growth and production of cotton in tropical and subtropical regions of the world, mineral nutrition has received special attention (Rochester, 2010; Serra et al., 2010; Dechorgnat et al., 2011). In Brazil, for instance, more than 90% of the cultivated area with cotton plant is located in the Savanna (Cerrado) ecosystem, where low-fertility Oxisols prevail (Ferreira et al., 2010). Thus, in those areas, most of the cotton producers recognize the need for an adequate program of soil fertilization to reach the productivity goals (Carvalho et al., 2001).

Nitrogen (N) is the nutrient most extracted from the soil by most of the crops (Megda et al., 2009; Hurtado et al., 2010). In most soils where cotton plant is cultivated, N is the main limiting factor for seed-cotton productivity. This nutrient, when supplied at appropriate levels, stimulates growth and flowering, regularizes the cycle of the cotton plant, increases productivity and improves the fiber length and resistance (Staut & Kurihara, 2001). Thus, adequate N fertilization has been promoting yield gains for the crop (Dong et al., 2010; Rosolem & Van Mellis, 2010).

Sulfur (S) is one of the macronutrients required in a lesser amount for most crops. For that and other reasons, differently from N, sulfur fertilization has been little explored in relation to other nutrients, inspite of its importance as a plant nutrient (Rheinheimer et al., 2007). However, the intensive cultivation of soils with low levels of organic matter, as for instance, the soils of the Brazilian Cerrado region, and in addition to the use of NPK fertilizers, poor in S can lead to the reduction of the availability of that nutrient for the plants, resulting in the decrease in crop production (Fernandes et al., 2007; Osório Filho et al., 2007; Rezende et al., 2009). The cotton plant requires a continuous S supply during its growth cycle and, low fertility soils, respond well to the application of that nutrient (Silva et al., 1981; Staut & Kurihara, 2001). Therefore, investigations of S fertilization in low fertility soils are of great importance for the seed-cotton crop.

This study aimed to evaluate the effects of N and S fertilization on the leaf N content, weight of 30 bolls, productivity and agronomic efficiency of cotton plants grown in a soil in the Brazilian Cerrado region.

Material and Methods

The study was carried out at the “Fundação Chapadão” experimental area (18°46'47" S, 52°38'40" W, 816 m asl), located in the municipal district of Chapadão do Sul-MS, Brazil, in a soil whose characteristics are described in Table 1. On August 2002, 500 kg ha⁻¹ of rock phosphate (Gafsa) were applied on the soil surface, and a month later, on September 2002, 1,600 kg ha⁻¹ of dolomitic lime were incorporated in a depth of 0-20 cm. Two independent field experiments were carried out simultaneously in a completely randomized block design, with four replications.

The first experiment was composed of five levels of N (17, 100, 150, 200 and 250 kg ha⁻¹) supplied as urea (Table 2). The cotton seeds were sown on December 28, 2002, together with 340 kg ha⁻¹ of NPK fertilizer (5, 20 e 15% of N, P₂O₅ and K₂O, respectively) applied as basal dressing. During the conduction of the experiment two fertilizations as top dressing were made (30 and 50 days after emergence), and in each fertilization 55 and 40 kg ha⁻¹ of K₂O and S were supplied, respectively, together with the application of the N treatments. As K₂O and S sources, KCl and Sulfurgran (95% S) were used, respectively. At the flowering stage of cotton, the fifth totally expanded leaf from the apex of the main stem was sampled, for determination of the leaf N content (Malavolta et al., 1997).

Table 2. Levels of N applied in the soil during the study period

Tabela 2. Níveis de N aplicados no solo durante o período estudado

N applied as basal dressing (kg ha ⁻¹)	N applied as top dressing (kg ha ⁻¹)		Applied total N (kg ha ⁻¹)
	30 DAE	50 DAE	
17	0	0	17
17	41.5	41.5	100
17	66.5	66.5	150
17	91.5	91.5	200
17	116.5	116.5	250

The second experiment was composed of five levels of S (24, 50, 75, 100 and 125 kg ha⁻¹), as described in Table 3. The cotton seeds were sown on December 27, 2002, together with 340 kg ha⁻¹ of NPK fertilizer (5, 20 e 15% of N, P₂O₅ and K₂O, respectively, and containing 6.5% of S) applied as basal dressing. During the conduction of the experiment two fertilizations as top dressing were made (30 and 50 days after plant emergence), and in each fertilization 55 kg ha⁻¹ of N and K₂O were supplied. As K₂O source KCl was used and combinations of urea and ammonium sulfate were made to supply the same dose of N and to vary only the dose of S among the treatments.

For both experiments, each experimental plot was made up of eight lines of 15 m, spaced at 0.9 m. The evaluations

Table 1. Soil chemical and physical composition (0-15 cm depth)

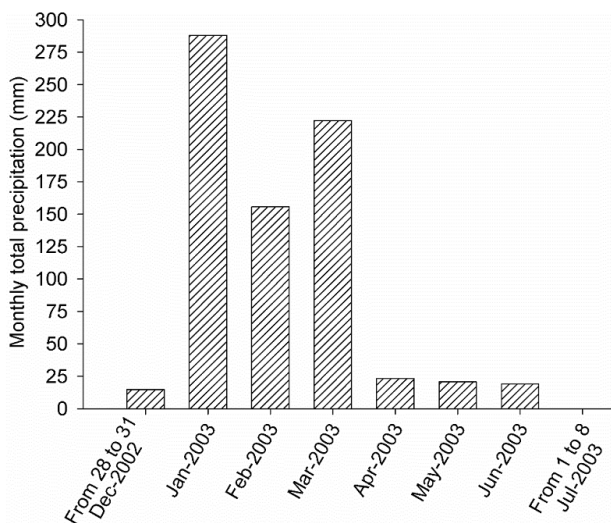
Tabela 1. Composição química e física do solo (profundidade de 0-15 cm)

Soil chemical composition														Soil physical composition			
pH _{water}	P _(Mehlich-1)	K	Zn	Cu	Mn	Fe	Ca	Mg	Al	H+Al	T	m	V	OM	Sand	Silt	Clay
	(mg dm ⁻³ of soil)							(cmol _c dm ⁻³ of soil)				(%)		(g kg ⁻¹)		(%)	
5.9	6.7	70.2	4.7	0.7	5.4	34.0	2.1	0.7	0.01	4.9	7.9	0.5	38	43.9	60	17	23

Table 3. Levels of S applied in the soil during the study period**Tabela 3.** Níveis de S aplicados no solo durante o período estudado

S applied as basal dressing (kg ha ⁻¹)	S applied as top dressing (kg ha ⁻¹)		Applied total S (kg ha ⁻¹)
	30 DAE	50 DAE	
24	0.0	0.0	24
24	13.0	13.0	50
24	25.5	25.5	75
24	38.0	38.0	100
24	50.5	50.5	125

were conducted in the plants of the two central rows (useful plot area), discarding 2 m of each extremity (border). Figure 1 shows the monthly precipitation occurred during the conduction of the experiments.

**Figure 1.** Monthly total precipitation at the experiment site during the study period**Figura 1.** Precipitação mensal total ocorrida na área experimental durante o período de estudo

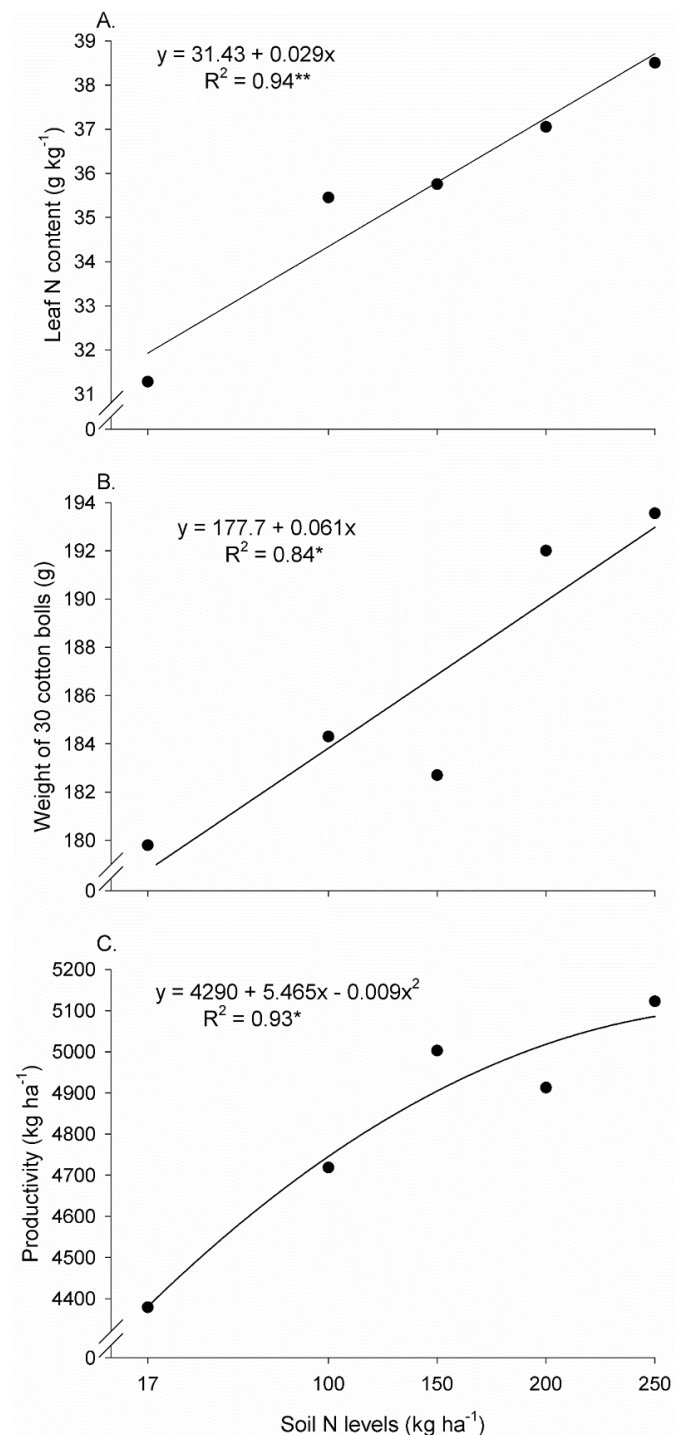
Crop harvest of both experiments was carried out on July 8, 2003. On that occasion the weight of 30 bolls from the medium third part of the plant and the seed-cotton productivity were evaluated, and the agronomic efficiency (EA) of N and S fertilization in the cotton plants was calculated according to the equation (Fageria, 1998): $EA = [(production\ for\ a\ determined\ applied\ nutrient\ level) - (production\ for\ the\ lowest\ nutrient\ level)] / [applied\ nutrient\ level]$.

The data were submitted to variance analysis according to the procedures of the SISVAR 4.3 software (Ferreira, 2003). The effects of the N e S levels on the variables were verified by polynomial regression analysis. The Pearson's coefficient of correlation between the leaf N content and the seed-cotton production was obtained through the SAEG version 9.1 software (Fundação Arthur Bernardes, 2007).

Results and Discussion

Experiment 1: nitrogen fertilization

The nitrogen levels (N) applied to the soil influenced the leaf N content ($p \leq 0.01$), weight of 30 bolls ($p \leq 0.05$) and productivity ($p \leq 0.05$) of the cotton plants (Figure 2).



* and ** Significant at 5% and 1% level of probability, respectively

Figure 2. Leaf N content (A), weight of 30 cotton bolls (B) and seed-cotton productivity (C) in cotton crops grown under different soil N levels**Figura 2.** Concentração de N na folha, peso de 30 capulhos e produtividade de algodão em caroço em algodoeiro cultivado sob diferentes níveis de N

The leaf N content increased linearly with the elevation of the N levels in the soil, and the values observed varied between 31.28 and 38.50 g kg⁻¹, representing an increase of 23% between the treatments of 17 and 250 kg ha⁻¹ of N in the soil. According to the estimate of the regression equation, for each unit (in kg ha⁻¹) of N supplied in the soil, there was an increase of 0.029 g kg⁻¹ in the leaf N content (Figure 2A).

The nitrate and the ammonium are the main soil N forms absorbed by plants. When the nitrate is abundant in the soil, N uptake by roots occurs in larger amounts than the current plant need, and is known as luxury consumption, being the N excess largely stored in the vacuoles. The accumulated N in vacuoles, besides being a reserve of the nutrient for the plant in case of soil deficiency, has important function in the osmoregulation (Marschner, 1995; Van der Leij, 1998). Rosolem & Van Mellis (2010) found increases in the N content of leaf in cotton plants with the elevation of the N levels in the soil, corroborating with this work. Carvalho et al. (2001) related that foliar spray of N increased the leaf N content in cotton plants. The positive effect of N fertilization on leaf N content has also been described for other crops (Megda et al., 2009; Ávila et al., 2010; Soratto et al., 2011).

In the present study, it can be highlighted that the soil N levels inferior and superior to 123 kg ha⁻¹ resulted in ranges of leaf N content considered by Staut & Kurihara (2001), respectively, as low (< 35 g kg⁻¹) and adequate (35-43 g kg⁻¹) for cotton plant leaf in flowering stage. However, the range of leaf N content considered adequate for the cotton plant varies in function of the age of leaf and sampling time, besides other external factors that also affect the leaf content of a given nutrient (Faquin, 2005; Rosolem & Van Mellis, 2010).

As for the leaf N content, the weight of 30 bolls also increased linearly in function of the soil N levels. The values observed for that variable varied between 179.80 and 193.55 g, representing a slight increase of 7.6% between the treatments of 17 and 250 kg ha⁻¹ of N. According to the regression equation estimates, for each unit (in kg ha⁻¹) of N supplied in the soil, there was an increase of 0.061 g in the weight of 30 bolls (Figure 2B). The weight of a boll is an indirect measure of the cotton boll size. Other studies also relate increases in the weight of cotton boll with the addition of N in the soil (Silva et al., 1974; Sabino et al., 1994; Wiatrak et al., 2005). However, the foliar application of the nutrient seems not to exercise an effect on that variable (Carvalho et al., 2001).

The seed-cotton production increased with the N application in the soil, presenting a quadratic adjustment (Figure 2C). The observed productivity values varied between 4378.5 and 5122.5 kg ha⁻¹. Thus, the elevation of the soil N levels increased the leaf N content of cotton plants (Figure 2A), that in turn provided the highest seed-cotton productivity. In addition, studies of the Pearson's coefficient of correlation showed that there was a strong positive correlation ($r = 0.9$) between leaf N content and seed-cotton productivity. The productivity increase in function of N added in the soil is due to the high participation of that nutrient in the production of plant dry matter (Marschner, 1995; Faquin, 2005). Teixeira et al. (2008) found increases of seed-cotton production with the elevation of the N levels in an Oxisol, the highest productivity (3633 kg ha⁻¹) was obtained with the supply of 131 kg ha⁻¹ of N. Furlani Júnior et al. (2003), in studies with cotton crop in several regions of São Paulo State (Brazil), found increase of seed-cotton productivity with the increase in N fertilization as top dressing from 40 to 60 kg ha⁻¹. Carvalho et al. (2001) observed that foliar spraying of N elevated the seed-cotton productivity. The positive effect of the N fertilization on the

productivity of cotton plants has also been reported in other regions of the world (Wiatrak et al., 2005; Dong et al., 2010).

The agronomic efficiency has frequently been used to demonstrate the amount of grain produced per unit of nutrient applied in the soil. Analyzing the observed values, although the highest productivity (5,122.5 kg ha⁻¹) was found at the highest soil N level (250 kg ha⁻¹), the agronomic efficiency was higher at the N level of 150 kg ha⁻¹, when a seed-cotton productivity of 5,002.5 kg ha⁻¹ was obtained. Carvalho et al. (2003), evaluating the effect of N levels in cotton crop cultivated on brachiaria residues, reported 175 kg ha⁻¹ as the N level that provided the maximum economical productivity. However, it must be highlighted that the efficiency of the N fertilization under field conditions is dependent on several factors as, for instance, the cultivar and N source used, soil type, management adopted, and climatic conditions of the study area.

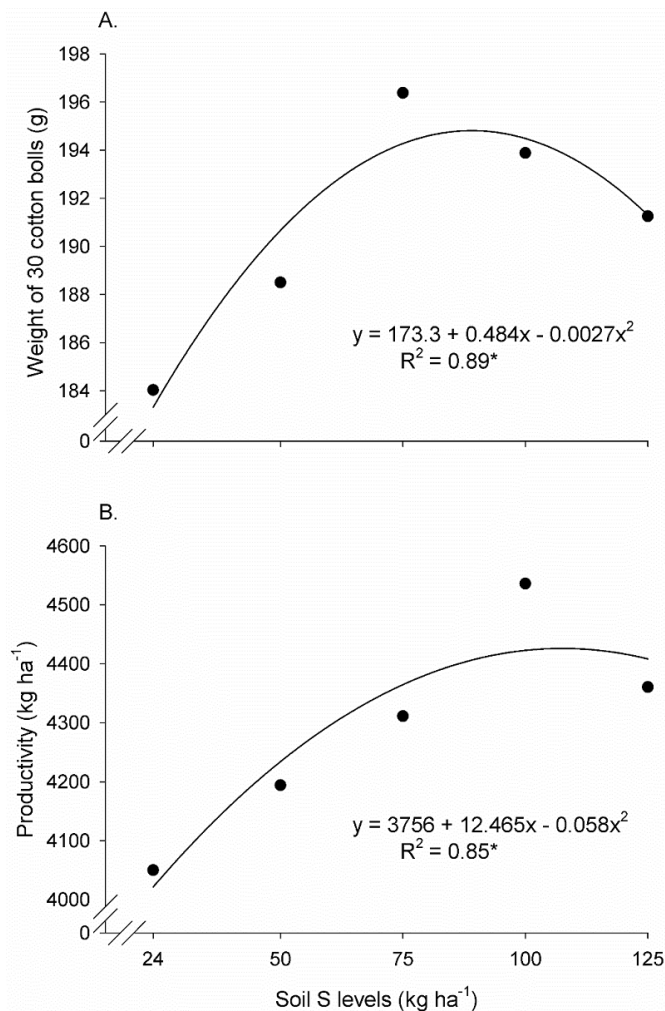
The urea, N source used in this work, was selected because is the most economically viable N fertilizer and, in the majority of the cases, has been the most used source of N in Brazil and in a large part of the world. On the other hand, the inadequate management of the urea has been causing high rates of N loss through volatilization, resulting in low efficiency of the N fertilization. Currently, this efficiency is only around 30% (Jayasundara et al., 2007).

Experiment 2: sulfur fertilization

The levels of sulfur (S) applied to the soil significantly influenced the weight of 30 bolls ($p \leq 0.05$) and the productivity ($p \leq 0.05$) of cotton crops (Figure 3).

The weight of 30 bolls had a quadratic adjustment in relation to the doses of S in the soil. According to the regression equation estimates, the minimum (183.4 g) and maximum (195 g) value of that variable was obtained at the levels of 24 and 89.6 kg ha⁻¹ of S, respectively (Figure 3A). Studies that related the effect of the sulfur fertilization on the weight of cotton bolls are restricted. Sabino & Silva (1984) did not find considerable differences in the weight of cotton bolls in plants fertilized with triple superphosphate (phosphorus source without S) or with simple superphosphate (phosphorus source with 12% S), in disagreement with the present work.

The seed-cotton production increased with the application of the S levels in the soil, presenting a quadratic adjustment. The highest productivity was observed at the level of 100 kg ha⁻¹ of S. However, analysing the estimated regression equation within the intervals of the studied S levels (24-125 kg ha⁻¹), the minimum (4,021.75 kg ha⁻¹) and maximum (4,425.7 kg ha⁻¹) value of that variable was obtained with the application of 24 and 107.5 kg ha⁻¹ of S, respectively (Figure 3B). Therefore, this work clearly shows the positive effects of the adequate S supply on the productivity of cotton crop grown in low fertility soils. In the Brazilian Cerrado region, where more than 90% of the cotton cultivated area is concentrated (Ferreira et al., 2010), more than 70% of the soils present problems of S deficiency (Malavolta & Kliemann, 1985). In addition, corroborating with this work, Staut & Kurihara (2001) related that the cotton crop requires a continuous S supply. Other studies have also been shown the responses of other crops to sulfur fertilization (Domingues et al., 2004; Fernandes et al., 2007; Rezende et



* Significant at 5% level of probability

Figure 3. Weight of 30 cotton bolls (A) and seed-cotton productivity (B) in cotton crop grown under different soil S levels

Figura 3. Peso de 30 capulhos e produtividade de algodão em caroço em algodoeiro cultivado sob diferentes níveis de N

al., 2009), and that those responses can vary in function of the plant species (Osório Filho et al., 2007; Rheinheimer et al., 2007).

Analysing the data observed for the seed-cotton productivity in function of the S levels applied to the soil, the agronomic efficiency of the sulfur fertilization was higher at the S level of 100 kg ha⁻¹. That result is quite meaningful, because 100 kg ha⁻¹ is well above the average S dose recommended for cotton crop (Staut & Kurihara (2001). Studies that report agronomic efficiency of the S fertilization under field conditions are limited for the cotton crop. On the other hand, as for the N fertilization, the agronomic efficiency of the sulfur fertilization under field conditions is dependent on several factors, such as the cultivar used, soil type and management adopted, and climatic conditions of the area.

CONCLUSIONS

The leaf N content of the cotton crop increases linearly with the supply of up to 250 kg ha⁻¹ of N in the soil.

The cotton crop cultivated in low fertility soil respond satisfactorily to adequate application of N and S.

The maximum agronomic efficiency of N and S fertilization in cotton crop grown in the Brazilian Cerrado region was obtained with the application of 150 and 100 kg ha⁻¹ of N and S, respectively.

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