COINTER PDVAgro 2022
VII INTERNATIONAL CONGRESS OF AGRICULTURAL SCIENCES
100% virtual edition | 29, 30 Nov to 1 Dec
ISSN: 2526-7701 | PREFIXO DOI: 10.31692/2526-7701

ACUMULAÇÃO E DISTRIBUIÇÃO DE ENXOFRE EM PLANTAS DE FEIJÃO-CAUPI SOB DÉFICIT HÍDRICO AFETADO PELA SUPLEMENTAÇÃO DE ENXOFRE

ACUMULACIÓN Y DISTRIBUCIÓN DE AZUFRE EN PLANTAS DE COWPEA BAJO DÉFICIT HÍDRICO AFECTADAS POR LA SUPLEMENTACIÓN DE AZUFRE

SULFUR ACCUMULATION AND DISTRIBUTION IN COWPEA PLANTS UNDER WATER DEFICIT AS AFFECTED BY SULFUR SUPPLEMENTATION

Apresentação: Comunicação Oral

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DOI: https://doi.org/10.31692/2526-7701.VIICOINTERPDVAgro.0072

RESUMO

O feijão-caupi é uma cultura que se destaca pelo alto valor proteico, baixo custo de produção e grande importância socioeconômica para os núcleos familiares das regiões Norte e Nordeste do Brasil. Apesar da sua capacidade de tolerância à seca, ainda sofre com a baixa disponibilidade hídrica em seu cultivo, sendo um dos fatores limitantes para expressão do potencial produtivo da cultura. Alguns estudos reportam estratégias de cultivo e/ou métodos capazes de intensificar a defesa em plantas, a fim de amenizar os efeitos deletérios do déficit hídrico. Nesse contexto, a suplementação com enxofre (S) surge como uma alternativa para auxiliar as plantas nesse processo. O presente estudo teve como objetivo investigar a incorporação do enxofre nos tecidos das plantas e no solo após adubação com diferentes doses de S como tentativa de induzir a tolerância ao déficit hídrico em plantas de feijão-caupi [*Vigna unguiculata* (L.) Walp.]. Os experimentos foram conduzidos em dois ambientes de cultivo, casa de vegetação e campo experimental, utilizando duas cultivares de feijão-caupi (Xique-xique e Novaera) submetidas a dois níveis hídricos [controle (75% da capacidade de campo - CC) e estresse hídrico (45% CC)] e três doses de S (S-40, S-80 e S-120 kg ha^{-1}). O estresse foi aplicado quando as plantas atingiram o estágio V4 , com duração de 21 dias em casa de vegetação e 28 dias no campo, e as coletas foram realizadas no final do estádio vegetativo. Plantas crescidas em casa de vegetação mostraram maiores valores absolutos de S nas folhas, caules e parte aérea quando comparadas àquelas cultivadas no campo.

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Além disso, a suplementação com S nas doses S-80 e S-120 no solo promoveu incrementos no acúmulo de S em todos os tecidos das plantas cultivadas em casa de vegetação, em comparação a dose S-40, exceto para o caule do genótipo Novaera. No campo, incrementos no acúmulo de S pela suplementação S-80 e S-120 foram registrados apenas nas folhas e parte aérea das plantas Novaera estressadas e no caule da cultivar Xique-xique sob estresse. No solo, houve maior acúmulo de S quando o nutriente foi suprido nas maiores doses, mas apenas nos experimentos em casa de vegetação, ao passo que não houve essa repostas no solo do campo. Os dados demostraram claramente que o acúmulo e distribuição de S são regulados diferencialmente nos tecidos das plantas e no solo a depender do ambiente de cultivo e da suplementação com S.

Palavras-Chave: Ambiente de cultivo, déficit hídrico, dinâmica nutricional, suplementação com enxofre, Vigna unguiculata (L.) Walp.

RESUMEN

El caupí es un cultivo que se destaca por su alto valor proteico, bajo costo de producción y gran importancia socioeconómica para los hogares de las regiones Norte y Nordeste de Brasil. A pesar de su capacidad para tolerar la sequía, aún sufre de baja disponibilidad de agua en su cultivo, lo cual es uno de los factores limitantes para la expresión del potencial productivo del cultivo. Algunos estudios reportan estrategias de cultivo y/o métodos capaces de intensificar las defensas de las plantas para mitigar los efectos deletéreos del déficit hídrico. En este contexto, la suplementación con azufre (S) aparece como una alternativa para ayudar a las plantas en este proceso. El presente estudio tuvo como objetivo investigar la incorporación de azufre en los tejidos vegetales y el suelo después de la fertilización con diferentes dosis de S en un intento de inducir tolerancia al déficit hídrico en el caupí [Vigna unguiculata (L.) Walp.]. Los experimentos se realizaron en dos ambientes de cultivo, invernadero y campo experimental, utilizando dos cultivares de caupí (Xique-xique y Novaera) sometidos a dos niveles de agua [testigo (75% de capacidad de campo - CC) y estrés hídrico (45% CC)] y tres dosis de S (S-40, S-80 y S-120 kg ha-1). El estrés se aplicó cuando las plantas alcanzaron la etapa V4, con una duración de 21 días en invernadero y 28 días en campo, y las colectas se realizaron al final de la etapa vegetativa. Las plantas cultivadas en invernadero mostraron mayores valores absolutos de S en hojas, tallos y brotes en comparación con las cultivadas en campo. Além disso, a suplementação com S nas doses S-80 e S-120 no solo promoveu incrementos no acúmulo de S em todos os tecidos das plantas cultivadas em casa de vegetação, em comparação a dose S-40, exceto para o caule do genótipo Nueva era. En el campo, los incrementos en la acumulación de S por la suplementación con S-80 y S-120 se registraron solo en las hojas y brotes de las plantas Novaera estresadas y en el tallo del cultivar Xique-xique estresado. En el suelo hubo una mayor acumulación de S cuando el nutriente se suministró en las dosis más altas, pero solo en los experimentos de invernadero, mientras que en el suelo de campo no hubo tal respuesta. Los datos mostraron claramente que la acumulación y distribución de S están reguladas de manera diferente en los tejidos de las plantas y el suelo dependiendo del ambiente de cultivo y la suplementación de S.

Palabras clave: Ambiente de cultivo, déficit hídrico, dinámica nutricional, suplementación de azufre, Vigna unguiculata (L.) Walp

ABSTRACT

Cowpea is a crop that presents high protein value, low production cost and great socioeconomic importance in the world, especially in the North and Northeast regions of Brazil. Despite its ability to tolerate drought, it still suffers from low water availability during the vegetative and reproductive cycles, constituting the main factor for the expression of the crop's productive potential. Some studies have employed cultivation strategies and/or methods capable of intensifying plant defense to mitigate the deleterious effects of water deficit. In this context, sulfur (S) supplementation has emerged as an alternative to help plants in this process. The present study aimed to investigate the incorporation of sulfur into plant tissues and soil after fertilization with different doses of S in an attempt to induce tolerance to water deficit in cowpea [*Vigna unguiculata* (L.) Walp]. The experiments were carried out in two growing environments, a greenhouse and an experimental field, using two cowpea cultivars (Xique-xique and Novaera) subjected to two water levels [control (75% of field capacity - FC) and stress water (45% FC)] and three doses of S (S-40, S-80 and S-120 kg ha^{-1}). Stress was applied when the plants reached the V4 stage, lasting 21 days in a greenhouse and 28 days in the field, and harvests were performed at the end of the vegetative stage. Plants grown in a greenhouse showed absolute S values in leaves, stems and shoots higher than those of plants grown in the field. In addition, supplementation with S at doses S-80 and S-120 in the soil promoted increments in the accumulation of S in all tissues of plants grown in the greenhouse compared to the S-40 dose, except for the stem of the Novaera cultivar. In the field, increments in S accumulation by S-80 and S-120 supplementation were observed only in the leaves and shoots of stressed Novaera plants and in the stem of the stressed Xique-xique cultivar. In the soil, there was a greater accumulation of S when the nutrient was supplied at the highest doses, but only in the greenhouse experiments, while there was no such response in the field soil. The data clearly showed that S accumulation and distribution are differentially regulated in plant tissues and soil depending on the cultivation environment and S supplementation.

Keywords: Cultivation environment, water deficit, nutritional dynamics, sulfur supplementation, *Vigna unguiculata* (L.) Walp

INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp.] is a legume of great relevance in several countries due to its versatility and appreciable nutritional composition, linked to low demand for soil fertility and tolerance to high temperatures and drought, allowing it to be cultivated in tropical regions under rainfed conditions (RAMOS et al., 2015).

In Brazil, the Northeast region has the highest percentage of cultivated area, playing an important socioeconomic role because it is the main source of protein, especially for the rural population (ALMEIDA, 2010), and acts in the generation of employment and income in rural areas. region (FREIRE FILHO et al., 2011). Even though the crop has a good adaptive response to different soil and climatic conditions and a certain tolerance to the low level of water in the soil, studies indicate that the water deficit has become one of the most aggravating abiotic stresses for the bean crop, compromising its functioning in the different phases. most sensitive of its cycle, either in the germination process or in the initial development (FREITAS et al., 2017).

Recent evidence has shown that sulfur (S) may play a major role in stress defense. In plants subjected to salt stress, S activated antioxidant defense mechanisms, preventing oxidative damage (NAZAR et al., 2011). Furthermore, studies show that the transport of sulfate (SO42-) in the plant vascular system, its assimilation in the leaves and the recycling of S-containing compounds are related to the signaling and response to water stress (HAWKESFORD, 2012).

In this context, exogenous S supplementation contributes to plant development under stressful conditions, helping its metabolic process, regulating chlorophyll and nitrogen content, photosynthetic enzyme activity, protein synthesis and the electron transport system (MARSCHNER, 2011). According to Fatma (2014), sulfur can be a determinant of photosynthetic function in salt-stressed environments, mitigating salinity-induced oxidative stress.

Thus, studying the accumulation of this nutrient as a parameter for recommending fertilization is a strategy to improve cowpea crop performance under water deficit conditions. For this reason, the hypothesis that the management (application doses) of S interferes with the dynamics of accumulation by the plant in water deficit was tested, altering the absorption and export of this nutrient in two cowpea genotypes. In view of the above, the objective was to evaluate the absorption and accumulation of sulfur at the end of the vegetative cycle of the crop, as well as the export to the aerial part in two cowpea genotypes under water deficit as a function of different doses of the nutrient.

THEORETICAL FOUNDATION

The cowpea crop

Cowpea [*Vigna unguiculata* (L.) Walp.] is a legume of African origin that has been planted in Brazil for a long time, occupying a prominent place in human food, mainly in the Northeast region, due to its social and economic role in the development of this region (FREIRE FILHO et al., 2011). It is an annual plant with a production cycle ranging from 60 to 80 days depending on the cultivar and with low nutrient and water requirements. However, extreme variations can interfere with or reduce the growth of this plant species (ANDRADE JÚNIOR et al., 2003). Thus, all stages of plant development and growth can be affected depending on the level of stress and the stage of occurrence in the production cycle (VERBREE et al., 2015).

According to data from the National Supply Company (CONAB) of Brazil, the amount produced only of cowpea in the 2020/2021 season was 656.9 thousand tons, corresponding to approximately 22% of the entire bean production in the country. In the 2021/2022 season, there was a reduction in the planted area of the second crop cowpea compared to the previous season due to the loss of area for other crops, such as corn, which has shown more attractive prices.

Thus, even with the best prospects for average yield due to a more beneficial climate for the crop, the estimate is for production below 2020/2021, reaching 430.5 thousand tons (CONAB, 2022).

Water stress in plants

Water stress, for the most part, occurs when the plant is subjected to drought episodes, when effective precipitation is not replenished and the available water content drops below the critical limit for the crop (JIMÉNEZ-DONAIRE, GIRÁLDEZ and VANWALLEGHEM, 2020). In these situations, air temperature and humidity also have a great impact, considering the water dynamics in the entire soil–plant-atmosphere system and how this relationship influences the availability of water for the plant, so that these effects are greater in arid and/or semiarid climate conditions, where high temperatures and low water availability cause annual evaporative rates to be higher than rainfall replacement (HUANG et al., 2021).

Notably, the soil is a water reservoir for plants, and when its content is less than the water requirement, the plant loses turgidity, which directly affects growth by ceasing elongation due to the water inflow being responsible for cell expansion. and, indirectly, because the limitation of water impairs the photosynthetic machinery, compromising the production of energy for the synthesis of metabolites that promote cell division (RAZI and MUNEER, 2021). In addition, water scarcity also affects leaf gas exchange, phloem transport, tissue stiffness and mechanical stability (Razi and Muneer, 2021).

Role of sulfur in the plant

Sulfur (S) is a secondary macronutrient that is associated with several metabolic pathways in plants. Although it ranks fourth as a major nutrient, it plays a vital role in regulating many plant processes after being absorbed and translocated to plastids in leaves, where it is assimilated into organic products (LI, GAO, and YANG, 2020). Pioneering studies have confirmed its signaling function through the synthesis of compounds such as glutathione (GSH), hydrogen sulfide (H2S), methionine (Met), cysteine (Cys), phytochelatin (PC), ATP sulfurylase (ATPS) and protein thiols that improve antioxidant defense by promoting the elimination of excess reactive oxygen species (ROS) under different abiotic stresses (HASANUZZAMAN et al., 2018).

Its essentiality characteristics are linked to benefits both under normal and stressful conditions (SAMANTA et al., 2020), being crucial for physiological functions, growth and development (BORPATRAGOHAIN et al., 2019). Regarding photosynthesis, sulfur plays a fundamental role in the formation of the photosynthetic apparatus and in the electron transport system, in addition to having an influence on the content and activity of Rubisco (FATMA et al., 2014).

According to Aarabi et al. (2020), the requirement for sulfur varies between crops, with the family to which beans belong being the second most demanding in terms of availability of this element. Sulfur deficiency in crops has increased worldwide due to the decrease in sulfur inputs with a focus on supplementation, often occurring only with NPK in the soil system, and the increase in sulfur outputs in removal by the plant (DICK, KOST and CHEN, 2015).

LEE et al. (2016), evaluating the varietal difference of Brassica napus cultivars 'Mosa' and 'Saturnin' in sulfur use efficiency (EUS) and water stress tolerance, concluded that use and assimilation efficiency were significant in alleviating negative responses in photosynthetic activity to water stress. Thus, EUS is certainly a desired trait for crop management under water deficit and for breeding programs aimed at improving plant tolerance to stress.

Nutrient accumulation

The accumulation and export of nutrients by the plant is variable depending on the organ, species, cultivar, type of nutrient, management and soil and climate conditions where the cultivation takes place (SILVA et al., 2015). According to Courbet et al. (2019), plants have the ability to regulate their mineral composition through the absorption, binding, translocation, storage, remobilization and sequestration of nutrients, which ensures efficient use for their development and prevents the accumulation that causes toxicity. These same authors suggest that, at different levels of sulfur availability, positive and negative interactions will occur between this and other elements, such as its deficiency, which reduces the absorption of nitrogen, magnesium and potassium (COURBET et al., 2019). A study developed by Nascente et al. (2017) demonstrated that differential fertilization with S promotes an increase in the productivity of common bean plants, in which a dose of 15 mg dm-3 of sulfur increased the production of common bean grains by 19% in relation to plots without S.

Although there are already studies showing the beneficial role of S in the defense of plants against certain stresses and its influence on the productive contribution in the common bean crop, little is known about its accumulation in cowpea plants under water deficit.

METHODOLOGY

The experiment was carried out in the field and in a greenhouse of the Campus Professora Cinobelina Elvas, Federal University of Piauí, located in the municipality of Bom Jesus-PI, at 9°04'46” south latitude, 44°19'38” west longitude and an altitude of 277 meters. The climate in the region is Aw, hot and semihumid, according to the Köppen classification (1948). During the experiments, the environmental conditions included an average temperature of 33.7 and 31 °C and an average relative humidity of approximately 33.7 and 37.9% for the greenhouse and field, respectively.

The experiments were carried out in a completely randomized design (DIC) for a greenhouse and a randomized block design (DBC) for the field, with four replications, in a 2 × 2 × 3 factorial scheme, with two water treatments [control - 75% of the field capacity (CC) and water deficit – 45% CC], two cowpea cultivars (Xique-xique and Novaera) and three doses of sulfur (40, 80 and 120 mg kg^{-1} of S in the soil), which were applied in the form of agricultural plaster.

Before the experiment in a greenhouse, soil samples were collected in a 0 - 0.20 m layer and used for the physical-chemical assays. The soil was employed to fill 11 dm³ plastic pots for planting, with a total of 48 pots. During sowing, five seeds were sown per pot. The plants were irrigated daily, and the weight of the pots was measured to maintain a soil moisture equivalent to 75% CC during the first 21 days, both for the greenhouse and the field. Seven days after sowing, the first thinning was performed, and three plants were kept in each pot. At 14 days, the second thinning was performed, leaving only one plant per pot. After 21 days of sowing, the plants were subjected to water deficit treatments that lasted another 21 days, totaling 42 days of cultivation at the end of the experiment.

The field experiment was conducted in the experimental area of the UFPI-CPCE. The experiment had plots of 8.0 x 18.0 m corresponding to water treatments; subplots of 8.0 x 6.0 m constituting the treatments with doses of S; and subsubplots 2.0 x 3.0 m corresponding to the cowpea cultivars, composed of 4 rows of 3.0 m, for each linear metre had 8 plants. Sowing was carried out by manual planting, and fertilization was carried out according to soil chemical analysis based on crop requirements. At 21 days after sowing, stress treatments were applied for 28 days, totalling 48 days of cultivation.

Fertilization was performed by fertigation, with the exception of sulfur treatments, which were applied manually in each treatment line using bags containing heavy agricultural gypsum according to the established amounts. The method of localized irrigation was used through hoses with self-compensating drippers, and the replacement of water depths was based on evapotranspiration calculations recommended by Penman–Monteith-FAO, using data from the meteorological station present at the CPCE/UFPI.

The quantification of sulfur was determined in the soil samples before and after conducting the experiments in the field and in a greenhouse. For this, 10 cm^3 of soil was homogenized in extracting solution and stirred for 30 minutes; then, 0.25 g of activated carbon was added, with stirring for another three minutes. After filtration, 0.25 g of activated carbon was again added to obtain the supernatant. Subsequently, in test tubes, 10 mL of the supernatant and 1 ml of 6.0 M HCl containing 20 mg of sulfur and 500 mg of barium chloride ($BaCl_2$) were added. The tubes were shaken for 30 seconds, and the absorbance was read in a spectrophotometer at 420 nm (Silva, 2009).

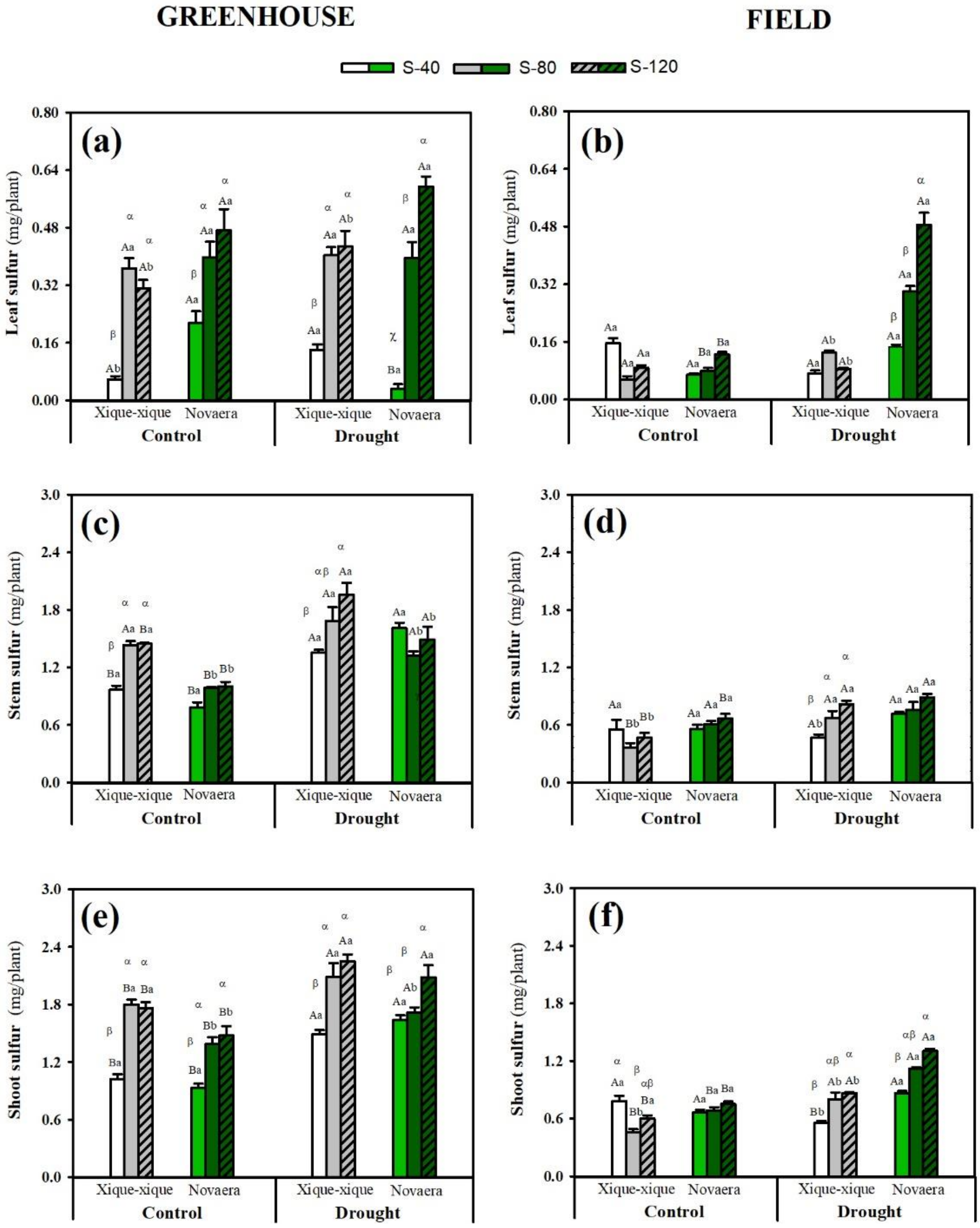
In plant tissues (leaves and stems), sulfur content was also quantified by the barium chloride ($BaCl_2$) turbidimetry method (Silva, 2009), in which crude extracts were prepared from leaf and stem samples with a digestion solution (6.0 M HCl, containing 20.0 mg L^{-1} S and 0.5% BaCl2). To obtain the extracts, 500 mg of samples were macerated in porcelain crucibles and placed in an electric muffle furnace for 3 h at 500 °C, and then 25 mL of HNO_3 was added. Then, the supernatant was subjected to absorbance readings at 420 nm, and the S contents were estimated based on a standard curve obtained from solutions with increasing concentrations of potassium sulfate (K_2SO_4).

The results were submitted to analysis of variance (ANOVA) by the F test at 5% probability, the means were compared by the Tukey test ($P \leq 0.05$) using the Sisvar program, and the graphs were made using SigmaPlot software (version 11.0).

RESULTS AND DISCUSSION

One of the great challenges of experimentation and repeatability is that, generally, studies carried out in a greenhouse, a controlled environment, are rarely repeated in the field, where the variation in climatic parameters such as wind, temperature, relative humidity and light, as well as greater chemical and biological interactions in the soil, causes plant responses to be different in the two environments.

Figure 01 – Accumulation of sulfur (S) in leaves (a, b), stems (c, d) and shoots (e, f) of cultivars Xique-xique and Novaera subjected to the control and water deficit treatments and supplied with S at doses of S-40, S-80 and S-120 kg ha^{-1}. Capital letters compare stress levels in the same cultivar and S dose; lowercase letters compare cultivars at the same S dose and stress level; and symbols ($^{\beta}\alpha^{\gamma}$) compare S doses in the same cultivar and stress level. Means followed by different letters and symbols differ statistically from each other, according to Tukey's test ($p < 0.05$).



Source: own (2022).

In the greenhouse environment, leaf sulfur contents increased both in control and drought-stressed plants, and Xique-xique and Novaera cultivars were responsive to doses S-80 and S-120, with increments higher than dose S-40 (Figure 1a, e). In the stem, this phenomenon was only reported for the Xique-xique cultivar (Figure 1c). Significant changes in leaf S contents in response to stress were observed only in the Novaera cultivar under the S-40 dose, in which stressed plants showed lower S values than control plants (Figure 1a). In contrast, in the stem and shoot, the water deficit promoted significant increases in S contents in all cultivars and S doses (Figure 01c, e).

In field experiments, little or no significant variation was observed in S contents among cowpea cultivars under control conditions, except for the stem, in which Novaera plants at doses S-80 and S-120 showed greater accumulation of S than Xique-xique plants (Figure 01-d). For the cultivar Novaera, increases in S levels in response to water deficit were observed only in plants of treatments S-80 and S-120 in all analysed tissues, except for the stem of plants fertilized with S-80. Additionally, under water deficit, supplementation at dose S-120 promoted a significant increase in S contents in leaves and shoots of Novaera plants compared to dose S-40 (Figure 01-b, f), and stressed Novaera plants showed higher S contents than Xique-xique plants under water deficit.

In a study carried out by Furtini et al. (2000), the application of S promoted significant increases in the production of shoot dry matter (MSPA), but with different responses, depending on the cultivars used, with the accumulation of sulfur, the same behavior. The increase in absorption seems to be due to the greater demand for nutrients and the production of biomass. The authors also concluded that genetic variability makes it possible to select more efficient cultivars for cultivation under conditions of low sulfur availability.

Kolling and Ozelame (2017), when studying different combinations of nitrogen and sulfur dozen in off-season black beans, found that the combined use of nitrogen and sulfur resulted in higher grain yield, a higher number of grains per pod and longer pod length, increasing the yield of these components, in addition to the higher yield of grains per area. Pereira et al. (2021), when studying the application of different sulfur dozens in the BRS Guariba and BRS Tumucumaque cowpea varieties under optimal irrigation conditions, found that the vegetative characteristics of these varieties were not influenced by the treatments, and the nutrient content available in the soil (32 mg dm-3) was sufficient for normal plant development.

The results of the chemical analyses of the soil and sulfur contents are presented before and after the experiments in the greenhouse and in the field (Table 01).

Table 01- Soil chemical analysis before and after experiments in a greenhouse and field with cowpea plants under three doses of S (S-40, S-80 and S-120 mg kg-1). Hydrogen potential; Ca (calcium), Mg (magnesium), Al (exchangeable acidity), H+Al (potential acidity at pH 7.0), K (potassium), SB (total exchangeable bases), T (cation exchange capacity at pH 7.0), P (ascitable phosphorus), V (base saturation) and OM (organic matter).

Depth	Treatment	pH	Ca	Mg	Al	H+Al	K	SB	T	P	V	OM
m		H_2O	--------------------cmol$_c$ dm^{-3}-------------------							mg dm^{-3}	%	g kg^{-1}
GREEN HOUSE												
Before rehearsals												
0.0 - 0.02	**S – 40**	5.2	1.58	0.31	0.50	1.81	0.42	2.31	4.12	100.00	56.10	7.20
	S – 80	5.0	2.36	0.49	0.25	1.81	0.45	3.30	5.11	97.00	64.60	7.90
	S – 120	5.1	1.93	0.28	0.50	1.93	0.44	2.64	4.57	153.00	57.80	8.10
After rehearsals												
0.0 - 0.02	**S – 40**	4.8	2.40	1.50	1.50	-	0.50	4.50	-	204.00	-	9.50
	S – 80	4.8	3.00	1.60	1.50	-	0.60	5.30	-	238.80	-	10.40
	S – 120	4.8	3.10	1.50	0.70	-	0.50	5.20	-	134.50	-	10.00
FIELD												
Before rehearsals												
0.0 - 0.02	**S – 40**	5.6	1.56	0.61	0.25	1.79	0.22	2.40	4.18	20.30	56.90	8.90
	S – 80	6.0	2.00	0.89	0.00	1.59	0.23	3.22	4.82	22.10	66.90	9.60
	S – 120	6.3	2.25	1.10	0.00	1.28	0.25	3.61	4.89	23.40	73.80	9.50
After rehearsals												
0.0 - 0.02	**S – 40**	6.0	2.29	0.75	0.00	0.66	0.09	3.14	3.80	17.40	82.20	-
	S – 80	6.0	2.09	0.65	0.00	0.66	0.12	2.87	3.53	19.00	80.40	-
	S – 120	6.1	1.86	0.59	0.00	0.66	0.11	2.57	4.85	15.90	79.40	-

Source: own (2022).

In the greenhouse, it was observed that the pH range between 5.0 and 5.52 in the plots, before receiving the different doses of sulfur, dropped to 4.8 after the tests, which is explained by the absorption of mineral elements with cationic charge, since hydrogen ions are released into the medium as the positively charged ions are absorbed by the root cells (ALAOUI et al., 2022). Calcium increased in all plots after the tests as the doses of sulfur were increased. The same behavior was observed for magnesium, potassium, phosphorus and organic matter. According to De Oliveira Araújo et al. (2012) and Gerrano et al. (2018), cowpea cultivars have different efficiencies in absorbing, transporting and assimilating nutrients.

In the field, base saturation increased in all treatments, especially at the S-40 dose, increasing from 56.90 to 82.20% after the tests, which allows us to infer that the additional dose of S-40 contributes to the increase in base saturation and, consequently, improved soil fertility, since the V% is indicative of the general conditions of soil fertility, with values ≥50% considered fertile (RAWAL et al., (2019). According to Courbet et al. (2019), different amounts of sulfur can influence interactions that increase or restrict the availability of other elements, corroborating the results observed in the present study in a greenhouse, in which the doses tested increased the percentage of exchangeable bases.

Under field conditions, the calcium content in the soil increased only at the dose of 40 kg ha-1 after the tests, while in the other doses, it remained the same or suffered few changes, which may be linked to the efficiency of the plant in absorbing this element (Table 01). On the other hand, magnesium decreased at doses S-80 and S-120, and potassium decreased in all treatments, allowing us to infer that sulfur contributed to greater absorption of these nutrients by plants. Assimilable phosphorus increased at doses S-40 and S-80 and decreased at dose S-120 after the tests in the greenhouse. In the field, the content decreased at all dosages and remained below the initial values of the crop (table 01). The sulfur contents in the soil before and after the tests in the greenhouse and in the field are presented in Table 02.

Table 02- Sulfur content (S) for doses S-40, S-80 and S-120 kg ha-1 in the soil used for experiments in the greenhouse and field before and after the tests.

		GREEN HOUSE	
Soil sample	Fixed	Before the assays	After the assays
		(kg/ha)	
S – 40	40.0	18.0	46.6
S – 80	80.0	33.4	93.0
S – 120	120.0	55.8	200.0
		FIELD	
S – 40	40.0	31.4	26.82
S – 80	80.0	36.4	28.48
S – 120	120.0	34.4	28.14

Source: own (2022).

In the greenhouse, all S supplementation treatments promoted an increase in the sulfur content of the soil after the tests, with an emphasis on the S-120 treatment, whose increase was 66.6% above the applied dose, which may be related to the higher sulfur concentration. In addition, in contrast to Figure 1, it is possible to observe that sulfur was significantly more incorporated and accumulated by plants in the greenhouse than in the field environment.

In the field, the values of sulfur in the soil, after the tests, were much lower than expected, with values between 26.82 and 28.48 kg ha^{-1}, which were below the initial supplemented values. This differential sulfur was not incorporated by the plant, since lower levels of S were verified in its parts in this cultivation environment (figure 1b, d and f). This may be related to leaching by irrigation water before planting, since it was applied in the form of agricultural gypsum in the planting line 03 days before sowing.

CONCLUSIONS

- ✓ Cowpea plants tend to accumulate large amounts of sulfur under greenhouse cultivation even under water restriction;
- ✓ Drought promotes little or no significant alteration in S accumulation of cowpea cultivars in the field;
- ✓ Sulfur supplementation increases the availability of exchangeable bases in the soil;
- ✓ More studies are needed to validate the role of S supplementation in cowpea plants, especially in relation to the accumulation at intervals of days after sowing until the productive cycle of the crop.

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