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CROP PRODUCTION

Growth performance of cowpea plants grown under different ionic concentrations of the nutrient solution

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ABSTRACT: Cowpea is a food crop representing an important source of proteins and income, mainly for people living in the north and northeast of Brazil. This study aimed to evaluate the growth performance of two cowpea cultivars under four different ionic concentrations of the growth solution. Thus, a pot experiment was performed using the sand culture technique and set up in a completely randomized design with a 2 x 4 factorial scheme, using four replications and one plant per plot. After the period of growth, the parameters such as length of the shoot, stem diameter, number of leaves, number of secondary branches, number of pods, fresh weight of the stem, stem dry mass, leaf dry mass, shoot dry mass, and root/shoot ratio were obtained. The results pointed out that there was a significant interaction effect on parameters like stem diameter, leaf dry mass, shoot dry mass, and number of leaves. Both cultivars were strongly responsive to changes in ionic concentration, indicating a greater biomass production at ionic concentrations of 90% and 120%. A greater growth performance for BRS Rouxinol than BRS Itaim was observed, while the second cultivar indicated a high tolerance as exposed to the highest ionic concentrations.

Key words: hydroponic culture, abiotic stress, BRS Rouxinol, nutrient use-efficiency.

Performance de crescimento do feijão caupi sob diferentes concentrações iônicas da solução nutritiva

RESUMO: O feijão-caupi é um alimento que representa uma importante fonte de proteínas, e também de renda, sobretudo para os produtores rurais do Norte e Nordeste do Brasil. O objetivo deste estudo foi avaliar o desempenho de crescimento de duas cultivares de feijão caupi sob diferentes concentrações iônicas da solução nutritiva. Para tanto, um experimento em vasos foi conduzido em delineamento inteiramento casualizado com arranjo fatorial 2 x 4, utilizando quatro repetições e um planta por parcela. Após o período de crescimento, os parâmetros tais como: comprimento do ramo principal, diâmetro do caule, número de folhas, número de ramos secundários, número de vagens, peso fresco do caule, peso seco do caule, peso seco das folhas, peso seco da parte aérea e a relação raiz parte aérea foram obtidas. Os resultados apontaram que houve interação significativa dos fatores sobre o diâmetro do caule, peso seco das folhas, peso seco da parte aérea e o número de folhas. Ambas as cultivares foram responsivas a mudança na concentração iônica da soução, revelando maior rendimento de biomassa nas concentrações de 90% e 120%. Uma maior performance de crescimento foi constatada para BRS Rouxinol comparado a BRS Itaim, enquanto a segunda cultivar mostrou elevada tolerância às altas concentrações iônicas na solução.

Palavras-chave: cultivo hidropônico, estresse abiótico, BRS Rouxinol, eficiência no uso de nutrientes.

INTRODUCTION

The world population is predicted to increase by over 9 billion people by 2050 and food demand by around 85% (FAO, 2017). This suggests that increasing agricultural production is an urgent issue (GODFRAY et al., 2010; DIOUF, 2011), mainly with increasing concern about the global food security caused by the impacts of abiotic stress on crop plants (GODOY et al., 2021; SILVA & SANTOS, 2023). Cowpea [*Vigna unguiculata* (L.) Walp.] is a very important crop with high nutritional value (AKIBODE & MAREDIA, 2012), representing an important source of protein, minerals, and also income, especially for people living in the north and most north of Brazil(FREIRE FILHOet al 2011; HONAISER et al., 2022). Nowadays, this crop has also been quite cultivated in the Mid-West region of Brazil (FREITAS et al., 2022). In most of these regions, the cultivation of cowpea is made mainly by traditional practices using low levels of technologies, which is a hamper for increasing food production and nutritional security (TAVARES et al., 2021; MELO et al., 2022).

Cowpea is known as "feijão de corda" or "feijão macassar" with wide global importance and distribution, mainly in tropical regions (CAVALCANTE JUNIOR et al., 2016). Nigeria is a leading producer of cowpea in the world (HERNITER et al., 2020), while Brazil is the third

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largest producer (FREITAS et al., 2022). This grain legume is considered an essential component of the basic basket in Africa, and in the north and northeast of Brazil (HONAISER et al., 2022). This crop also plays a fundamental role because of its high tolerance to abiotic stress, such as water deficit and low demand for agricultural inputs (MELO et al., 2022). Other studies have also stood out cowpea as a rustic crop, which can grow in poor soils and with low organic matter content, and also is quite tolerant to drought and heat conditions (MELO et al., 1996; CORREA et al., 2012). Despite its relevance to agriculture in the developing world and its resilience to stress, studies on cowpea are relatively scarce (CARVALHO et al., 2017).

According to EPSTEIN & BLOOM (2006), the appropriate supply of macro- and micronutrients is essential to ensure the successful growth and development of cultivated plants. In controlled experiments, the hydroponic technique has been largely used as a scientific tool for understanding the role of the concentration of these nutrients and their effects on plant growth and physiology. For instance, low concentrations can result in reduced growth and nutritional deficiency, whilst very high concentrations can lead to physiological disturbance, such as stress by water loss (i.e. wilting) and leaf burn (COMETTI et al., 2008). It is pointed out that excess nutrients decrease the profitability of agricultural activity due to chemical fertilizer high-costs. Moreover, there is a growing concern about the environmental impacts of such chemical amounts resulting from agricultural practices, especially N and P (HOBBIE et al., 2017), which also increases the need for optimizing crop input use efficiency. Because of this, there is a great demand for crop plants with low demand for agricultural inputs and with high resilience to abiotic stress (NIEVES-CORDONES et al., 2020).

Therefore, the development of research on cowpea growth is important in contributing to optimizing nutrient-use efficiency and increasing food production and nutritional security. In this context, this study aimed to evaluate the growth performance of two cowpea cultivars grown under four different ionic concentrations of Hogland`s nutrient solution.

MATERIALS AND METHODS

Plant material, environmental conditions, and experimental design

The pot experiment was performed at the Faculty of Agricultural Sciences of the Federal University of Amazon (UFAM), located in the municipality of Manaus-AM, Brazil (03º 06’ 01.94” S, 59º 58’ 34.59” W). Cowpea plants were grown in a greenhouse under natural sunlight and environmental conditions with average temperature and relative humidity of around 35 °C and 70%, respectively. This experiment was set up in a completely randomized design using a 2 x 4 factorial scheme, in which two cowpea cultivars (BRS Rouxinol and BRS Itaim) were exposed to four relative ionic concentrations of Hoagland`s nutrient solution (30%, 60%, 90%, and 120 %), with four replications and one plant per plot, totalizing 32 experimental plots.

Substrate preparation, growth conditions, and plant analysis

The pot experiment was performed using washed sand as substrate and fertilized with Hogland solution. Previously, the used substrate was washed to remove any impurities. For that, sand particles were submitted to several washes with running water and then submerged in an acid solution (0.5 mol L-1 HCl) for 24 hours. Next, this substrate was again washed several times in running water and finally with deionized water, according to methodological procedures used by SILVA (2020) and SILVA & SANTOS (2023). The substrate was then air-dried and transferred into plastic vessels. Such pots were painted externally with aluminum metallic paint to minimize an increase in solution temperature due to sunlight incidence.

Cowpea seeds were treated with 1% (w/v) sodium hypochlorite solution for 5 min, washed with tap water, and then submersed in deionized water for 4h. Next, the seeds were germinated in a polypropylene tray using washed sand as a substrate. At 15 days after sowing, healthy and uniform seedlings were selected and transplanted into plastic pots filled with sand substrate. During the period of growth, such plants were supplied with growth solution to reach up to 65% of substrate saturation capacity in each pot. The treatments presented values of electrical conductivity (EC) such as 0.7, 1.4, 2.1, and 2.8 dS m^{-1}, corresponding to 30%, 60%, 90%, and 120 %, respectively.

The chemical composition of the treatments was formulated based on the complete (full strength) nutrient solution proposed by HOAGLAND & ARNON (1950), as follows in mg L^{-1}: $N\text{-}NO^{3-}$ = 196; $N\text{-}NH^{4+}$ = 14; P = 31; K^+ = 234; Ca^{2+} = 160; Mg = 48,6; S = 70; Fe-EDTA = 5; Mn = 0.5; Cu = 0.02; Zn = 0.05; B = 0.5; Mo = 0.01. For solution preparation, deionized water was used. The used growth solution was composed of the following sources: $NH_4H_2PO_4$; $Mg(NO_3)_2.2H_2O$; K_2SO_4; $Ca(NO_3)_2.4H_2O$; $MgSO_4.7H_2O$; H_3BO_3; $MnCl_2$; $ZnCl_2$; $CuCl_2$; $H_2MoO_4.H_2O$; Fe-EDTA. Additionally, the pH value of the hydroponic solutions was kept at 5.8 by adding a 0.5 mol L^{-1} NaOH or 0.5 mol L^{-1} HCl solution. To prevent substrate salinization, E.C. of the nutrient solution was monitored, and when needed the substrate of each pot was washed with deionized water, and then treatments were reapplied.

At 58 days after sowing, the length of the shoot (LMS), stem diameter (SD), number of leaves (NL), number of secondary branches (NSB), and number of pods (NP) were measured. Afterward, all plants were harvested and separated into root, stem, and leaves. The shoot was weighed to obtain the fresh weight of the stem (FWS). The root length (RL) was also measured. All of these parts, i.e. root, and shoot (stem + leaves) were carefully washed with deionized water, placed in paper bags, and dried in a ventilated oven at 65 °C for 72 hours. Then, such materials were weighed to obtain stem dry mass (SDM), leaf dry mass (LDM), shoot dry mass (SHDM), and root dry mass (RDM)/shoot dry mass (SHDM) ratio.

Data analysis

The data obtained were subjected to analysis of variance (ANOVA) by the F test. The variables with qualitative factor (cultivars), when significant ($P \leq 0.05$), the means among treatments were compared by the Tukey test ($P \leq 0.05$). For quantitative factors (ionic concentrations) and interactions a polynomial regression model was used.

RESULTS AND DISCUSSION

There was a significant interaction of the factors (cultivars and ionic concentration) on the analyzed parameters, such as stem diameter, leaf dry mass, shoot dry mass, and number of leaves. It was also detected that the effect isolated of the ionic strength of the nutrient solution had a significant impact on most growth parameters studied, except the length of shoot and root length. The isolated effect of the factor cultivar had a significant effect on LMS, FWS, SDM, LDM, and NL parameters. The statistical analysis of the qualitative factor pointed to significantly greater performance concerning biomass yield for cv. BRS Rouxinol compared to cv. BRS Itaim (Table 1).

The parameters significantly influenced by the interaction of the factors (cultivars and ionic concentration), as well as by the isolated effect of the ionic concentration are presented in figures 1 and 2. In general, both cultivars showed a greater performance in terms of biomass production when cultivated with Hoagland solution under ionic concentrations of 90% and 120%. While, under a concentration of 30%, reduced growth and lower biomass yield for both cultivars were found. Such a result possibly occurred because plants produced a lower leaf area, which consequently led to reduced photosynthetic efficiency under growth conditions with low nutrient concentration.

For the BRS Itaim cultivar, a quadratic polynomial modeling ($r^2 = 0.98$) fitted nicely the relationship between stem diameter and ionic concentration, indicating that this model explained 98% of the variation. While, for BRS Rouxinol, a significant correlation ($P < 0.01$) with a positive linear relationship was observed ($r^2 = 0.94$), explaining around 94.35% of the variability (Figure 1A). Regarding the fresh weight of stem, cv. BRS Rouxinol presented a significant ($P < 0.01$) and higher performance of biomass yield (Figure 1C), in which a quadratic equation model best fitted the data ($r^2 = 0.98$). However, in terms of the number of pods, this cultivar displayed a lower performance than BRS Itaim (Figure 1B). The result related to this parameter, probably is due to the precocity of this cultivar compared to BRS Rouxinol (FREIRE FILHO, 2011).

Thus, at high ionic strength of 120%, a mean value of 16 pods per plant was obtained. While, under a concentration of 30%, the lowest mean value was observed, indicating that there was an increase of 82.21% as cultivated under an ionic concentration of 120%. SMITH & PORTER (1989) studying the response of cowpea to variations in planting and nutrient levels, found that plants were responsive to changes in the ionic strength of the nutrient solution and that biomass yield varied by up to 44%. In addition, for this cultivar, a mean value of about 10.75 pods per plant has been observed in a field study carried out in the state of Bahia by SILVA et al. (2014). Concerning the number of secondary branches (Figure 1D), only BRS Itaim was significantly influenced by the ionic strength of the nutrient solution, demonstrating a positive linear relationship. This model showed that this parameter is strongly influenced by the ionic concentration, explaining nearly 93% of the variability.

Leaf dry mass, stem dry mass, and shoot dry mass parameters were strongly correlated with the ionic concentration of the nutrient solution, specially the BRS Rouxinol cultivar compared to BRS Itaim (Figure 2A, 2B, and 2C). For the first cultivar, a quadratic equation model best-described data for growth performance,

Table 1 - Analysis of variance for shoot length (LMS), root length (RL), stem diameter (SD), fresh weight of stem (FWS), stem dry mass (SDM), leaf dry mass (LDM), shoot dry mass (SHDM), number of leaves (NL), number of secondary branches (NSB), number of pods (NP) and root dry mass (RDM)/SHDM ratio.

Source of variation	--Mean square (growth parameters)--										
	LMS	RL	SD	FWS	SDM	LDM	SHDM	NL	NSB	NP	RDM/SHDM
Cultivars (C)	5.46^{**}	138.20^{ns}	0.33^{ns}	4608.00^{**}	231.13^{**}	242.00^{**}	71.40^{ns}	190.13^{**}	0.00^{ns}	66.13^{ns}	0.00^{ns}
Ionic concentration (IC)	0.85^{ns}	40.04^{ns}	21.76^{**}	14141.67^{**}	482.46^{**}	400.33^{**}	2625.67^{**}	62.33^{*}	5.25^{*}	184.42^{**}	0.04^{**}
Interaction (C x IC)	0.29^{ns}	24.69^{ns}	0.02^{*}	111.00^{ns}	17.46^{ns}	23.00^{*}	122.40^{*}	69.79^{*}	2.58^{ns}	18.88^{ns}	0.00^{ns}
Cultivar											
BRS Itaim	1.60b[1]	20.19a	6.72a	71.00 b	15.25b	11.00b	37.00a	16.93b	2.25a	7.81a	0.15a
BRS Rouxinol	2.42a	24.34a	6.92a	95.00 a	20.62a	16.50a	39.98a	21.81a	2.25a	4.93a	0.17a

* and ** respectively, significant at 5 and 1% by the F test; ns = not significant. [1]Means followed by the same letter, in the column for each cultivar, do not differ significantly by Tukey test at $P \leq 0.05$.

whilst a positive linear relationship better fitted the data for the second one. These results pointed out that under a relative ionic concentration of 90%, optimum plant growth can be obtained. Therefore, this solution concentration improved plant growth, revealing a great potential to grow cowpea plants efficiently compared to that with a concentration of 120%. The model also indicated that there was a decrease in biomass yield for

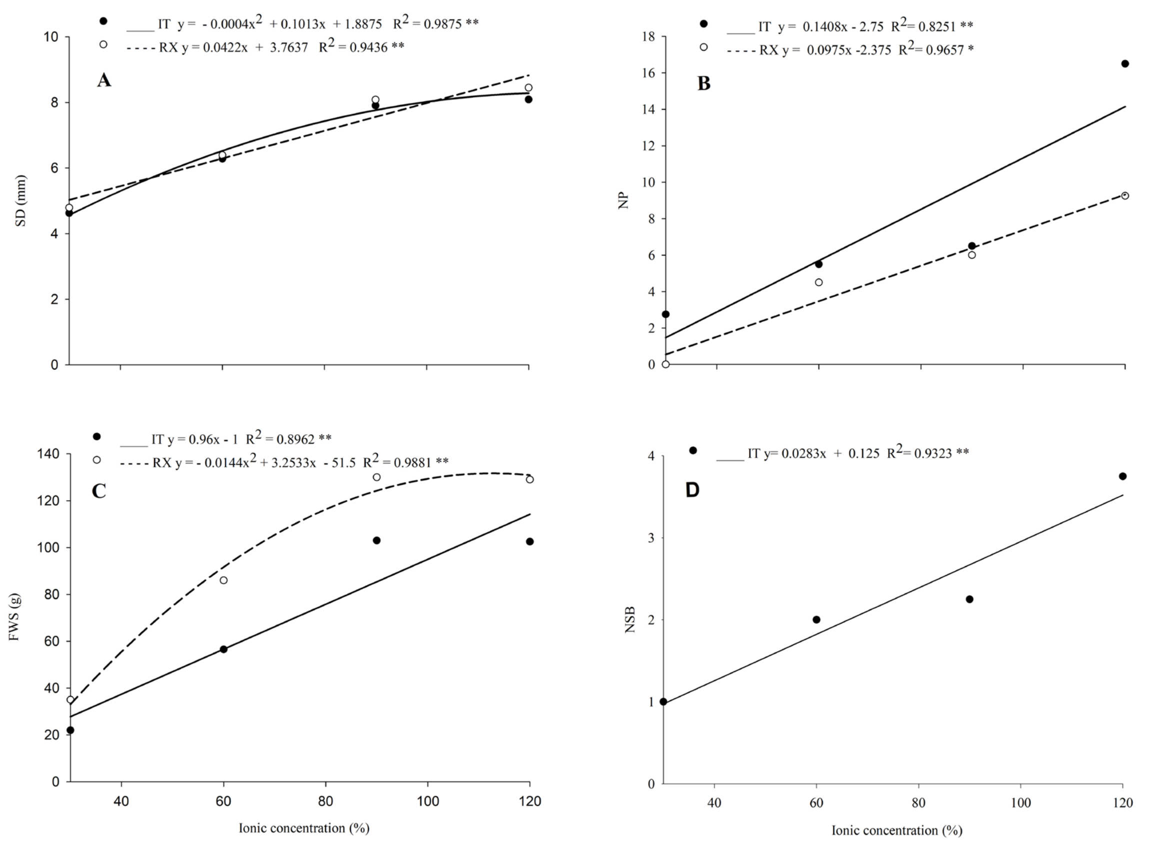

Figure 1 - Stem diameter (SD), number of pods (NP), fresh weight of stem (FWS) and number of secondary branches (NSB) of two cowpea cultivars (BRS Rouxinol - RX and BRS Itaim - IT), as a function of the ionic concentration (%). * and **, respectively, significant at 5 and 1% by Tukey test.

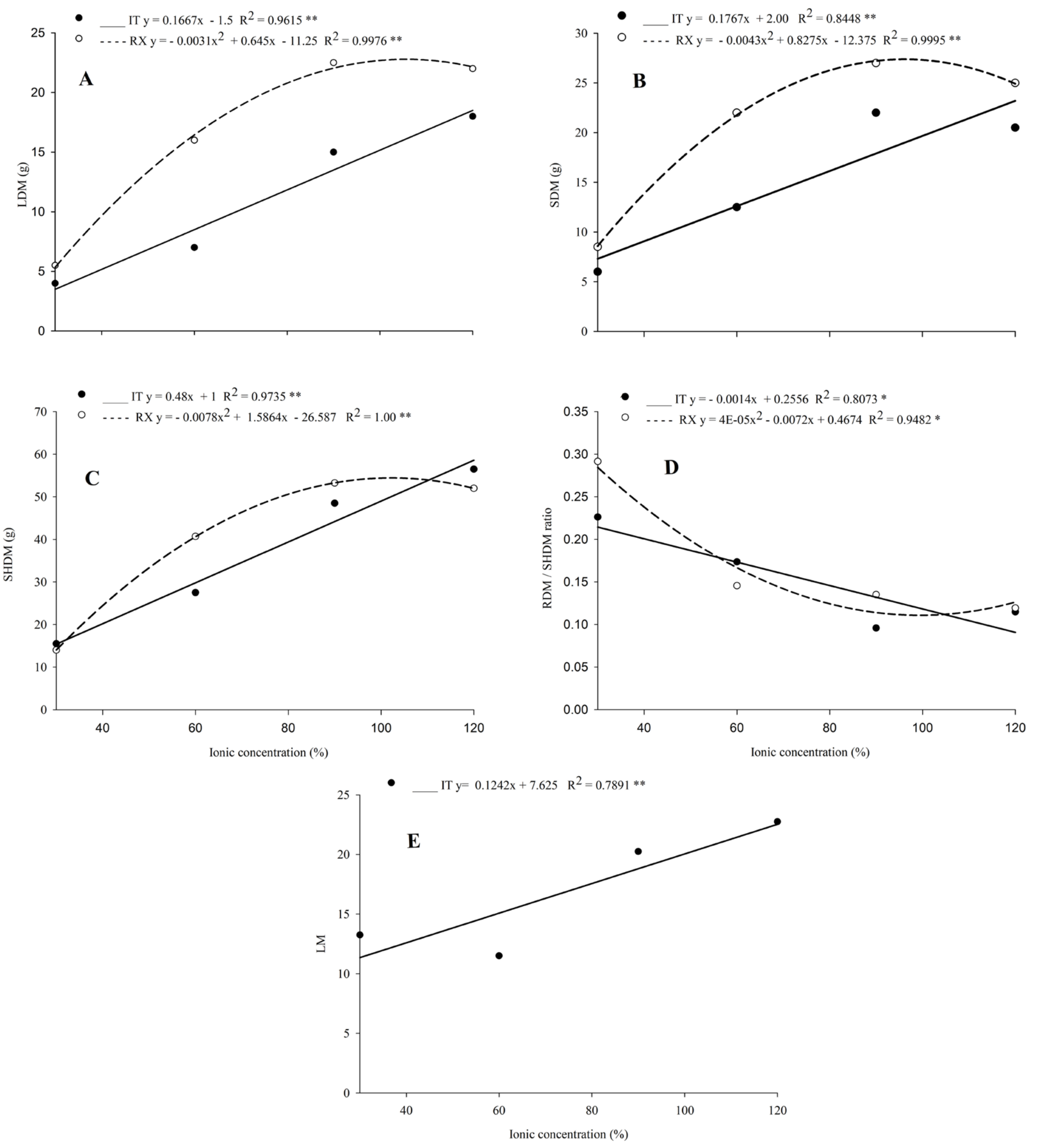

Figure 2 - Leaf dry mass (LDM), stem dry mass (SDM), shoot dry mass (SHDM), number of leaves (NL) and root: shoot ratio (RDM/SHDM) of two cowpea cultivars (BRS Rouxinol - RX and BRS Itaim - IT), as a function of the ionic concentration (%). * and **, respectivily, significant at 5 and 1% by Tukey test.

plants grown at the highest relative ionic concentration (120%), which is due to the abiotic stress effect on the physiology plant, i.e. negative effects of high EC of the growth solution. Therefore, the model can help to enhance nutrient use-efficiency, by reducing losses through nutrient excess on crop cultivation. Moreover, it is also important to point out that further studies related to mineral nutrition to understand the effect on the nutritional quality of the plants can be developed.

The root-shoot relationship provides information about the partitioning of biomass and allocation of photoassimilates within plants. This parameter was well-correlated with ionic concentration of the growth solution, specially for BRS Rouxinol cultivar, in which a quadratic polynomial model best fit the data ($r^2 = 0.94$), explaining about 94% of the variability (Figure 2D). While, a negative linear equation best fitted ($r^2 = 0.80$) for BRS Itaim cultivar, indicating a weaker correlation and that this model explained 80% of the variation in root: shoot ratio. Concerning the first cowpea cultivar, the results showed that there was increased partitioning of biomass towards the shoot with increasing ionic concentration and that at the highest concentration of 120%, plants increased biomass allocation to root biomass.

KANG & VAN LERSEL (2004) reported that plants grown at higher fertilizer concentrations allocated more photoassimilates to shoot than those grown with lower concentrations, which can be attributed to the fact that plants grown under high fertilizer concentrations can produce more leaf area. These results, therefore, suggest that under growth conditions with the highest ionic concentrations studied (120%), the second cultivar was quite tolerant and developed better than the first one, notably under stress by high levels of fertilizers in solution. According to RAVELOMBOLA et al. (2019), providing farmers with genotypes that tolerate salt-stress conditions would contribute to reducing the negative impact of abiotic stress on crop production.

About the number of leaves (NL) (Figure 2E), only cv. BRS Itaim was significative responsive to changes in the ionic strength, indicating that a positive linear relationship best described the data behavior. The linear increasing response illustrates an increase in the NL per plant with increasing the ionic concentration of the nutrient solution. Thus, this cultivar displayed around 25 leaves per plant at the highest concentration of 120%. A field study carried out by ALMEIDA et al. (2017) on cowpea performance in the Cerrado region, found a number ranging between 17 and 22 leaves per plant for the same cultivar.

CONCLUSION

Cowpea plants cv. BRS Rouxinol revealed a greater performance of biomass yield than cv. BRS Itaim when submitted to different concentrations of the nutrient solution. Both cowpea cultivars were strongly responsive to changes in the relative ionic concentration of the nutrient solution, presenting the lowest performance when cultivated with Hoagland solution at an ionic concentration of 30%, and highest at 90% and 120%.

The quadratic polynomial equation has best described the most evaluated parameters for the BRS Rouxinol cultivar, indicating that cultivation with a Hoagland solution of 90% resulted in optimum growth and greater nutrient-use efficiency compared with that of 120%. While, for BRS Itaim, the modeling indicated an increased biomass production with increasing in ionic concentration, pointing to a high-stress tolerance under higher chemical fertilizer concentrations in solution.

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DECLARATION OF CONFLICT OF INTEREST

The authors state no conflict of interest.

AUTHORS' CONTRIBUTIONS

The authors contributed equally to the manuscript.

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