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Absorption of nutrients by cowpea irrigated with saline water under different leaching fractions

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A B S T R A C T
Salinity is one of the main environmental problems that negatively affect plant growth and metabolism, besides being one of the factors responsible for the decrease in the yield of crops, especially in arid and semiarid regions. Thus, the aim of this study was to evaluate the effects of soil salinity on the mineral nutrition of irrigated cowpea. The experiment was conducted in drainage lysimeters in a greenhouse, in a completely randomized design with seven treatments, one irrigated with freshwater (control) and six irrigated with saline water with different leaching fractions (5, 10, 15, 20, 30 and 40%) of the applied irrigation depth, with three replicates. The irrigation with saline water treatments did not affect significantly the contents of macronutrients and Na in the cowpea leaves, while the opposite behavior occurred with the micronutrients.

Palavras-chave:
salinidade
lâminas de lixiviação
irrigação

Absorção de nutrientes pelo feijão caupi irrigado com água salina sob diferentes frações de lixiviação

R E S U M O
A salinidade constitui um dos principais problemas ambientais que afetam negativamente o crescimento e o metabolismo vegetal, além de ser um dos fatores responsáveis pelo decréscimo da produtividade das culturas, sobretudo nas regiões áridas e semiáridas. Objetivou-se com este estudo, avaliar os efeitos da salinidade do solo na nutrição mineral do feijão caupi irrigado. O experimento foi conduzido em lisímetros de drenagem, em casa de vegetação, no delineamento inteiramente casualizado com sete tratamentos constituídos de um irrigado com água doce (testemunha) e seis irrigados com água salina com diferentes frações de lixiviação (5, 10, 15, 20, 30 e 40%) da lâmina de irrigação aplicada e três repetições. A irrigação com água salina não influenciou de forma significativa as concentrações dos macronutrientes e de Na nas folhas do feijão caupi ocorrendo comportamento contrário com os micronutrientes.

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Introduction

Salinity is one of the main abiotic factors that contribute to the reduction of crop yield and its effect is more pronounced in arid and semiarid regions. The high concentrations of salts in the soil, besides reducing the water potential, can cause toxic effects on the plants, leading to functional disorders and injuries in the metabolism (Debouba et al., 2006; Munns & Tester, 2008).

Cavalcante et al. (2010) report that the salt stress leads to a reduction in plant development due to the nutritional imbalances caused by the excess of salts in the absorption and transport of nutrients. Farias et al. (2009) claim that salinity reduces the activity of the ions in solution and alters the processes of absorption, transport, assimilation and distribution of nutrients in the plant. Among these ions, nitrate is the most affected (Aragão et al., 2010; Meloni et al., 2004).

In arid and semiarid regions, such as in Northeast Brazil, there has been an increase in the use of water from tube wells for irrigation, which has usually increased the levels of dissolved salts. In this situation, when irrigation is not properly conducted, due to either failures in design or inadequate management, it can cause soil salinization. In order to avoid or reduce the problems generated by soil salinization, it is necessary to use, in each irrigation, an excess water depth in order to leach the salts to below the root zone of the crops.

Regarding the use of irrigation water with high contents of salts and different values of electrical conductivity, many studies have already been conducted with the cowpea crop, such as Medeiros et al. (2008), Coelho et al. (2013) and Souza et al. (2014). However, there are only a few studies involving the species and its cultivars subjected to saline water irrigation with various leaching fractions, such as Assis Júnior et al. (2007).

Studies of this nature allow to define, for the irrigators and producers of this crop, the ideal leaching fraction that must be used to maintain soil salinity adequate to the crop, taking into consideration irrigation water salinity and crop sensitivity. Therefore, this study aimed to evaluate the mineral nutrition of cowpea subjected to saline water irrigation with different leaching fractions.

Material and Methods

The study was carried out from March to June 2013 in a protected environment, in the experimental area of the State University of Southeast Bahia (UESB), using 21 drainage lysimeters with width of 1.0 m, length of 1.40 m and depth of 0.80 m.

The lysimeters were filled with soil material collected in the B horizon of a haplic Yellow Latosol, predominant in the region, which was air-dried, homogenized and sieved through a 4-mm-mesh sieve.

The saline water used in the irrigations was prepared by adding NaCl and $CaCl_2$ to the freshwater obtained from a well, in amounts necessary to obtain an electrical conductivity (CEw) of 2.4 dS m^{-1} and an ionic relationship, in weight, equivalent to 3Na:2Ca, which are common characteristics in Northeast Brazil. The characteristics of the waters used in the experiment are presented in Table 1.

The experiment was set in a completely randomized design, with seven treatments and three replicates. The treatments consisted of one irrigated with freshwater (without leaching) and six irrigated with saline water, added to leaching fractions of 40, 30, 20, 15, 10 and 5% of the applied irrigation depth. The leaching fractions were selected because they are used as a criterion for the design of irrigation systems and the most commonly used are those of 5 to 20%.

The planting of cowpea, variety ‘BRS Guariba’, widely used by the producers of the region, was performed inside and outside the lysimeters in furrows spaced by 0.50 m, with 20 seeds per linear meter. Thinning was performed 15 days after emergence, leaving 26 plants per lysimeter.

Pre-planting fertilization was applied in the furrow using NPK (4-14-08) at the dose of 20 g per linear meter, as the sources of nutrients, and taking into consideration the results of the soil analysis (Table 2) and the requirements of the crop.

At 20 and 50 days after sowing (DAS), top-dressing fertilization was performed using urea at the dose of 20 kg ha^{-1} of N. The other cultivation practices, such as weeding and control of pests and diseases, were manually performed along the crop cycle.

The irrigation depths were calculated based on crop evapotranspiration (ETc) and on the leaching fraction corresponding to each treatment, using Eq. 1. Irrigations were applied with intervals of two days.

$$\mathrm{IWD} = \frac{\mathrm{ET_c}}{1 - \mathrm{LF}} \tag{1}$$

where:

IWD - irrigation water depth, in mm;
ETc - crop evapotranspiration, in mm; and,
LF - leaching fraction, decimal.

Table 1. Characteristics of the waters used in the irrigation of cowpea

Characteristics	Freshwater (FW)	Saline water (SW)
Potential of hydrogen (pH)	6.00	5.70
Electrical conductivity (dS m^{-1})	0.20	2.40
Sodium ($mmol_c$ L^{-1})	1.30	16.50
Calcium ($mmol_c$ L^{-1})	0.10	6.40
Magnesium ($mmol_c$ L^{-1})	0.10	0.30
Potassium ($mmol_c$ L^{-1})	0.02	0.01
SAR	4.10	9.00
Water classification for irrigation	C_1S_1	C_4S_1

Table 2. Chemical characteristics of the soil before planting and after harvesting the cowpea crop

Period	pH	P	K^+	Ca^{++}	Mg^{++}	Al^{+++}	H^+	Na^+	SB	t	T	V	m	ESP	OM
	H_2O	mg dm^{-3}	$cmol_c$ dm^{-3}									%			g dm^{-3}
Before	5.8	156	0.72	2.6	1.0	0	1.8	0.22	4.8	4.8	6.6	73	0	3	18
After	5.1	50.2	0.32	3.2	1.3	0.2	2.1	0.44	3.3	3.4	5.5	59	4.8	7.8	-

Crop evapotranspiration (ETc) was calculated based on the daily reference evapotranspiration (ET_0), estimated through the FAO-56 Penman-Monteith method, correcting the values by the crop coefficients (Kc) of 0.90, 1.00, 1.20 and 1.00 for the initial, vegetative, reproductive and grain filling stages, respectively.

At 30, 55 and 80 DAS, soil samples were collected in each experimental unit in the layers of 0-20, 20-40 and 40-60 cm for the determination of the balance of salts in the soil profile, evaluated based on the direct measurement of the electrical conductivity of the saturated soil extract. The mean values of electrical conductivity of the saturated soil extract (ECse) along the entire crop cycle were 0.99, 1.63, 1.73, 2.10, 2.30, 2.67 and 3.24 dS m^{-1}, corresponding to the treatments with water and leaching fractions of 5, 10, 15, 20, 30 and 40%, respectively.

For the chemical analysis of the leaf tissue, recently matured leaves were collected from the apex, at the beginning of the grain filling stage. These leaves were placed in paper bags, dried in an oven at 70 °C until constant weight and taken to the Laboratory of Leaf Analysis of the Soil Department of the Federal University of Viçosa.

The data were analyzed through a contrast between the saline treatments and the freshwater, at a significance level of 0.05 by the t-test.

Results and Discussion

Table 3 shows the mean values of the contents of nutrients in cowpea leaves as a function of leaching fractions and irrigation water quality, besides the adequate and deficient values of nutrients in cowpea tissues.

According to the results presented in Table 3, in general, the contents of macronutrients are adequate for the crop, except for Ca and K, which are below the values considered as adequate by Oliveira & Dantas (1984). Lacerda (2005) mentions that the duration of the stress and the age of the sampled leaf can produce different results and interpretations, and may be related to the differences in the rates of K^+ retranslocation between the treatments.

In addition, there was no expressive tendency of the contents of nutrients to increase or decrease due to the leaching fractions; however, in general, the content of nutrients in the leaf tissues was higher for the leaching fractions of 5 to 20%, compared with the results obtained for freshwater.

These results corroborate those obtained by Blanco et al. (2008), Neves et al. (2009) and Gurgel et al. (2010), who report that the nutritional stress in plants subjected to salt stress can be related to the excessive accumulation of certain ions and to the reduction of others due to the alterations in the availability of nutrients, competition in the process of absorption and inhibition of the transport in the plant.

The contents of micronutrients, in general, were adequate for the crop, except for Fe, which has content considered as deficient according to Oliveira & Dantas (1984). Souza et al. (2007) evidenced that the acquisition of micronutrients, such as Fe and Mn, by the plant can be affected by the composition of the saline medium, and there is a reduction in the absorption of these micronutrients due to the antagonism with the calcium ion in excess.

The saline treatments, defined by the leaching fractions, did not affect significantly the contents of macronutrients and Na in the leaf tissue, and the opposite behavior occurred with the micronutrients (Table 4).

Regarding the macronutrients, the observed results corroborate those of Garcia et al. (2012), who studied the effects of saline water on the nutrition of conilon coffee and observed that the leaf contents of N, P, K, Ca, Mg and S did not show significant effects with the increase in irrigation water electrical conductivity; only Na content increased with water salinity.

Among the macronutrients in the leaves, only N decreased with the application of saline water, compared with freshwater,

Table 4. Contrasts between mean contents of nutrients in leaves of cowpea cultivated in lysimeters irrigated with saline water with different leaching fractions (SW) versus freshwater (FW)

Characteristic	Unit	Difference (SW-FW)	Significance
N	dag kg^{-1}	-0.16	ns
P	dag kg^{-1}	0.05	ns
K	dag kg^{-1}	0.23	ns
Ca	dag kg^{-1}	1.10	ns
Mg	dag kg^{-1}	0.56	ns
S	dag kg^{-1}	0.02	ns
Na	dag kg^{-1}	0.0003	ns
Cu	mg kg^{-1}	5.35	*
Fe	mg kg^{-1}	-21.27	*
Zn	mg kg^{-1}	44.74	*
Mn	mg kg^{-1}	-40.31	*
B	mg kg^{-1}	28.18	*

* Significant at 0.05 probability level by t-test; ns - Not significant

Table 3. Mean values of contents of nutrients in cowpea leaves as a function of leaching fractions and irrigation water quality

LF	ECse	N	P	K	Ca	Mg	S	Cu	Fe	Zn	Mn	B	Na
%	dS m^{-1}	dag kg^{-1}						mg kg^{-1}					dag kg^{-1}
FW	0.2	2.4	0.10	1.2	2.2	0.3	0.08	7.0	127	37	420	44	0.002
5	3.2	2.7	0.15	1.3	2.5	0.6	0.11	10.8	125	65	293	64	0.002
10	2.7	2.3	0.14	1.5	2.6	1.0	0.13	23.1	141	54	499	104	0.002
15	2.3	2.0	0.14	1.2	2.8	0.7	0.07	13.2	107	87	385	65	0.002
20	2.1	2.3	0.14	1.5	3.0	0.7	0.07	10.0	100	55	307	65	0.002
30	1.7	1.5	0.12	1.1	2.1	0.8	0.06	10.3	80	85	406	75	0.002
40	1.6	1.4	0.13	1.4	2.6	0.9	0.10	6.8	84	43	386	58	0.002
Adequate*		1.97	0.14	3.2	5.4	0.7	0.15	6	817	43	418	202	-
Deficient*		1.28	0.02	0.6	1.8	0.1	0.05	5	337	24	24	44	-

* Adapted from Oliveira & Dantas (1984); FW - Fresh water without leaching

corroborating the results obtained by Viégas et al. (2004) in a study with cashew cultivated in NaCl nutrient solution. According to Gheyi et al. (1997), the reduction in leaf N content can be related to the inhibition of the nitrification process, which becomes absolute at ESP > 7.0, a value confirmed in Table 1.

The consequences caused by NaCl on the reduction of nitrate absorption can be related to the ionic and/or osmotic effect of Cl^- by the absorption sites and not to the effect of the environment (Silva et al., 2009) and also by the antagonistic relationship existing between nitrate and chloride or the reduction of evapotranspiration (Oliveira et al., 2011).

Leaf P content was not affected by the application of leaching fractions or soil salinity, in comparison to freshwater, corroborating the results obtained by Neves et al. (2009) and contrary to those obtained by Bosco et al. (2009), who reported linear increment for the P content in the leaf tissue of eggplant as a function of the salinity.

The observed results can be associated with the low activity of $H_2PO_4^-$ in the soil solution, due to the increase in NaCl content (Al-Karaki, 1997). In addition, some experimental results show that the P contents in plants cultivated in saline environments vary along crop growth and development (Neves et al., 2009).

The K content in the leaf tissues was not affected by the application of leaching fractions, but showed an increase, although not significant, as a function of these fractions (Table 4). In spite of that, its content in the leaf tissue is close to the value considered as deficient for the crop (Table 3).

The low content in the leaf tissue can be associated, according to Fernandes et al. (2002), to its accumulation in the roots and not in the leaves, since K is an expressive inorganic solute in the plant and its main contribution is to reduce the osmotic potential of root cells. Furthermore, the increase in K content in the leaf tissue indicates, according to Calvet et al. (2013), that water salinity did not damage K dynamics from the roots to the other organs.

The contents of Ca and Mg in the leaves increased with the application of leaching fractions (Table 3) and the highest values of these nutrients were observed for leaching fractions higher than 10%, although there was no significant difference between the saline treatments and freshwater (Table 4), corroborating with Assis Júnior et al. (2007).

In the case of Ca, the increase can be associated with the increment in the availability of this nutrient in the soil (Table 1), since it was present in the water of the saline treatments. Similar results were found by Souza et al. (2007), who evaluated the effects of salinity and chemical composition of the irrigation water on the vegetative growth and mineral nutrition of cowpea (*Vigna unguiculata* (L.) Walp.), cv. Pitiúba.

The increase in Mg content in the leaf tissues can be related to its increase in the soil, due to the application of saline water, as can be observed in Table 1. Lucena et al. (2011) report that, despite the importance of this nutrient in plant metabolism, the literature referring to studies on its contents in plants cultivated under salt stress is very limited, for both watermelon and other species.

Results different from those obtained in the present study were reported by Freire et al. (2010), in which the increase in NaCl doses from 0 to 62 mmol L^{-1} caused a reduction in Mg contents in the shoots of leucaena, indicating that its transport to the aerial organs was compromised.

The application of leaching fractions (saline treatments), compared with freshwater, did not affect significantly the Na content in the leaf tissue, despite the increase in its concentration in the soil, due to the leaching fractions (Table 1). Alves et al. (2011), evaluating the effect of the addition of Ca on the absorption and transport of Na and K in cashew plantlets, observed that the presence of Ca in the medium containing NaCl increased Na absorption and accumulation in the various organs. Contrary results were found by Souza et al. (2007), who studied the effect of salinity on cowpea plants and observed a significant increase in the contents of Na and Cl in the stem; however, in the leaves, the salinity influenced only the contents of chloride.

Santos et al. (2009), studying the response of the bean crop to salinity, observed that the Na content decreases in the order of stem > roots > petioles > leaves, indicating the capacity of the plants to decrease the content of this element in the photosynthetically active organ, which is a positive factor in the definition of the tolerance to saline stress.

The increase in soil salinity resulting from the application of leaching fractions caused a significant reduction in Fe and Mn contents and a significant increase in Zn and B contents in the leaf tissues of cowpea (Table 4). In the case of Fe and Mn, the results corroborate those found by Souza et al. (2007), who claim that the acquisition of micronutrients, such as Fe and Mn, by the plant can be affected by the composition of the saline medium, and there is absorption of these micronutrients due to the antagonism with the calcium ion in excess.

Conclusions

1. The mean results of the saline treatments, in comparison to freshwater, did not affect significantly the contents of micronutrients or Na in cowpea leaves, while the opposite occurred for the micronutrients.
2. The contents of nutrients in the leaf tissues were, in general, higher for the leaching fractions of up to 20%, compared with the results obtained for the freshwater.

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