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Research Article

Influence of intercropping and monocropping systems on fava bean cultivation under saline stress[1]

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ABSTRACT

The fava bean crop makes an important socioeconomic contribution to the Northeast region of Brazil. However, in this region, there is a quantitative and qualitative shortage of water, being necessary the use of brackish water for irrigation. This study aimed to evaluate the saline stress on the yield and water-use efficiency in fava bean crop cultivated under monoculture and intercropping systems. The experiment was conducted under field conditions, using a randomized blocks experimental design, in a 5 x 2 factorial arrangement, with four replications. The first factor corresponded to five levels of electrical conductivity of irrigation water (1.0, 2.0, 3.0, 4.0 and 5.0 dS m^{-1}) and the second comprised two cropping systems: fava bean grown in monoculture and intercropped with corn. The salt stress negatively affected the number of pods in the intercropped system, but with less intensity. The increase of salts in the irrigation water reduces the pod length, diameter and mass, as well as the yield and water-use efficiency, while the monoculture system is less affected by these effects.

KEYWORDS: *Phaseolus lunatus* L., *Zea mays* L., irrigation with brackish water.

RESUMO

Influência do sistema consorciado e monocultivo na cultura de fava sob estresse salino

A cultura da fava desempenha importante contribuição socioeconômica para a região Nordeste do Brasil. Contudo, nessa região, há escassez quantitativa e qualitativa de água, sendo necessária a utilização de água salobra para a irrigação. Objetivou-se avaliar o estresse salino na produtividade e eficiência do uso de água na cultura de fava cultivada em sistemas de monocultivo e consorciado. O experimento foi conduzido em condições de campo, com delineamento experimental em blocos ao acaso, em arranjo fatorial 5 x 2, com quatro repetições. O primeiro fator correspondeu a cinco níveis de condutividade elétrica da água de irrigação (1,0; 2,0; 3,0; 4,0; e 5,0 dS m^{-1}) e o segundo compreendeu dois sistemas de cultivo: fava cultivada em monocultivo e em consórcio com milho. O estresse salino afetou negativamente o número de vagens no sistema consorciado, porém com menor intensidade. O aumento dos sais da água de irrigação reduz o comprimento, diâmetro e massa de vagens, produtividade e eficiência no uso da água, sendo que o sistema de monocultivo é menos afetado por esses efeitos.

PALAVRAS-CHAVE: *Phaseolus lunatus* L., *Zea mays* L., irrigação com água salobra.

INTRODUCTION

The fava bean crop (*Phaseolus lunatus* L.) is the second most important species of the *Phaseolus* genus in the world, widely cultivated in tropical regions. It is characterized by its high genetic diversity and productive potential, and is considered an alternative source of income and food (Martínez-Nieto et al. 2020, Gomes et al. 2022).

In Brazil, it is mostly grown in the Northeast region, usually associated with other crops such as maize. This region is responsible for 99 % of the national production, grown mainly by small farmers, in an estimated area of around 33,357 ha, with the Ceará state being the largest producer with 4,139 t, followed by Paraíba (2,059 t) and Pernambuco (1,248 t) (IBGE 2021).

Despite its high socio-economic importance, the fava bean crop still has a low yield, which is explained by the lack of commercial cultivars and strategies to boost its productive performance, such as fertilization, an efficient cultivation system and

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irrigation management (Costa et al. 2021, Sousa et al. 2022).

Irrigation is one of the techniques that allow crops to achieve a maximum production, but the amount of good quality water in semi-arid regions, such as the Northeast, may not be sufficient to maintain an irrigated agriculture, due to high evapotranspiration rates, higher than rainfall, which favor the accumulation of salts in the water sources available for irrigation, culminating in water of inferior quality, such as brackish water (Lima et al. 2020a, Minhas et al. 2020).

Salinity is one of the abiotic stresses that most restricts plant productivity worldwide, causing deleterious effects on growth, physiology and production in most crops, due to the osmotic and toxic effects on plants (Cavalcante et al. 2021, Goes et al. 2021a). In the case of fava bean, there have been studies on the effect of salts in irrigation water on emergence (Ceita et al. 2020), growth and gas exchange (Sousa et al. 2018), but there is little research for these effects on crop production, especially when grown in monoculture and intercropping systems.

Thus, this study aimed to evaluate the salt stress on the yield and water-use efficiency in broad bean crops grown in monoculture and intercropping systems.

MATERIAL AND METHODS

The experiment was conducted under field conditions, at the experimental farm of the Universidade da Integração Internacional da Lusofonia Afro-Brasileira, in Redenção, Ceará state, Brazil (04º14'53"S, 38º45'10"W and average altitude of 240 m), from August to November 2018.

The region's climate is of the BSh' type, which means very hot temperatures, with rainfall predominating in the summer and fall seasons (Alvares et al. 2013). The average temperature and average relative humidity data for the experimental period (August to November 2018) are shown in Figure 1.

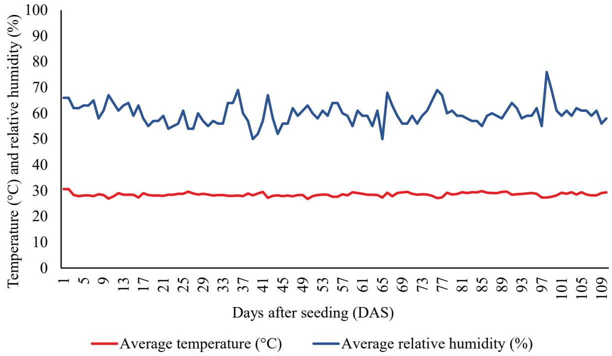

Figure 1. Average temperature and relative humidity during the experimental period (August to November 2018, in Redenção, Ceará state, Brazil).

The soil in the experimental area is classified as Argissolo Vermelho-Amarelo (Embrapa 2018) or Ultisol (USDA 2010). Before setting up the experiment, soil samples were collected and sent to the laboratory to determine their chemical attributes (Table 1), following the methodology described by Teixeira et al. (2017).

A randomized experimental blocks design was used, in a 5 x 2 factorial arrangement, with four replications. The first factor corresponded to five levels (1.0, 2.0, 3.0, 4.0 and 5.0 dS m^{-1}) of electrical conductivity of the irrigation water (ECw) and the second comprised two cropping systems: monoculture and intercropping.

Sowing was carried out manually, placing three seeds of each crop per hole, with a depth of 10 cm and spacing of 1.0 x 0.3 m between rows and plants, respectively, thus allowing the crop to develop better.

The amount of NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$ salts used to prepare the irrigation water was arranged in such a way as to obtain a 7:2:1 ratio, following the relationship between the water's electrical conductivity and its concentration [$mmol_c$ L^{-1} = electrical conductivity (EC) x 10] (Rhoades et al. 2000). The plants were thinned out at 8 days after sowing (DAS) and irrigation began with water with different ECs.

Table 1. Chemical characteristics of the soil before the treatments.

OM[1]	N	P	K^+	Ca^{2+}	Mg^{2+}	Na^+	$H^+ + Al^{3+}$	SB[2]	PES[3]	ECse[4]	pH
g kg^{-1}		mg kg^{-1}	$cmol_c$ kg^{-1}						%	dS m^{-1}	H_2O
16.96	0.92	8.0	0.3	2.7	2.1	0.03	1.82	5.1	1.21	0.23	6.1

[1] OM: organic matter; [2] SB: sum of bases; [3] PES: percentage of exchangeable sodium; [4] ECse: electrical conductivity of the soil saturation extract.

Self-compensating 8 L h^{-1} drippers were used for irrigation, spaced at 0.3 m between plants, and the distribution uniformity coefficient assessed using the Keller & Karmelli (1975) methodology was approximately 92 %. Irrigation management was estimated using reference evapotranspiration at an irrigation frequency of two days, using data from the Class A evaporimetric tank located near the experimental area. The potential crop evapotranspiration was determined in accordance with Bernardo et al. (2019), following the equation: ETPc = ETo × Kc, where: EPTc is the potential crop evapotranspiration (mm day^{-1}), ETo the reference evapotranspiration estimated by the Class A Tank (mm day^{-1}) and Kc the crop coefficient.

The following crop coefficients (Kc) were adopted: 0.87 (from emergence to 20 days after emergence - DAE); 1.52 (from 21 to 40 DAS); 1.55 (from 41 to 60 DAS); 1.49 (from 61 to 80 DAS); and 1.38 (from 81 to 110 DAS) (Simeão et al. 2013). Each irrigation event was determined according to the quation Ti = [(ETPc x Ep)/(Ei x q)] x 60, where: Ti is the irrigation time (min); ETPc the crop evapotranspiration (mm); Ep the spacing between drippers; Ei the irrigation efficiency (0.828); and q the flow rate (8.0 L h^{-1}).

At the end of the fava bean crop cycle (110 DAS), when the pods were completely dry to obtain dry grains, the pods were collected from groups of six plants in each useful plot (central rows). The analyzed variables were: number of pods per plant - manual counting and tabulation of the number per plant; pod diameter - using a digital caliper (cm); pod length - using a graduated ruler (cm); pod mass - using a digital scale (g). The yield was estimated based on the total mass of grains harvested from the plots, adjusted to the area occupied by the plants, in kg ha^{-1}. The water-use efficiency, in kg m^{-3}, was obtained from the yield and water consumption records.

The variables assessed during the research were analyzed using the Kolmogorov-Smirnov test ($p \leq 0.05$) to assess normality. The data were submitted to analysis of variance (Anova) using the F test ($p \leq 0.05$) and the Assistat 7.7 Beta software (Silva & Azevedo 2016).

RESULTS AND DISCUSSION

The summary of the analysis of variance (Table 2) shows that, for the evaluated variables, including the number of pods, pod length, pod diameter, pod mass, yield and water-use efficiency, there was a significant interaction ($0.01 > p < 0.05$) between the factors salinity and cropping systems.

The number of pods per plant was reduced linearly with the increase in the electrical conductivity of the irrigation water in both the cultivation systems (Figure 2), where the increase in ECw from 1.0 to 5.0 dS m^{-1} led to reductions of up to 36.5 % for the monoculture and 51.2 % for the intercropping system.

The reduction in the number of pods per plant as a result of increases in ECw for both the cropping systems is related to the fact that salt stress promotes adverse conditions related to morphophysiological processes, affecting the net CO_2 assimilation and, consequently, causing early leaf senescence, reducing photosynthetic capacity to the detriment of leaf reduction, generating lower production and compartmentalization of photoassimilates, what leads to a lower capacity for pod formation (Canjá et al. 2021, Khatri & Rathore 2022).

Table 2. Summary of the analysis of variance for the variables number of pods (NP), pod length (PL), pod diameter (PD), pod mass (PM), yield and water-use efficiency (WUE) of the fava bean crop grown under monoculture and intercropping system irrigated with different electrical conductivities of the irrigation water.

Source of variation	DF	Mean square					
		NP	PL	PD	PM	Yield	WUE
Salinity (S)	4	225.03**	269.47**	2,173.81**	41.72^{ns}	2,215,482.6**	0.0992**
Residue (S)	15	20.27	9.19	47.31	55.31	16,844.1	0.0007
Cultivation system (CS)	1	105.62^{ns}	7.48^{ns}	308.54**	1.88^{ns}	291,379.1**	0.0132**
Interaction (S x CS)	4	71.43**	36.13*	2,593.41**	341.24**	1,277,749.2**	0.0545**
Residue (CS)	15	26.94	7.59	22.95	23.02	16,426.7	0.0007
CV (%) S		19.95	22.39	18.49	33.31	19.44	19.61
CV (%) CS		22.99	20.36	12.88	27.94	19.21	19.47

DF: Degrees of freedom. ^{ns}, ** and *: not significant and significant at 1 and 5 % of probability, respectively, by the F test.

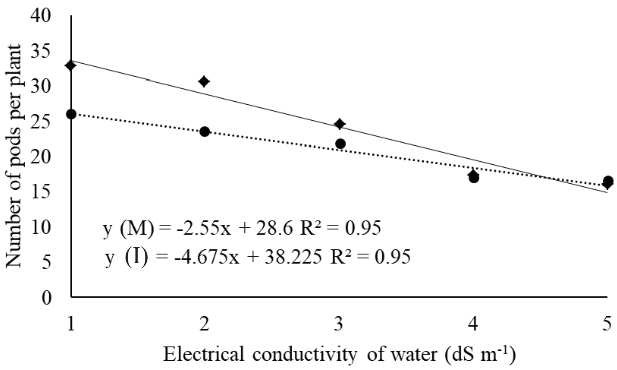

Figure 2. Number of pods per plant of the fava bean crop grown under monoculture (M) and intercropping (I) system irrigated with different electrical conductivities of the irrigation water.

A study carried out by Sousa et al. (2023) under field conditions with peanut crop in a monoculture system also recorded a significant reduction in the number of pods as the electrical conductivity of the irrigation water increased. In pot conditions, Oliveira et al. (2015), working with cowpea under monoculture, found that from the ECw of 2.1 dS m^{-1} there was a linear decrease in the number of pods per plant.

For the pod length variable (Figure 3) obtained in the consortium system, there was a significant decrease in the order of 61.1 %, when comparing the ECw of 1.0 dS m^{-1} to that of 5.0 dS m^{-1}. For the fava bean grown under monoculture, the quadratic polynomial model was the one that best fitted the data, with a maximum pod length of 19.03 cm when the ECw reached 1.71 dS m^{-1}.

Under conditions of salt stress, reductions in production components such as pod length may be related to the plants response to absorb less water as a defense strategy, since potentially toxic ions (Na^+ and Cl^-) promote disturbances in the plant metabolism (Munns & Gilliham 2015, Lima et al. 2020a).

It can be seen that satisfactory results were obtained for the fava bean grown under monoculture up to an ECw of 1.71 dS m^{-1}. It should be noted that the salinity threshold for fava bean crops is based on the electrical conductivity of the soil saturation extract of 1.6 dS m^{-1}. From this point onwards, as shown in this study, there is a linear reduction in the crop performance, what is in line with a previous finding by Mass & Hoffman 1977.

Similarly to what was found in this study, Goes et al. (2021b), investigating the peanut crop under monoculture irrigated with saline water of 4.0 dS m^{-1}, also detected a reduction in pod length.

With the increase in the electrical conductivity of the irrigation water, the pod diameter of the fava bean plants grown in consortium was reduced linearly, with decreases of up to 76.6 %, when comparing the control treatment with the ECw of 5.0 dS m^{-1} (Figure 4). For the single crop, the model that best fitted the data was the quadratic polynomial one, in which the ECw of 1.76 dS m^{-1} promoted the maximum pod diameter, reaching 22.2 mm.

Reductions in pod diameter caused by salt stress are the result of morphophysiological changes that tend to occur as a strategy to acclimatize the plant to the stress condition it is subjected to, including influencing the formation of pods, as well as a

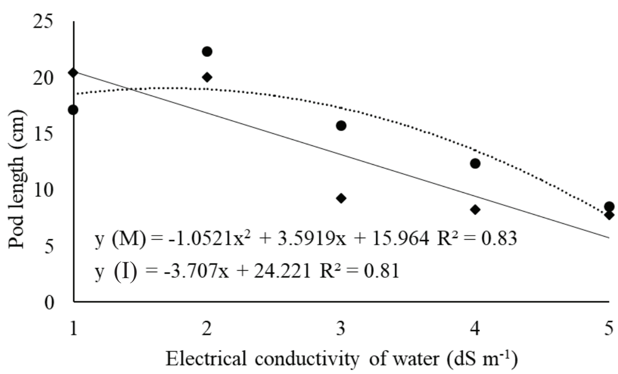

Figure 3. Pod length of the fava bean crop grown under monoculture (M) and intercropping (I) system irrigated with different electrical conductivities of the irrigation water.

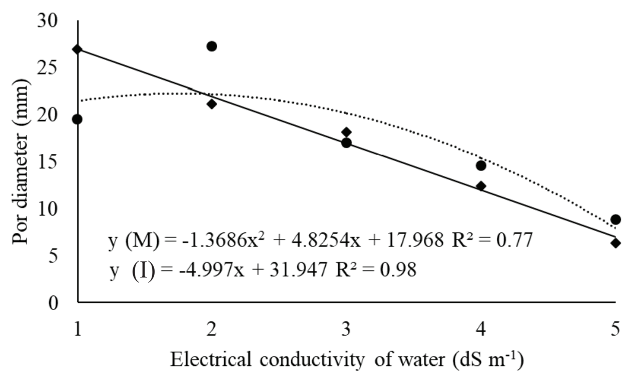

Figure 4. Pod diameter of the fava bean crop grown under monoculture (M) and intercropping (I) system irrigated with different electrical conductivities of the irrigation water.

reduction in their diameter (Khatri & Rathore 2022, Sousa et al. 2023).

Similar results were obtained by Sousa et al. (2023), in which the diameter of peanut pods grown under monoculture was reduced as the ECw increased, where the obtained averages were 12.35 and 11.94 mm for the 0.8 and 4 dS m^{-1} levels, respectively, corresponding to a reduction of 3.32 %. In contrast, Canjá et al. (2021) obtained a 4.64 % increase in the diameter of peanut pods, when comparing the ECw of 5.0 dS m^{-1} with the control (0.9 dS m^{-1}).

The continuous increase in the electrical conductivity of the irrigation water led to a linear reduction in pod mass in the intercropping system of 34.2, 60.3, 68.2 and 73.1 %, when using the ECw of 2.0, 3.0, 4.0 and 5.0 dS m^{-1}, respectively, if compared to the control treatment (1.0 dS m^{-1}). For the monoculture system, the maximum pod mass (57.45 g) was obtained when using the ECw of 1.4 dS m^{-1}, reducing by 73.3 % when irrigated with the ECw of 5.0 dS m^{-1} (Figure 5).

Salt stress not only reduces pod formation, but also grain filling, possibly due to the deleterious effect of the high concentration of salts, which interferes with the flow of water in the plant, translocation of photoassimilates and absorption of essential elements such as potassium (Taiz et al. 2017, Canjá et al. 2021).

It is worth noting that the negative effect of salinity on pod mass in peanut plants irrigated with brackish water was reported by Sousa et al. (2023). Similarly, Lima et al. (2020b), using brackish water during the fruiting phase of the sesame crop under monoculture, also found a negative effect on pod mass.

For the yield variable (Figure 6) obtained in the consortium system, there were decreases in the order of 40.1, 59.5, 69.3 and 83.5 % for the waters with ECw of 2.0, 3.0, 4.0 and 5.0 dS m^{-1}, respectively, when compared with the ECw of 1.0 dS m^{-1}. Growing fava bean under monoculture and irrigated with ECw of 1.05 dS m^{-1} led to the maximum yield of 1,690.13 kg ha^{-1}, while increasing the ECw to 5.0 dS m^{-1} reduced the crop yield by 79.5 %.

It is important to note that, in absolute terms of production, up to ECw levels of 4.0 dS m^{-1}, the yields obtained in the two studied systems are above the national average of 315 kg ha^{-1} (IBGE 2021), showing the important benefit of irrigation for agriculture, even with inferior quality water (Cavalcante et al. 2021).

Under saline conditions, glycophyte plants often expend energy and metabolic resources in an attempt to adapt to the increased saline stress. In addition, high salinity water reduces the water absorption capacity and the nutritional imbalance caused by the excess of salts in the soil solution, what can antagonize the absorption of essential nutrients for crops such as nitrogen and potassium and reduce their yield (Lima et al. 2020a, Costa et. al. 2022, Sousa et al. 2022).

In contrast to the results obtained in this study, Araújo et al. (2021), working with a consortium between cowpea and corn, found that the effects of salts on plant yield were more significant in plants under monoculture, especially for the cowpea crop. According to the authors, the microclimatic

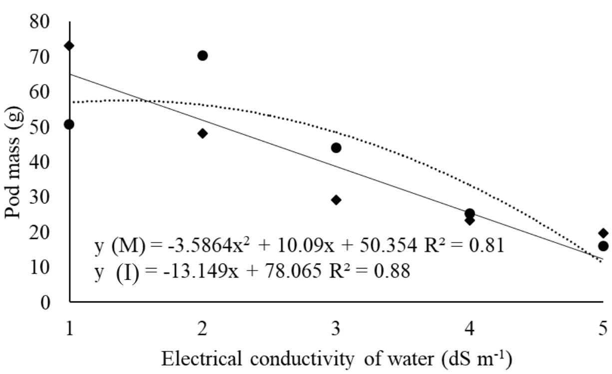

Figure 5. Pod mass of the fava bean crop grown under monoculture (M) and intercropping (I) system irrigated with different electrical conductivities of the irrigation water.

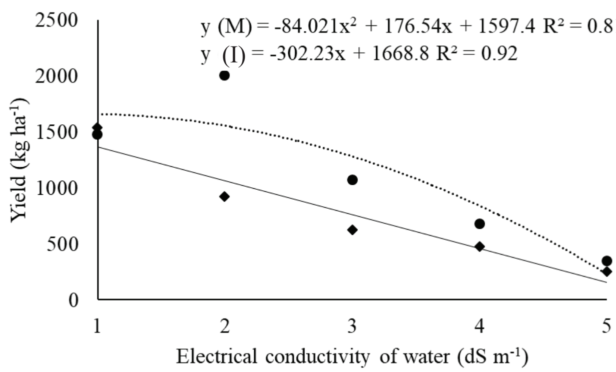

Figure 6. Yield of the fava bean crop grown under monoculture (M) and intercropping (I) system irrigated with different electrical conductivities of the irrigation water.

conditions of the consortium system may have contributed to reducing the influence of salinity on yield, especially for the string bean crop.

Neves et al. (2015), working with the cowpea crop, found restrictions in yield when irrigation with saline water was used throughout the crop cycle. A reduction in yield with an increase in the electrical conductivity of the irrigation water was also obtained by Goes et al. (2021b), working with peanut crop irrigated with water of increasing salinity (1.0 and 4.0 dS m^{-1}).

The continuous increase in the electrical conductivity of the irrigation water caused linear reductions in the water-use efficiency (Figure 7) of 28.1, 56.3, 70.3 and 79.7 %, when using ECw of 2.0, 3.0, 4.0 and 5.0 dS m^{-1}, respectively, if compared to the control treatment (1.0 dS m^{-1}), in the cultivation of fava bean in consortium. For the intercropping system, the quadratic polynomial model was the one that best fitted the data, while the maximum water-use efficiency (0.43 kg m^{-3}) was obtained when using the ECw of 1.08 dS m^{-1}, reducing by 79.1 % when irrigated with the ECw of 5.0 dS m^{-1}.

It can be seen that the negative effects of salinity were significant on both the yield and water-use efficiency, due to the reductions found, demonstrating the harmful effects of salinity, possibly associated with a reduction in the plants' osmotic potential, resulting in lower water absorption due to insufficient suction pressure to overcome osmotic pressure (Taiz et al. 2017, Sousa et al. 2023).

It should also be noted that the lowest water-use efficiency was obtained in the consortium treatment, what is justified by the fact that this treatment received a greater (11.0 %) water input from the irrigation water, when compared to the other treatments. This is due to the fact that the demand for water in an intercropping system can be higher if compared to a monocropping system, as previously demonstrated for corn intercropped with cowpea (Araújo et al. 2021), thus contributing to the greater presence of salts in the plants' root zone, reducing yield and, consequently, water-use efficiency.

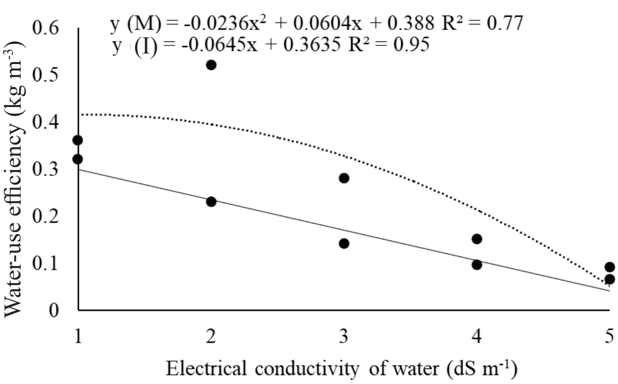

Figure 7. Water-use efficiency of the fava bean crop grown under monoculture (M) and intercropping (I) system irrigated with different electrical conductivities of the irrigation water.

Working with the peanut crop under field conditions, Sousa et al. (2023) obtained a lower water-use efficiency as the ECw increased from 0.8 to 4.0 dS m^{-1}. Canjá et al. (2021), working with the BR-1 peanut crop under pot conditions, obtained similar results to the present study, with a reduction in the water-use efficiency as the ECw increased.

CONCLUSIONS

1. Salt stress negatively affects the number of pods, but, under low salinity conditions (1.0 dS m^{-1}), there is less intensity for the fava bean and maize intercropping system;
2. The increase of salts in the irrigation water reduces the pod length, diameter and mass, yield and water-use efficiency, being less affected in the monoculture system when irrigated up to moderate electrical conductivity of the irrigation water levels (3.0 dS m^{-1}).

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