Journal of Agricultural Science; Vol. 11, No. 3; 2019
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Biomass Accumulation and Growth of Common Bean Plants Under Water and Salt Stresses

Gustavo da S. Vieira[1], Fernando R. Cabral Filho[1], Fernando N. Cunha[1], Carlos R. Rodrigues[1], Marconi B. Teixeira[1], Tatiana M. Rodrigues[1], Samara S. Viana[1], Vitor M. Veneziano[1], Renato G. Guimarães Júnior[1], Frederico A. L. Soares[1], Cicero T. S. Costa[1] & Vitória R. de C. Martins[1]

[1] Center of Agricultural Sciences, Federal Institute of Goiás (Instituto Federal Goiano-IF Goiano), Campus Rio Verde, Goiás, Brazil

Correspondence: Fernando N. Cunha, Center of Agricultural Sciences, Instituto Federal Goiano, Campus Rio Verde, Goiás, Brazil. Tel: 55-64-3620-5600. E-mail: fernandonobrecunha@hotmail.com

Received: November 18, 2018 Accepted: December 26, 2018 Online Published: February 15, 2019

doi:10.5539/jas.v11n3p350 URL: https://doi.org/10.5539/jas.v11n3p350

Abstract

When it is said about quality and quantity of water supplied through irrigation, for common bean cultivation, it is considered sensitive to water and saline stress. The objective of this work was to evaluate the biomass accumulation and growth of common bean plants (*Phaseolus vulgaris* L.) subjected to irrigation with different water depths, using water with different electrical conductivities. The experiment was carried out in pots under a protected environment located in an experimental area of the Federal Institute of Goiás, Rio Verde Campus, in the city of Rio Verde, Goiás. The design was a randomized complete block design in a 4 × 2 factorial scheme with three replications. 25, 50, 75 and 100% of the evapotranspiration of the crop, and two types of electrical conductivity of irrigation water equal to 0.6 and 3.0 dS m^{-1}. All variables were analyzed using the SISVAR® software, whose mean values for the electrical conductivity treatments were compared by Tukey test at 0.05% probability and water replacement by regression analysis, when significant. The use of irrigation water with electrical conductivity of 3 dS m^{-1} reduces plant height, number of green leaves and stem diameter at 35 days after sowing, thus reducing dry biomass accumulation and aerial part water accumulation at 20 and 70 days after sowing. The deleterious effects under the dry mass of the aerial part at 70 days after sowing, when using an electrical conductivity of 3 dS m^{-1}, are accentuated by the increase of the water dephts.

Keywords: *Phaseolus vulgaris* L., water dephts, salinity

1. Introduction

The common bean crop (*Phaseolus vulgaris* L.) is one of the most traditional foods, with significant social and economic importance, moreover, is the most important crop legume for human consumption, accounting for 50% of the grain legumes consumed worldwide (Bastos et al., 2016; Ayra et al., 2018). Brazil stands out as the largest producer and consumer of beans in the world (Bastos et al., 2016).

Environmental stresses and climate change impact agricultural production and the food supply and are the primary causes of crop losses (Bray et al., 2000; Bisbis et al., 2018); between environmental stresses stands out water deficit that is one of the main causes of reduced yields, especially when it occurs in three critical stages, which are germination, flowering, and grain filling, leading to low grain yield (Soratto et al., 2003; Carvalho et al., 2014).

The bean also is extremely salt sensitive species, suffers yield losses even at soil salinity of less than 2 dSm^{-1} (Pessarakli,1999), so salinity is a serious problem to crop production since it affects around 30% of the arable land worldwide (Mahajan & Tuteja, 2005).

Salinization reduces the productivity of various crops, due to morphological changes caused by saline solutions, such as a reduction in germination, and in the vegetative growth attributed to osmotic stress (Machado et al., 2007; Andréo-Souza et al., 2010; Saeidi-Sar et al., 2013); consequently the salinity affects plant physiology through changes of water and ionic status in the cells because of ionic imbalance due to excessive accumulation of Na and Cl and reduced uptake of other mineral nutrients, such as K, Ca and Mg (Pessarakli, 1999; Hasegawa et al., 2000; Aydin et al., 2012).

The combination of suitable cultivars, use of modern irrigation systems and optimization of cultivation management practices can improve cost-effectiveness and minimize problems of water shortages with a particular emphasis on sustainable resource management and environmental protection (Saleh et al., 2018).

The objective of this work was to evaluate the biomass accumulation and growth of common bean plants (*Phaseolus vulgaris*) subjected to irrigation with different water depths, using water with different electrical conductivities.

2. Materials and Methods

The experiment was conducted in a protected environment at the experimental area of the Federal Institute of Goiás, Rio Verde campus, Rio Verde, Goiás, Brazil (17°48′28″ S, 50°53′57″ W, and average elevation of 720 m). The climate of the region is Aw, with dry winter and rainy summer, according to the Köppen classification (Alvares et al., 2013), presenting annual average temperature of 20 to 25 °C, and annual rainfall above 1500 mm. The soil was characterized as Red Oxisol of Cerrado (savannah) phase (Embrapa, 2013).

A randomized block design was used, with three replications, and a 4 × 2 factorial arrangement consisting of four water depths (WD) (25, 50, 75, and 100% of the crop evapotranspiration), and two salt concentrations (EC) (electrical conductivities of 0.6 dS m^{-1} and 3.0 dS m^{-1}).

The water depths were calculated using 4 electronic weighing lysimeters with 2 different dimensions: area of 0.502 m^2 and volume of 0.377 m^3 (lysimeters 1 and 4), and area of 0.385 m^2 and volume of 0.289 m^3 (lysimeters 2 and 3). Data were collected using a datalogger (CR 1000, Campbell Scientific Ltd, Edmonton, Canada).

The irrigation was performed using a drip irrigation system equipped with pressure-compensating emitters (Click Tif-PC) coupled to a low-density 16-mm polyethylene hose, with water pressurized by a motor pump using a flow rate of 2.0 L h^{-1}. The water was distributed by 2 main lines with individual supplying systems; one conducting water with electrical conductivity (EC) of 0.6 dS m^{-1}, and other with EC of 3.0 dS m^{-1}. Irrigation using water with EC of 0.6 dS m^{-1} was performed first, followed by irrigation with water of higher EC (3.0 dS m^{-1}).

The EC were obtained by adding sodium chloride (NaCl) to the irrigation water until reaching the expected EC, using the equation $NaCl = 640 \times (ECt - ECi)$ proposed by Richards (1954), where, $NaCl$ is the amount of NaCl (mg L^{-1}) required to raise the EC of the water, ECt is the water electrical conductivity (dS m^{-1}) of the treatment; and ECi is the initial water electrical conductivity (dS m^{-1}) before the addition of the NaCl. A portable digital conductivity meter was used to measure the conductivities.

Common bean (*Phaseolus vulgaris*) seeds were sown in 50-liter pots. Organic matter from bovine manure (2%), monoammonium phosphate (MAP), and boric acid were incorporated into the soil before sowing the common bean seeds, based on recommendations of Sousa and Lobato (2004), and soil chemical analysis. The moisture of the soil in the pots and lysimeters was set to field capacity. Twelve common bean seeds (cultivar Carioca BRS Estilo) were planted per pot/lysimeter. The treatments (WD and EC) were applied at 10 days after sowing (DAS), when 80% of germination had occurred.

Plant height (PH), stem diameter (SD), number of green leaves (NGL), number of leaves (NL), leaf area (LA), and number of internodes (NI) at 35 DAS were evaluated. PH, SD, NGL, and NL were evaluated again at 70 DAS. Shoot fresh and dry weights, root fresh and dry weights, shoot water weight, root water weight, and total water weight were evaluated at 20 DAS. The plant stem dry weight, and leaf dry weight were evaluated at 70 DAS.

Leaf area was calculated using the equation described by Figueiredo et al. (2012), $\sum LA = 0.575 \times (L \times W)$, where, LA is the leaf area of all green leaves (cm^2), L is the mean leaf length (cm), and W is the mean leaf width (cm).

The plants were thinned, placed in identified paper bags (treatments) and taken to a forced-air circulation oven at 65 ºC for 72 hours to determine their dry weights, using a precision analytical balance with resolution of 0.001 g.

The data were subjected to analysis of variance, and significant means were compared by the Tukey's test at 0.05% of probability (electrical conductivity treatments) and by regression analysis (water depth treatments). All analyses were performed using the SISVAR® program (Ferreira, 2011).

3. Results and Discussion

The electrical conductivity (EC) affected significantly the stem diameter (SD) at 35 and 70 days after sowing (DAS), and the plant height (PH) at 35 DAS (Table 1).

Table 1. Analysis of variance for plant height (PH) and stem diameter (SD) at 35 and 70 days after sowing (DAS), and number of internodes (NI) at 35 DAS of common bean plants as a function of water depths (WD) and electrical conductivities (EC) of the irrigation water

Source of variation	DF	Mean square				
		PH		SD		NI
		35 DAS	70 DAS[1]	35 DAS	70 DAS	35 DAS
Block	2	13.83^{ns}	0.53^{ns}	0.25^{ns}	0.21^{ns}	0.51^{ns}
WD	3	36.77^{ns}	2.05^{ns}	0.46^{ns}	0.20^{ns}	0.98^{ns}
EC	1	1714.50**	2.48^{ns}	5.00**	3.35*	7.31^{ns}
WD × EC	3	39.12^{ns}	0.29^{ns}	0.10^{ns}	0.37^{ns}	0.02^{ns}
Residue	14	51.64^{ns}	2.05^{ns}	0.23^{ns}	0.27^{ns}	1.92^{ns}
CV (%)		18.19	18.89	9.90	9.56	21.15

Note. ** Significant at 0.01 of probability, * significant at 0.05 of probability, ^{ns} not significant by the F test; degree of freedom (DF); coefficient of variation (CV). [1]Data transformed into X-Root.

The water depths (WD) affected significantly the number of green leaves (NGL) at 35 DAS (Table 2). Beckmann-Cavalcante et al. (2008) observed that for all the parameters adopted for plant evaluation, the variance analyses show significant differences as among saline levels such as between bean species, for all variables studied.

Table 2. Analysis of variance for number of green leaves (NGL) at 35 and 70 days after sowing (DAS), number of leaves (NL) at 70 DAS, and leaf area (LA) at 35 DAS of common bean plants as a function of water depths (WD) and electrical conductivities (EC) of the irrigation water

Source of variation	DF	Mean square			
		NGL		NL	LA
		35 DAS	70 DAS[1]	70 DAS[1]	35 DAS[1]
Block	2	2.84^{ns}	1.15^{ns}	0.87^{ns}	0.01^{ns}
WD	3	642.39**	1.69^{ns}	0.56^{ns}	0.00^{ns}
EC	1	1528.01**	3.13^{ns}	4.45^{ns}	0.00^{ns}
WD × EC	3	252.03^{ns}	0.54^{ns}	1.24^{ns}	0.01^{ns}
Residue	14	100.51^{ns}	1.51^{ns}	1.45^{ns}	0.00^{ns}
CV (%)		24.42	19.86	22.27	17.16

Note. ** Significant at 0.01 of probability, * significant at 0.05 of probability, ^{ns} not significant by the F test; degree of freedom (DF); coefficient of variation (CV). [1]Data transformed into X-Root.

The number of leaves and leaf size are important to determine the leaf area (LA); the LA was not affected by the EC of the irrigation water, despite of differences in NGL. According to Figueiredo et al. (2012), leaf length and width are adequate variables to estimate the LA of common bean (*Phaseolus vulgaris* cv. Pérola).

The salinity of the irrigation water (0.6, and 3.0 dS m^{-1}) reduced the SD at 35 and 70 DAS in 0.91 and 0.75 mm, resulting in decreases of 17% and 13%, respectively (Table 3); and the PH (16.9 cm) and NGL (15.96) at 35 DAS, resulting in decreases of 35% and 33%, respectively (Table 3). According to Assimakopoulou et al. (2015) the main effect of NaCl imposition on plant growth parameters was that plants under 75 mM NaCl presented significantly decreased values as compared to those of plants without NaCl imposition.

Table 3. Stem diameter (SD) at 35 and 70 days after sowing (DAS), plant height (PH) and number of green leaves (NGL) at 35 DAS of common bean plants as a function of electrical conductivities (EC) of the irrigation water

EC[1] (dS m^{-1})	SD (mm)		PH (cm)	NGL
	35 DAS	70 DAS	35 DAS	
0.60	5.34a	5.81a	47.95a	49.04a
3.00	4.43b	5.06b	31.05b	33.08b

Note. [1]Means followed by different letters, lowercase in the column, differ by Tukey test ($p < 0.05$).

Oliveira et al. (2016) found decreases in SD in popcorn maize irrigated with salt water (4.5 dS m^{-1}). According to Andrade Júnior et al. (2011), salinity affects water absorption by plants and plant growth because of the decreased water potential of the soil solution caused by the Na^+ and Cl^- ions.

Each increase of 25% of the crop evapotranspiration in the water depth increased, on average, 19.83% in NGL, representing 7.41 leaves (Figure 1). The WD of 25%, and 100% of the crop evapotranspiration (ETc) resulted in the lowest NGL (30), and in the highest NGL (52), respectively.

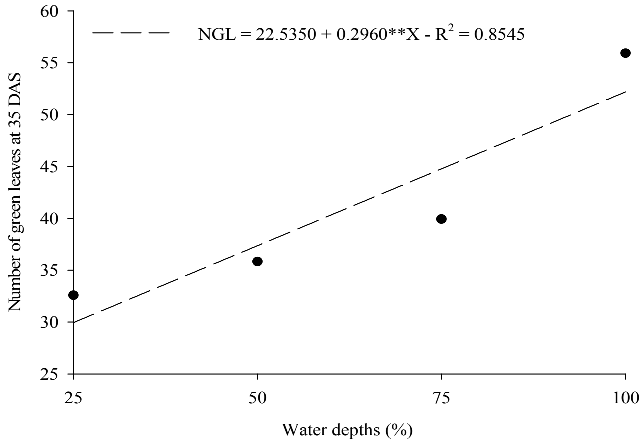

Figure 1. Number of green leaves (NGL) of common bean plants at 35 days after sowing (DAS) as a function of water depths (WD)

Note. ** F value significant at 1% of probability.

Decreases in NGL of plants due to water stress are expected due to physiological adjustments of the plants when transpiration rate of leaves is greater than the capacity of the plant to absorb water from the soil or, in this case, because of the low water availability. Gomes et al. (2000) evaluated the response of several common bean cultivars grown under water stress and found decreases in shoot biomass, development of productive components, and growth rate.

The planning of common bean crops in regions with water deficit, or varied and not well-distributed rainfall is important. Soybean and maize crops in Goiás, Brazil, for example, are less sensitive to water deficit than common bean crops (Viçosi et al., 2017).

The WD had no significant effect on shoot fresh weight (SFW), shoot dry weight (SDW), root fresh weight (RFW), root dry weight (RDW), shoot water weight (SWW), root water weight (RWW), and total water weight (TWW) at 20 DAS (Table 4). The shoot of the plants was significantly affected by the EC at 20 DAS.

Table 4. Analysis of variance for shoot fresh weights (SFW), root fresh weights (RFW), shoot dry weights (SDW), root dry weights (RDW), shoot water weight (SWW), root water weight (RWW) and total water weight (TWW) of common bean plants at 20 days after sowing as a function of water depths (WD) and electrical conductivities (EC) of the irrigation water

SV	DF	Mean square						
		SFW	RFW	SDW	RDW	SWW	RWW	TWW
Block	3	24.18^{ns}	3.60^{ns}	1.02^{ns}	0.04^{ns}	16.12^{ns}	2.79^{ns}	25.40^{ns}
WD	1	734.05^{ns}	1.63^{ns}	5.79^{ns}	0.03^{ns}	609.13^{ns}	2.79^{ns}	694.34^{ns}
EC	2	69.79^{**}	0.75^{ns}	0.03^{**}	0.00^{ns}	66.57^{**}	1.63^{ns}	110.62^{**}
WD × EC	3	69.44^{ns}	4.54^{ns}	0.92^{ns}	0.06^{ns}	57.69^{ns}	2.10^{ns}	69.38^{ns}
Residue	14	41.03	0.96	0.53	0.01	36.26	1.06	41.83
CV (%)		17.04	14.5	17.18	16.74	18.05	17.16	16.55

Note. [1] ** Significant at 0.01 of probability, * significant at 0.05 of probability, ^{ns} not significant by the F test; source of variation (SV); degree of freedom (DF); coefficient of variation (CV).

The EC of the irrigation water reduced the SFW, SDW, SWW, and TWW at 20 DAS in 11, 1, 10, and 11 g plant^{-1}, resulting in decreases of 26%, 21%, 26%, and 24%, respectively (Table 5). These decreases are due to morphological changes during germination and initial development of the plants when salt solutions are used (Saeidi-Sar et al., 2013; Guilhen et al., 2016).

Table 5. Means test for shoot fresh weights (SFW), root fresh weights (RFW), shoot dry weights (SDW), root dry weights (RDW), shoot water weight (SWW), root water weight (RWW) and total water weight (TWW) of common bean plants at 20 days after sowing as a function electrical conductivities (EC) of the irrigation water

EC (dS m^{-1})	SFW	RFW	SDW	RDW	SWW	RWW	TWW
	-- g --						
0.60	43.11a	6.70a	4.71a	0.65a	38.40a	6.05a	44.45a
3.00	32.05b	6.17a	3.73b	0.54a	28.32b	5.37a	33.69b

Note. [1]Means followed by different letters, lowercase in the column, differ by Tukey test ($p < 0.05$).

Roots of common bean plants are more tolerant to salinity than their shoots because roots have faster osmotic adjustments and slower turgor loss (Oliveira et al., 2016).

The treatments affected the stem and leaf biomass accumulation of the plants; the interaction between WD and EC was significant for stem (StDW), leaf (LDW), and total (TDW) dry weights (Table 6).

Table 6. Analysis of variance for stem dry weight (StDW), leaf dry weight (LDW) and total dry weight (TDW) of common bean plants at 70 days after sowing (DAS) as a function of water depths (WD) and electrical conductivities (EC) of the irrigation water

SV	DF	Mean square		
		StDW	LDW	TDW
Block	3	5.12^{ns}	3.69^{ns}	5.94^{ns}
WD	1	109.78^{ns}	47.74^{ns}	302.11^{ns}
EC	2	4.10^{ns}	1.95^{ns}	11.52^{ns}
WD × EC	3	9.89ns*	10.63**	40.29**
Residue	14	1.82	0.96	2.51
CV (%)		16.38	16.36	11.15

Note. [1] ** Significant at 0.01 of probability, * significant at 0.05 of probability, ^{ns} not significant by the F test; source of variation (SV); degree of freedom (DF); coefficient of variation (CV).

Each increase of 25% in the WD resulted in average increases of 9.25% in StDW when using the EC of 0.6 dS m^{-1}, representing 1.12 g plant^{-1} (Figure 2A). These increases in WD decreased the StDW in approximately 10% (0.73 g plant^{-1}) when using the EC of 3 dS m^{-1}. The StDW response to EC was not significant when using the WD of 25% and 50% (Figure 2B); the EC of 3 dS m^{-1} combined with the WD of 75% and 100% decreased the StDW in 46% and 62%, respectively.

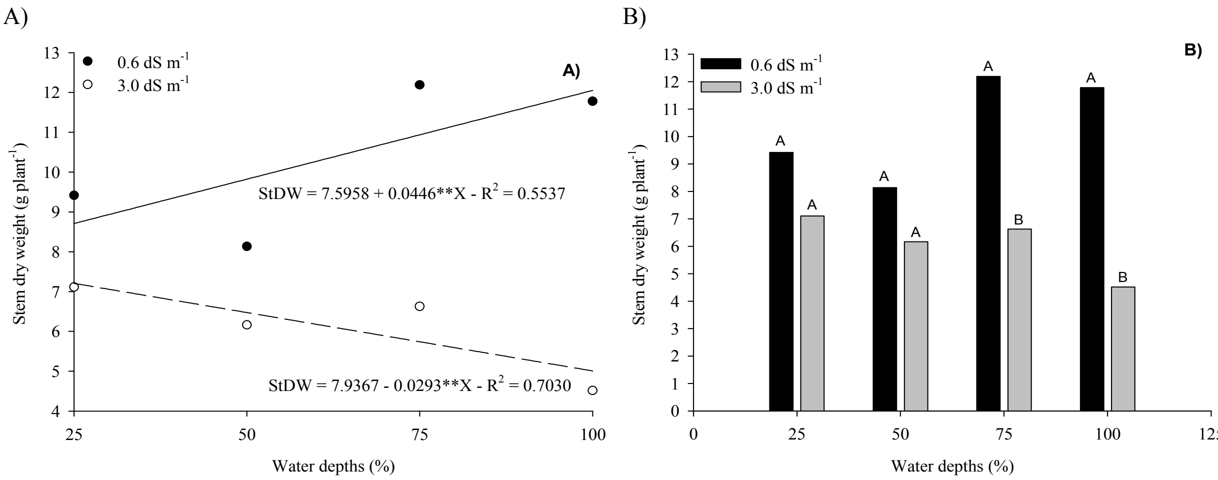

Figure 2. Stem dry weight of common bean plants at 70 days after sowing (DAS) as a function of water depths (A) and electrical conductivities (B) of the irrigation water

Note. ** F value significant at 1% of probability.

Oliveira et al., (2016) found decreases in stem, leaf, root, and total dry weights in popcorn maize irrigated with salt water (4.5 dS m^{-1}).

The lowest LDW (5.88 g $plant^{-1}$) and TDW (15.13 g $plant^{-1}$) were found when using WD of 41% and EC of 0.6 dS m^{-1} (Figure 3a and 4a); WD above 41% increased the LDW and TDW, on average, in 9.25% and 10.8%, respectively. The increases in WD decreased the LDW in 9.26% (0.49 $plant^{-1}$) and the TDW in 9.81% (1.23 g $plant^{-1}$) when using the EC of 3 dS m^{-1}.

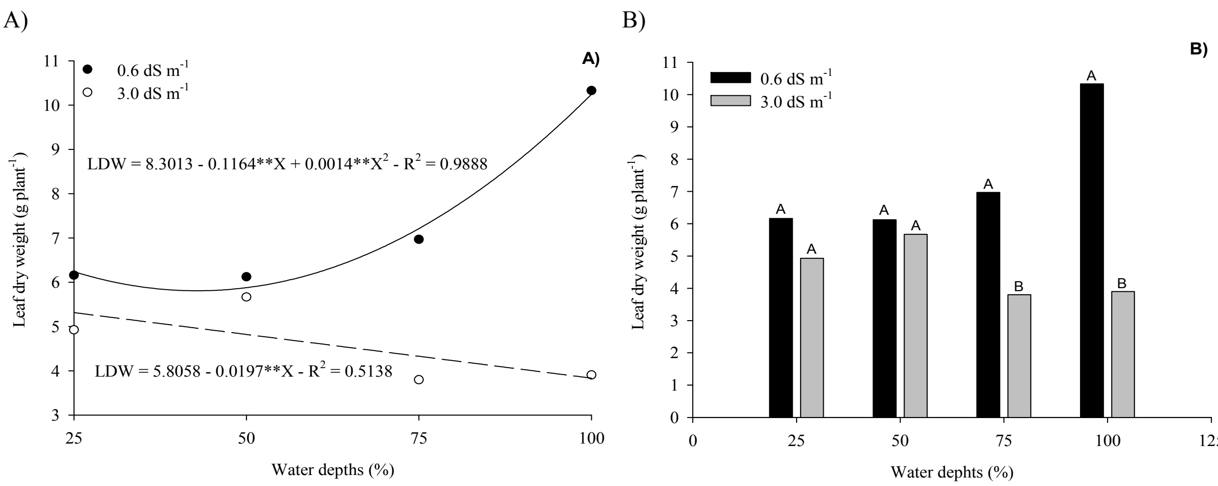

Figure 3. Leaf dry weight of common bean plants at 70 days after sowing (DAS) as a function of water depths (A) and electrical conductivities (B) of the irrigation water

Note. ** F value significant at 1% of probability.

According to Stoeva and Kaymakanova (2008) in case of salt treatment with 50 mM NaCl and Na_2SO_4, the inhibition of the fresh and dry biomass was within the limits of 17-3%.

The EC did not affect the LDW when using the WD of 25% and 50%. However, the WD of 75% and 100% combined with the EC of 3 dS m^{-1} decreased the mean LDW of 46% and 62%, respectively (Figure 3B).

The EC did not affect the TDW only when using the WD of 50%. The WD of 25%, 75%, and 100% combined with the EC of 3 dS m^{-1} decreased the mean TDW in 24%, 46%, and 62%, respectively (Figure 4B).

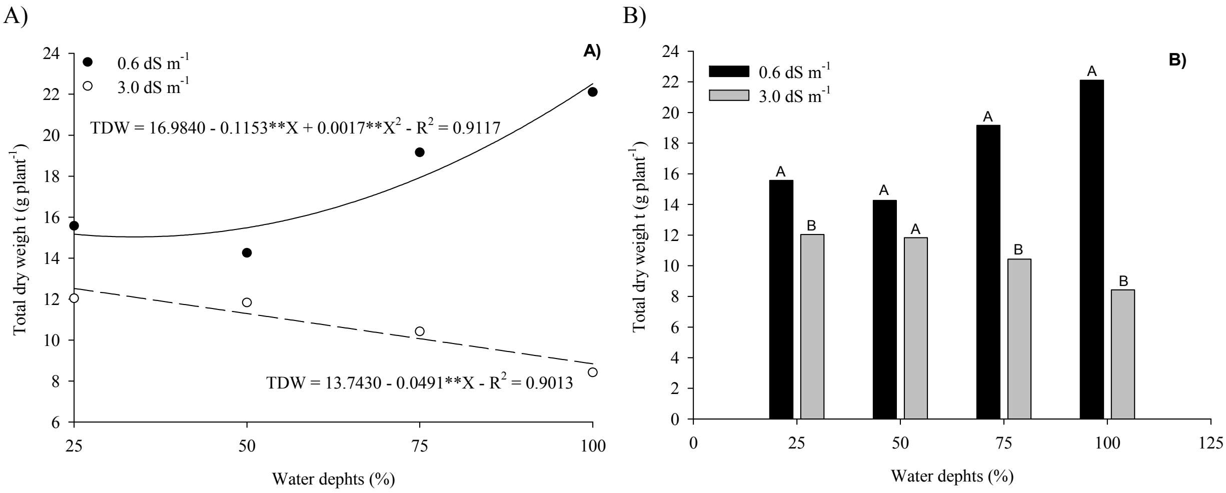

Figure 4. Total dry weight of common bean plants at 70 days after sowing (DAS) as a function of water depths (A) and electrical conductivities (B) of the irrigation water

Note. ** F value significant at 1% of probability.

Overall, the variations in LDW were highly correlated to the final TDW when plants were subjected to water stress, in both salinities (Figure 3A and 4A).

The decreases in StDW, LDW, and TDW with increasing WD in the treatment with EC of 3 dS m^{-1} can be explained by the high supply of salts (NaCl) due to the high amount of water applied to the plants, which increased the deleterious effects of salinity.

Gomes et al. (2000) evaluated the responses of several common bean cultivars to water stress and found reductions in shoot weight, productive components, and growth rate.

Decreases in StDW, LDW, and consequently, in total shoot dry weight of common bean plants subjected to salt stress (EC of 3 dS m^{-1}) occur, partly because of a redistribution of the plant's energy due to the soil salinity, i.e., due to a metabolic energy cost (Garcia et al., 2007). According to Taiz and Zeiger (2017), plant dry matter accumulation decreases when the plant is subjected to salt stress.

In general, effects of salt stress on plants are associated with osmotic, toxic, and nutritional processes, and result in early senescence of leaves and, consequently, in a decreased net photosynthesis, and losses in dry biomass accumulation that could be redistributed for grain production and filling (Silva et al., 2013).

4. Conclusion

The common bean plants evaluated were sensitive to irrigation with salt water with electrical conductivity (EC) of 3 dS m^{-1}, with decreases of up to 35% in stem diameter, plant height, and number of leaves.

The use of irrigation water with EC of 3 dS m^{-1} decreases shoot dry weight, and water accumulation in common bean plants at 20 days after sowing (DAS). Moreover, common bean plants present decreases in stem dry weight, leaf dry weight, and total dry weight at 70 DAS.

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