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PRODUCTION COMPONENTS OF *Vigna unguiculata* (L. Walp) IRRIGATED WITH BRACKISH WATER UNDER DIFFERENT LEACHING FRACTIONS[1]

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ABSTRACT - The objective of this work was to evaluate the production components of cowpea (*Vigna unguiculata* L. Walp) subjected to irrigation with brackish water and different leaching fractions. The experiment was conducted in a lysimeter system of the Department of Agricultural Engineering of the Federal Rural University of Pernambuco, Recife campus. The treatments, consisting of two water salinity levels (ECw) (1.2 and 3.3 dS m^{-1}) and five leaching fractions (0, 5, 10, 15 and 20%), were evaluated using a completely randomized design in a 2x5 factorial arrangement with four replications. The variables evaluated were: number of pods per plant, 100-grain weight, number of grains per pod, grain and shoot dry weight, grain yield and harvest index. The soil salinity increased with increasing salinity of the water used for irrigation, and reduced with increasing leaching fraction. The salinity of the water used for irrigation influenced only the variables number of pods per plant and grain yield. The estimated leaching fractions of 9.1% and 9.6% inhibited the damage caused by salinity on the number of pods per plant and grain yield, respectively. Therefore, the production of *V. unguiculata* irrigated with brackish water, leaching salts from the plant root environment, is possible under the conditions evaluated.

Keywords: Cowpea. Yield. Water salinity. Irrigation management.

COMPONENTES DE PRODUÇÃO DE *Vigna unguiculata* (L. Walp) IRRIGADO COM ÁGUA SALOBRA SOB FRAÇÕES DE LIXIVIAÇÃO

RESUMO - Objetivou-se, com este trabalho, avaliar os componentes de produção do feijão-caupi (*Vigna unguiculata*) submetido à irrigação com água salobra e frações de lixiviação. O estudo foi conduzido em sistema de lisimetria no Departamento de Engenharia Agrícola da Universidade Federal Rural de Pernambuco, Campus Recife. Os tratamentos consistiram em dois níveis de salinidade da água (CEa - 1,2 e 3,3 dS m^{-1}) e de cinco frações de lixiviação (0, 5, 10, 15 e 20%), em delineamento inteiramente casualizado em esquema fatorial 2 x 5, com quatro repetições. As variáveis avaliadas foram: número de vagens por planta, massa de 100 grãos, número de grãos por vagem, biomassa seca de grãos e da parte aérea, produtividade de grãos e índice de colheita. A salinidade do solo aumentou com a salinidade da água de irrigação, mas foi reduzida com a fração de lixiviação. Exceto o número de vagens por planta e a produtividade de grãos, as demais variáveis não foram influenciadas pelas salinidades da água de irrigação. As frações de lixiviação estimadas de 9,1 e 9,6% inibem os danos provocados pela salinidade sobre o número de vagens por planta e produtividade de grãos, respectivamente. Nas condições estudadas, é possível se produzir feijão-caupi irrigado com água salobra sob lixiviação de sais do ambiente radicular das plantas.

Palavras-chave: Feijão-caupi. Rendimento. Salinidade da água. Manejo da irrigação.

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INTRODUTION

Cowpea (*Vigna unguiculata* L. Walp) is the main legume grown in the Northeast region of Brazil and part of the diet of most families in this region. It is a rich source of protein and iron used as fodder, hay, silage, feed (flour) and green manure and for soil protection (SANTOS et al., 2009).

This crop has a short cycle and relatively high water requirements, thus, irrigation is a viable alternative to improve this crop yield in the Brazilian semiarid, due to the precipitation irregularity in this region (ASSIS JÚNIOR et al., 2007).

Irrigated agriculture depends on the water quantity and quality. Although, the importance of water quality has been recognized only from the beginning of the last century, because of the reduction in the availability of low salinity water due to the increased demand for drinking water. Thus, the use of lower quality water for irrigation became an alternative, i.e., water with salt content previously not recommended for agricultural use (CAVALCANTE et al., 2012).

The concentration of soluble salts is among the characteristics that determine the water quality for irrigation, since it is a limiting factor for the development of some crops (ASSIS JÚNIOR et al., 2007; SILVA et al., 2011), and can cause serious consequences to the soil, compromising even its use for crop productions.

The excess of salts in the soil affects the crop growth and yield, due to direct effects of osmotic potential reductions and high concentrations of toxic ions in the soil (MEDEIROS, DUARTE, DIAS, 2009; LIMA JÚNIOR; SILVA, 2010; MEDEIROS et al., 2011). Assis Júnior et al. (2007) and Bezerra et al. (2010) stated that the use of saline water for irrigation of *Vigna unguiculata* caused accumulation of salts in the soil and reduced vegetative growth and grain yield. Santana, Silveira and Vieira (2009) evaluated the effects of irrigation with saline water (0.1, 1.0, 2.5, 4.0 and 5.5 dS m^{-1}) on common bean and found reductions in grain yield, number of grains per pod and number of pods per plant.

The use of irrigation with saline water for grain productions can be achieved through the application of various techniques, such as the use of water depths above the crop requirements for leaching the excess of salts from the soil in the active root environment of the plants (AYERS; WESTCOT, 1999).

The adequate use of this technique, which has low cost and easy access to farmers, allows the rational use of lower quality water, contributing to reduce soil degradation processes, income loss and production quality caused by salinity (BEZERRA et al., 2010).

Assis Júnior et al. (2007) evaluated the effects of irrigation with saline water under different leaching fractions on *V. unguiculata* yield and the accumulation of salts in a dystrophic Ultisol (SiBSC, 2006) and found that the water salinity of 5,0 dS m^{-1} increased the soil salinity and sodicity, however, these effects were partly reversed by the increase in the leaching fraction and completely by rainwater. Carvalho et al. (2012) evaluated maize (*Zea mays* L.) irrigated with increasing salinity and leaching fractions and also found positive effects of leaching fractions on the crop performance.

In this context, the objective of this work was to evaluate the production components of cowpea (*V. unguiculata* L. Walp) plants subjected to irrigation with brackish water under different leaching fractions.

MATERIAL AND METHODS

The experiment was conducted in a lysimeter system of the Department of Agricultural Engineering of the Federal Rural University of Pernambuco, Recife campus (8°01'05"S, 34° 56'48"W and altitude of 6.5 m). The climate of the experiment area is As', tropical megathermal (wet tropical), according to the Koppen classification, with average annual temperature of 27ºC. The precipitation during the trial period was 153 mm (132.5 mm during the first 30 days).

The soil used for filling the lysimeters was collected from the 0-20 cm layer of a sandy Entisol (SiBCS, 2006). The chemical, physical and hydraulic characteristics of the soil were evaluated (Table 1) according to methodologies of the Embrapa (2011).

Considering the fertility analysis of the soil used to fill the lysimeters (Table 1), 2,058 Mg ha^{-1} of lime (46% CaO, 5% MgO and TNP of 80%) was applied 60 days before planting. The need for liming was calculated according to the method adopted by the Agronomic Institute of Campinas (base saturation), using the formula NC = (V2 - V1) T/100, where V2 is the base saturation desired for the *V. unguiculata* (90%) crop; V1 is the soil base saturation (44.5%); and T is the CEC at pH 7 (3.62 cmolc dm^{-3}).

Planting fertilization was carried out before sowing, using 24 kg ha^{-1} of N, 24 kg ha^{-1} of P_2O_5 and 25 kg ha^{-1} of K_2O, respectively from nitromag (27% N, 4% Ca and 2% Mg), single superphosphate (18% P_2O_5, 16% Ca and 8% S) and potassium chloride (58% K_2O and 45% Cl). Topdressing was carried out 30 days after planting, with 27 kg ha^{-1} of N (nitromag). Both planting and topdressing fertilizations were performed according to soil analysis collected before the experiment, followed the recommendation of Cavalcanti (2008).

Table 1. Chemical, physical and hydraulic characteristics of the soil used in the lysimeters, evaluated before the experiment implementation.

Chemical characteristics	Values	Physical characteristics	Values
pH	4.6	Sand (g kg^{-1})	911
Organic Carbon (g kg^{-1})	6.28	Silt (g kg^{-1})	53
P (mg dm^{-3})	5	Clay (g kg^{-1})	36
K ($cmol_c$ dm^{-3})	0.04	Water dispersible clay (g kg^{-1})	36
Na ($cmol_c$ dm^{-3})	0.07	Flocculation (%)	0
Ca ($cmol_c$ dm^{-3})	1.05	Dispersion index (%)	100
Mg ($cmol_c$ dm^{-3})	0.45	Soil density (kg m^{-3})	1,650
Al ($cmol_c$ dm^{-3})	0.40	Particle Density (kg m^{-3})	2,570
H + Al ($cmol_c$ dm^{-3})	2.01	Total porosity (m^3 m^{-3})	0.36
BS ($cmol_c$ dm^{-3})	1.61	Soil moisture - 0.1 atm (%)	6.39
CEC ($cmol_c$ dm^{-3})	3.62	Soil moisture - 15 atm (%)	2.01
V (%)	44.5	Available water	4.3
EST (%)	1.93		

BS = Base Saturation; CEC = Cation Exchange Capacity; EST = Exchangeable Sodium Percentage.

The experiment was conducted on a total area of 464.40 m² (18.0 x 25.8 m), equipped with 40 drainage lysimeters, equidistant 1.2 m, with bottom drains connected to a tank to collect the effluent. A piezometer with millimeter scale was installed in each drain system to measure the water level variations in the lysimeters.

The lysimeters had area of 1.45 m^2 each, round in shape, and made of asbestos and cement, with depth for root growth of 0.75 m and board above soil surface of 0.10 m. The area evaluated within each lysimeter consisted of three rows of 0.70 m spaced 0.60 m apart with plants spaced 0.10 m apart.

Seeds of cowper cultivar BRS-Tumucumaque, acquired from the germplasm bank of the Embrapa Meio Norte, were placed manually to a depth of 3 cm, using a seeding density of 20 plants per meter, totaling 42 seeds per lysimeter. The plots were thinned, leaving 22 plants per lysimeter, representing a planting density of 151,724 plants ha^{-1}.

Irrigation was carried out using a drip irrigation system, with pressure compensating emitters spaced 0.5 m apart in lines of 15 meters spaced 0.6 m apart, average flow of 4.06 L h^{-1} and pressure of 13.5 mWC. The irrigation system was evaluated by determining the distribution uniformity coefficient (DUC), Christiansen's uniformity coefficient (CUC) and the coefficient of statistical uniformity (CSU), whose values were 87.97, 95.93 and 94.64%, respectively.

Irrigations were carried out daily following the Penman-Monteith model for determination of the reference evapotranspiration (ETo), according to the method proposed by the FAO 56 (ALLEN et al., 2006). The water depths were estimated based on the crop evapotranspiration (ETc), according to Equation 1,

$$ETc = ETo * Kc * Klave \quad (1)$$

where:

$ETc =$ crop evapotranspiration (mm dia^{-1})

$ETo =$ reference evapotranspiration by the Penman-Monteith model (mm dia^{-1})

$Kc =$ crop coefficient (dimensionless)

$Klave =$ average location coefficient (dimensionless)

Klave was determined by the average of four coefficient locations (Kl) (PIZARRO, 1996).

The ETo data used in the Penman-Monteith model and the precipitation data for estimate irrigation of the different treatments were obtained from an automated weather station installed in the experimental area. The Kc values were daily used according to the crop phenological stage, which were 0.40 from 1 to 17 days after sowing (DAS), 1.1 from 18 to 54 DAS and 0.6 from 55 to 60 DAS (Allen et al., 2006).

The saline water used for irrigation were prepared in two 500 L tanks, in which a salt (NaCl 370 g kg^{-1} and $CaCl_2$ 630 g kg^{-1}) was slowly added to reach the electrical conductivities (ECs) of 1.2 and 3.3 dS m^{-1}, in order to reproduce similar conditions to those found in the Brazilian semiarid region. The electrical conductivity was monitored with a portable conductivity measurer (DIGIMED CD-2P).

Four soil sampling were collected during the experiment, at 11, 37, 53 and 62 days after seedling emergence (DAE). Each sample had 400 g, consisted of two simple samples per lysimeter, one in the 0-20 cm and another in the 20-40 cm layer, totaling of 320 samples. The samples were air dried, disaggregated and sieved in a 2 mm mesh sieve. A saturated soil extract was prepared with 250 g of air-dried soil per sample and measured for electrical conductivity (EC), in order to verify the temporal effect of soil salinization throughout the experiment. Analytical procedures were performed according to Embrapa (2011).

Plants were harvested 62 days after sowing, when the pods were dry. The production components (number of pods per plant (NP), 100-grain weight (100GW), number of grains per pod (NGP), grain dry weight (GDW), shoot dry weight (SDW), grain yield (GY) and harvest index (HI)), were evaluated on five plants of the central row of each treatment. Ten randomly pods, two pods of each of the five plants evaluated, were used for quantifications. GY was obtained by weighing the dry grains and expressed in kg ha^{-1}. After harvesting, ten plants with leaves, petioles, stems and branches were dried in an oven with forced-air circulation at 65°C to a constant weight and weighed in a semi analytical scale (accuracy of 0.01g) to evaluate the dry biomass. HI was estimated by the ratio GDW/SDW.

Data were subjected to analysis of variance by the F test ($p \leq 0.05$), which is conclusive for the averages of the two water salinity levels, and to regression for the quantitative data on the leaching fractions.

RESULTS AND DISCUSSION

The electrical conductivity averages of the saturated soil extract were below the limit to cause economic yield loss in the crops and classify the soil as salinized (RIBEIRO, 2012; PEDROTTI et al., 2015), despite the increases in soil salinity over time and regardless of the salinity of the water used for irrigation and soil depths (Table 2). The highest electrical conductivity values of the saturated soil extract were found in the treatment with the most saline water (3.3 dS m^{-1}), however, these values decreased with increasing leaching fraction, regardless of water salinity.

Table 2. Electrical conductivity of saturated soil extracts at different times and depths, depending on the electrical conductivity of the water used for irrigation (ECw) and leaching fractions (LF).

Layer (cm)	ECw (dS m^{-1})	LF (%)	11 DAE	37 DAE	53 DAE	62 DAE
0 – 20	1.2	0	0.73	0.98	1.15	1.32
		5	0.72	0.98	1.12	1.25
		10	0.69	0.92	1.09	1.17
		15	0.61	0.75	1.03	0.84
		20	0.49	0.72	0.97	0.77
	3.3	0	0.77	1.64	1.93	2.22
		5	0.72	1.31	1.46	1.33
		10	0.55	1.28	1.42	1.19
		15	0.48	0.93	1.19	1.12
		20	0.47	0.83	1.17	1.05
20 – 40	1.2	0	0.65	1.29	1.42	1.55
		5	0.58	0.93	1.33	1.40
		10	0.52	0.90	1.22	0.94
		15	0.50	0.86	1.05	0.67
		20	0.49	0.86	1.04	0.63
	3.3	0	0.97	1.55	1.50	1.55
		5	0.95	1.52	1.43	1.11
		10	0.83	1.35	1.36	1.09
		15	0.71	1.06	1.26	1.07
		20	0.53	0.93	1.17	0.94

DAE = days after emergence.

The salt concentrations in the soil increased over time because the brackish water applied, regardless the leaching fractions. This results confirm those found by Murtaza, Ghafoor and Qadir (2006), evaluating the use of sodium saline water for cotton (*Gossypium hirsutum* L.) and wheat (*Triticum* spp.) irrigation, and Bezerra et al. (2010), evaluating salt accumulations in the soil over growth and yield of a crop rotation of *V. unguiculata* and maize, who found increases in salt concentrations in the soil with increasing salt concentrations in the water used for irrigation.

The leaching fractions caused progressive reductions in the soil salinity levels throughout the experiment (Table 2), despite the increased salt concentrations in both soil layers caused by irrigation with saline water, indicating that it is an alternative to control the gradual increase of salts in the root zone (ASSIS JÚNIOR, 2007; SILVA et al., 2011), and contribute to the tolerance to problems caused by salinity in irrigated agriculture (RITZEMA et al., 2008; BEZERRA et al., 2010), especially in places where the precipitation and the availability of good quality water for irrigation is scarce.

Similar to the present work, Oliveira et al. (2005) evaluated water stress index of common bean *(Phaseolus vulgaris* L.*)* irrigated with saline water and found that the increase in the leaching fraction reduced the soil salinity. Assis Júnior et al. (2007), evaluating soils under a *V. Unguiculata* crop irrigated with different water conductivities (0.8 dS m^{-1} to 5.0 dS m^{-1}) in a dystrophic Ultisol (SiBSC, 2006), with and without leaching fractions of 14% and 28%, found reductions in soil salts with the leaching fractions, and a more efficient salt leaching from the root zone with the leaching fraction of 28%. These findings in different researches show the importance in adopting this technic, using water depths over the plant requirements in order to leach salts by drainage.

The interaction between water salinity and leaching fractions had no significant effect on the variables evaluated, except for the 100-grain weight (100GW) (Table 3). The water salinity levels and leaching fractions influenced NP, GY and 100GW. The leachings fractions influenced NGP, GDW, SDW and HI.

Table 3. Analysis of variance of the production variables number of pods per plant (NP), 100-grain weight (100GW), number of grains per pod (NGP), grain dry weight (GDW), grain yield (GY), shoot dry weight (SDW) and harvest index (HI) of (*V. unguiculata)*, depending on irrigation with brackish water under leaching fractions.

Source of variation	Teste F						
	NP	100GW	NGP	GDW	GY	SDW	HI
ECw	15.21**	210.3**	0.095^{ns}	0.397^{ns}	9.54**	0.003^{ns}	2.50^{ns}
LF	4.93**	75.8**	29.39**	164.71**	15.0**	6.62**	5.33**
ECw x LF	1.32^{ns}	21.3**	0.275^{ns}	0.518^{ns}	1.36^{ns}	1.95^{ns}	2.24^{ns}
CV (%)	9.89	0.84	5.65	4.14	7.74	10.66	12.55

^{ns} = not significant; ** = significant at 1% probability; ECw = electrical conductivity of the water used for irrigation; LF = leaching fraction; ECw x LF = interaction between factors; CV = coefficient of variation.

The highest NP (Figure 1A) and GY (Figure 1B) were found with ECw of 1.2 dS m^{-1}. Plants at this soil salinity showed average values of 7.02 pods per plant, and 6.21 at 3.3 dS m^{-1} (Figure 1A). Thus, increasing the water salinity (1.2 to 3.3 dS m^{-1}) resulted in a loss in NP of 11.5%. GY (Figure 1B) was 2,000 kg ha^{-1} at 1.2 dS m^{-1} and 1,860 kg ha^{-1} at 3.3 dS m^{-1}, a yield loss of 7% due to the higher water salinity.

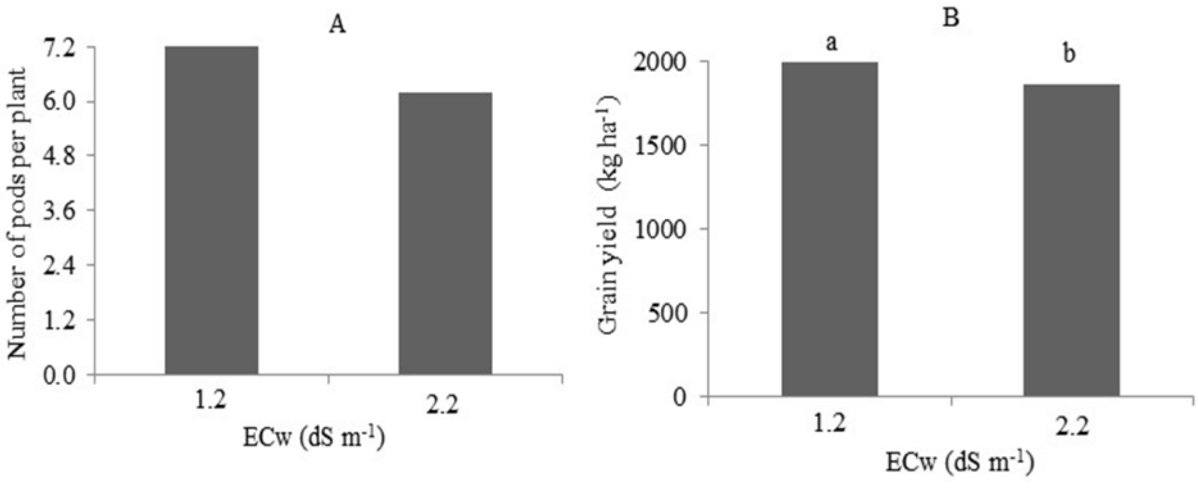

Figure 1. Number of pods per plant (A) and grain yield (B) depending on the electrical conductivity of the water used for irrigation (ECw).

The water salinity increase affected the emission of reproductive branches, reducing the NP and consequently, the GY, since the NP is one of the most important production components used for evaluating the *V. unguiculata* yield (CARDOSO, MELO; LIMA, 2005).

The average values of NP were similar to those found by Bezerra et al. (2010) in a crop rotation of *V. unguiculata* and maize, with salinity levels of 1.2 dS m^{-1} (7.46), and 3.3 dS m^{-1} (5.62).

Santana, Silveira and Vieira (2009) found even greater reductions in NP due to increasing water salinity levels, with 7.32 in the control (0.1 dS m^{-1}), 5.61 at 1.2 dS m^{-1} and 2.34 at 3.3 dS m^{-1}. According to these authors, the effects of saline water in the soil reduce the osmotic potential to levels not normally supported by common bean plants, reducing their NP and yield.

The GY (Figure 1B) was 7% lower in the treatment with the highest salt level (1,860 kg ha^{-1}) compared to the treatment with the lowest salt level (2,000 kg ha^{-1}), due to the salt concentration in the soil during the crop cycle. The use of brackish water for irrigation of *V. unguiculata* reduced GY, which was also observed in other studies (WILSON et al.; 2006; SANTANA; SILVEIRA; VIEIRA, 2009; BEZERRA et al., 2010).

Moreover, despite the *V. unguiculata* yield reduction with the increase in the salinity of the water used for irrigation from 1.2 dS m^{-1} to 3.3 dS m^{-1}, the yield found in the highest salinity evaluated is consistent with results in the literature (CARDOSO; MELO; LIMA, 2005; ASSIS JÚNIOR et al., 2007; NEVES et al., 2009), which range from 1,500 to 2,000 kg ha^{-1} under conditions of irrigation with saline water in the Brazilian Northeast region.

The results showed that the *V. unguiculata* yield was promising, even under irrigation with water salinity of 3.3 dS m^{-1}, probably due to the leaching fractions used, which prevented the salt concentrations in the root zone to reach the crop critical level.

Regardless of the salt concentration in the water used for irrigation, the greatest NP found by the regression model was 7, with a leaching fraction of 9.1% (Figure 2A). The highest GY estimated by the regression model was 2,150 kg ha^{-1}, with a leaching fraction of 9.6% (Figure 2B).

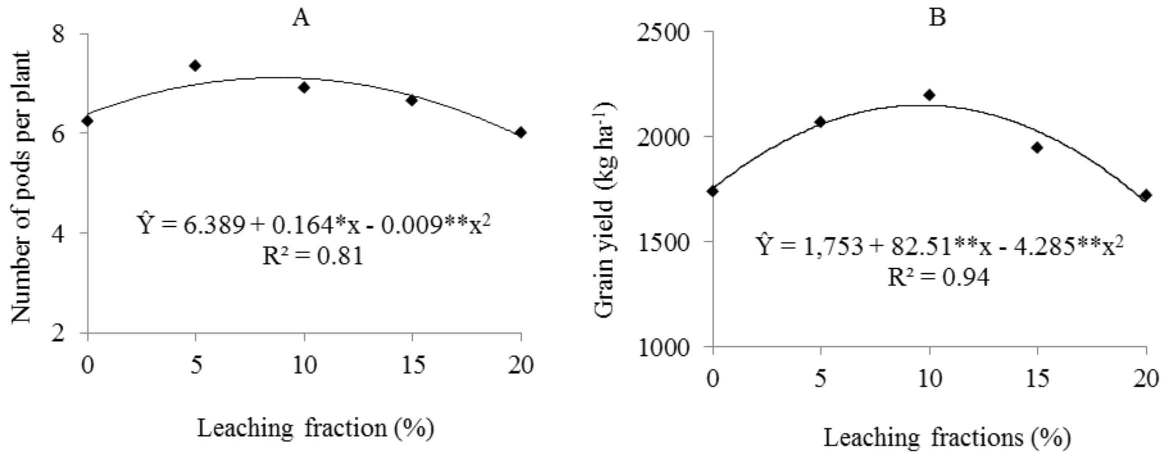

Figure 2. Number of pods per plant (A) and grain yield of (*V. unguiculata*) (B) depending on leaching fractions.

The lowest values of NP (Figure 2A) and GY (Figure 2B) found in the extreme leaching fractions were probably due two simultaneous and adverse effects of nutritional imbalance: the more pronounced effect of leaching of salts from the soil profile, which leached some of the crop essential nutrients (deficiency), reducing the values for these components; and the effect of excess of salts.

According to Santana, Silveira and Vieira (2009), the excess of salts causes nutritional imbalance due to high ion concentration, especially sodium, limiting the absorption of other ions, as well as the toxic effects due to salt accumulation in the plasma.

GY results were similar to other studies (OLIVEIRA et al., 2005; ASSIS JÚNIOR et al., 2007), which also evaluated leaching fractions under field conditions and found significant yield increases using saline water for irrigation and different leaching fractions.

The leaching fraction that resulted in the highest NP (9.1%) (Figure 2A) was close to the one that resulted in the highest grain yield (9.6%) (Figure 2B), thus confirming the relationship between the *V. unguiculata* NP and GY reported by Cardoso; Melo and Lima (2005). The 100GW was affected by the water salinities used for irrigation and leaching fractions (Figure 3).

The highest 100GW (39.53 g) was found with the use of water with ECw of 3.3 dS m^{1} and leaching fraction of 5.7%, while the water with ECw of 1.2 dS m^{-1} resulted in an average 100GW of 38.24 g with leaching fraction of 4.9%. This result was due to the repeated leaching fractions and probably due to a selective mechanism for ions input by the plant roots to the grains of the *V. unguiculata* cultivar used. Dantas et al. (2002) studied *V. unguiculata* genotypes and stated that some cultivars develop mechanisms of tolerance to soil salinity levels from 3 to 6 dS m^{-1}. The production component 100GW is resistant to changes induced by environmental stress, such as the stress caused by salinity (LOCATELI ET AL., 2014).

The production component 100GW had lower values in the extreme leaching fractions and higher values in the intermediate leaching fractions (Figure 3), similarly to the NP (Figure 2A) and GY (Figure 2B), with two simultaneous and adverse effects probably due to nutritional imbalance: the salt leaching from the soil (deficiency), which was more pronounced in plants irrigated with water salinity of 1.2dS m^{-1}; and the effect of excess of salts.

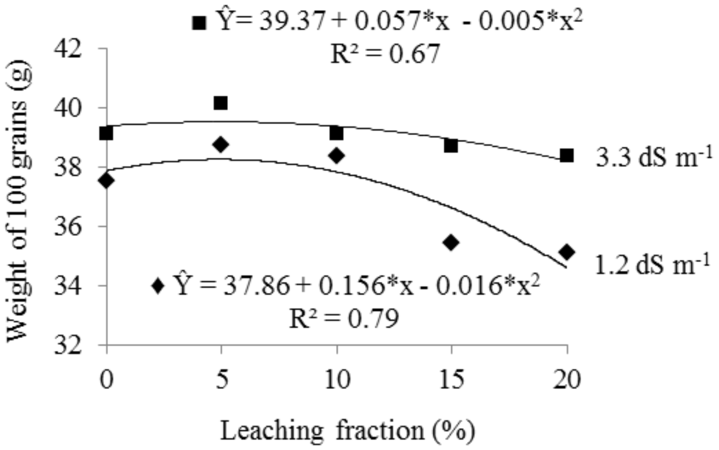

Figure 3. Weight of 100-grains of (*V. unguiculata*), depending on the water electrical conductivity used for irrigation (ECw) and leaching fractions.

The 100GW results differed from those found by Assis Júnior et al. (2007), who evaluated the *V. unguiculata* (cultivar EPACE 10) yield and the salt accumulation in the soil, depending on leaching fractions and salinity of the water used for irrigation, and found no effect in this variable, so the *V. unguiculata* 100GW responses to salinity are variable and depend also on other factors, such as the cultivar used.

The leaching fractions had positive action on the NGP (Figure 4A) and GDW (Figure 4B). The greatest NGP estimated by the regression model was 10, with a leaching fraction of 9.19% (Figure 4A) and the greatest estimated GDW was 30 g, with a leaching fraction of 9.82% (Figure 4B). The extreme leaching fractions had the lowest values for both variables, probably due to the two simultaneous and adverse effects of nutritional imbalance (leaching fractions greater than 9.19% for NGP and 9.82% for GDW) and the effect of excess of salts (leaching fractions lower than 9.19% for NGP and 9.82% for GDW).

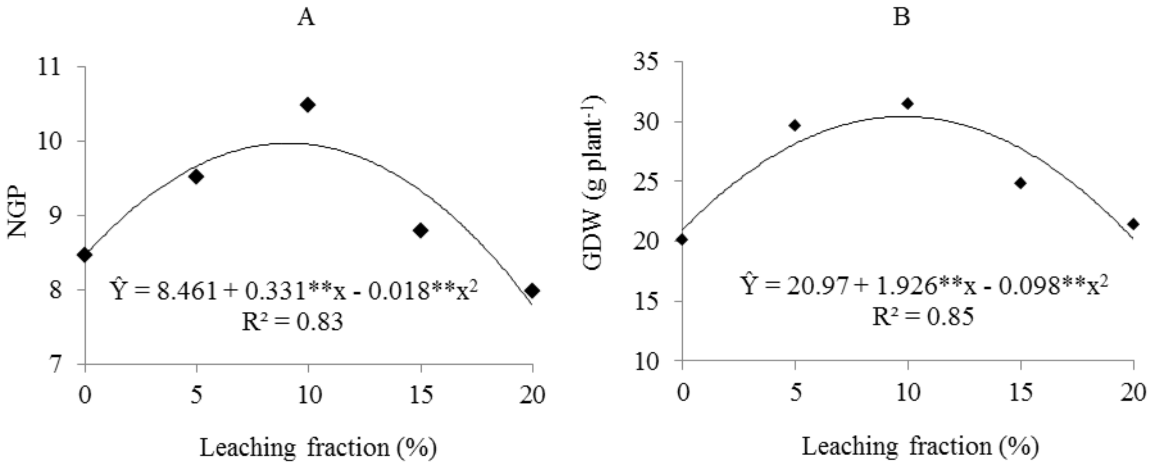

Figure 4. Number of grains per pod (NGP) (A) and grain dry weight (GDW) (Figure 4B) of (*V. unguiculata*), depending on leaching fractions.

The leaching fractions that presented the highest NGP (9.19%) and GDW (9.82%) were similar to the one that had the highest GY (9.6%) (Figure 2B), confirming the results of other studies (CARDOSO; MELO; LIMA, 2005; ASSIS JÚNIOR et al., 2007) that found positive correlation between these production components and the *V. unguiculata* GY.

The NGP and GDW results confirm those found by Bezerra et al. (2010), who evaluated the effect of increasing salinity of the water used for irrigation on the NGP and also found no significant reductions for the variable, although, they found effect on the GDW.

The maximum NGP found was 10 grains (Figure 4A), which was higher than that found by Santos (2013), who evaluated the same cultivar in the State of Paraiba, under arid conditions and found an average NGP of 8.67, without the use of saline water for irrigation. The highest GDW was 30 g, exceeding the average values of 22 g reported by Assis Júnior et al. (2007).

The SDW (Figure 5A) and HI (Figure 5B) were affected by the leaching fractions.

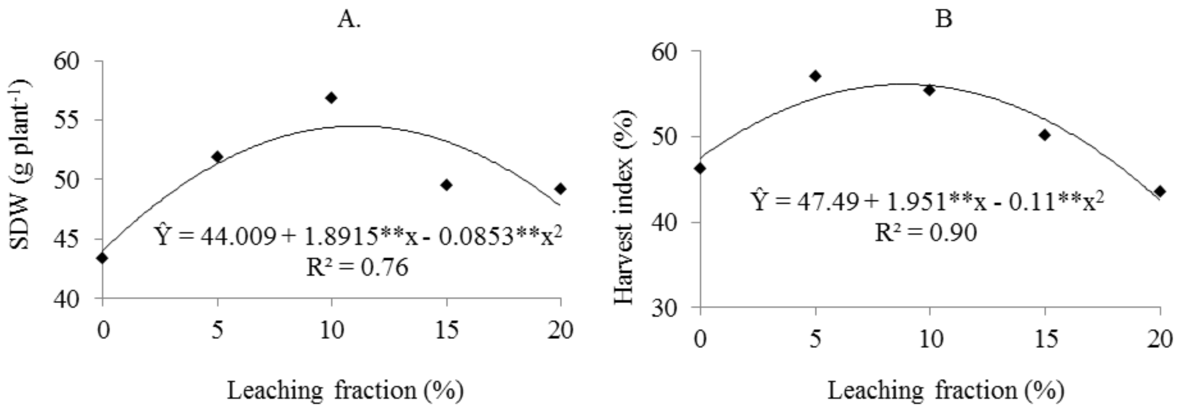

Figure 5. Shoot Dry Weight (SDW) and harvest index of (*V. unguiculata*), depending on leaching fractions.

The regression equation model that best fitted the SDW and HI data was the quadratic (Figures 5A and 5B), showing lower values for the extreme leaching fractions, similarly to the results on the effects of leaching fractions for all variables above (Figures 2, 3 and 4), probably due to the nutritional imbalance caused by the effect of the leaching of salts from the soil profile (leaching fractions greater than 11.09 for SDW and 8.9% for HI) and the effect of excess of salts (less than 11.09 for SDW and less than 8.9% for HI).

According to the regression estimates, the greatest SDW was 54.5 g plan^{-1} (Figure 5A), with a leaching fraction of 11.09%, while the highest HI was 56.1% (Figure 5B), with a leaching fraction of 8.9%.

Assis Júnior et al. (2007) evaluated the irrigation of *V. unguiculata* (cultivar EPACE 10) using water with EC of 5 dS m^{-1} under leaching fractions of up to 28%, and found different results, with no effect of these fractions on the SDW, however, the SDW values were lower than those found in the present work, denoting that the SDW responses also depend on the cultivar.

The increases in SDW and HI with increasing leaching fractions (up to the maximum efficiency) were probably due to reductions of the osmotic effect of salts around the roots and the lower accumulation of potential toxic ions (Na^+ and Cl^-) in the leaf tissue due to the leaching of salts by the leaching fractions.

According to Souza et al. (2011), the osmotic effect of salts around the plant roots and its accumulation in the leaf tissues reduces the plant photosynthesis rate and growth and thus, the SDW, GY and HI.

The results found for the HI depending on the water salinities evaluated confirm those found by Silva et al. (2013), who evaluated the effect of the salinity of the water used for irrigation (0.5, 2.2, 3.6 and 5.0 dS m^{-1}) on *V. unguiculata* gas exchange and yield and also found no influence of salinity on the crop harvest index

HI has been used to evaluate responses of *V. unguiculata* cultivars to salt stress conditions. Bezerra et al. (2010) evaluated a crop rotation of *V. unguiculata* and maize under irrigation with saline water and found yield reductions with increasing salinity rates, with HI values (31.2 to 34.7%) lower than those found in the present work. The HI values found here were also higher than those by Assis Júnior et al. (2007), that ranged from 43 to 47%, and those by Neves et al. (2009), who found HI of 40% for treatments with low and high salinity.

The grain harvest index (grain yield/shoot dry weight) expresses the efficiency of the crop in converting biomass to grain yield (PETTER et al., 2012) and ranges from 39 to 58%, depending on the cultivar (SNYDER; CARLSON, 1984). Thus, the cultivar Tumucumaque had a good translocation of assimilates from the leaves to the grains under the conditions in which this experiment was conducted, i.e., the efficiency in converting biomass in grains was satisfactory, even when the plants were subjected to different salinities of the water used for irrigation, showing the importance of adopting the leaching fractions used.

CONCLUSIONS

The estimated leaching fractions of 9.1 and 9.6% are sufficient for irrigation of *V. unguiculata* with water salinity of 3.3 dS m^{-1}.

The production of *V. unguiculata* irrigated with brackish water, using leaching fractions to remove salts from the plant root environment, is possible under the conditions evaluated.

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