ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.28, n.3, e272197, 2024
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v28n3exxxxxx ORIGINAL ARTICLE

Frequencies of irrigation in millet crop under salt stress[1]

Frequências de irrigação na cultura do milheto sob estresse salino

Francisco H. R. Costa[2*], Geocleber G. de Sousa[3], José M. dos P. Lima[3], Murilo de S. Almeida[4], Henderson C. Sousa[2], Silas P. Gomes[3], Elizeu M. da Cruz Filho[5] & Benito M. de Azevedo[2]

[1] Research developed at Universidade da Integração Internacional da Lusofonia Afro-Brasileira, Unidade de Produção de Mudas Auroras, Redenção, CE, Brazil
[2] Universidade Federal do Ceará/Departamento de Engenharia Agrícola, Fortaleza, CE, Brazil
[3] Universidade da Integração Internacional da Lusofonia Afro-Brasileira/Instituto de Desenvolvimento Rural, Redenção, CE, Brazil
[4] Universidade Federal do Ceará/Departamento de Ciências do Solo, Fortaleza, CE, Brazil
[5] Universidade Federal Rural de Pernambuco/Departamento de Engenharia Agrícola, Recife, PE, Brazil

HIGHLIGHTS:

Irrigation with brackish water (5.0 dS m⁻¹) negatively affects the agronomic performance of millet.
Millet has significant decreases in growth with decreasing irrigation frequency beyond two days.
The combination of salt and water stresses compromises the forage potential of millet due to the decrease in biomass.

ABSTRACT: The semi-arid region faces problems related to water deficit and the presence of brackish water that compromise crop performance. Therefore, irrigation frequency can enhance the growth of agricultural crops of interest even under salt stress conditions. In this context, the objective of the present study was to evaluate different irrigation frequencies with water of higher and lower salinity on the agronomic performance of millet. The experiment was conducted from September to November 2020, in the experimental area of the Auroras Seedling Production Unit, belonging to the Universidade da Integração Internacional da Lusofonia Afro-Brasileira, Redenção, Ceará, Brazil. The experimental design used was completely randomized in a 4 × 2 factorial arrangement, with five repetitions. The first factor corresponded to four irrigation frequencies (F1 - daily irrigation; F2 - irrigation every two days; F3 - irrigation every three days; F4 - irrigation every four days) and the second factor consisted of two levels of electrical conductivity of irrigation water (0.3 and 5.0 dS m^{-1}). Salt stress (5.0 dS m^{-1}) negatively affected leaf area, plant height, stalk diameter, panicle length, and leaf, stem, panicle, and total dry mass of millet, under daily and four-day irrigation frequencies. Increasing the interval in irrigation frequency to beyond two days negatively affects the agronomic performance of millet crop, regardless of the electrical conductivity of water used (0.3 or 5.0 dS m^{-1}). Under salt stress conditions, adopting irrigation frequencies between two and three days can be a viable alternative for irrigation management in pearl millet crop.

Key words: *Pennisetum glaucum*, abiotic stresses, salinity, irrigation management

RESUMO: A região semiárida apresenta problemas relacionados ao déficit hídrico e presença de água salobra que comprometem o desempenho das culturas. Assim, a frequência de irrigação pode promover melhores condições de desenvolvimento das culturas de interesse agrícola mesmo em condições de estresse salino. Neste sentido, objetivou-se avaliar diferentes frequências de irrigação com água de maior e menor salinidade sobre desempenho agronômico do milheto. O experimento foi realizado no período de setembro a novembro de 2020, na área experimental da Unidade de Produção de Mudas Auroras, pertencente a Universidade da Integração Internacional da Lusofonia Afro-Brasileira, Redenção, Ceará. O delineamento experimental utilizado foi inteiramente casualizado em arranjo fatorial 4 × 2, com cinco repetições. O primeiro fator corresponde a quatro frequências de irrigação (F1 - irrigação diária; F2 - irrigação a cada dois dias; F3 - irrigação a cada três dias; F4 - irrigação a cada quatro dias) e o segundo consistiu em dois níveis de condutividade elétrica da água de irrigação (0,3 e 5,0 dS m^{-1}). O estresse salino (5,0 dS m^{-1}) afetou negativamente a área foliar, altura da planta, diâmetro do colmo, comprimento da panícula, massa seca da folha, caule, panícula e total do milheto, sob irrigação diária e cada quatro dias. O aumento do intervalo na frequência de irrigação acima de dois dias afeta o desempenho agronômico do milheto, independente da condutividade elétrica da água (0,3 ou 5,0 dS m^{-1}). Em condições de estresse salino, adotar frequências de irrigação entre dois e três dias pode ser uma alternativa viável para o manejo da irrigação do milheto.

Palavras-chave: *Pennisetum glaucum*, estresses abióticos, salinidade, manejo da irrigação

• Ref. 272197 – Received 19 Feb, 2023
* Corresponding author - E-mail: hermesonrc@gmail.com
• Accepted 12 Dec, 2023 • Published 03 Jan, 2024
Editors: Lauriane Almeida dos Anjos Soares & Hans Raj Gheyi

Introduction

Millet (*Pennisetum glaucum*) is considered an important forage for animal feed in view of its high nutritional value (Araújo et al., 2021), and the value of crude protein is higher than those of maize and sorghum (Araújo Júnior et al., 2023). According to Lima et al. (2020), it is a crop that adapts to a wide variety of edaphoclimatic conditions, showing good development in semi-arid regions (Silva et al., 2022). Furthermore, according to classification reported by Maas (1986), it is classified as a plant moderately sensitive to salinity. This condition allows cultivation under biosaline conditions, albeit with the requirement of implementing irrigation strategies.

Thus, under conditions of irrigation with brackish water, it becomes essential to adopt efficient irrigation management to maximize crop yields in arid and semi-arid regions (Pereira Filho et al., 2019; Goes et al., 2021; Ma et al., 2023). The frequency of irrigation required by a crop is dependent on factors such as climate, soil, plant, and management. It is emphasized that excess or lack of water entails injuries, disrupting the physiological and biochemical functions of plants, and may lead to delayed growth and yield (Carvalho et al., 2016; Amaral et al., 2019).

The use of brackish water in irrigation can cause several problems in the soil due to the accumulation of salts, especially in the form of sodium chloride, when these salts are not leached (Queiroz et al., 2023). Salt stress inhibits plant growth due to the reduction of soil osmotic potential, leading to excessive accumulation of ions in plant tissues, causing nutritional imbalance, in addition to reducing the yield of agricultural crops (Goes et al., 2021; Silva et al., 2022).

In the search for efficient irrigation management to ensure safe agricultural production, it is believed that the frequency of irrigation or the interval in days between successive irrigations should be determined aiming at the ideal conditions for crop development, and consequently, enabling greater yield even under conditions of high salinity (Sousa et al., 2014; Maniçoba et al., 2021).

In this context, the objective of this study was to evaluate different frequencies of irrigation under electrical conductivities of irrigation water on the agronomic performance of millet.

Material and Methods

The experiment was conducted under field conditions from September to November 2020, in the experimental area of the Auroras Seedling Production Unit - UPMA, belonging to the Universidade da Integração Internacional da Lusofonia Afro-Brasileira - UNILAB, Auroras Campus, Redenção, in the state of Ceará, Brazil (4° 13’ 33” S; 38° 43’ 50” W and altitude of 92 m). According to Köppen’s global classification system, the region’s climate is classified as BSh’, with very hot temperatures and predominant rainfall in the summer and autumn seasons (Alvares et al., 2013). The meteorological data during the period of the experiment (September to November 2020) were monitored by a Data logger (HOBO® U12-012 Temp/RH/Light/Ext) (Figure 1).

The experimental design was completely randomized in a 4 × 2 factorial arrangement, with five repetitions, where the first factor corresponded to four irrigation frequencies (F1 - daily irrigation; F2 - irrigation every two days; F3 - irrigation every three days; F4 - irrigation every four days) and the second factor consisted of two levels of salinity of irrigation water - ECw (A1 - 0.3 dS m^{-1} and A2 - 5.0 dS m^{-1}).

The water salinity levels of 0.3 dS m^{-1} (control) and 5.0 dS m^{-1} tested in this study are commonly observed in the semi-arid region of Northeastern Brazil. The irrigation frequencies were based on a study conducted by Lessa et al. (2019) using brackish water.

Millet seeds of the commercial variety BRS 1501 (Developed by Embrapa Milho e Sorgo), which has a short growth cycle, high dry matter production, and a high grain production potential, besides good adaptation to water stress, were sown in flexible plastic pots of 25 dm^{-3} capacity containing substrate in a 5:3:1 (v/v) ratio of arisco (sandy material with light texture normally used in constructions in Northeast Brazil), sand, and bovine manure, respectively. Samples of the substrates were sent to the laboratory of the Universidade Federal do Ceará - UFC, for analyses of chemical and physical attributes (Table 1).

The seeds were sown at a depth of 2 cm in a linear manner, with three lines per pot, in order to ensure a minimum plant

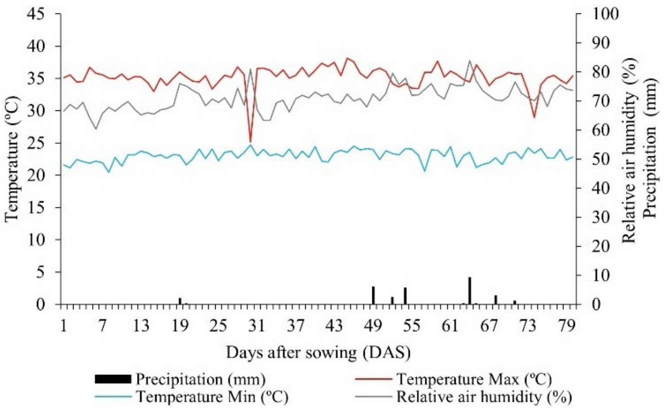


Figure 1. Mean values of maximum (Max) and minimum (Min) temperatures, precipitation, and relative air humidity observed during the experimental period (01 September to 20 November 2020)

Table 1. Chemical and physical characteristics of the substrate used before the application of treatments

O.M	N	pH	P	K	Ca	Mg	Na	ESP	ECse
(g kg^{-1})		(in water)	(mg kg^{-1})	($cmol_c$ dm^{-3})				(%)	(dS m^{-1})
4.34	0.26	6.20	65	0.65	1.20	1.20	0.33	7.00	1.19

SD (kg dm^{-3})		CS	FS	Silt	Clay	Textural classification
Bulk	Particle	(g kg^{-1})				
1.45	2.74	663	201	92	42	Loamy sand

O.M - Organic matter; ESP - Exchangeable sodium percentage; ECse - Electrical conductivity of the soil saturation extract; SD - Soil density; CS - Coarse sand; FS - Fine sand stand in each pot. Until the establishment of the seedlings, at 10 days after sowing (DAS), the plants were irrigated with water of the lowest conductivity (0.3 dS m^{-1}), and then they were thinned, leaving a single plant per pot. At 11 DAS, irrigation with brackish water was started, following the irrigation frequency according to the treatments mentioned above.

Mineral fertilization was based on the recommendation of Costa et al. (2020), which comprises 80 kg ha^{-1} of N, 30 kg ha^{-1} of P_2O_5, and 40 kg ha^{-1} of K_2O, applying 8 g of urea as a source of nitrogen, 3 g of single superphosphate as a source of phosphorus, and 4 g of potassium chloride as a source of potassium. The doses were applied in a split manner (six applications) as topdressing throughout the experiment.

Brackish water was prepared using the salts of NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$, in the proportion of 7:2:1 (Rhoades et al., 2000), following the relationship between ECw and the respective concentration ($mmol_c\ L^{-1} = EC \times 10$) according to Richards (1954).

Irrigation was performed manually, and the volume applied was calculated according to the drainage lysimeter principle, according to irrigation frequencies, applying a fixed leaching fraction of 15% in each irrigation event, as recommended by Ayers & Westcot (1999) after starting the differentiation of treatments. Drainage lysimeters were prepared by drilling a hole into the bottom of each pot and attaching a hose to drain the excess water. To prevent leaks, the hoses were connected to 1 L PET bottles sealed with glue, which received the water drained. The volume of water to be applied to the plants was determined by (Eq.1):

$$VI = \frac{(Vp - Vd)}{(1 - LF)} \quad (1)$$

where:

VI - volume of water to be applied in the irrigation event (mL);

Vp - Volume of water applied in the previous irrigation event (mL);

Vd - Volume of water drained (mL); and,

LF - Leaching fraction of 0.15.

The irrigation events and the respective volume applied to the plants according to the treatments were quantified throughout the experimental period (Table 2).

At 80 DAS the following variables were analyzed: leaf area (LA), estimated by the non-destructive method (length versus width of leaves), multiplying by the correction factor (Fc = 0.68) indicated by Payne et al. (1991); plant height (PH), using

Table 2. Volume of water applied to millet under different frequencies of irrigation and two levels of salinity of irrigation water

ECw (dS m^{-1})	Irrigation frequencies (days)	Irrigation management	
		Irrigation event	Total depth applied (L)
0.3	1	80	64.00
	2	40	64.00
	3	26	62.40
	4	20	64.00
5.0	1	80	64.00
	2	40	64.00
	3	26	62.40
	4	20	64.00

a graduated tape measure (cm), as the distance between the collar and the apex of the plant; stalk diameter (SD), using a digital caliper with results expressed in millimeters; number of leaves (NL), by direct counting of fully developed leaves; panicle length (PL), with the aid of a graduated ruler. For the determination of leaf dry mass (LDM), stem dry mass (SDM), and panicle dry mass (PDM), during the same period (80 DAS) the plant parts were placed in paper bags for a period of 72 hours in an oven to attain constant mass. Weighing was performed with the aid of a precision scale, and the total dry mass (TDM) was calculated as the sum of LDM+SDM.

To evaluate normality, the data obtained were subjected to the Kolmogorov-Smirnov test ($p \leq 0.05$). After verifying normality, the data were subjected to variance analysis by the F test. In cases of significance, for frequency of irrigation regression analysis was performed, while in cases of significance of interaction, the ECw levels were analyzed considering each frequency of irrigation and the ECw data were subjected to the Tukey test ($p \leq 0.05$), using the Assistat software 7.7 Beta (Silva & Azevedo, 2016).

Results and Discussion

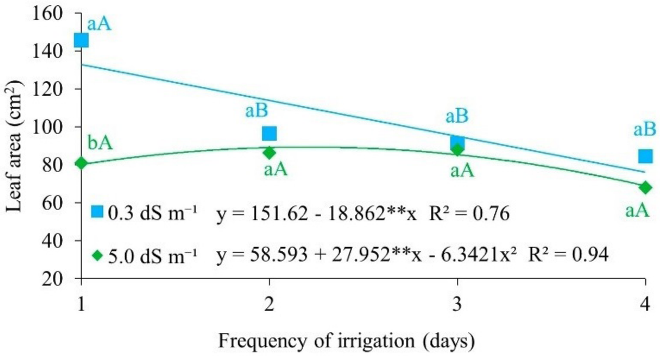
In the analysis of variance presented in Table 3, the interaction between the factors irrigation frequency and salinity of irrigation water (F × SL) significantly influenced leaf area (LA), stalk diameter (SD), and panicle length (PL) at $p \leq 0.01$ and $p \leq 0.05$ significance levels by the F test. The plant height (PH) variable had an isolated effect for both factors studied, while the number of leaves (NL) had no significant effect.

According to the decomposition of the factors in Figure 2, there was a decrease in the leaf area for water of lower electrical conductivity (0.3 dS m^{-1}), causing a reduction of 42.62% between frequencies of irrigation of 1 and 4 days. For water

Table 3. Summary of variance analysis for leaf area (LA), plant height (PH), stalk diameter (SD), number of leaves (NL), and panicle length (PL) of millet plant as a function of different irrigation frequencies and salinity levels in irrigation water

Source of variation	DF	Mean squares				
		LA	PH	SD	NL	PL
Irrigation Frequency (F)	3	4.23*	3.53*	3.43*	0.48^{ns}	2.35^{ns}
Salinity levels in irrigation water (SL)	1	13.90**	34.95**	2.65^{ns}	1.37^{ns}	76.95**
F × SL	3	5.06**	2.11^{ns}	3.75*	2.40^{ns}	4.40*
Residual	32	385.05	67.55	1.28	0.34	5.49
CV (%)		20.94	12.14	13.68	12.43	12.68

DF - Degrees of freedom; * - Significant by F test at $p \leq 0.05$; ** - Significant by F test at $p \leq 0.01$; ns - Not significant; CV - Coefficient of variation



** - Significant at $p \leq 0.01$ by F test; Lowercase letters differentiate at the same frequency of irrigation, and uppercase letters differentiate at the same salinity level the frequencies of irrigation by the Tukey test ($p \leq 0.05$)

Figure 2. Leaf area of millet plants subjected to different frequencies of irrigation and two levels of salinity of irrigation water

of higher salinity (5.0 dS m^{-1}), the statistical model that best fitted the data was the quadratic polynomial, with a maximum estimated of 89.39 cm^2 for the irrigation frequency of 2.2 days.

This result reflects the behavior of the plants under water and salt stresses, i.e., they tend to reduce their leaf area as a defense mechanism in order to reduce water losses by transpiration, since the water absorption capacity of plants is directly affected by the concentration of salts and the water content in the soil (Sousa et al., 2022; Silva Júnior et al., 2021).

A similar result to that found in this study was observed by Lessa et al. (2019). These same authors found reductions in the leaf area of sorghum crop irrigated with brackish water of 4.0 dS m^{-1}, with irrigation interval varying from one to four days. Pereira Filho et al. (2020) also verified a linear reduction in the leaf area of cowpea (*Phaseolus lunatus* L.) under water deficit and salt stress with an average reduction of 12.30%.

According to the data presented in Figure 3A, the millet crop showed greater plant height in the treatment with water of lower salinity (75.38 cm), differing statistically from the water of higher salinity (60 cm), with a reduction of 20.39% in plant height. Under saline conditions, plants limit their growth, because high levels of salts in irrigation water hinders the absorption of water by the roots and consequently reduces plant growth (Sousa et al., 2022).

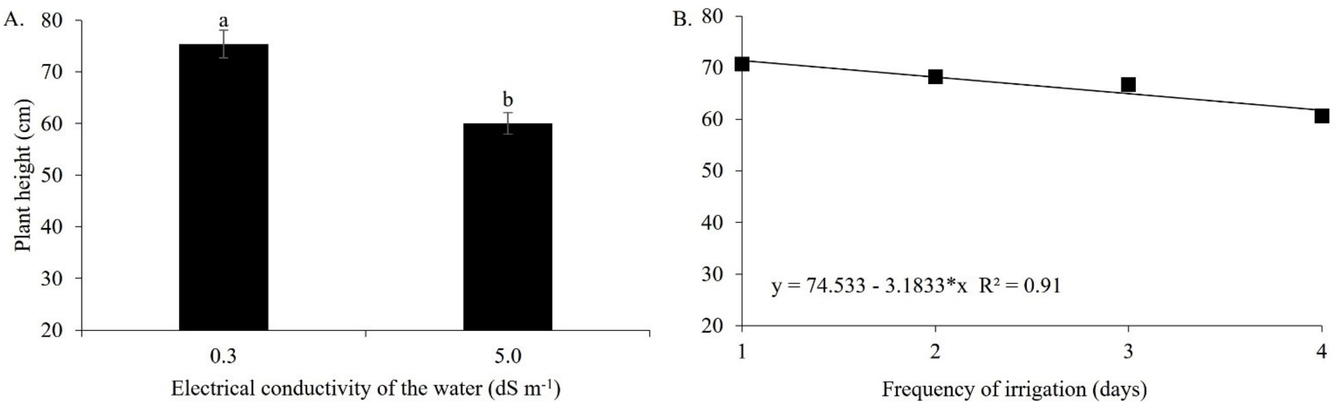
Similar results to those found in the present study were also obtained by Almeida et al. (2020), who verified lower performance in height of millet plants with the increase of the electrical conductivity of the irrigation water from 0.03 to 4.0 dS m^{-1}. Lima et al. (2020) observed that the height of millet plants at 35 DAS was negatively affected by water with higher salinity (5 dS m^{-1}), with a reduction of 35.64% compared to lower salinity (1 dS m^{-1}).

Figure 3B shows the effect of irrigation frequency on the height of millet plants, and by the analysis of the linear regression equation, a reduction of 4.27% for each unitary increase in the irrigation interval is observed. This decrease evidences a response of the crop to water stress. It is worth noting that water deficit decreases turgor pressure, inhibiting photosynthesis and causing a reduction in plant growth. Additionally, a reduction in irrigation frequency can result in a strategy for the crop by reducing the metabolic cost for tissue maintenance (Sousa et al., 2014; Sousa et al., 2022). Similar results were reported by Lessa et al. (2019), who also observed a 30.07% reduction in the height of sorghum plants under water stress (irrigation frequency of four days) compared to irrigation carried out daily. Similar results were observed in a millet irrigation study, where higher irrigation levels resulted in larger plants, and a reduced irrigation level yielded plants with shorter height (Bhattarai et al., 2020).

Sousa et al. (2014) state that irrigation intervals longer than two days can lead to water deficit in plants, possibly due to root confinement in a limited soil volume, resulting in significant reductions in the amounts of water and nutrients available to the plants.

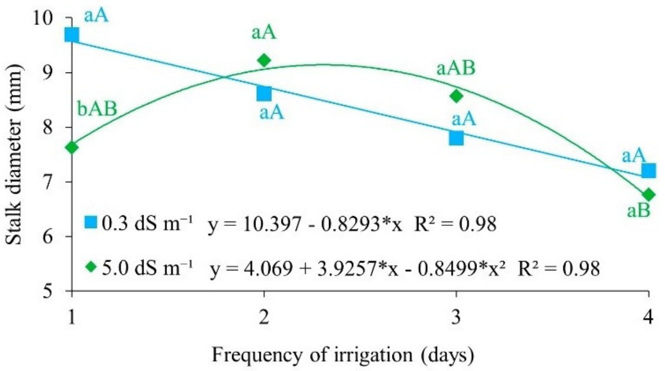
When analyzing the effect of irrigation frequencies and the electrical conductivity of irrigation water on the diameter of the millet plant stalk (Figure 4), it was found according to the equation that, for low-salinity water (0.3 dS m^{-1}), there was a linear reduction in stalk diameter, with a decrease of 7.97% for each increment of one day in irrigation frequency. For water with higher salinity (5.0 dS m^{-1}), the equation that best represented the response of the plants was quadratic polynomial, with a maximum estimated value of 9.14 mm for an irrigation frequency of 2.3 days.

This reduction in stalk diameter may be related to the physiological disturbance that the plant suffers when exposed to water and salt stress (over two days), morphologically adapting to guarantee the absorption of water from the soil to



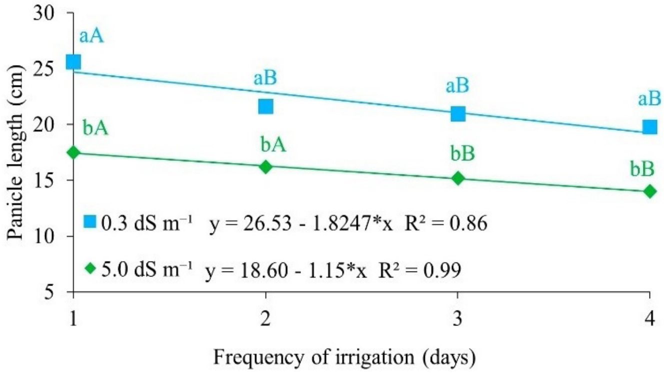
* - Significant at $p \leq 0.05$ by F test; Lowercase letters differentiate the means by the Tukey test ($p \leq 0.05$)

Figure 3. Plant height of millet plants as a function of two levels of irrigation water salinity (A) and different irrigation frequencies (B)



* - Significant at p ≤ 0.05 by F test; Lowercase letters differentiate at the same frequency of irrigation, and uppercase letters differentiate at the same salinity level the frequencies of irrigation by the Tukey test (p ≤ 0.05)

Figure 4. Stalk diameter of millet plants subjected to different irrigation frequencies and two levels of irrigation water salinity



* - Significant at p ≤ 0.05 by F test; Lowercase letters differentiate at the same frequency of irrigation, and uppercase letters differentiate at the same salinity level the frequencies of irrigation by the Tukey test (p ≤ 0.05)

Figure 5. Panicle length of millet plants subjected to different irrigation frequencies and two levels of irrigation water salinity

partially maintain its physiological activity, causing a decrease in stem diameter development in plants under conditions of multiple stress (water and salt) (Pereira Filho et al., 2019; Ma et al., 2023). Under conditions of shorter irrigation intervals (frequencies of 1 and 2 days), it is observed that these conditions may potentially facilitate improved water distribution and the maintenance of optimal soil moisture levels throughout the crop cycle. This can reduce water losses due to drainage and the occurrence of water stress periods in the crop, thereby promoting better stem development (Pereira Filho et al., 2014).

Similarly, Almeida et al. (2020), when evaluating agronomic characteristics of millet subjected to salt and water stress through different irrigation depths, also found a reduction in stalk diameter with the application of the lowest irrigation depth, both with low (0.03 dS m^{-1}) and high (4.0 dS m^{-1}) salinity water.

Panicle length decreased linearly with the decrease of irrigation frequency, and according to the decomposition of the equations reductions of 22.14 and 19.77% were observed between the extreme intervals of irrigation frequency (one and four days), in water with lower and higher salinity, respectively (Figure 5).

Plants have specific physiological responses when exposed to water and salt stress conditions, and this reduction in panicle length under the conditions shown in this study probably occurred because these stresses together cause the closure of stomata, in order to restrict water loss by reducing transpiration, sacrificing the uptake of CO_2 leading as a consequence to reductions in photosynthetic rates, reducing the accumulation of photoassimilates and therefore affecting reproductive organs (Amaral et al., 2019).

Salt stress can also cause toxicity in tissues due to the excess accumulation of Na^+ and Cl^- ions, affecting other physiological and metabolic processes in embryonic tissues, so nutrient uptake by the plant is compromised (Pereira Filho et al., 2020).

The variables leaf dry mass (LDM), stem dry mass (SDM), panicle dry mass (PDM), and total dry mass (TDM) were significantly influenced by the interaction between the studied factors, irrigation frequency and water salinity (Table 4).

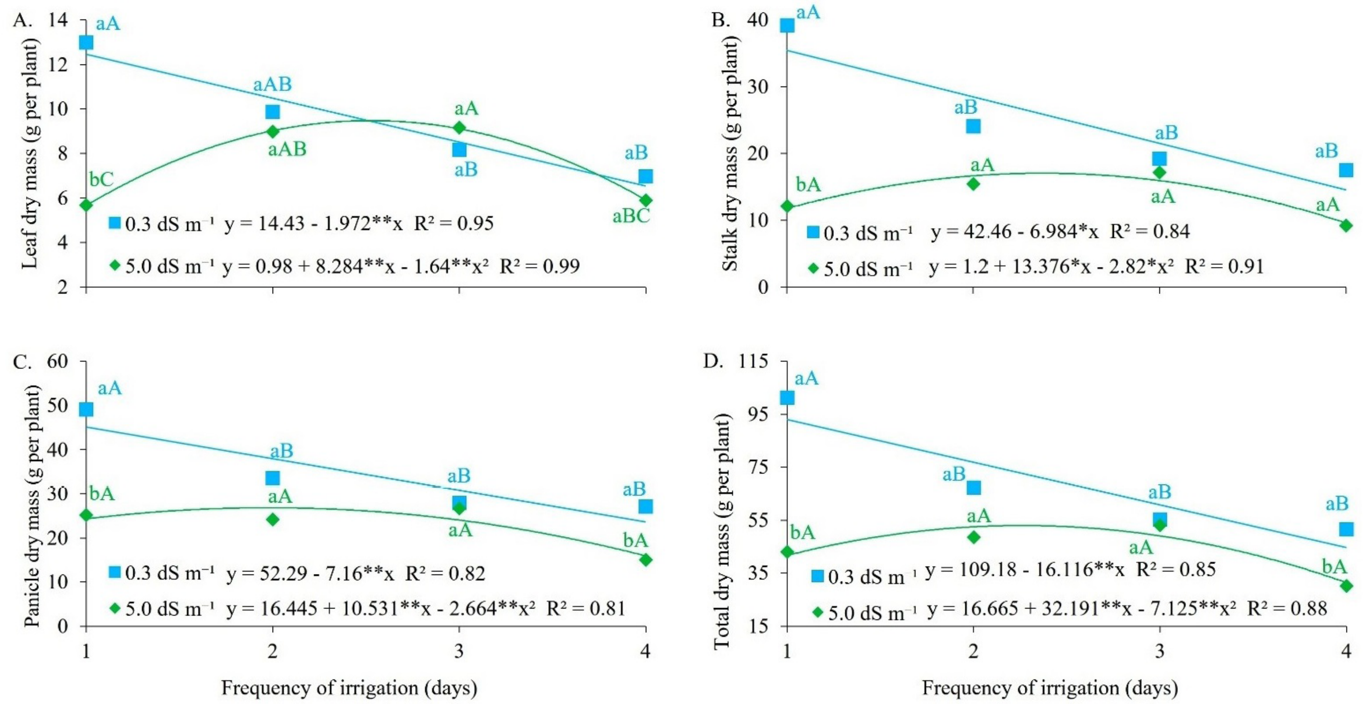
For leaf dry mass (LDM), according to the analysis of the equations, there was a quadratic effect for the water with the higher salinity (5.0 dS m^{-1}), with a maximum value of 9.48 g for an irrigation frequency every 2.52 days, while for the water with the low salinity (0.3 dS m^{-1}) there was a linear decrease of 1.97 g for each unitary increase in the interval of irrigation frequency (Figure 6A). This decrease in LDM is an indication that under water and salt stress conditions, throughout the crop cycle, the photoassimilates are less used for the formation of the photosynthetic apparatus and consequently less photoassimilates are allocated to the leaves, which directly affect the biomass of the plants (Bhattarai et al., 2020; Lima et al., 2020).

This result describes the effect of salt and water stress, which can inhibit or delay plant growth due to ionic and osmotic effects. Under conditions of low water availability, absorption is compromised by reduced water potentials, and as a result, plant growth is affected by decreased cellular expansion and elongation, as well as biomass. Salt stress can also induce tissue toxicity due to the excessive accumulation of Na^+ and/or Cl^- ions, affecting other physiological and metabolic processes in embryonic tissues, including cell division and differentiation, enzyme activity, and the uptake and distribution of nutrients (Pereira Filho et al., 2020; Sousa et al., 2022). Working under

Table 4. Summary of variance analysis for leaf dry mass (LDM), stem dry mass (SDM), panicle dry mass (PDM), and total dry mass (TDM) as a function of different irrigation frequencies and salinity levels in irrigation water

Source of variation	DF	Mean squares			
		LDM	SDM	PDM	TDM
Irrigation Frequency (F)	3	13.15*	216.56^{ns}	432.08**	1456.99**
Salinity levels in irrigation water (SL)	1	54.05**	1190.28**	1213.30**	5880.62**
F × SL	3	31.57**	329.65*	251.00**	1558.48**
Residual	32	3.34	94.43	49.70	257.75
CV (%)		21.29	20.63	24.99	28.67

DF - Degrees of freedom; (*) - Significant by F test at p ≤ 0.05; (**) - Significant by F test at p ≤ 0.01; ns - Not significant; CV - Coefficient of variation



** - Significant at $p \leq 0.01$ by F test; Lowercase letters differentiate at the same frequency of irrigation, and uppercase letters differentiate at the same salinity level the frequencies of irrigation by the Tukey test ($p \leq 0.05$)

Figure 6. Leaf (A), stalk (B), panicle (C), and total (D) dry mass of millet plants subjected to different irrigation frequencies and two levels of irrigation water salinity

protected environment conditions, Amaral et al. (2019) evaluated the influence of water stress and salinity on the agronomic performance of sunflower and also verified a reduction in leaf dry mass.

In Figure 6B it can be observed that the decrease in irrigation frequency caused a linear decrease in the stalk dry mass (SDM) for water of lower salinity (0.3 dS m^{-1}), providing a unitary decrease for each day of increase in the irrigation interval of 16.44%. On the other hand, as a function of the frequency of irrigation with water of higher conductivity (5.0 dS m^{-1}) a quadratic polynomial model was fitted, showing a maximum value of 18.15 g for an irrigation frequency every 2.4 days, according to the equation obtained.

Water stress associated with salt stress promotes closure of leaf stomata and a reduction in transpiration and CO_2 assimilation, which consequently causes a decrease in the biomass production of the plants (Silva Júnior et al., 2021). Oliveira et al. (2016), under greenhouse conditions, also observed a reduction in stalk dry mass in corn plants when subjected to irrigation with water of higher salinity (4.5 dS m^{-1}) at a daily irrigation frequency. Amaral et al. (2019), also verified a reduction in the dry mass of the sunflower (*Helianthus annus* L.) stalk under water deficit and saline conditions.

Ma et al. (2023), working with foxtail millet, state that the crop, when subjected to combined water and salt stresses, triggers osmoregulation mechanisms and inhibition of evapotranspiration, consequently reducing the overall biomass of plant organs. These authors also report that an increase in applied water content can neutralize the effect of salts.

When analyzing the effect of irrigation frequencies on panicle dry mass (PDM), for water of lower salinity (0.3 dS m^{-1}), the analysis of the regression equation showed that there was a reduction of the order of 7.16 g in panicle dry mass for each unit increase in the irrigation frequency interval (Figure 6C). Under higher salinity (5.0 dS m^{-1}), the best model was the quadratic polynomial, obtaining a maximum value of 26.96 g for an irrigation frequency every two days (Figure 6C).

This effect may be related to water deficit, which provokes alterations in plant behavior, causing a reduction in the amount of photoassimilates exported from the leaves, and to salt stress, which inhibits the absorption of nutrients, ultimately affecting the reproductive organs of the plants (Bhattarai et al., 2020; Goes et al., 2021).

Figure 6D shows the effect of irrigation frequencies and electrical conductivity of water on total dry mass (TDM). By regression analysis, it was found that for water with lower salinity (0.3 dS m^{-1}) as the frequency of irrigation decreased the response of plants was linear, corresponding according to the equation to a decrease of 16.11 g per unit increase in irrigation frequency. For water with higher salinity (5.0 dS m^{-1}), the best-fitting equation was the quadratic polynomial type with a maximum value of 53.02 g, according to the decomposition of the equation for an irrigation frequency every 2.25 days.

The reduction in plant biomass may be a consequence of reduced leaf production and photosynthetic rate and the deviation of energy intended for growth to the activation and maintenance of metabolic activity associated with adaptation to salinity and water deficit (Sousa et al., 2022; Queiroz et al., 2023). This fact demonstrates the interdependence among growth-related variables. Whatever the effects of salt and/or water stress on one of the millet organs, the others are affected. This indicates the crop's sensitivity to abiotic stresses in plant development, both in terms of drought and salinity sensitivity (Queiroz et al., 2023). Similarly, Lima et al. (2020), when evaluating the effect of salt stress of irrigation water on millet crop, also observed a linear reduction with increasing ECw, with an estimated decrease of 55.69% between salinity levels similar to those of this study (1 and 5 dS m^{-1}) for total dry mass.

The reduction in the initial growth of plants, under both water and salt stress, implies a substantial expenditure of energy by the plant to maintain its turgidity, even at critical levels. This disadvantage under conditions of water deficit and/or salinity is in addition to the energy required for water absorption from the soil at field capacity, under favorable soil moisture conditions. Consequently, plants require greater imbibition force to extract a unit mass of water from the soil when faced with water deficit caused by excess salts or lack of water, compared to the effort needed under favorable total soil water potential conditions (Sousa et al., 2014; Maniçoba et al., 2021; Sousa et al., 2022).

Thus, the results suggest that frequencies of up to a maximum of two days under salt stress possibly led to increased salt leaching due to the irrigation volume applied, providing better development conditions. Additionally, it is worth noting that infrequent irrigation with high depths can promote nutrient leaching for the plants. However, very frequent irrigations with lower depths may not be suitable, as they tend to moisten only the surface soil layer, facilitating greater water loss through the evaporation process and salt accumulation in this region. This also limits the volume of soil effectively explored by the roots (Pereira Filho et al., 2014; Seabra Filho et al., 2020).

Therefore, determining the appropriate irrigation frequency for each type of crop is of utmost importance to maintain the soil with an optimal water content, promoting crop development and consequently achieving higher yields and economic returns.

Conclusions

1. Salt stress (5.0 dS m^{-1}) negatively affected leaf area, plant height, stalk diameter, panicle length, and leaf, stem, panicle and total dry mass of millet, under daily and four-day irrigation frequencies.

2. Increasing the interval in irrigation frequency to above two days negatively affects the agronomic performance of millet crop, regardless of the electrical conductivity of water used (0.3 and 5.0 dS m^{-1}).

3. Under salt stress conditions, adopting irrigation frequencies between two and three days can be a viable alternative for irrigation management in pearl millet crop.

Literature Cited

Almeida, M. C. R. de; Leite, M. L. de M. V.; Souza, L. S. B. de; Simões, V. J. L. P.; Pessoa, L. G. M.; Lucena, L. R. R. de; Cruz, M. G. da; Sá Júnior, E. H. de. Agronomic characteristics of the *Pennisetum glaucum* submitted to water and saline stresses. Acta Scientiarum. Animal Sciences, v.43, p.1-11 2020. https://doi.org/10.4025/actascianimsci.v43i1.50468

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. L. de M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013.

Amaral, A. M.; Teixeira, M. B.; Soares, F. A. L.; Cabral Filho, F. R.; Vidal, V. M.; Morais, W. A.; Bastos, F. J. C. Influência do estresse hídrico e da salinidade moderada no crescimento e produção do girassol cv. Charrua. Revista Global Science and Technology, v.12, p.14-29, 2019.

Araújo, C. de A.; Lira, J. B. de; Magalhães, A. L. R.; Silva, T. G. F. da; Gois, G. C.; Andrade, A. P. de; Araújo, G. G. L. de; Campos, F. S. Pearl millet cultivation with brackish water and organic fertilizer alters soil properties. Ciência Animal Brasileira, v.22, p.1-16, 2021. https://doi.org/10.1590/1809-6891v22e-70056

Araújo Júnior, G do. N.; Morais, J. E. F. de; Steidle Neto, A. J.; Souza, L. S. B. de; Alves, C. P.; Silva, G. I. N. da; Leite, R. M. C.; Silva, M. J. da; Jardim, A. M. da R. F.; Montenegro, A. A. de A.; Silva, T. G. F. da. Use of intercropping and mulch to improve the water and natural resources use efficiencies of forage cactus and millet production in a semiarid region. Field Crops Research, v.304, p.109071, 2023. https://doi.org/10.1016/j.fcr.2023.109171

Ayers, R. S.; Westcot, D. W. A qualidade da água na agricultura. 2.ed. Campina Grande: UFPB, 1999. 153p. Estudos FAO: Irrigação e Drenagem, 29

Bhattarai, B.; Singh, S.; West, C. P.; Ritchie, G. L.; Trostle, C. L. Effect of deficit irrigation on physiology and forage yield of forage sorghum, pearl millet, and corn. Crop Science, v.60, p.2167-2179, 2020. https://doi.org/10.1002/csc2.20171

Carvalho, D. F. de; Oliveira Neto, D. H. de; Felix, L. F.; Guerra, J. G. M.; Salvador, C. A. Produtividade, eficiência no uso da água e fator de resposta em produção de cenoura sob diferentes lâminas de irrigação. Ciência Rural, v.46, p.1145-1150, 2016. https://doi.org/10.1590/0103-8478cr20150363

Costa, J. G. J da.; Gomes, S. P.; Sousa, G. G. de; Conrado, J. A. de A.; Albuquerque, A. L. B.; Pimentel, P. G.; Rocha, A. C.; Sousa, H. C. Crescimento e trocas gasosas em milheto sob diferentes doses e fontes de nitrogênio. Research, Society and Development, v.9, e820974988, 2020. http://dx.doi.org/10.33448/rsd-v9i7.4988

Goes, G. F.; Sousa, G. G. de; Santos, S. de O.; Silva Júnior, F. B. da; Ceita, E. D. R. de; Leite, K. N. Produtividade da cultura do amendoim sob diferentes supressões da irrigação com água salina. Irriga, v.26, p.210-220, 2021. https://doi.org/10.15809/irriga.2021v26n2p210-220

Lessa, C. I. N.; Oliveira, A. C. N de; Magalhães, C. L.; Sousa, J. T. M. de; Sousa, G. G. de. Estresse salino, cobertura morta e turno de rega na cultura do sorgo. Revista Brasileira de Agricultura Irrigada, v.13, p.3637-3645, 2019. https://doi.org/10.7127/rbai.v13n5001122

Lima, A. F.; Sousa, G. G. de; Souza, M. V. P. de; Silva Junior, F. B. da; Gomes, S. P.; Magalhães, C. L. Cultivo do milheto irrigado com água salina em diferentes coberturas mortas. Irriga, v.25, p.347-360, 2020. https://doi.org/10.15809/irriga.2020v25n2p347-360

Maas, E. V. Salt tolerance of plants. Applied Agricultural Research, v.1, p.12-25, 1986.

Maniçoba, R. M.; Espínola Sobrinho, J.; Zonta, J. H.; Cavalcante Junior, E. G.; Oliveira, A. K. S. de; Freitas, I. A. da S. Resposta do algodoeiro à supressão hídrica em diferentes fases fenológicas no semiárido brasileiro. Irriga, v.26, p.123-133, 2021. http://dx.doi.org/10.15809/irriga.2021v26n1p123-133

Ma, Y.; Liu, W.; Qiao, Y.; Qiao, W.; Yang, H.; Zhong, Y.; Yang, H.; Wang, H.; Li, Y.; Dong, B.; Liu, M. Effects of soil salinity on foxtail millet osmoregulation, grain yield, and soil water utilization under varying water conditions. Agricultural Water Management, v.284, p.108354, 2023. https://doi.org/10.1016/j.agwat.2023.108354

Oliveira, F. A.; Medeiros, J. F.; Cunha, R. C. da; Souza, M. W. de L.; Lima, L. A. Uso de bioestimulante como agente amenizador do estresse salino na cultura do milho pipoca. Revista Ciência Agronômica, v.47, p.307-315, 2016. https://doi.org/10.5935/1806-6690.20160036

Payne, W. A.; Wendt, C.W.; Hossner, L. R.; Gates, C. E. Estimating pearl millet leaf area and specific leaf area. Agronomy Journal, v.83, p.937-941, 1991. https://doi.org/10.2134/agronj1991.00021962008300060004x

Pereira Filho, J. V.; Bezerra, F. M. L.; Silva, A. R. A da; Sousa, C. C. M. de; Castro J. M de. Frequência de irrigação e aplicação de N em meloeiro irrigado por gotejamento nas condições semiáridas do Nordeste. Científica, v.42, p.11-22, 2014.

Pereira Filho, J. V.; Mendonça, A. de M.; Sousa, G. G. de; Viana, T. V. de A.; Ribeiro, R. M. R.; Canjá, J. F. Crescimento inicial da cultura da fava irrigada sob estresse salino e hídrico. Revista Brasileira de Agricultura Irrigada, v.14, p.4036-4046, 2020. https://doi.org/10.7127/rbai.v14n101139

Pereira Filho, J. V.; Viana, T. V. de A.; Sousa, G. G.; Chagas, K. L.; Azevedo, B. M de; Pereira, C. C. M. de S. Physiological responses of lima bean subjected to salt and water stresses. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.959-965, 2019. https://doi.org/10.1590/1807-1929/agriambi.v23n12p959-965

Queiroz, G. C. M. de; Medeiros, J. F. de; Silva, R. R. da; Morais, F. M. da S.; Sousa, L. V. de; Soza, M. V. P. de; Santos, E. da N.; Ferreira, F. N.; Silva, J. M. C. da; Clemente, M. I. B.; Granjeiro, J. C. de C.; Sales, M. N. de A.; Constante, Nobre, R. G.; Sá, F. V. da S. Growth, solute accumulation, and ion distribution in sweet sorghum under salt and drought stresses in a Brazilian potiguar semiarid area. Agriculture, v.13, p.1-22, 2023. https://doi.org/10.3390/agriculture13040803

Rhoades, J. D.; Kandiah, A.; Mashali, A. M. Uso de águas salinas para produção agrícola. Campina Grande: UFPB. 2000, 117p. Estudos da FAO, Irrigação e Drenagem

Richards, L. A. Diagnosis and improvement of saline and alkali soils. Washington: US Department of Agriculture, 1954. 160 p. USDA Agriculture Handbook, 60

Seabra Filho, M.; Vieira, L. R.; Menezes, A. S.; Pinheiro Neto, L. G.; Azevedo, B. M.; Sousa, P. G. R. Produção de óleo e produtividade de girassol sob diferentes frequências de irrigação no semiárido cearense. Revista Brasileira de agricultura Irrigada, v.14, p.4297-4304, 2020. https://doi.org/10.7127/rbai.v14n501236

Silva, F. de A. S.; Azevedo, C. A. V. de. The assistat software version 7.7 and its use in the analysis of experimental data. African Journal of Agricultural Research, v.11, p.3733-3740, 2016. https://doi.org/10.5897/AJAR2016.11522

Silva, J. O. N. da; Santos, J. P. A. de S.; Salvador, K. R. da S.; Leite, R. M. C.; Aviz, R. O. de; Silva, N. S. G. da; Amaral, E. M.; Leite, M. L. M. V. Can the use of saline water irrigation reduce the forage deficit in the Brazilian semi arid region? Research, Society and Development, v.11, p.1-11, 2022. https://doi.org/10.33448/rsd-v11i5.28357

Silva Júnior, J. V. da; Bezerra, A. A. de C.; Silva, E. M. da. Crescimento desenvolvimento de cultivares de feijão-caupi em função da salinidade da água de irrigação. Irriga, v.26, p.346-366, 2021. https://doi.org/10.15809/irriga.2021v26n2p343-366

Sousa, G. G. de; Azevedo, B. M. de; Fernandes, C. N. V.; Viana, T. V. de A.; Silva, M. L. S. Growth, gas exchange and yield of peanut in frequency of irrigation. Revista Ciência Agronômica, v.45, p.27-34, 2014. https://doi.org/10.1590/S1806-66902014000100004

Sousa, H. C.; Sousa, G. G. de; Cambissa, P. B.; Lessa, C. I. N.; Goes, G. F.; Silva, F. D. B. da; Abreu, F. S.; Viana, T. V. de A. Gas exchange and growth of zucchini crop subjected to salt and water stress. Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.815-822, 2022. https://doi.org/10.1590/1807-1929/agriambi.v26n11p815-822