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Agronomic performance of forage sorghum and millet grown under irrigation with saline water and nitrogen doses in the Brazilian semi-arid

Desempenho agronômico de sorgo forrageiro e milheto cultivados sob irrigação com água salina e doses de nitrogênio no semiárido Brasileiro

Rendimiento agronómico de sorgo forrajero y mijo cultivados bajo riego con agua salina y dosis de nitrógeno en el semiárido Brasileño

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Denizard Oresca
ORCID: https://orcid.org/0000-0002-0810-3448
Federal University of Pernambuco, Brazil
E-mail: dndhaiti@gmail.com
Alexandre Campelo de Oliveira
ORCID: https://orcid.org/0000-0002-9300-8081
Federal Rural University of Pernambuco, Brazil
E-mail: alexandre_solos@hotmail.com
Thieres George Freire da Silva
ORCID: https://orcid.org/0000-0002-8355-4935
Federal Rural University of Pernambuco, Brazil
E-mail: thigeoprossional@hotmail.com
Luiz Guilherme Medeiro Pessoa
ORCID: https://orcid.org/0000-0003-1937-526X
Federal Rural University of Pernambuco, Brazil
E-mail: pessoa.lgm@gmail.com
Jamiles Carvalho Gonçalves de Souza
ORCID: https://orcid.org/0000-0002-0999-2478
Federal Rural University of Pernambuco, Brazil
E-mail: jamilesdesouza28@gmailcom
Lucas Henrique Maciel
ORCID: https://orcid.org/0000-0003-4976-3087
Federal Rural University of Pernambuco, Brazil
E-mail: badjockey56@yahoo.com

Abstract
The saline and water stresses are part of the main factors that limit agricultural production. In semi-arid regions, these stresses are potentiated due to high rates of evapotranspiration and low precipitation. However, the supply of water and nutrients via fertilization can favor the maximization of crop production. In this sense, aimed to evaluate the agronomic and nutritional performance of sorghum and millet, submitted to different irrigation blades and increasing nitrogen doses. The research was conducted at Academic Unit of Serra Talhada-PE. The experimental design was a randomized block, arranged in subdivided plots, with four replications, arranged in the 4 x 4 factorial scheme, referring to 4 irrigation blades (28%, 36%, 44%, 52% ETc) and 4 nitrogen doses (0, 100, 200, 300 kg ha^{-1}), adopting the Sorghum + Millet system, being sorghum the main crop. Seeding was carried out on April 7, 2017, with an average of 14 plants per linear. The irrigation blades were based on the ETc (ETc = ETo x Kc of sorghum). Nitrogen fertilization consisted of 1/3 in sowing and 2/3 in covering. Ended each cycle crop, plant height, stem diameter were measured, the number of live leaves was counted, green and dry mass yield was estimated, N-total, Na^+, K^+ and Cl^- content were determined. Data were submitted to analysis of variance and variables adjusted to the regression model, using SAS Software. Nitrogen fertilization and irrigation with saline water benefited the growth of sorghum and millet crop. Nitrogen favors the absorption of N-total and potassium by plants and inhibited the absorption of chloride and sodium.
Keywords: Irrigation; Nitrogen fertilization; Forage production; Semi-arid.

Resumo
Os estresses salino e hídrico são parte dos principais fatores que limitam a produção agrícola. Em regiões semiáridas, esses estresses são potencializados devido às altas taxas de evapotranspiração e baixa precipitação pluviométricas. Porém, o fornecimento de água por irrigação e nutrientes via adubação pode favorecer a maximização de produção das culturas. Nesse sentido, objetivou-se avaliar o desempenho agronômico e nutricional de sorgo e milheto, submetidos a diferentes lâminas de irrigação e doses crescentes de nitrogênio. A pesquisa foi realizada na Unidade

Acadêmica de Serra Talhada-PE. O delineamento experimental foi em blocos casualizados, dispostos em parcelas subdivididas, com quatro repetições, arranjados em esquema fatorial 4 x 4, referentes a 4 lâminas de irrigação (28%, 36%, 44%, 52% ETc) e 4 doses de nitrogênio (0, 100, 200, 300 kg ha^{-1}), adotando o sistema Sorgo + Millet, sendo o sorgo a cultura principal. A semeadura foi realizada em 7 de abril de 2017, com média de 14 plantas por linear. As lâminas de irrigação foram baseadas na ETc (ETc = ETo x Kc do sorgo). A adubação nitrogenada consistiu no parcelamento de 1/3 na semeadura e 2/3 na cobertura. Ao final de cada ciclo da cultura, a altura da planta e o diâmetro do caule foram medidos, o número de folhas vivas foi contado, a produção de massa verde e seca foi estimada, o teor de N-total, Na^+, K^+ e Cl^- foram determinados. Os dados foram submetidos à análise de variância e as variáveis ajustadas ao modelo de regressão, por meio do software SAS. A adubação nitrogenada e a irrigação com água salina beneficiaram o crescimento da cultura do sorgo e do milheto. O nitrogênio favorece a absorção de N-total e potássio pelas plantas e inibe a absorção de cloreto e sódio.
Palavras-chave: Irrigação; Adubação nitrogenada; Produção de forragem; Semiárido.

Resumen
El estrés hídrico y salino es parte de los principales factores que limitan la producción agrícola. En las regiones semiáridas, estas tensiones aumentan debido a las altas tasas de evapotranspiración y la escasez de precipitaciones. Sin embargo, el suministro de agua a través del riego y de nutrientes a través de la fertilización puede favorecer la maximización de la producción de cultivos. En este sentido, el objetivo fue evaluar el rendimiento agronómico y nutricional del sorgo y el mijo, sometidos a diferentes niveles de riego y dosis crecientes de nitrógeno. La envestigación se realizó en la Unidad Académica de Serra Talhada-PE. El diseño experimental fue en bloques al azar, dispuestos en parcelas subdivididas, con cuatro repeticiones, ordenados en el esquema factorial 4 x 4, referido a 4 niveles de riego (28%, 36%, 44%, 52% ETc) y 4 dosis de nitrógeno (0, 100, 200, 300 kg ha^{-1}), adoptando el sistema Sorgo + Mijo, siendo el sorgo el cultivo principal. La siembra se realizó el 7 de abril de 2017, con un promedio de 14 plantas por lineal. Los niveles de riego se basaron en la ETc (ETc = ETo x Kc de sorgo). La fertilización con nitrógeno consistió en 1/3 en siembra y 2/3 en cobertura. Terminado cada ciclo de cultivo, se midió la altura de la planta, el diámetro del tallo, se contó el número de hojas vivas, se estimó el rendimiento de masa verde y seca, se determinó el contenido de N-total, Na^+, K^+ y Cl^- . Los datos se sometieron a análisis de varianza y las variables se ajustaron al modelo de regresión, utilizando el software SAS. La fertilización con nitrógeno y el riego con agua salina beneficiaron el crecimiento de la cosecha de sorgo y mijo. El nitrógeno favorece la absorción de N-total y potasio por las plantas e inhibe la absorción de cloro y sodio.
Palabras clave: Riego; Fertilización nitrogenada; Producción de forrajes; Semiárido.

1. Introduction

According to estimates made by the United Nations, the projected population for 2100 is 11.2 billion, which increases the challenges of agriculture to meet the demands of food for both humans and animals. There are several factors that limit this challenge like occurrence of pests, rainfall limitation, soil degradation that composes, among others, desertification, water restriction and salinization of the soil (Liliane & Charles, 2020).

Every day, the arid and semi-arid regions of the world have aroused more concern looks because they have rainfall and irregularities deficiency, high temperatures and evapotranspiration (Parihar et al., 2015; Ongom et al., 2016; Silva & Azevedo, 2020), which make these regions present a considerable water restriction precisely in times of drought.

Often, the only water resources found in arid and semi-arid environments are considered unsuitable for use in irrigation because they have a considerable amount of salts in their composition (Sá et al., 2020). Studies have shown that the use of saline waters increases soil electrical conductivity (Mesquita et al., 2012), making the soil less productive because the saline environment presents a physical and chemical barrier to seed germination and plant growth (Dias & Flavio, 2010; Dehnavi et al., 2020).

Environments that present water restrictions and salt content exert negative effects on plant ecophysiological processes, including growth inhibition, loss of protective enzyme activity, water and nutrient absorption, cell membrane permeability (Dogan et al., 2010; Gopala Krishnan & Kumar, 2021), besides damaging, the foliar contents of chlorophyll and foliar carotenoids, compromising the photosynthetic activity, which reflects in the reduction of crop production (Cavalcante et al., 2011; Taiz et al., 2017).

Thus, the cultivation of plants such as sorghum (*Sorghum bicolor* L. Moench) and millet (*Pennisetum glaucum* L.), originating in the African tropics, which adapt to a wide range of environments (Magalhães et al., 2015) and which present certain water and salt tolerances (Lira et al., 1999; Aquino et al., 2007) have been widely adopted and considered a strategy to produce and provide fodder to animals in time of drought. Sorghum and millet have a significant importance, particularly in the tropical zone due to their adaptation to low fertility soils and other risk factors such as water stress and saline, although they also respond favorably to irrigation and higher rainfall (Pholsen & Suskri, 2007; Serme et al. 2018)

Although the adaptation of these crops on poor soils, studies show that they respond significantly to fertilization and showed maximum yield potential when nitrogen is used (Shamme et al., 2016). For most cultivated plants, nitrogen is considered an essential nutrient because it is present in the composition of the most important biomolecules, such as ATP, NADPH, NADH, chlorophyll, proteins and enzymes (Giordano and Raven, 2014), as well as to attenuate the effects of salinity because nitrate (NO_3^-) reduces the absorption of chloride (Cl^-) by plants due to the competitive actions of these elements (Kafkafi et al., 1982; Feijão et al., 2013), since there is an allosteric influence of NO_3^- at the sites of Cl^- uptake (Cram, 1973; Camalle et al., 2020).

In many production systems, nitrogen availability is almost a limiting factor, since this element influences plant growth more than any other nutrient (Epstein & Bloom, 2005). Its deficiency causes poor formation and low density of chlorophyll in the leaves (Thomsom and Weier, 1962, Taiz et al., 2017), interfering directly in crop productivity.

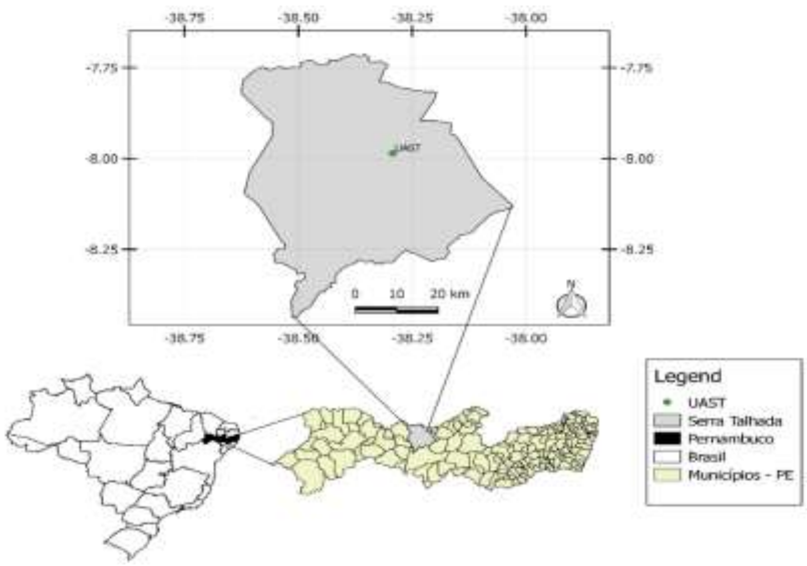
Thus, aimed to evaluate the agronomic performance of sorghum and millet grown under irrigation with saline water and nitrogen doses in the Brazilian semiarid region.

2. Methodology

2.1 Experimental area

The experiment was carried out in the municipality of Serra Talhada - PE, located under the geographical coordinates 7º 59 '7 "South, 38º 17' 34" West and 443 meters high, during the period from April to July 2017 (Figure 1). The climate of the municipality is type BSwh which means hot and dry semiarid (Alvares et al., 2013), with summer rains, beginning in December with end in April. The average annual rainfall is 632 mm (SECTMA, 2006).

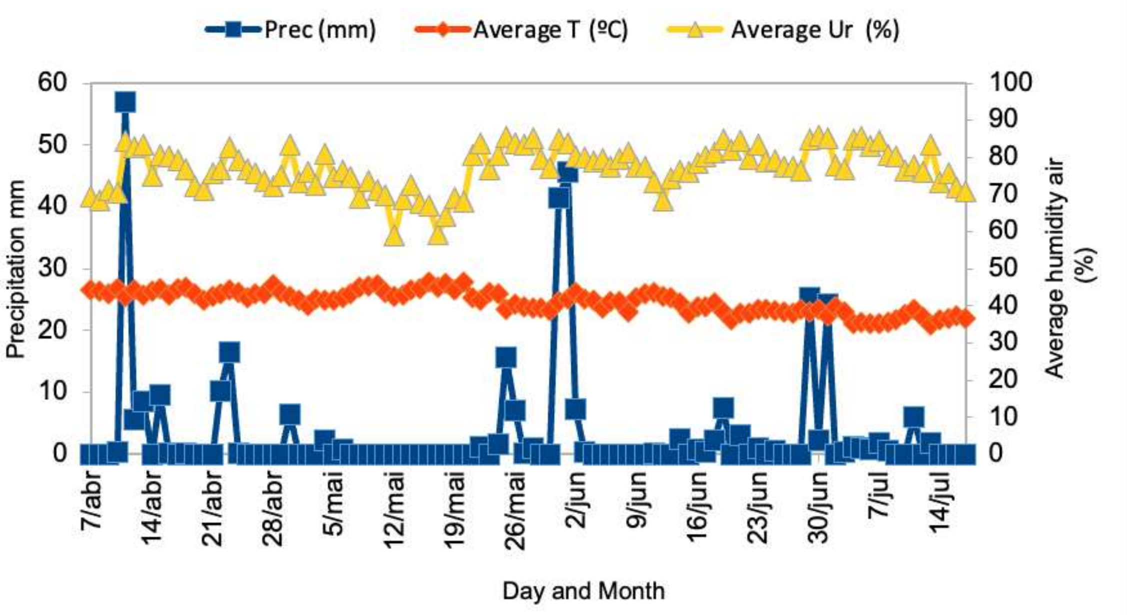
Figure 1. Location of the experimental area, Pajeú Pernambucano backwoods, Serra Talhada - PE, Brazil. Source: Authors (2021).



Source: Authors.

Durante the entire period of experiment conduction, rainfall, relative humidity and temperature were monitored through the automatic meteorological station located at 300 meters from the experimental area (Figure 2).

Figure 2. Rainfall, humidity and temperature monitored during the conduction of the experiment, Serra Talhada – PE, Brazil. Source: Authors (2021).



Source: Authors.

2.2 Physical and chemical soil analysis of the experimental area.

Before the implantation of the experiment, soil samples of 0 to 60 cm were collected, with layers of 20 cm depth, which were characterized physically and chemically (Table 1), according to the methodology proposed by EMBRAPA (2011). The soil of the experimental area was classified as Haplic Cambisol Typical Eutrophic Ta (Santos et al., 2013).

Table 1. Results of the physical and chemical analysis of the soil collected from 0 to 60 cm before the installation of the experiment, Serra Talhada, PE.

Physical Attributes										
Depths (cm)	SD	PD	TP	NC	DF	T-S	TS	FC	Silt	Clay
	---- g cm^{-3} ----		------------ % -------------			------- Granulometric Composition % -------				
00 – 20	1.61	2.53	36.26	4.32	59.00	73.6	44.50	29.10	15.9	10.5
20 – 40	1.66	2.47	32.80	4.39	58.31	72.2	48.88	23.34	17.2	10.5
40 – 60	1.58	2.47	36.07	6.39	49.01	71.8	48.24	23.52	15.7	12.5

SB = Sum of base – SB = SB = Ca2+ + Mg2+ + K+ + Na+; CEC = Cation exchange capacity– CEC = SB+ (H+ + Al3+); V = Saturation per

Chemical Attributes													
Depths (cm)	P mg/dm^{-3}	pH	K	Na	Al	Ca	Mg	H+Al	SB	CEC	V	C	ESP	O.M
			------------------------ cmol$_c$ dm^{-3} --------------------------								--------------% -------------			
00 – 20	380	7.1	0.88	0.11	0.00	1.20	0.10	1.0	2.29	3.29	69.60	0.72	3.34	1.24
20 – 40	360	7.1	0.68	0.27	0.00	1.30	0.30	1.0	2.55	3.55	71.80	0.51	7.60	0.88
40 – 60	320	7.2	0.38	0.29	0.00	1.10	0.10	1.0	1.87	2.87	65.11	0.31	10.1	0.53

base = (SB/CEC) *100; C = carbon; m = Aluminum Saturation; O. M = organic matter; ESP Exchangeable sodium percentage, PES = (Na+ /CEC)*100; SD = Soil density; PD = Particle density; TP = Total porosity; NC = Natural clay; DF = Degree of floculation; T-S = Total sand; TS = Thick sand; FC = Fine clay. Source: Authors (2021).

2.3 Conducting the experiment

The work was carried out evaluating two forage species, sorghum and millet, planted in a consortium, being sorghum considered the main crop, when irrigated with different irrigation blades and nitrogen doses. In this way, the experimental design was in blocks, arranged in the factorial scheme 4 x 4, referring to the four irrigation blades (28%, 36%, 44% and 52%) with saline water and four nitrogen doses (0, 100, 200, 300 kg ha^{-1}), that represent the subplots.

Experiment consisted of 4 (repetitions) blocks and each block is composed of 4 irrigation blades or strips, being these considered as the main plots. Each plot is formed by 4 subplots where N doses were applied, that is, 4 main parcels and 16 subplots form each block. Each main plot that corresponds to an irrigation blade is composed of 5 drip lines, spaced 0.75 m from each other, with 12 m length, totaling 45 m^2. Each subplot was composed of 5 drip lines, spaced at 0.75 m, with 3 m length, totaling 11.25 m^2 of total area. The effect of border was taken into account, so a useful area was determined, in each subplot, used for the evaluations, consisting of 3 central drip lines, spaced by 0.75 m and 2 m length, totaling 4.5 m^2.

The cultivars BRS 1501 (millet) and IPA 467 - 4 - 2 (forage sorghum) were sown in grooves located next to the drip tape, spaced at 0.25 m. Seeding was carried out on April 6, 2017, with an average of 30 seeds per linear meter. At 15 days after the emergency, thinning was performed, leaving an average of 14 plants per linear meter.

In order to avoid the loss of nitrogen both by volatilization and leaching, its application was carried out in a piecemeal manner, with 1/3 of the application in the sowing furrow, simultaneously with the sowing of crops, and the remaining 2/3 at 25 days after emergence, using urea as the source of N.

The irrigation blades were based on the Evapotranspiration of the Culture (ETc), adopting a water management under deficit conditions, in order to minimize the amount of salts applied through irrigation. To do this, the blades were calculated based on levels of 28%, 36%, 44% and 52% in ETC being obtained by the equation Etc = ETo x Kc where ETo is the reference evapotranspiration and Kc values, coefficient of culture, reflect the water needs of plants in their vegetative and reproductive stages. The ETo was determined by the Penman Monteith Method parameterized in FAO Bulletin 56 (ALLEN et al., 1998), expressed in the equation below.

$$\mathrm{ETo} = \frac{0{,}408\Delta(\mathrm{Rn} - \mathrm{G}) + \gamma\left(\frac{900}{t + 273}\right) u_2 \,(e_s - e)}{\Delta + \gamma(1 + 0{,}34 u_2)}$$

Being, *ETo* reference evapotranspiration; *Rn* balance of surface radiation; *G* soil heat flux density; *t* is the average daily air temperature at 2 m in height; u_2 is wind speed at 2 m in height; e_s is the saturation vapor pressure; *e* is the current vapor pressure; Δ is the slope of the vapor pressure curve; γ is the psychrometric constant.

The water was replenished three times a week using the drip irrigation system. The control of the irrigation slides was performed by ball records located at the beginning of the five tapes of each irrigation band, the volume being applied as a function of the system flow rate and the opening time of the records at a pressure of 1 atm. For the ETo calculation, precipitation and other climatic data were obtained by the automatic meteorological station near the experimental field. The irrigation blades by treatment totaled 55 mm, 71 mm, 87 mm and 105 mm, which added to the rainfall (334 mm), resulted in the following water blades: 389 mm, 405 mm, 422 mm and 439 mm. During the millet cycle, which was earlier than the sorghum, the irrigation blades were 28 mm, 57 mm, 66 mm and 74 mm, with precipitation (239 mm), resulting in: 287 mm, 296 mm, 305 mm and 313 mm.

The chemical analysis of water used for irrigation was done monthly during the conduction of the experiment. Based on the methodology proposed by RICHARD (1954), water is classified as C3 and has on average electrical conductivity = 1.62 dS m^{-1}, pH = 6.84; Na^+ = 3.48 µmol L^{-1}, K^+ = 0.26 µmol L^{-1} and Cl^- = 9280 µmol L^{-1}.

2.4 Biometric and biomass Analysis

At 65 and 103 days after sowing of millet and sorghum, respectively, the growth of the crops, expressed in height, stem diameter and live leaves numbers, was evaluated in the useful area of each plots in four pre-identified plants. At the same age, when the grains were present in the pasty phase, tending the farinaceous, the fresh biomass crops shoot was obtained from the weight of mass of 12 plants harvested in the useful area of each plot and then extrapolated to t ha^{-1}.

Immediately after properly weighed for green biomass, the plants were ground in a forage machine. After homogenizing manually, 500 g subsamples were removed. These were placed in previously identified paper bags and dried in an oven with forced air circulation at 55 °C until constant weight and then weighed in semi-analytical balance to obtain the dry biomass crops shoot, extrapolated to t ha^{-1}, subsequently ground in a Wiley mill (1 mm sieve) in order to determine the levels of the mineral elements sodium (Na), potassium (K), chloride (Cl) and total nitrogen (N-Total).

2.5 Nutritional analysis

The extraction of Na^+, K^+ and Cl^- was performed as described by Maia et al. (2010). The Na^+, K^+ readings were made in flame photometry, while the chloride content was obtained by titration. N-total contents were obtained by sulfur digestion. Quantification was done through a Kjeldahl distiller, according to EMBRAPA methodology (2011).

2.6 Statistical analysis

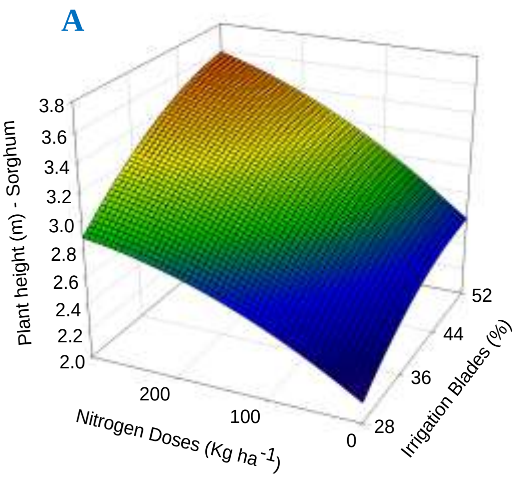
The results were submitted to the Shapiro - Wilk and Cochran tests to test the normality of the data and the homogeneity of the variances, and then the analysis of variance was applied. The averages of the quantitative factors were submitted to regression analysis using SAS/STAT® software version 9.3 (SAS Institute, 2011).

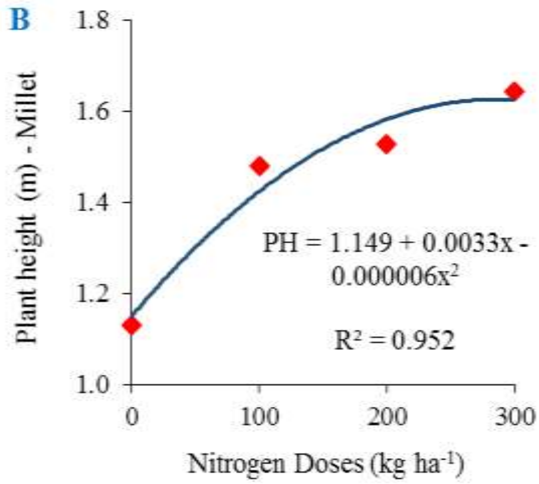
3. Results

3.1 Biometric analysis

The increase in sorghum height was affected by the interaction of irrigation blades and nitrogen (L x N), whereas pearl millet was affected only by fertilization. The highest height of sorghum, about 3.6 m, was obtained with the highest nitrogen dose (300 kg ha^{-1}) and irrigation blade (52%), that is, as the nitrogen doses and the irrigation blades increased, consequently, there was a concomitant increase of plants height (Figure 3A). Millet, in turn, was affected only by nitrogen fertilization, where the dose of 275 kg ha^{-1} of nitrogen provided higher plant height, being 1.64 m (Figure 3B).

Figure 3. Height of Sorghum (A) plants and millet (B) as a function of different irrigation blades with saline water and increasing doses of nitrogen, grown in a consortium, Serra Talhada - PE.





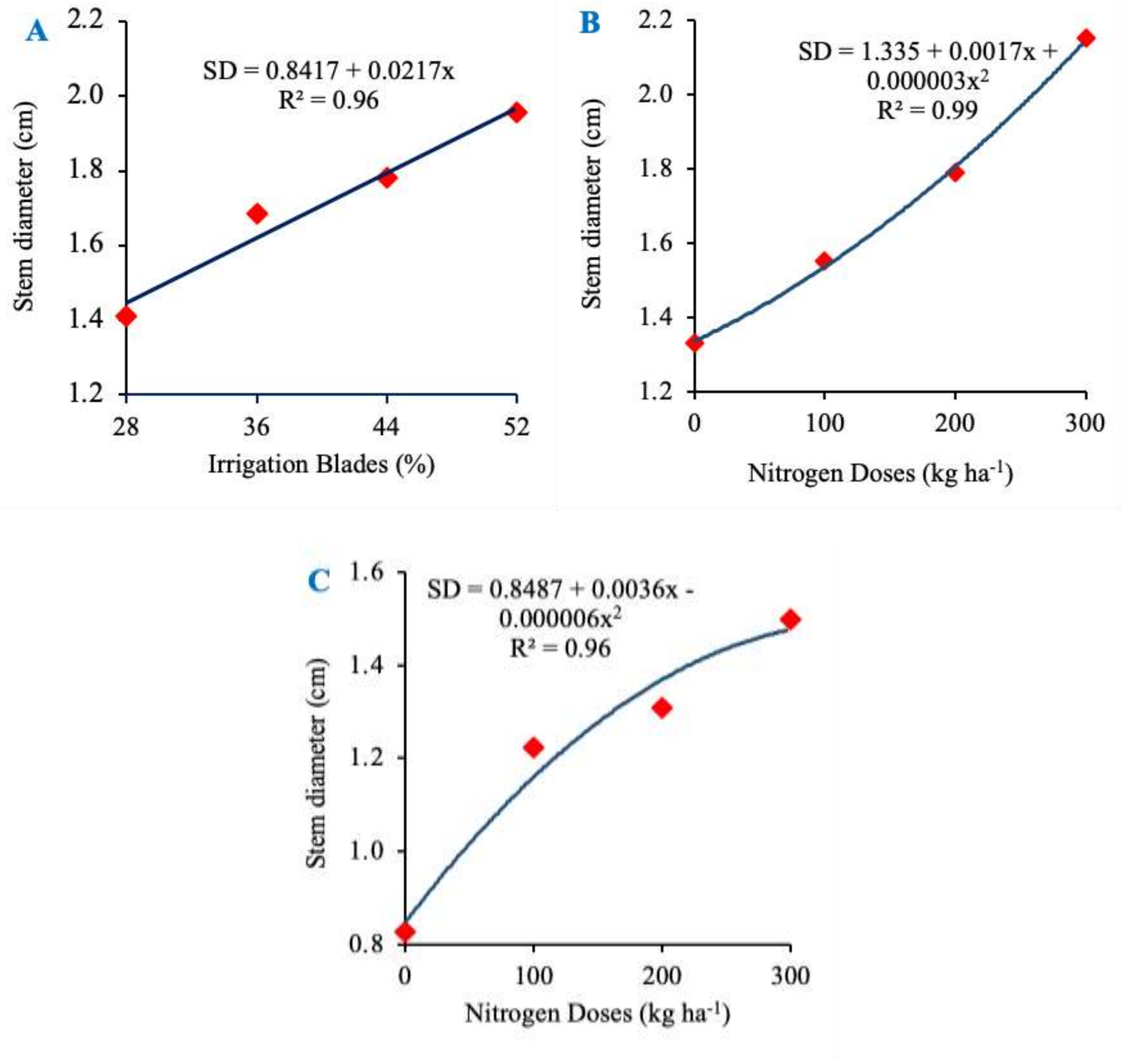
$Ph = 0.376 + 0.087 L + 0.003 N - 0.001 L^2 – 0.000005 N^2 + 0.00004 L*N \qquad R^2 = 0.99$

Source: Authors (2021).

The sorghum diameter had an isolated effect of irrigation and nitrogen fertilization, whereas millet was significantly affected only by nitrogen fertilization (Figure 4A, 4B and 4C). Probably, the application of the irrigation blades did not have a significant effect on the millet due to the precipitation that occurred during its growth cycle, which revolves around 60 to 80 days. It was noted that, as the water and nitrogen supply increased, there was an increase in stem diameter, where the sorghum crop had a mean diameter of 2.15 cm with the highest nitrogen dose against 1.33 cm in the absence of nitrogen fertilizer, causing a percentage increase of 61.1%. Similar behavior was observed when evaluating millet, where the dose 300 kg ha^{-1} of

N increased the stem diameter from 0.8 cm to 1.5 cm, causing a percentage gain of 87.5%, from the lowest to the highest dose of nitrogen. In the same way, the increase of the irrigation blade linearly increased the sorghum diameter from 1.41 to 1.96 cm, from the lowest to the highest irrigation blade, with an estimated percentage gain of 39%.

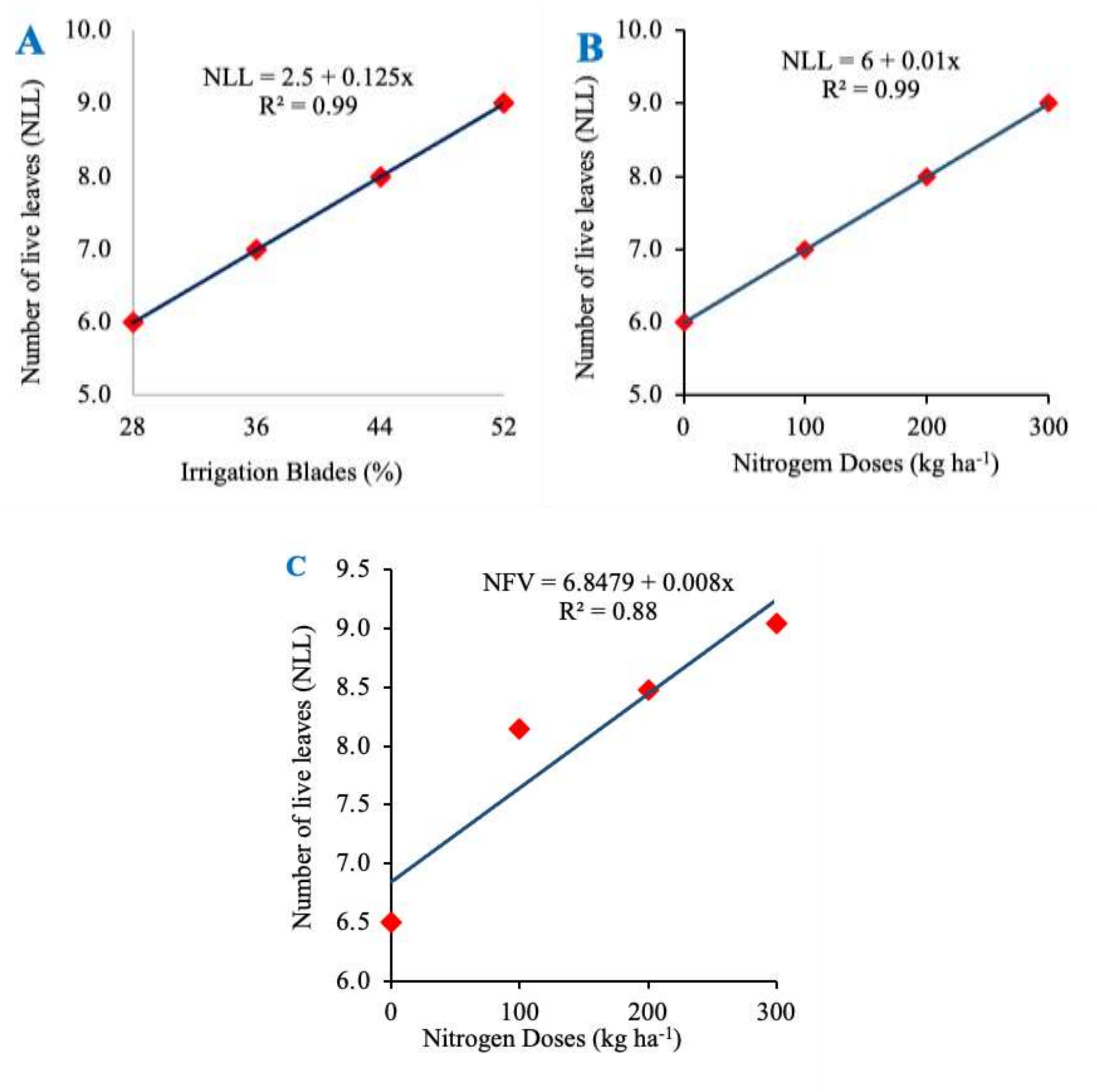
Figure 4. Stem diameter of Sorghum (A and B) plants and millet (C) as a function of different irrigation blades with saline water and increasing doses of nitrogen, cultivated in a consortium, Serra Talhada - PE. Source: Authors (2021).



Source: Authors (2021).

The number of live leaves per plant is an important index of growth and development of the plant that determines the ability of the plant to capture solar radiation for photosynthesis and is essential for the production of photoassimilates. According to the results obtained in this study, it was observed that the number of live leaves of the sorghum crop was affected, in a linear way, by the factors irrigation blades and nitrogen, increasing from 6 to 9 live leaves per plant in both conditions, with a percentage increase estimated at 50% (Figure 5A and 5B). However, for the millet crop, only nitrogen fertilization had a significant effect on the number of live leaves, with an average of 6.5 to 9 live leaves per plant, in the absence (0 kg ha^{-1}) and the highest dose of N (300 kg ha^{-1}), respectively, with a percentage of foliar photosynthetically active gain estimated at 38.46% (Figure 5C).

Figure 5. Number of live leaves of Sorghum (A and B) plants and millet (C) as a function of different irrigation blades with saline water and increasing doses of nitrogen, cultivated in a consortium, Serra Talhada - PE.

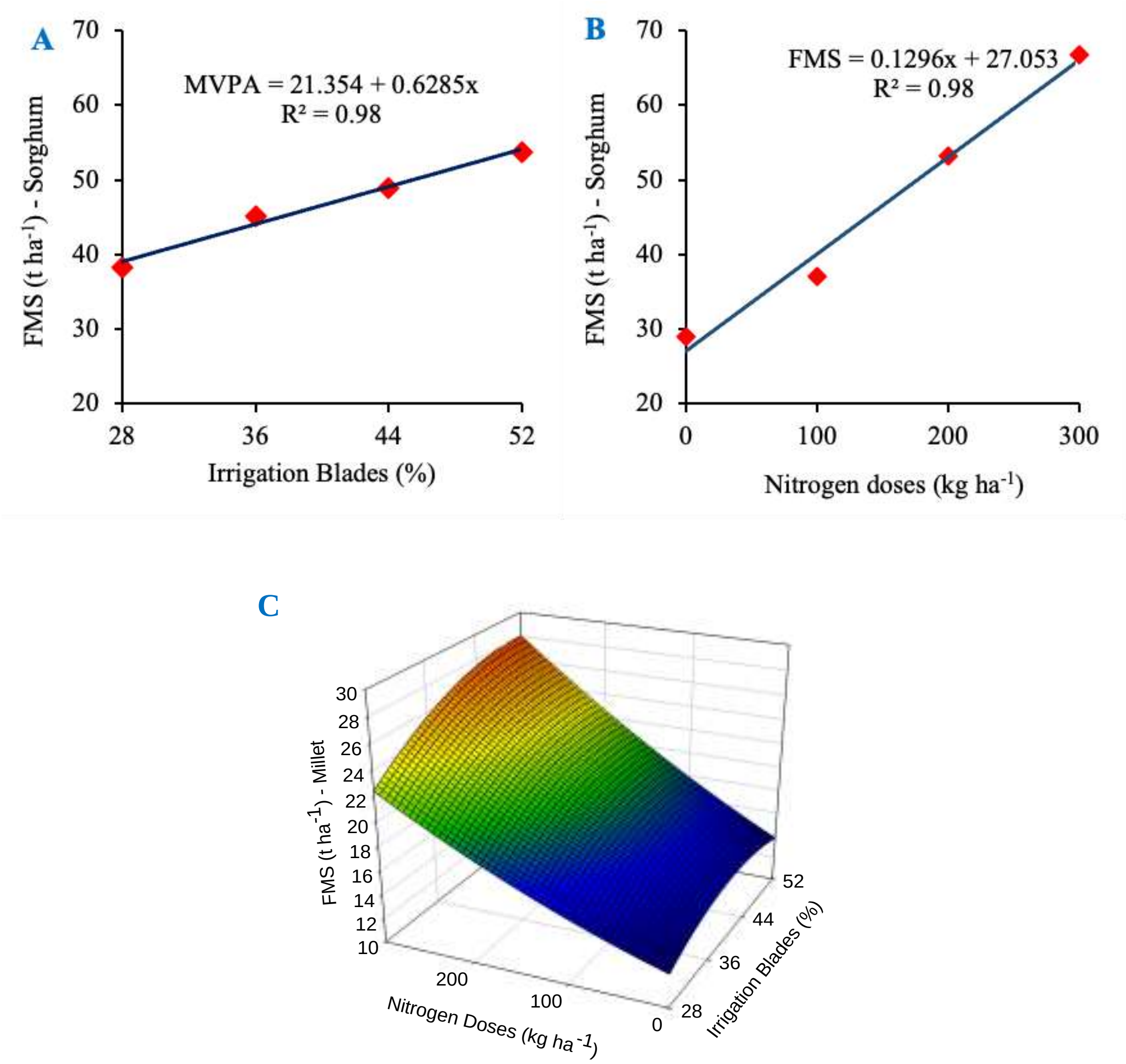


Source: Authors (2021).

3.2 Biomass variables

The production of fresh mass of shoots (FMS) had a linear effect (p <0.01) in response to the increase of nitrogen fertilization and irrigation with saline water, in both cultures. For the sorghum crop, there was a significant effect for N and L, being in an isolated manner, but for the millet crop, there was interaction L x N for the analyzed variable (Figure 6A, 6B and 6C). The maximum yield of the sorghum green mass was obtained when the highest (52%) irrigation blade was applied with saline water and 300 kg ha^{-1} of nitrogen, being 53, 76 t ha^{-1} and 66,79 t ha^{-1} , which represents a percentage increment in the order of 40.40% and 130.46%, respectively, in relation to the lowest irrigation blade and nitrogen dose. On the other hand, for the millet crop, the highest irrigation blades associated with the highest nitrogen dose benefited the green mass of crop shoot, from approximately 13 t ha^{-1} when no nitrogen applied to 28 t ha^{-1} with 300 kg ha^{-1}, causing an estimated percentage increase 115.38%.

Figure 6. Yield fresh biomass of shoot of Sorghum - FMS (A and B) plants and millet (C) as a function of different irrigation blades with saline water and increasing doses of nitrogen, cultivated in a consortium, Serra Talhada - PE.

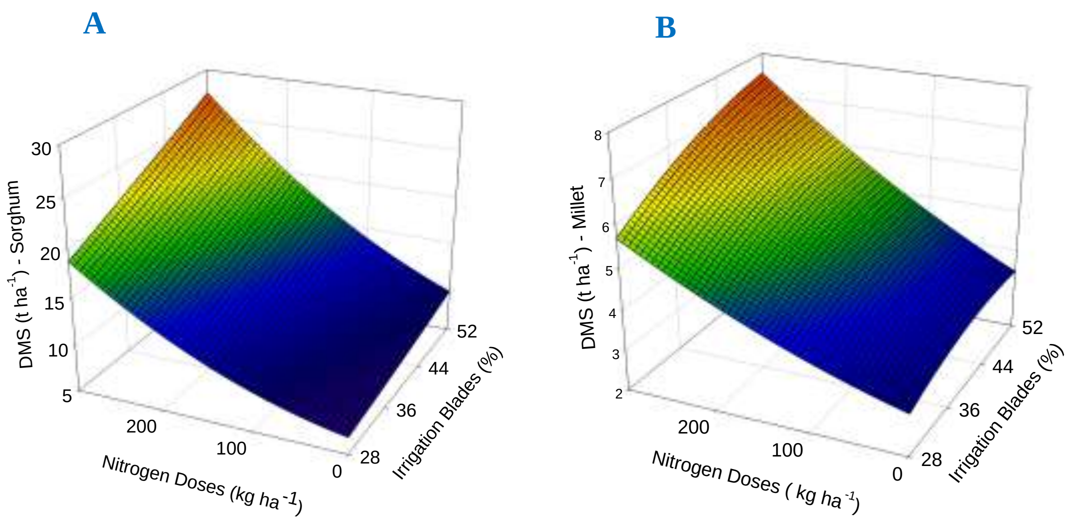


$FMS = -3.667 + 0.878\ L + 0.004\ N - 0.010\ L^2 + 0.000032\ N^2 + 0.0006\ L*N \qquad R^2 = 0.91$

Source: Authors (2021).

The results showed that the dry mass yield (DMS) of cultivars BRS1501 and IPA467-4-2 (Figure 7A, 7B) was significantly influenced by the N x L interaction, where the maximum dry mass yield was obtained as the nitrogen doses increased and the irrigation blades, simultaneously, values being 7.6 t ha^{-1} and 27.40 t ha^{-1} for millet and sorghum, respectively

Figure 7. Yield of shoot dry matter of Sorghum - DMS (A) plants and millet (B) as a function of different irrigation blades with saline water and increasing doses of nitrogen, cultivated in a consortium, Serra Talhada - PE.



$DMS_{sorghum}$ = 4.797 + 0.049 L - 0.008 N + 0.0008 L^2 + 0.00008 N^2 + 0.0008 L*N R^2 = 0.97

DMS_{millet} = -0.008 + 0.157 L + 0.0002 N - 0.002 L^2 + 0.00001 N^2 + 0.0002 L*N R^2 = 0.97

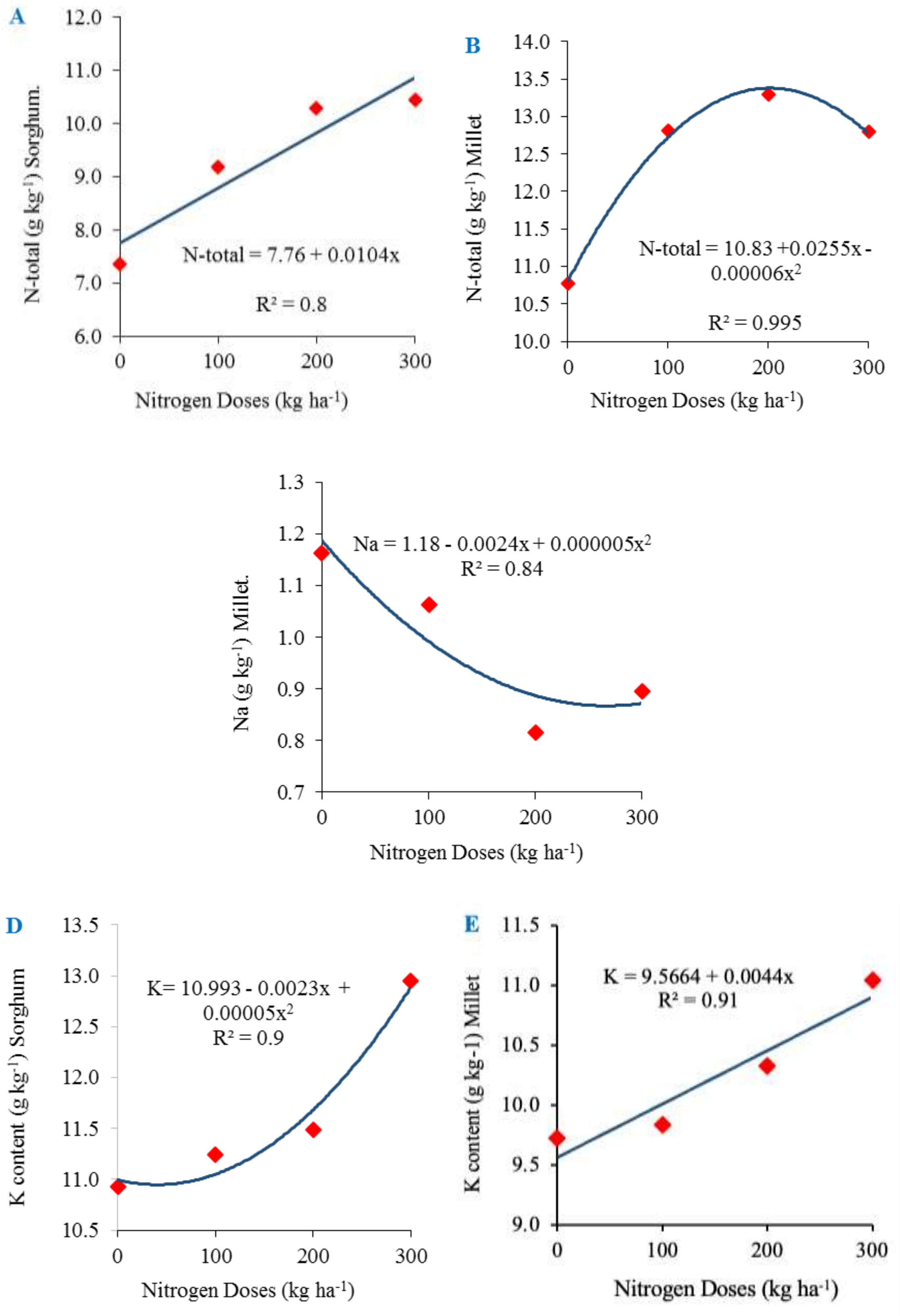
Source: Authors (2021).

3.3 Nutritional response

According to the results obtained in this study, total nitrogen (N), sodium (Na) and potassium (K) levels were significantly affected only by nitrogen fertilization (Figure 8A and B, 8C, 8D and E). For N-total, a linear increase of this element in the sorghum crop shoot is observed, i.e, as the N doses increased in the soil, consequently increased the content of this nutrient in the plants, being 7.36 g kg^{-1} versus 10.45 g kg^{-1}, in the absence and presence of 300 kg ha^{-1} of N, respectively, resulting in an estimated percentage gain of 41.98%. The higher nitrogen concentrations in sorghum plants causes higher crude protein content and, consequently, the better the nutritional quality.

For the millet crop, there was a quadratic behavior as a result of the nitrogen supply in the soil, and the maximum concentration 13.54 g kg^{-1} of N-total in the shoot of the plants was found when applied 212.5 kg ha^{-1} of N. It was observed that the nitrogen supply in the soil favored the absorption of K^+ in both cultivars; however, it inhibited Na^+ absorption only in the millet crop, being a quadratic way.

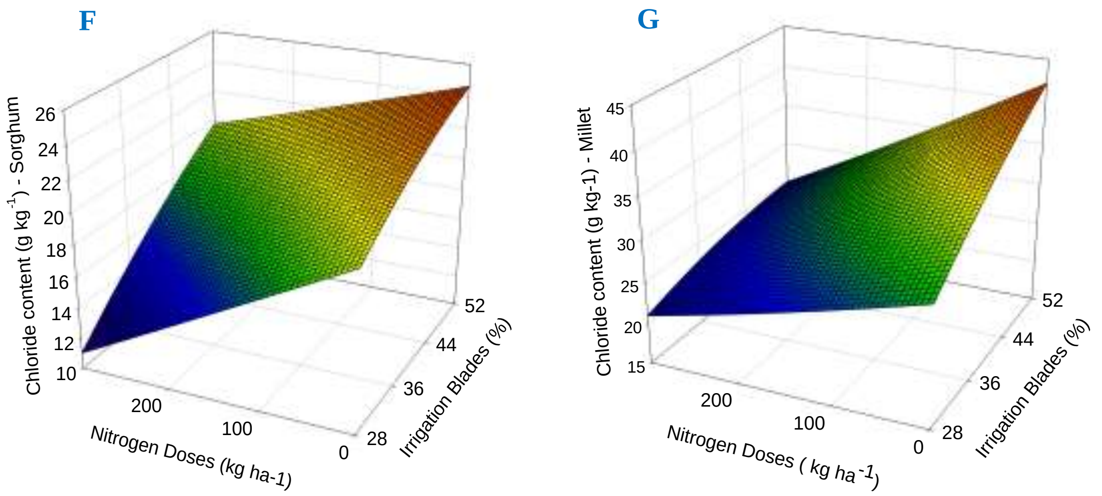
Figure 8. N-total, Na and K content of Sorghum (A, D) plants and millet (B, C and E) as a function of different irrigation blades with saline water and increasing doses of nitrogen, cultivated in a consortium, Serra Talhada - PE.



Source: Authors (2021).

Chloride contents were significantly influenced by N x L interaction for both sorghum and millet culture (Figure 9F and 9G). It was observed that, as the irrigation blades were increased, the chloride contents increased in the shoot of the plants, with a maximum concentration of 25.2 g kg^{-1} of dry mass for sorghum and 44 g kg^{-1} of dry mass for millet, when irrigated 52% blade. On the other hand, the supply of nitrogen caused a decrease in the concentration of chloride content in the crop shoot.

Figure 9. Chloride content of Sorghum (9F) plants and millet (9G) as a function of different irrigation blades with saline water and increasing doses of nitrogen, cultivated in a consortium, Serra Talhada - PE.



$Cl_{sorghum} = 9.424 + 0.482\,L - 0.047\,N - 0.004\,L^2 + 0.000002\,N^2 + 0.0006\,L{*}N$ $\quad R^2 = 0.96$

$Cl_{millet} = 6.692 + 0.963\,L + 0.003\,N - 0.005\,L^2 + 0.000012\,N^2 - 0.001\,L{*}N$ $\quad R^2 = 0.95$

Source: Authors (2021).

4. Discussion

4.1 Biometric aspects

The growth of both crops, expressed in height, stem diameter and number of live leaves, was benefited by the water availability of nitrogen. This fact is due to these factors acting on vegetative growth directly influencing the greater stretching, expansion, and cell division due to the greater maintenance of the cellular turgidity and photosynthetic process, thus promoting increase in the growth and development of plants (SILVA et al., 2005) , as observed in this study. This fact could also have occurred due to the greater availability of nutrients in the soil as well as its better extraction by roots and, therefore, translocation within the plant system (RANA et al., 2013).

As previously mentioned, nitrogen is a structural nutrient because it is a constituent of proteins; it is part of a molecule of chlorophyll, in the production of carbohydrate, besides participating in several organic compounds, playing a fundamental role in plant metabolism. Sawargaonkar et al. (2013), Pradhan et al. (2015) and Shamme et al. (2016) studied the forage sorghum cultivars, which realized an increase in plant height as the addition of nitrogen.

The elevation of the diameter of the crops is due to the nitrogen absorbed by the plants combine with carbon skeletons to produce amino acids, which result in proteins that are stored in plant tissues. According to Steiner et al. (2011), the larger the shoot diameter, the greater the capacity of the plants to store photoassimilates that will contribute to a higher production of biomass and grain filling. Fernandes et al. (1991) obtained results that corroborate with those observed in this study.

For the number of live leaves, the results observed in this study corroborate with those obtained by Pietro-Souza et al. (2013), which verified an increase in the number of leaves, due to the increase in nitrogen doses, when evaluating the initial development of wheat plants (Guamirim cv.), under nitrogen doses, in Red Latosol. Hastenpflug et al. (2011) also found an increase in the production of leaf production, studying four wheat cultivars in Red Nitosol dystrophic, due to nitrogen levels in the state of Paraná.

It was observed that the water supply promoted a greater increment in the growth of the plants, particularly in the sorghum crop, because, besides the benefits in the expansion and cellular growth, the plants were under less water stress, causing them remain with the stomata open which results in the greater uptake of CO_2 from the atmosphere to the production of photoassimilates through photosynthesis (Taiz et al., 2017).

Studies carried out by Souza et al. (2017), noticed an increase in the height of the sorghum with the increment of the blades, corroborating with the results observed in this study. These same authors evaluating the diameter of the sorghum crop under different irrigation blades and mulching, found similar behavior to our work.

It was observed that the irrigation lamina factor did not have a significant effect on millet growth parameters due to rainfall events that occurred during the cycle of this crop, which is more precocious (around 60 to 70 days) than forage sorghum (90 to 110 days).

Although irrigation water was classified as C3, it did not affect the growth and development of plants, probably because the sorghum crop is considered as moderately tolerant to salinity. For this crop, the threshold salinity that can affect its yield is estimated at 6.8 dS m^{-1} of the soil saturation extract (Massa & Hoffman, 1977) and, for reduction of up to 50% in both emergence and production, a salinity of 13 to 15 dS m^{-1} is required (Rhoades et al., 1992).

4.2 Fresh and dry Biomass

The increase in the MVPA yield of the cultivars is due to the higher growth of the cultures expressed in height, stem diameter and number of live leaves of the plants, caused by nitrogen supply and water availability. As previously mentioned, nitrogen is a macronutrient essential for the development and growth of plants, for their relevant functions in the production and amino acids synthesis. These results confirm the importance of nitrogen in the growth of sorghum and millet plants, where the increase in nitrogen doses resulted in greater nutrient availability to plants, higher carbohydrate accumulation resulting from photosynthesis that stimulates growth, resulting in higher mass production of plants shoot.

Due to the high efficiency of water use, water supply in the presence of nitrogen promoted an increase in dry matter content. According to studies, sorghum and millet crops require approximately 310 and 280 kg of water, respectively, to produce one kg of dry matter (Tabosa et al., 1998a; Lima, 1996), which differ from other crops grain.

The results obtained in this study for the sorghum crop when the nitrogen was applied are superior to those obtained by Nirmal et al. (2016) evaluating forage sorghum cultivars under different levels of nitrogen and irrigation, obtained 60.6 t ha^{-1} of fresh biomass with the highest percentage of nitrogen supplied. According to these same authors, the increase in forage yield with the increase of nitrogen was mainly associated to higher plant height, number of $plant^{-1}$ leaves and stem diameter. Souza et al. (2005), evaluating the cultivar IPA 467-4-2 in irrigation conditions and organic and mineral fertilization, obtained yields of total green mass of 64 t ha^{-1}

4.3 Nutrition aspects

The nitrogen fertilizer supply increased the N-total concentration in the aerial part of the sorghum and millet plants. This increase in N-total accumulation in plants due to nitrogen supply is probably due to the rapid uptake of $NH4^+$ by the roots and their subsequent translocation to the aerial parts.

The nitrogen supply in the soil favors K uptake in both cultivars. Probably, this fact occurred due to the nitrogen availability in a considerable quantity, near the root zone, essential ions such as NH_4^+ and $N0_3^-$ which are preferred by the plants, inhibiting the absorption of nonessential elements and harmful to the metabolism of most cultivated plants. Another factor that may be related to the decrease in Na uptake is probably due to the increase in K uptake, causing a direct competition between K and Na through the absorption sites in the plasma membrane of the roots. Nitrogen supply inhibited the absorption of Na only in the millet crop, being quadratic way. Studies carried out by Restelatto et al. (2015), evaluating the nitrogen efficiency and nutrient absorption by suckling of sorghum and oats, showed a quadratic growth, where the maximum N and K extraction was obtained with a dose of 250 kg ha^{-1} of nitrogen, being stabilized up to the highest dose applied.

In the pearl millet crop, the maximum concentration 13.54 g kg^{-1} of N-total in the part of the plants was found when 212.5 kg ha^{-1} of N was applied. This probably occurred due to the dose above 212, 5 kg ha^{-1} of N compromise nutrient uptake by millet plants, since every crop has a limiting dose to express all its productive potency, and that when that dose is exceeded, it can cause an imbalance of other nutrients, causing a fall in production and unnecessary expenditure on fertilizers.

The water supply led to the concentration of chloride in the aerial part of the plants. This fact is probably due to the considerable presence of chloride in the water used for irrigation since it was a saline water, that is, the larger the blade, the greater the amount of this element incorporated in the soil and, consequently, the greater its absorption plants. Mehdi-Tounsi et al., (2017), evaluating the long-term field response of pistachios (Pistacia vera L.) to salinity of irrigation water, observed an increase in chloride accumulation in the plants, as concentrations increased of salts in irrigation water.

On the other hand, the availability of nitrogen promoted a reduction in the absorption of chloride, which is considered a toxic element for most glycophytes when it is in great quantity. This reduction of the chloride contents in the aerial part of the plants is due to the antagonistic action of the nitrate ions (NO_3^-) present in the urea, i.e. the nitrate acts as a competitive inhibitor of chloride absorption by the plants. According to Cram (1973), increased nitrate concentration may inhibit chloride uptake due to an allosteric influence of nitrate at the chlorine uptake sites, further reducing chloride accumulation by the plant.

In corn plants submitted to saline stress, Feijão et al. (2013) observed that with the increase of the NO_3^- concentration in the medium, there was an improvement in the absorption of this ion, leading to the reduction of the absorption of Cl^-. Kafkafi et al. (1982) observed similar behavior in the tomato crop, where the chloride content in the plant decreased as the NO_3^- concentration in the solution increased. In the peppermint crop, Yasuor et al. (2017) found an increase in Cl^- in the leaves of plants due to exposure to salinity. However, the same authors realized that the increase of N reduces the absorption and accumulation of Cl^- in the organs of plants.

According to Figures 8 (F and G), it can be seen that there was a greater accumulation of Cl^- in millet shoot when compared to sorghum. Possibly, this fact can be explained because the physiological cycle of the millet is shorter than that of the sorghum, thus absorbing the maximum of nutrients. Another factor related to this would be the high natural ability of the millet crop to extract nutrients from the soil due to its deep root system (Evangelista, 2016), which suggests that this crop can be used as phytoremediation.

5. Conclusion

According to the results obtained in this experiment, it can be concluded that nitrogen fertilization and irrigation with saline water benefited the growth of the sorghum crop, expressed in height, stem diameter, number of live leaves, fresh and dry matter. For the millet crop, nitrogen fertilization was more influential.

The nitrogen supply in the soil favors the accumulation of nitrogen total (N-total) and potassium (K) by the plants, on the other hand, caused a decrease in the accumulation of sodium (Na) and chloride (Cl) by the plants in the same condition.

Irrigation caused greater chloride accumulation in both cultures shoot evaluated in this study.

Despite the promising results found in this work, researchers are encouraged to perform experiments with several growing seasons (at least three) for assessment of consistency of results and effect of climate conditions on results

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References

Allen, R. G., Pereira, L. S., Raes, D., Smith, M**.** **(**1998). *Crop evapotranspiration: Guidelines for computing crop water requirements*. Rome: FAO, 300 p. (FAO – Irrigation and Drainage Paper, 56).

Alvares, C. A. et al. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22(6), 711-728.

Aquino A. J. S., Lacerda, C. F., Bezerra, M. A., Gomes filho, E., Costa, R. N. T. (2007). Crescimento, partição de matéria seca e retenção de na^+, k^+ e cl^- em dois genótipos de sorgo irrigados com águas salinas. *Revista Brasileira de Ciência do Solo*, 31(5), 961-971.

Camalle, M., Standing, D., Jitan, M., Muhaisen, R., Bader, N., Bsoul, M. (2020). Effect of Salinity and Nitrogen on the Leaf Quality, Biomass, and Metabolic Response of Two Ecotypes *of Portulaca oleracea*. *Agronomy*, 10(656). DOI: 10.3390/agronomy10050656.

Cavalcante, L. F., Rebequi, A. M., Sena, G. S. A., Nunes, J. C. (2011). Irrigation with salt water and use of bovine biofertilizer in the formation of jatropha seedlings. *Irriga***,** 16(3), 288-300.

Cram, W. J. (1973). Internal factors regulating nitrate and chloride influx in plant cells. *Journal of Experimental Botany*, 24(2), 328-341.

Dehnavi, A. R., Zahedi, M., Ludwiczak, A., Perez, S. C., Piernik, A. (2020). Effect of Salinity on Seed Germination and Seedling Development of Sorghum (*Sorghum Bicolor* (L.) Moench) Genotypes. *Agronomy*, 10(859). DOI:http//doi.10.33990/agronomy10060859

Dogan, M. Tipirdama, Z. R., Demir Y. (2010). Salt resistance of tomato species grown in sand culture. *Plant, Soil and Environment*, 56(11), 499-507.

Embrapa. (2011). Centro Nacional de Pesquisa de Solos. *Manual de métodos de análise do solo*. 3a ed. Rio de Janeiro, (Embrapa – CNPS. Documentos, 132). p. 230.

Epstein, E., Bloom, A. J. (2005). *Mineral Nutrition of Plants*: Principles and Perspectives. 2nd Edition, Sinauer Associates, Inc., Sunderland, p.380.

Evangelista, A. F., Borges, L. S., Silva, A. N. F., Vogado, W. F., Marques, K. A. (2016). *Características de produção e crescimento de espécies forrageiras para produção de silagem*: revisão de literatura, 13(6), 1-7.

Feijão, A. R., Marques, E. C., DA Silva, J. C.B., Lacerda, C. F, Prisco, J. T., Gomes-Filho, E. (2013). Nitrato modula os teores de cloreto e compostos nitrogenados em plantas de milho submetidas à salinidade. *Bragantia*, Campinas, 72(1), 10-19.

Fernandes, V. L. B., Nunes Filho, M., Souza, V. A., Fernandes, M. B. (1991). Absorção e utilização de nitrogênio em planta de sorgo cultivado em solução nutritiva. *Ciência Agronômica*, Fortaleza, 22(1), 89-96.

Giordano, M., Raven, J. A. (2014). Nitrogen and sulfur assimilation in plants and algae**.** *Aquatic Botany***,** 118(1), 45-61.

Gopalakrishnan, T., Kumar, L. (2021). Linking long-term changes in soil salinity to paddy land abandonment in Jaffna Peninsula, Sri Lanka. *Agriculture*, 11(211). DOI: http//doi.org/10.3390/agriculture11030211

Hastenpflug, M., Braida, J. A., Martin, T. N., Ziech, M. F., Simionatto, C. C., Castagnino, D. S. (2011). Cultivares de trigo duplo propósito submetidos ao manejo nitrogenado e a regimes de corte. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, 63(1), 196-202.

Kafkafi, U., Valoras, N., Letey, J. (1982). Chloride interaction with nitrate and phosphate nutrition in tomato (*Lycopersicon esculentum* L.). *Journal of Plant Nutrition*, 5(12), 1369-1385.

Lima, G. S. (1998). *Estudo comparativo da resistência à seca no sorgo forrageiro (Sorghum bicolor (L.) Moench) em diferentes estádios de desenvolvimento*. Recife: UFRPE, pp.128. (Dissertação de Mestrado).

Liliane, T. N., Charles, M. S. (2020). Factors affecting yield of crops, agronomy – *Climate Change and Food Security*, Amanullah, IntechOpen. DOI:105.5772/intechopen.96672. Available from: http://www.intechopen.com/books/agronomy-climate-change-food-security/factors-affecting-yield-of-crops.

Lira, M. A., Dubeux Junior, J. C. B., Oliveira, C. F., Tabosa, J. N. (1999). Competição de cultivares de Capim-elefante x milheto (*Pennisetum americanum* (L.) Leeke) sob pastejo. *Revista Brasileira de Zootecnia*, 28(5), 936-946.

Mass, E. V., Hoffman, G. J. (1997). Crop salt tolerance – current assessment. *Journal Irrigation and Drainage Division*, ASCE. 103 (IR2): 115 – 134.
Mehdi-Tounsi, H., Chelli-Chaabouni, A., Mahjoub-Boujnah, D., Boukhris, M. (2017). Long-term field response of pistachio to irrigation water salinity**.** *Agricultural Water Management***,** 185(185), 1-12.

Mesquita, F. O., Cavalcante, L. F., Pereira, W. E., Rebequi, A. M., Lima Neto, A. J., Nunes, J. C. (2012). Produção de mudas de maracujazeiro amarelo submetidas à salinidade em solo com biofertilizante bovino**.** *Ciencia del Suelo*, 30(1), 31-41.

Nirmal, S. S., Solanke, A. V., Dudhade, D. D., Shinde, M. S., Gadakh, S. R., Durgude, A. G., Damame, S. V. (2016). Response of forage sorghum [sorghum bicolor (l). Moench] cultivars to nitrogen levels. *International Journal of Science, Environment and Technology*, 5(4), 2605 – 2609.

Ongom, P. Q., Adeyanju, A., Gobena, D., Rich, P., Ejeta G. (2016). Sorghum MAGIC population: structure and potential for genetics research and breeding. Proc of the Plant and Animal Genome Conference. International Plant & Animal Genome; San Diego, CA: p. Po859.

Parihar, P., Singh, S., Singh, R., Singh, V.P., Prasad, S.M. (2015). Effect of salinity stress on plants and its tolerance strategies: a review. *Environmental Science and Pollution Research*, v. 22, n. 6, 4056-4075.

Pietro-Souza, W., Bonfim-Silva, E. M., Schlichting, A. F., Silva, M. C. (2013). Desenvolvimento inicial de trigo sob doses de nitrogênio em Latossolo Vermelho de Cerrado. *Revista Brasileira de Engenharia Agrícola Ambiental*, 17(6), 575-580.

Pradhan, J., Himangshu DAS, H., Kundu, C., Pintoo Bandopadhyay, P. (2015). Response of fodder sorghum to irrigation scheduling and nitrogen levels. *International Journal of Farm Sciences*, 5(2), 15-20.

Rana D. S., Singh, B., Gupta K., Dhaka A. K. (2013). Performance of single cut forage sorghum genotypes to different fertility levels. *Forage Research***,** 39, 96-98.

Restelatto, R., Pavinato, P. S., Sartori, L. R., Einsfeld, S. E., Baldicera, F. P. (2015. Nitrogen Efficiency and Nutrient Absorption by a Sorghum-Oats Forage Succession**.** *Advances in Agriculture*. Article ID 702650, p.12.

Rhoades, J. P., Kandiah, A., Mashali, A. M. (1992). *The use saline waters for crops production*. Roma: FAO, pp.133. (FAO. Irrigation and Drainage Paper, 48)

Santos, H. G. et al. (2013). *Sistema brasileiro de classificação de solos*. 3. ed. Rio de Janeiro: Embrapa Solos, pp. 353.

Sá, F. V da S., Santos, M. G., Barros Junior, A. P., Albuquerque, J. R. T. (2020). Tolerance of peanut (*Arachis hypogea*) genotypes to salt stress in the initial phase. *Revista Brasileira de Engenharia Ambiental*, 42, 37-43.

SAS Institute. (2011). SAS/STAT: user's Guide. Version 9.3. Cary: *SAS Institute Inc*, pp. 8621.

Sawargaonkar, G. L., Patil, M. D., Wani, S. P., Pavani, E., Reddy, B. V. S. R.; Marimuthu, S. (2013). Nitrogen response and water use efficiency of sweet sorghum cultivars. *Field Crops Research***,** 149, 245-251.

Serme, I., Arzouma, B.A., Ouattara, K., Wortmann, C. (2018). Pearl Millet and Sorghum Response to Fertilizer in the Sahel of Burkina Faso. *Journal of Agriculture Studies*, v.6, 177-188.

Shamme S. K., Raghavaiah C. V., Balemi T., Hamza I. (2016). Sorghum (Sorghum bicolor L.) Growth, Productivity, Nitrogen Removal, N- Use Efficiencies and Economics in Relation to Genotypes and Nitrogen Nutrition in Kellem- Wollega Zone of Ethiopia, East Africa. *Advances in Crop Science and Technology*, 4, 218.

Silva, E. C., Ferreira, S. M., Silva, G. P., Assis, R. L., Guimarães, G. L. (2005). Épocas e formas de aplicação de nitrogênio no milho sob plantio direto em solo de Cerrado. *Revista Brasileira de Ciência do Solo*, 29, 725-733.

Silva, F. J. B. C., Azevedo, J. R. G. (2020). Temporal trend of drought and aridity indices in semi-arid Pernambucano to determine susceptibility to desertification. *Brazilian Journal of Water Resources*, 25(32), 1-18.

Sousa, P. G. R., Viana, T. V. A., Carvalho, C. M., Sousa, A. M., Costa, C. P. M., Azevedo, B. M. (2017). Efeito de diferentes lâminas de irrigação e cobertura do solo no crescimento da cultura do sorgo. *Revista Brasileira de Agricultura Irrigada***,** 11(4), 1528-1537.

Souza, C. C., Dantas, J. P., Silva, S. M., Souza, V. C., Almeida, F. A., Silva, L. E. (2005). Produtividade do sorgo granífero cv. sacarino e qualidade de produtos formulados isoladamente ou combinados ao caldo de cana-de-açúcar1. *Ciênc. Tecnol. Aliment***.** 25(3), 512-517.

Steiner, F., Tiago Zoz, T., Junior, A. S. P., Frandoloso, J. F., Ruppenthal, V., Janegitz, M. C. (2011). Zinco e nitrogênio no desempenho agronômico do milho safrinha. Global Science of Technology, v. 04(02), 09-17.

Taiz, L., Zeiger, E., Møller, I. M., Murphy, A. (2017). *Plant Physiology and Development*. 6. ed. Porto Alegre: Artmed, Pp.858.

Tabosa, J. N., Azevedo Neto, A. D., Reis, O. V., Farias, I., Tavares Filho, J. J., Lira, M. A., Tavares, J. A., Brito, A. R. de M. B., Lima, G. S., Santos, M. de C.S. (1998b). Ponto de utilização do milheto forrageiro (Pennisetum americanum (L.) Leeke) no Semi-Árido de Pernambuco. In: *CONGRESSO NACIONAL DE MILHO E SORGO*, 22. Recife. Arq. 199. CD ROM

Thomson, W. W., Weier, T. E. (1962). The Fine Structure of Chloroplasts from Mineral-Deficient Leaves of Phaseolus vulgaris. *American Journal of Botany*, 49(10), 1047-1055.

Yasuor, H., Tamir, G., Stein, A., Cohen, S., Bar-Tal, A., Ben-Gal, A., Yermiyahu, U. (2017). Does water salinity affect pepper plant response to nitrogen fertigation? *Agricultural Water Management*, 191, 57-66.