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Organic matter and shading on ion accumulation in soil cultivated with noni under salinity[1]

Matéria orgânica e sombreamento no acúmulo de íons em solo cultivado com noni sob salinidade

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HIGHLIGHTS:
Addition of cattle manure has antagonistic effects on soil fertility under saline conditions.
Partial shading reduces salt accumulation in the soil profile.
Irrigation with brackish water reduces the K^+/Na^+ ratio in the soil profile.

ABSTRACT: This study aimed to evaluate the influence of organic matter on the salt accumulation in three layers of soil cultivated with noni plants irrigated with brackish water, in open field and under partial shading conditions. The experimental design was in randomized blocks, arranged in a split-split-plot scheme with five replicates. The plots were constituted by the cultivation environments (open and shaded field), the subplots by the electrical conductivity of the irrigation water (0.3, 1.5, 3.0, 4.5, and 6.0 dS m^{-1}), and the sub-subplots by the absence and presence of organic matter. At 110 days after application of the treatments, the electrical conductivity of the saturation extract and the potassium, sodium, calcium, and magnesium concentrations were determined in three soil layers (0-10, 10-20, and 20-30 cm). Partial shading reduced the total accumulation of salts and sodium in the soil compared to the open field. Increasing the electrical conductivity of irrigation water reduced potassium concentrations in the soil, but this effect is offset by the addition of organic matter, which releases potassium, calcium, and magnesium for plant nutrition. However, cattle manure increases sodium accumulation in the soil in treatments with the highest water salinity.

Key words: *Morinda citrifolia* L., soil salinity, organic fertilization

RESUMO: Este trabalho teve como objetivo avaliar a influência da matéria orgânica no acúmulo de sais em três camadas de solo cultivado com plantas de noni irrigadas com água salobra, em condições de campo aberto e sombreamento parcial. O delineamento experimental foi em blocos ao acaso, disposto no esquema de parcelas subsubdivididas com cinco repetições. As parcelas foram constituídas pelos ambientes de cultivo (campo aberto e telado), as subparcelas pelas condutividades elétricas da água de irrigação (0,3; 1,5; 3,0; 4,5 e 6,0 dS m^{-1}) e as subsubparcelas pela ausência e presença de matéria orgânica. Aos 110 dias após aplicação dos tratamentos, foram determinados a condutividade elétrica do extrato de saturação do solo e as concentrações de potássio, sódio, cálcio e magnésio em três camadas do solo (0-10, 10-20 e 20-30 cm). O sombreamento parcial reduziu o acúmulo total de sais e sódio no solo em relação ao campo aberto. O aumento da condutividade elétrica da água de irrigação reduziu as concentrações de potássio no solo, mas esse efeito foi compensado pela adição de matéria orgânica, que libera potássio, cálcio e magnésio para a nutrição das plantas. No entanto, o esterco bovino provoca acúmulo de sódio no solo nos tratamentos com maior salinidade da água.

Palavras-chave: *Morinda citrifolia* L., salinidade do solo, adubação orgânica

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Introduction

Noni (*Morinda citrifolia* L.) is a perennial plant belonging to the Rubiaceae family, which stands out for its ability to tolerate environmental stresses, such as salinity (Nivas et al., 2011; Barraza-Elenes et al., 2019). This species can be cultivated in the Brazilian Northeast, a region that has problems with the accumulation of salts in the soil and water sources, especially in semi-arid areas (Lucena et al., 2018).

Soil salinization is linked not only to natural causes, but also to climate change, excessive use of groundwater, use of brackish water in irrigation, and poor drainage (Machado & Serralheiro, 2017). These factors accelerate and contribute to the accumulation of salts in the soil profile, causing physicochemical changes and a reduction in crop yield (Li et al., 2019; Bezerra et al., 2020; Martínez et al., 2022).

Alternatives have been tested to improve the fertility of salt-affected soils, such as applying organic compounds (Naveed et al., 2021; Rahem-Bader et al., 2021). Cattle manure is widely used as an organic fertilizer due to its rapid mineralization (Adekiya & Agbede, 2017; Canjá et al., 2021). It provides basic levels of organic matter and macronutrients, such as nitrogen, phosphorus, potassium, calcium, and magnesium, improving soil structure and the availability of elements to meet the nutritional demand of plants (Monsalve et al., 2017; Ge et al., 2022).

The addition of cattle manure can be an alternative to attenuate the adverse effects caused by the increase in the electrical conductivity of irrigation water on the chemical characteristics of the soil. However, this interaction between water salinity and organic matter can be influenced by the partial shading of the growing environment. In this context, this study aimed to evaluate the influence of organic matter on the salt accumulation in three soil layers in an area cultivated with noni plants irrigated with brackish water, in open field and under partial shading conditions.

Material and Methods

The experiment lasted approximately seven months and was carried out in the municipality of Sobral (03° 41' 10" S; 40° 20' 59" W, 70 m), Ceará, Brazil (Figure 1).

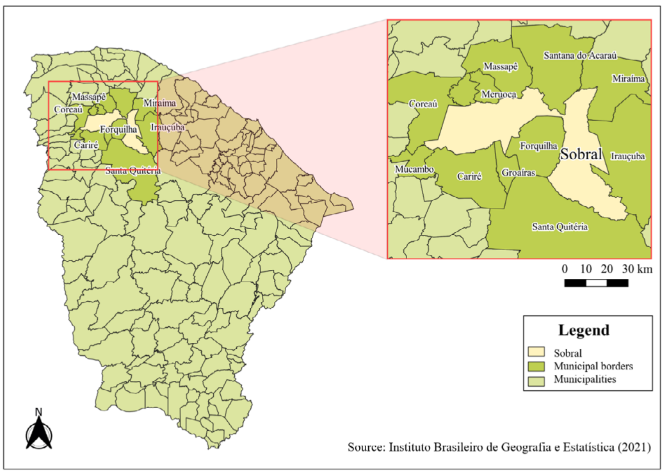


Figure 1. Location map of the experimental area

According to Köppen's classification, this region has a BSw'h' climate, hot semi-arid tropical climate, with summer rains (Alvares et al., 2013). Along the experimental period, the average rainfall was 39.52 mm and the average daily temperature was 28.8 °C (Figure 2). The climatic variation data were obtained through the National Institute of Meteorology – INMET (2014).

The experiment was conducted in a randomized block design, in split-split-plot scheme, with five replicates. Plots consisted of the cultivation environments (open field and under 50% shade net), subplots consisted of electrical conductivity of irrigation water (ECw: 0.3, 1.5, 3.0, 4.5, and 6.0 dS m^{-1}) and the sub-subplots were represented by the absence and presence of organic matter (5 L of cattle manure), with the experimental unit consisting of three pots (one plant per pot), totaling 300 pots.

Seeds were sown in cell-type trays containing substrate formulated from the mixture of 50% washed sand + 50% aged cattle manure, based on mass. Sixty days after sowing (DAS), the seedlings with 0.35 m height were transplanted into 2 L polyethylene bags, containing a mixture of cattle manure and soil, in the proportions of 1:1 (v/v). For every 20 L of this mixture, 500 g of the 4:14:8 (NPK) formulation was applied. The seedlings were irrigated daily with water with an electrical conductivity of 0.3 dS m^{-1} and at 80 DAS they were planted in pots with capacity of 20 L, for conducting the experiment.

The pots were filled with a 2 cm layer of gravel at the bottom, a 10 L layer of sandy soil (lower part), and the other half with a mixture of 5 L of sandy soil + 5 L of cattle manure (upper part). For the control treatment, pots filled with 20 L of sandy soil were used. Before installing the experiment, the physical and chemical attributes of the soil were analyzed using the Mehlich-1 extractor and the results are shown in Table 1.

Each pot received, as basal fertilization, 0.5 g of urea, 1.0 g of single superphosphate, and 0.5 g of potassium chloride, and, as top-dressing, 0.5 g of urea and 0.5 g of potassium chloride, at 30, 45, and 60 days after basal fertilization. At the second top-dressing application, 45 days after basal fertilization, 1 g per plant of micronutrient (FTE Br-12) was applied. At 60 days after basal fertilization, foliar fertilization was performed with 2 mM of magnesium sulfate and 1 mM of calcium sulfate only in plants of the control treatment.

To achieve the desired values of irrigation water electrical conductivity (ECw), different quantities of NaCl, $CaCl_2.2H_2O$,

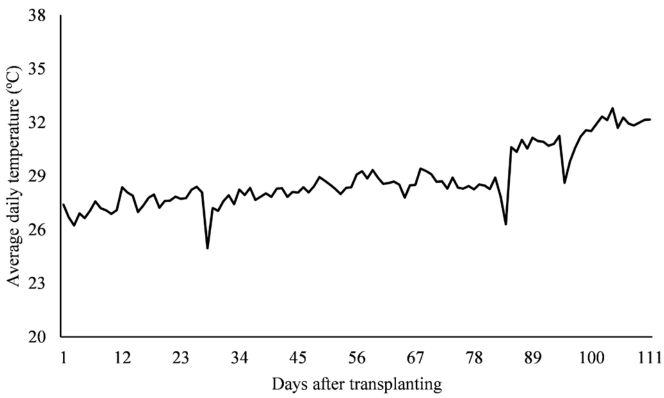


Figure 2. Daily average air temperature along the experimental period

Table 1. Physical and chemical attributes of the soil used in the experiment

Attributes	Treatment without organic matter	Treatment with organic matter
Textural classification	Sand	Sand
pH in water	6.20	7.00
EC (dS m^{-1})	0.14	1.40
P (mg dm^{-3})	74.00	669.00
Ca^{+2} ($mmol_c$ dm^{-3})	4.20	40.00
Mg^{+2} ($mmol_c$ dm^{-3})	6.00	37.00
Na^{+} ($mmol_c$ dm^{-3})	1.20	16.17
K^{+} ($mmol_c$ dm^{-3})	1.47	24.07
H^{+} + Al^{3+} ($mmol_c$ dm^{-3})	23.93	28.88
Organic matter (g kg^{-1})	3.72	24.72

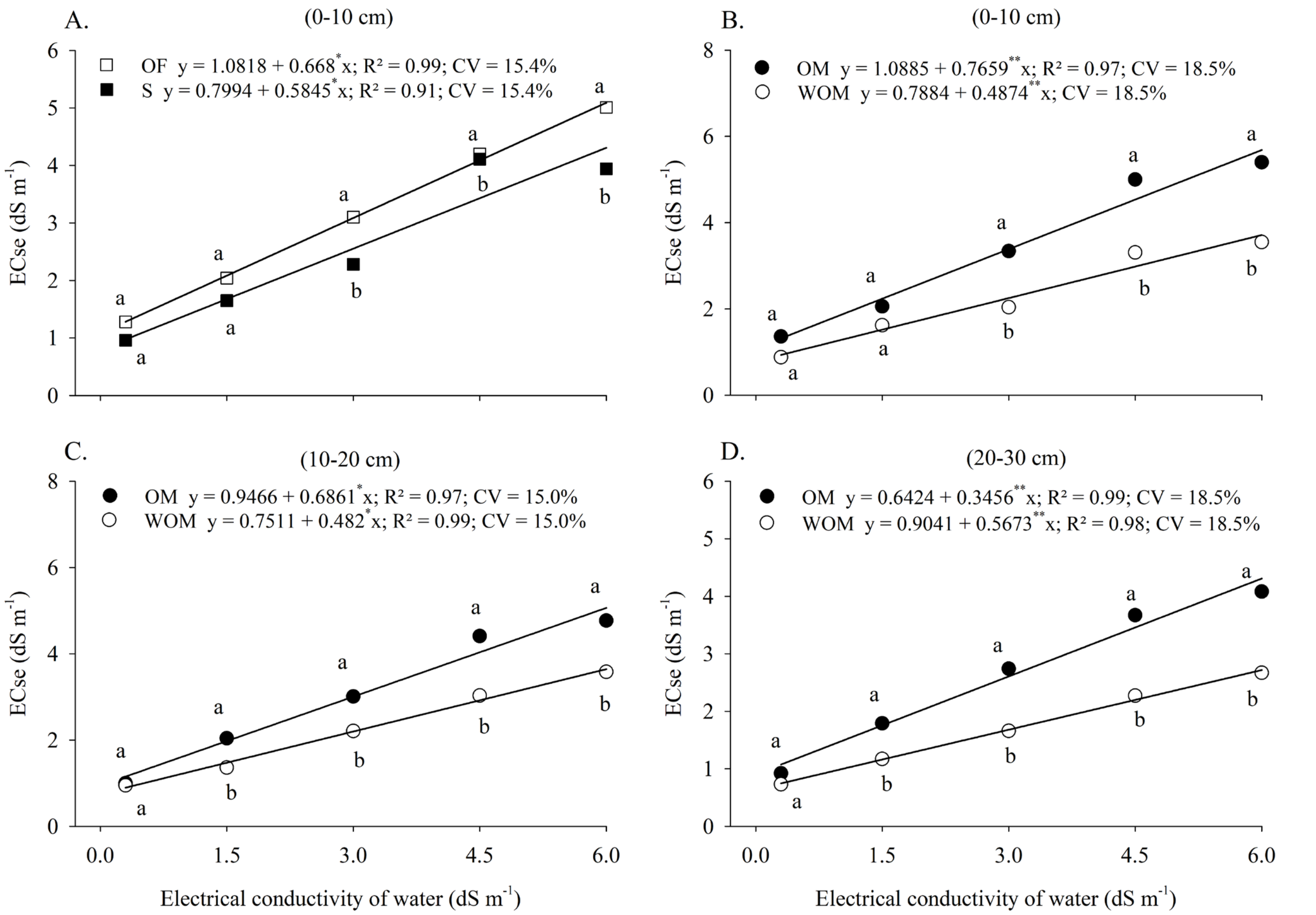
and $MgCl_2.6H_2O$ salts, in a 7:2:1 equivalent proportion, were added to the water of lowest salinity, according to the relationship between ECw and the concentration ($mmol_c$ L^{-1} ≈ EC × 10), cited by Richards (1954). Irrigation was performed on alternate days, and the volume of solution applied to the plants was based on the drainage lysimeter principle, keeping the soil at field capacity and adding a leaching fraction of 0.2 to favor the leaching of salts. Water application was made in a localized manner, to avoid direct contact with the leaves.

For analyses of the accumulation of salts in the soil, samples were collected in different soil layers (0 to 0.10; 0.10 to 0.20, and 0.20 to 0.30 m) 110 days after the application of treatments. The samples, after being dried, pounded, and sieved (2 mm), were used to determine the concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}, and to measure the electrical conductivity of the soil saturation extract - ECse (Silva, 2009).

The normality of the data was verified through the Shapiro-Wilk test and, later, the data were subjected to analysis of variance ($p \leq 0.05$). The means referring to the environments and the application of cattle manure were compared by Tukey test ($p \leq 0.05$), while the data of irrigation water electrical conductivity were subjected to polynomial regression ($p \leq 0.05$). Data analysis was carried out using the statistical program Assistat 7.7 Beta (Silva & Azevedo, 2016).

Results and Discussion

According to Figure 3A, the ECse in the soil showed a linear increase, reaching at the highest ECw (6.0 dS m^{-1}) values of 5.09 dS m^{-1} (open field) and 4.31 dS m^{-1} (shaded field), showing increases of 296.96 and 341.80% compared to the lower electrical conductivity of water, respectively. As for the interaction salinity × organic matter in the ECse of the soil in the 0-10 cm layer (Figure 3B), an increase can be seen as a function of the electrical conductivity of irrigation water, with differences of 331.16 and 297.25% in the presence and absence



*, ** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by F test, respectively. OF - Open field; S - Shaded environment; OM - With organic matter; WOM - Without organic matter; Lowercase letters compare means of treatments within the same EC_w level, according to Tukey test ($p \leq 0.05$)

Figure 3. Electrical conductivity of soil saturation extract (ECse) in 0-10 cm layer as a function of electrical conductivity of irrigation water in soils cultivated with noni plants in open field and under shaded environment (A), and in the layers of 0-10 cm (B), 10-20 cm (C), and 20-30 cm (D) in soils with and without organic matter

of organic matter, respectively; indicating the soil that received the organic matter accumulated more salts.

For ECse in the layer of 10-20 cm, the double interaction salinity × organic matter indicated linear increments; however, the soil with organic matter had the highest values of ECse, at all electrical conductivities of irrigation water. When comparing the results obtained at the lowest and highest salinity, we verified increments of 339.69 and 306.73% for treatments with and without organic matter, respectively (Figure 3C). For the layer of 20-30 cm, the double interaction salinity × organic matter indicated ECse increments as a function of salinity increase, regardless of the absence or presence of organic matter (Figure 3D). In this layer, the ECse values were higher in the soil with organic input and, when comparing the results of the lowest with the highest salinity, increments of 263.94 and 301.0% are observed for the absence and presence of organic matter, respectively. In the Figure 3D, it is also observed that there was no significant difference, only at the lowest level of electrical conductivity of the irrigation water.

ECse can vary depending on the addition of cations and anions to the soil solution, which may reflect, for example, the irrigation with brackish water and the mineralization of organic matter (Souza et al., 2019; Canjá et al., 2021; Corwin, 2021). This statement justifies the results presented in Figures 3B, C, and D, because as organic matter was added to the soil, greater amounts of ions were made available, which caused higher ECse values in all soil layers, especially under high salinity of the irrigation water.

Souto et al. (2016), working with noni and evaluating the effect of irrigation water salinity and leaching of salts on the biometrics of the crop, found similar results to those of the present study, in which the ECse increased as a function of the increase in the salinity of the irrigation water.

In the 0-10 cm soil layer, the open field environment contributed to the increase in ECse, regardless of the salinity of the irrigation water, which may be related to the higher temperature in the topsoil, culminating in intense evaporation of water and consequent increase in the concentration of salts (Paiva et al., 2019).

In the 0-10 cm soil layer, the interaction environment × salinity harmed potassium concentrations in the soil. Regardless of the cultivation environment, there was reduction of K^+ concentration as the electrical conductivity of the irrigation water increased. However, the reductions of this macronutrient reached 42.61 and 51.71% for open field and shaded environment, respectively (Figure 4A).

In the 0-10 cm soil layer, the interaction environment × organic matter indicated that the presence of organic matter promoted a significant increase in the potassium content in both cultivation environments, with the highest value in the open field environment (4.54 $mmol_c$ dm^{-3}), which was 47.88% higher compared to the same treatment in the shaded environment (Table 2).

For the 10-20 and 20-30 cm soil layers, the double interaction environment × salinity indicated that there was a reduction in K^+ concentrations as electrical conductivity of irrigation water was increased, in both cultivation environments. However, under the open field conditions, the soil showed higher concentrations of K^+ (Figures 4B and D). However, the differences between the environments decrease with the increase of salinity, being not significant at the highest electrical conductivity of the irrigation water. A similar effect was observed for the double interaction salinity × organic matter, in which salinity caused significant reductions in K^+ concentrations. However, when organic matter was added to the soil, it led to higher amounts of this element at all electrical conductivity levels of irrigation water evaluated (Figures 4C and E). However, the differences were greater at the lowest salinity levels of the irrigation water.

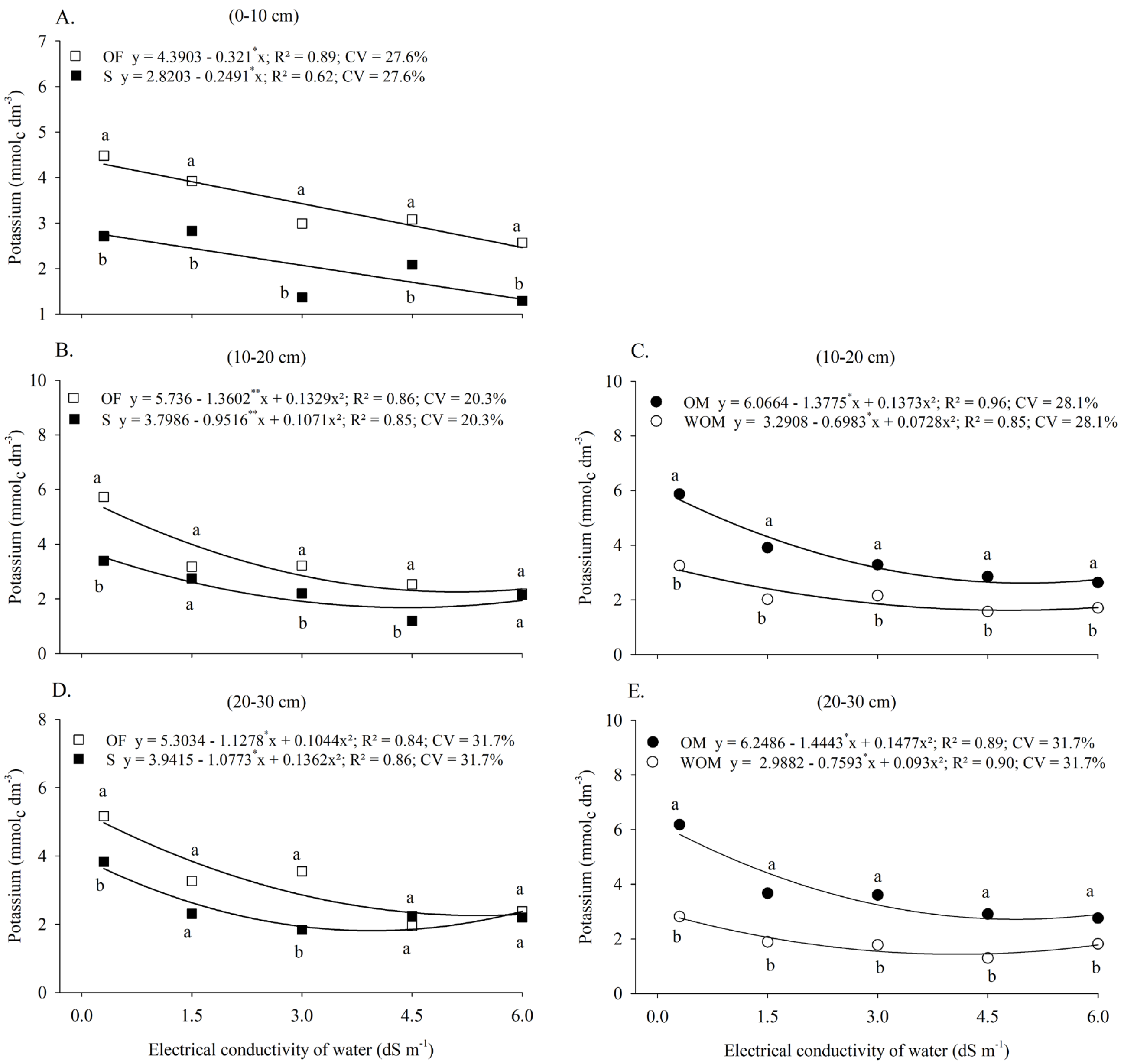
In general, the open field environment promoted higher accumulation of K^+ in the soil, as compared to the shaded area, regardless of the electrical conductivity of water. This result may be a consequence of the greater volume of brackish water added in open field cultivation of noni, since the evapotranspiration demand is normally higher under these conditions than in shaded environments.

It is important to highlight that the presence of organic matter in all treatments with salinity promoted greater K^+ increments when compared to soil without organic matter; however, the availability of this ion was directly affected by the increase in salinity, given the antagonistic effects promoted by the increase in the concentrations of Na^+, Ca^{2+}, and Mg^{2+}, which reduce the availability of K^+ by displacing it from the cation exchange complex (Martínez et al., 2022). Similar results were presented by Rodrigues et al. (2018), who evaluated the chemical attributes of a soil irrigated with saline water and found reductions in potassium concentrations in the soil as a function of the increase in irrigation water salinity up to 5 dS m^{-1}.

Thus, to mitigate the effect of irrigation water salinity, it is necessary to apply an organic fertilizer that contains enough K^+ to compensate for the high concentrations of Na^+, Ca^{2+}, and Mg^{2+} in the brackish water, increasing uptake by the crop (Rahem-Bader et al., 2021; Martínez et al., 2022). Taiwo et al. (2018) reported other benefits of applying organic fertilizers, such as poultry manure, which resulted in a large reduction in K^+ fixation, allowing better solubility and availability of this element for plant nutrition.

In the layer of 0-10 cm, the triple interaction indicated that both cultivation environments led to linear increase in sodium concentrations as a function of the increase in electrical conductivity of water in the absence and presence of organic matter. It is worth mentioning that this accumulation was potentiated by the addition of organic matter and, when comparing the lowest and the highest value of ECw in this treatment, increments of 910.77 and 1,012.73% of Na^+ were observed in the open field and shaded environment, respectively (Table 3).

When analyzing the layer of 10-20 cm, the interaction environment × salinity showed that, regardless of the cultivation environment, the increase in the electrical conductivity of the irrigation water led to linear increments in the sodium concentration (Figure 5A). However, there were only significant differences in the treatments of 3.0 and 4.5 dS m^{-1}. In the same layer, through the interaction salinity × organic matter, it was observed that the increase



*, ** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by F test, respectively. OF – Open field; S – Shaded environment; OM – With organic matter; WOM – Without organic matter. Lowercase letters compare means of treatments within the same EC_w level, according to Tukey test ($p \leq 0.05$)

Figure 4. Potassium (K^+) concentration in the layers of 0-10 cm (A), 10-20 cm (B), and 20-30 cm (D) as a function of electrical conductivity of irrigation water in soils cultivated with noni plants in open field and shaded environment; K^+ concentration in the layers of 10-20 cm (C) and 20-30 cm (E) in soils with and without organic matter

Table 2. Potassium concentration ($mmol_c$ dm^{-3}) in soils cultivated with noni plants irrigated with saline water in an open field and in shaded environment with and without organic matter originated from cattle manure, in the layer of 0-10 cm, 110 days after transplanting

Environment	Potassium ($mmol_c$ dm^{-3})	
	WOM	OM
Open field	1.88 aB	4.54 aA
Shaded	1.36 aB	3.07 bA

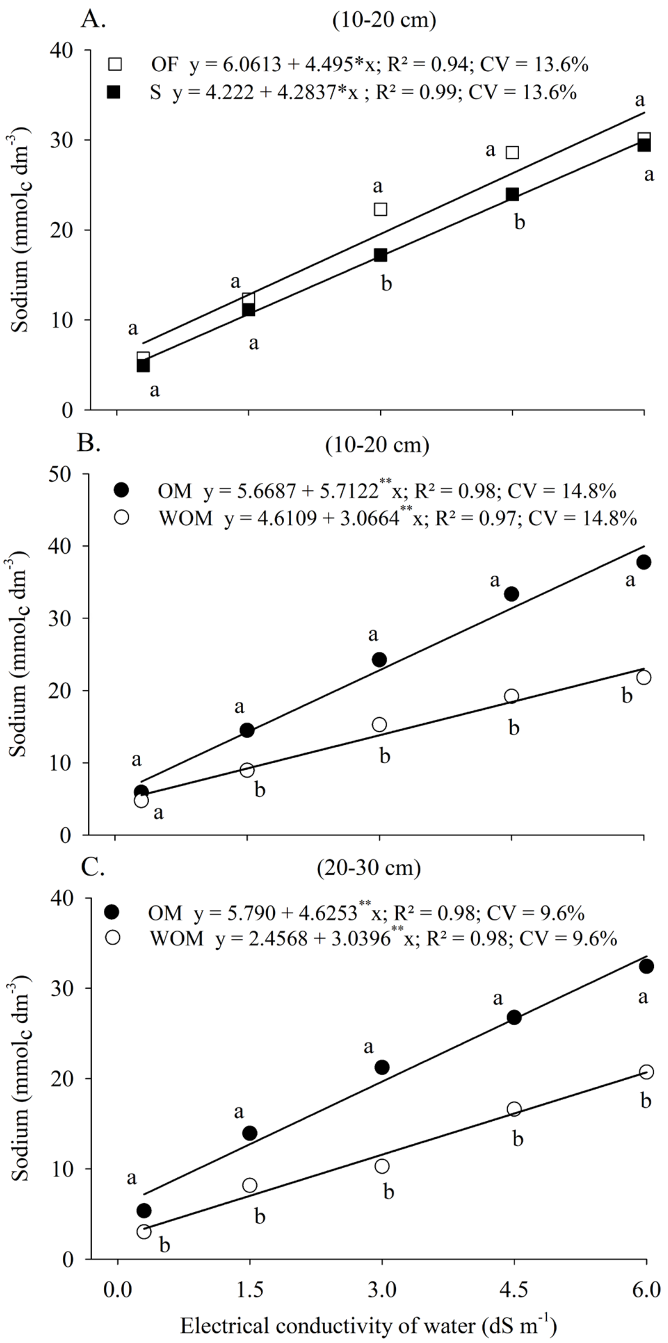
Means followed by the same lowercase letters in the columns and uppercase letters in the rows indicate no significant differences at $p \leq 0.05$ by Tukey test. WOM - Without organic matter; OM - With organic matter

in electrical conductivity of water caused linear increments of Na^+; however, when organic matter was added to the soil, these concentrations increased even more (Figure 5B). In this case, the difference was not significant only at the lowest level of salinity of the irrigation water.

Table 3. Sodium concentration ($mmol_c$ dm^{-3}) in soils cultivated with noni plants irrigated with saline water in an open field and under shaded environment with and without organic matter originated from cattle manure, in the layer of 0-10 cm, 110 days after transplanting

Environment	ECw ($dS\ m^{-1}$)	Sodium ($mmol_c$ dm^{-3})	
		WOM	OM
Open field	0.3	2.23 a	4.55 a
	1.5	2.21 b	18.32 a
	3.0	12.55 b	21.25 a
	4.5	18.96 b	45.15 a
	6.0	25.41 b	45.99 a
Shaded	0.3	3.35 a	3.85 a
	1.5	6.90 b	12.53 a
	3.0	8.46 b	21.28 a
	4.5	13.69 b	31.92 a
	6.0	25.30 b	42.84 a

Means followed by the same lowercase letters in the rows indicate no significant difference at $p \leq 0.01$ by Tukey test. WOM - Without organic matter; OM - With organic matter



*, ** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by F test, respectively. OF - Open field; S - Shaded environment; OM - With organic matter; WOM - Without organic matter. Lowercase letters compare means of treatments at the same EC_w level, according to Tukey test ($p \leq 0.05$)

Figure 5. Sodium (Na^+) concentration in the layer of 10-20 cm as a function of electrical conductivity of irrigation water in soils cultivated with noni plants in an open field and under shaded environment (A), with and without organic matter (B); Na^+ concentration in the layer of 20-30 cm in soils with and without organic matter cultivated with noni plants as a function of electrical conductivity of irrigation water (C)

In the layer of 10-20 cm, the interaction environment × organic matter showed that, regardless of the cultivation environment, when organic matter was added to the soil, there was a significant increase in Na^+ concentrations, with increases of 82.54 and 48.21% in the open field and shaded environments, respectively (Table 4). For the layer of 20-30 cm, the interaction environment × organic matter indicated increments of sodium as the organic matter was added, of the order of 74.32 and 63.82% for the open field and shaded environments, respectively (Table 4).

Table 4. Sodium concentration ($mmol_c\ dm^{-3}$) in soils cultivated with noni plants in open field and under shaded environment, with and without organic matter originated from cattle manure, in the soil layers of 10-20 and 20-30 cm, 110 days after transplanting

Environment	WOM	OM	WOM	OM
	10-20 cm		20-30 cm	
Open field	14.03 aB	25.61 aA	12.89 aB	22.47 aA
Shaded	13.96 aB	20.69 bA	10.64 bB	17.43 bA

Means followed by the same lowercase letters in the columns and uppercase letters in the rows indicate no significant difference at $p \leq 0.05$ by Tukey test. WOM – Without organic matter; OM – With organic matter

In the layer of 20-30 cm, with the salinity × organic matter interaction, it was observed that as the electrical conductivity of water increased, consequently there were linear increases of Na^+ in the soil, mainly in the treatments without organic matter. When comparing the concentrations of this element at the lowest and highest salinity, increases of 367.31 and 514.32% were observed in the soils cultivated with and without organic matter, respectively (Figure 5C).

The findings showed that the open field environment promoted higher concentration of Na^+ in the soil in all layers studied, especially when it was enriched with organic matter, which probably occurred due to greater volume of brackish water added in open field cultivation of noni and the addition of ions through mineralization of organic matter, as mentioned earlier. In this perspective, Almeida et al. (2018), evaluating the effect of salinity in the cultivation substrate of hybrids of tangerine with citrumelo, found that the increase in salinity levels caused an increase in the Na^+ concentrations of the cultivation substrates, associating these increases with the use of the same salts used to prepare saline water in the present study (NaCl, $CaCl_2$, and $MgCl_2$ in equivalent proportion of 7:2:1).

The increase in concentrations of Na^+ in the soil can cause a reduction in its fertility, disruption, increase in density, and consequent reduction in water infiltration. The effects of sodium on soil structure also reduces its capacity to store water, thus affecting plant growth, water absorption, and nutrition. It is important to consider that competitive interaction of the saline ions Na^+ and Cl^- with nutrients can affect the Cl^-/NO_3^-, Na^+/Ca^{+2}, and Na^+/K^+ ratios in the root medium (Freire et al., 2020).

In the open field, the presence of organic matter increased the Ca^{2+} concentration by 24.00% for the 0-10 cm soil layer, comparing the lowest and highest salinity of irrigation water. As for the shaded environment, there were increments of 48.65 and 225.64% for the absence and presence of organic matter, respectively, comparing the averages obtained at the electrical conductivities of 1.5 and 6.0 dS m^{-1} (Table 5).

Concerning the layer 10-20 cm, the double interaction environment × salinity in Ca^{2+} concentrations showed that, regardless of the cultivation environment, salinity promoted linear increments of this element, especially under shading. When comparing the results obtained at the lowest and highest electrical conductivity, a superiority of 18.03 and 39.30% for open field and shaded areas, respectively, can be

Table 5. Calcium concentration (mmol$_c$ dm^{-3}) in soils cultivated with noni plants irrigated with saline water in an open field and shaded environment, with and without organic matter originated from cattle manure, in the layers of 0-10 and 20-30 cm at 110 days after transplanting

Environment	ECw (dS m^{-1})	0-10 cm		20-30 cm	
		WOM	OM	WOM	OM
Open field	0.3	31.75 b	50.00 a	31.75 b	48.50 a
	1.5	38.25 b	48.00 a	29.25 b	45.75 a
	3.0	27.25 b	57.25 a	27.50 b	53.50 a
	4.5	31.50 b	56.00 a	24.25 b	47.25 a
	6.0	27.75 b	62.00 a	23.50 b	43.00 a
Shaded	0.3	20.75 b	53.00 a	20.00 b	25.25 a
	1.5	18.50 a	19.50 a	19.75 a	53.00 a
	3.0	18.75 b	58.25 a	20.00 b	52.25 a
	4.5	23.50 b	66.50 a	22.50 b	28.25 a
	6.0	27.50 b	63.50 a	16.50 a	18.50 a

Means followed by the same lowercase letters in the rows indicate no significant differences at p ≤ 0.01 by Tukey test. WOM – Without organic matter; OM – With organic matter

verified (Figure 6A). Likewise, the double interaction salinity × organic matter demonstrated that the increase in electrical conductivity of water caused significant linear increments in calcium concentration. In absolute terms, these values were higher in the presence of organic matter, regardless of the salinity of the irrigation water (Figure 6B).

Addition of organic matter in the soil contributed significantly to increase Ca^{2+} concentrations in the 10-20 cm soil layer, regardless of the cultivation environment (Table 6). It is noteworthy that Ca^{2+} concentration was higher in the open field environment than in the shaded area, both in the absence and in the presence of organic matter.

As for the triple interaction for calcium content in the layer of 20-30 cm (Table 5), the results indicated that, in the open field cultivation environment, there was a reduction in Ca^{2+} concentrations as a function of the increase in electrical conductivity of water, except at electrical conductivity of 3.0 dS m^{-1}; however, there were reductions comparing the lowest and highest electrical conductivity of irrigation water, which were 25.98 and 11.34% in the absence and presence of organic matter, respectively. It is worth mentioning that, under the shaded environment, the presence of organic matter increased calcium concentrations up to ECw of 3.0 dS m^{-1}.

Table 6. Calcium concentrations (mmol$_c$ dm^{-3}) in soils cultivated with noni plants, in an open field and shaded environment, with and without organic matter originated from cattle manure, in the layer of 10-20 cm, 110 days after transplanting

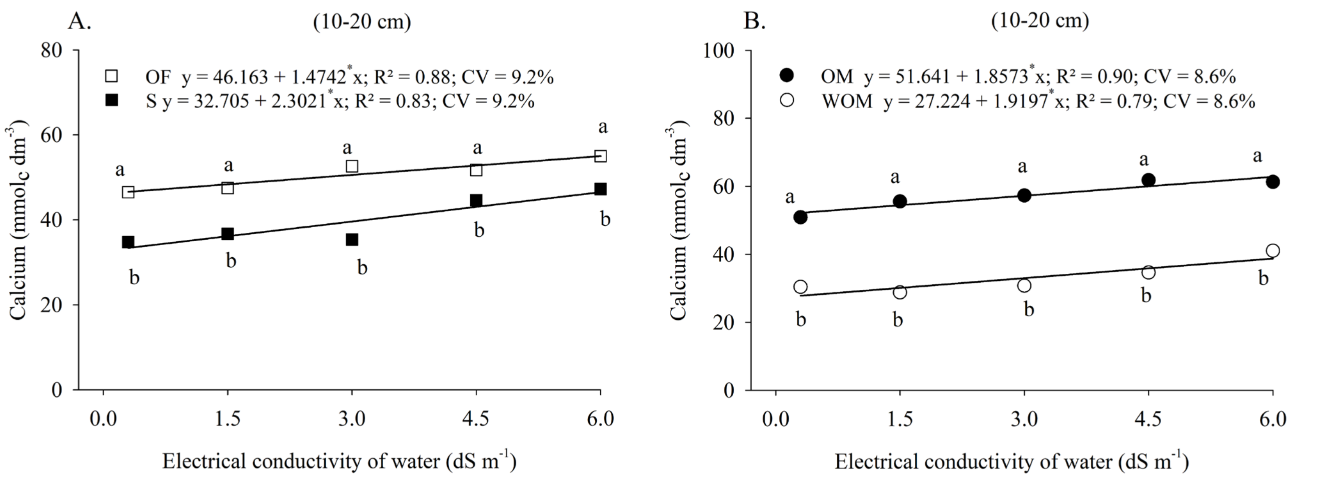
Environment	WOM	OM
Open field	41.70 aB	59.65 aA
Shaded	24.50 bB	55.00 bA

Means followed by the same lowercase letters in the columns and uppercase letters in the rows indicate no significant difference at p ≤ 0.05 by Tukey test. WOM - Without organic matter; OM - With organic matter

In general, the open field environment promoted higher concentration of Ca^{2+} in the soil, in all studied layers, especially in treatments with organic matter, which may have been a result of the addition of ions, both through mineralization of organic matter and the use of greater volume of brackish water in this environment (Almeida et al., 2018).

The boost in Ca^{2+} concentrations with the increase in ECw probably occurred due to the presence of this element in the composition of the saline water, which, when added to the soil, induced significant increases. Likewise, Moradi et al. (2019), evaluating the fertility of a saline soil under simple and enriched application of biochar, found that with increase in water salinity levels, the concentration of calcium in the soil also increased.

The addition of organic matter favored Mg^{2+} accumulation in the three analyzed soil layers, for the two types of environments studied (Table 7). This response may be related to the use of cattle manure as a source of organic matter, because in addition to improving the structure, chemical composition, and microbial activity of the soil, it also has rapid mineralization, providing nutrients such as Mg^{2+} to meet the nutritional demand of plants (Blaće et al., 2020; Naveed et al., 2021). Dias et al. (2015), when evaluating the chemical attributes of soil irrigated with saline water and the use of salt stress mitigators in yellow passion fruit, also observed that concentrations of Mg^{2+} in the soil increased as a function of increase in the electrical conductivity of irrigation water.



*, ** - Significant at p ≤ 0.05 and p ≤ 0.01 by F test, respectively. OF - Open field; S - Shaded environment; OM - With organic matter; WOM - Without organic matter. Lowercase letters compare means of treatments within the same EC_w level, according to Tukey test (p ≤ 0.05)

Figure 6. Calcium (Ca^{2+}) concentration in the layer of 10-20 cm as a function of electrical conductivity of irrigation water in soils cultivated with noni plants in open field and shaded environment (A), with and without organic matter (B)

Table 7. Magnesium concentration ($mmol_c\ dm^{-3}$) in soils cultivated with noni plants irrigated with saline water in an open field and under shaded environment, with and without organic matter originated from cattle manure, in the layers of 0-10, 10-20, and 20-30 cm, 110 days after transplanting

Environment	ECw ($dS\ m^{-1}$)	0-10 cm		10-20 cm		20-30 cm	
		WOM	OM	WOM	OM	WOM	OM
Open field	0.3	11.25 a	15.00 a	12.75 b	19.25 a	15.25 b	22.00 a
	1.5	13.50 a	17.00 a	16.25 b	20.25 a	22.50 a	24.75 a
	3.0	22.50 a	24.50 a	15.25 b	23.75 a	23.50 a	25.00 a
	4.5	12.75 a	16.25 a	16.25 b	24.00 a	24.75 b	28.00 a
	6.0	20.00 b	30.50 a	19.00 b	26.00 a	27.00 a	29.50 a
Shaded	0.3	7.00 b	14.00 a	9.50 a	12.50 a	6.25 a	8.75 a
	1.5	5.75 b	14.25 a	5.50 a	9.75 a	8.50 b	11.75 a
	3.0	9.50 b	20.00 a	13.25 b	19.50 a	13.75 b	19.25 a
	4.5	14.25 b	22.50 a	15.50 b	23.50 a	14.00 b	20.50 a
	6.0	20.50 a	24.00 a	19.25 a	24.50 a	15.25 b	21.50 a

Means followed by the same lowercase letters in the rows, for each soil layer, indicate no difference at $p \leq 0.05$ by Tukey test. WOM - Without organic matter; OM - With organic matter

Conclusions

1. Partial shading reduces the total accumulation of salts and sodium in the soil compared to open field.

2. Increasing the electrical conductivity of irrigation water reduces potassium concentrations in the soil.

3. Addition of cattle manure results in higher concentrations of potassium, calcium, and magnesium in the soil, regardless of the electrical conductivity of the irrigation water. However, cattle manure increases sodium concentration in the soil in treatments with the highest water salinity.

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