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Research Article

Hydrogel composed of potassium acrylate, acrylamide, and mineral as soil conditioner under saline conditions

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ABSTRACT: Hydrogels have potential as soil conditioners due to their high capacity to retain water and mitigate soil salinity. However, investigations under saline conditions are necessary because there are losses in both water absorption and salinity mitigation depending on the composition of hydrogel and ions involved in salinity. In this work, we studied a commercial hydrogel in two experiments. The first experiment was conducted in the laboratory to evaluate the absorption by the hydrogel of water with electrical conductivity (EC) of 0.5, 1.5, 3.0, and 4.5 dS m^{-1}, promoted by NaCl. The second experiment was conducted in a greenhouse in a 2 × 4 factorial scheme (with and without hydrogel × EC of the first experiment). Although salinity reduced water absorption by hydrogel by 84 %, the polymer applied in a sandy soil under saline conditions reduced water losses by 58 %. However, hydrogel did not increase the final soil moisture (~ 0.10 g g^{-1}). The polymer reduced Na^+ concentration in leachate from 1,499 to 1,219 mg L^{-1} at the highest salinity level (4.5 dS m^{-1}), but it increased Na^+ soil availability by 0.1 mg kg^{-1} in comparison with polymer absence. Hydrogel application increased Na^+ content in plants from 9 to 13 mg kg^{-1} at the highest salinity, while K^+ content was 10 to 16 mg kg^{-1} lower than that observed without a polymer. Hydrogel 0.07 % (w/w) reduced maize biomass, indicating damage by monovalent ions, compromising the polymer potential under salinity.

Keywords: superabsorbent gels, water salinity, soil sodicity, semi–arid region, soil amendment

Introduction

Superabsorbent hydrogels (SAHs) are composed of cross–linked and tridimensional polymers that absorb hundred folds of their weight in water (Essawy et al., 2016; Saha et al., 2020; Ai et al., 2020). Agricultural SAHs are commonly synthesized from K^+ acrylate and acrylamide as monomers, exhibiting water absorption capacity (WAC) according to cross–linking, as well as the presence of hydrophilic groups (Saha et al., 2020).

SAHs used as soil conditioners increase soil water retention and mitigate salinity effects, favoring plant growth (Coelho et al., 2018; Dehkordi, 2018; Saha et al., 2020; Ai et al., 2020). However, salts may negatively affect hydrogels, which reduce the osmotic pressure difference between the polymer network and the external solution, decreasing water absorption (Dorraji et al., 2010; Candido et al., 2012; Al Jabri et al., 2015; Zhang et al., 2014; Zain et al., 2018; Saha et al., 2020).

Under saline conditions, polymers are more damaged by polyvalent ions, which result in higher ionic strength than monovalent ones (Yu et al., 2011; Zhang et al., 2014; Al Jabri et al., 2015). Moreover, minerals added in the polymer synthesis may improve WAC under saline conditions by the increase of cross–linking points bonded with monomers, improving polymeric network structure (Qin et al., 2012; Magalhães et al., 2013; Banedjschafie and Durner, 2015). Therefore, hydrogel composed of K^+ acrylate, acrylamide, and mineral is expected to improve soil conditions and plant growth even when subjected to increasing salinity in which monovalent ions prevail.

This study was carried out based on the following hypotheses: 1) Increase in irrigation water salinity by monovalent ions reduces water absorption by the hydrogel; 2) Hydrogel application, when compared to its non–application, increases WAC of a sandy soil irrigated with saline water; 3) Hydrogel application in sandy soil reduces the salinity impacts on soil chemical attributes, favoring the initial development of maize (*Zea mays* L.).

In this study the objectives were: a) characterize a commercial polymer used in agriculture; b) evaluate the impacts of increasing salinity of irrigation water on water retention by the polymer under laboratory conditions; c) evaluate the impacts of increasing salinity of irrigation water on soil water retention in a greenhouse with and without polymer application; and d) evaluate the impacts of increasing salinity of irrigation water and polymer application on soil chemical attributes and initial development of maize.

Materials and Methods

Characterization of the hydrogel

The superabsorbent polymer used in this study was a commercial product described on its label as a potassium acrylate hydrogel for agricultural use, with the capacity to absorb 400 times its weight in water. To characterize the polymer used, we carried out analyses at room temperature (25 ± 1 °C), as described below:

The organic composition (acrylamide/acrylate ratio) of the superabsorbent polymer was obtained by

Fourier Transform Infrared Spectroscopy (FTIR) using a spectrometer within the range from 4,000 to 400 cm^{-1}. The non-hydrated hydrogel was crushed in nitrogen (N_2) for better sample homogeneity, then mixed with potassium bromide (KBr), and pressed.

The Thermal Gravimetric Analysis (TGA) curve was recorded. A non-hydrated hydrogel sample of 10 mg was placed in a platinum pan and heated in a synthetic air from room temperature to 1,000 °C. The heating ramp and air flow were 10 °C min^{-1} and 50 cm^3 min^{-1}, respectively. To determine elemental composition of the superabsorbent powder, X-ray fluorescence (XRF) measurements were carried out that provided percent (%) levels of the chemical elements.

The water retention capacity was determined through the addition of 500 mL of distilled water to saturate one gram of the hydrogel with five replicates. The saturated material was kept for 24 h in 500 mL beakers covered with plastic film to prevent evaporation, due to the time required to achieve the swelling balance of a superabsorbent polyacrylamide gel and for maintaining this balance (Leitão et al., 2015). After 24 h of saturation, the polymer samples were placed on a 0.5-mm-mesh sieve to drain the gravitational water. Subsequently, the material was weighed on a semi-analytical scale and WAC was determined based on the quantified mass.

Experiments

Two experiments were installed in the city of Fortaleza, Ceará, Brazil, in 2015. The first experiment was installed in laboratory at room temperature (25 ± 1 °C) with a completely randomized design and four treatments and four replicates, totaling 16 experimental units. Each experimental unit had a beaker with capacity for 1,000 mL. The treatments comprised saline solutions with electrical conductivity (EC) levels of 0.5, 1.5, 3.0 and 4.5 dS m^{-1} obtained by adding sodium chloride (NaCl) to distilled water until the desired EC was reached and measured by a conductivity meter.

The procedures to determine polymer saturation and water retention were the same as described for hydrogel characterization. However, saturation was performed with each saline solution comprising the treatments evaluated.

The second experiment was installed in a greenhouse (3°44′25.5″ S, 38°34′30.9″ W, 21 m a.s.l.) with no control of environmental conditions, in which the average air temperature and relative humidity were 32 °C and 70 %, respectively. The experiment was conducted in a 2 × 4 factorial scheme (treatment with and without hydrogel polymer: four and zero grams of hydrogel and the four levels of irrigation water salinity described for the first experiment), with a completely randomized design and four replicates, totaling 32 experimental units.

The experimental units consisted of polyvinyl chloride (PVC) columns with 10 cm in diameter and 50 cm in length and with the lower extremities sealed with a PVC cap. In these caps, 1.27 cm diameter holes were drilled to allow drainage and collection of the leached solution. A filter cloth was placed inside each cap to avoid soil loss during leaching.

The PVC columns were filled with the superficial layer (0 – 20 cm) of a soil classified as Arenosols (*Neossolo Quartzarênico* in the Brazilian Classification system) (Santos et al., 2018), corresponding to Quartzipsamment (Soil Survey Staff, 1999). The soil characteristics are presented in Table 1. Before filling the PVC columns, the soil collected in the field was air-dried, pounded to break clods, and sieved through a 2-mm mesh.

The columns were initially filled with soil up to 48 cm of its total length. After placing the soil in the columns, the treatments were performed for the application of 4 grams of hydrogel to correspond to the dose of 0.07 % (w/w), which is in the range from 0.05 to 0.1 % (w/w) evaluated in other studies with hydrogel applied in sandy soils (Hüttermann et al., 1999; Andry et al., 2009; Dorraji et al., 2010). In the columns with

Table 1 – Physical and chemical attributes of the surface layer (0–20 cm) of the Arenosol, also known as Quartzipsamment (Soil Survey Staff, 1999) or Neossolo Quartzarênico (Brazilian Classification system) used in the study.

Variables	Value
Exchange complex	
pH (H_2O)	5.40
EC[1] (dS m^{-1})	0.10
Ca^{2+} (cmol$_c$ kg^{-1})	0.60
Mg^{2+} (cmol$_c$ kg^{-1})	0.40
Na^+ (cmol$_c$ kg^{-1})	0.03
K^+ (cmol$_c$ kg^{-1})	0.09
H^+ + Al^{3+} (cmol$_c$ kg^{-1})	1.32
Al^{3+} (cmol$_c$ kg^{-1})	0.15
SB[2] (cmol$_c$ kg^{-1})	1.10
CEC[3] (cmol$_c$ kg^{-1})	2.40
V[4] (%)	46.0
ESP[5] (%)	1.00
OM[6] (g kg^{-1})	4.45
$P_{assimilable}$ (mg kg^{-1})	2.00
Soil particle size	
Coarse sand (g kg^{-1})	583
Fine sand (g kg^{-1})	345
Silt (g kg^{-1})	36
Clay (g kg^{-1})	36
Volumetric relations	
Bulk density (g cm^{-3})	1.57
Particle density (g cm^{-3})	2.66
Soil moisture	
Tension 33 kPa (g 100 g^{-1})	3.49
Tension 1,500 kPa (g 100 g^{-1})	2.61

[1]Electrical conductivity. [2]Sum of bases; [3]Cation exchange capacity; [4]Base saturation percentage; [5]Exchangeable sodium percentage; [6]Organic matter; Clay (≤ 2 µm); silt (> 2 – 53 µm); fine sand (> 53 – 200 µm); coarse sand (> 200 – 2,000 µm).

hydrogel, this product was mixed to soil while it was still dry, only in a portion close to the root system, simulating the planting in holes.

After hydrogel application, three seeds of maize (*Zea mays* L.), cultivar BR 205, were planted in each column. At 7 days after sowing, plants were thinned and only one was left in each column. Until thinning, the experiment was irrigated with distilled water, keeping the soil moisture up to 80 % of field capacity. After thinning, the saline solution was applied through irrigation according to each treatment. There was no application of amendments and/or fertilizers to alter the soil saline conditions.

The saline solution volume applied per day in the experimental units was calculated according to the average daily rainfall of the site for the month of March in a period of 5 years (2005 to 2009), according to data from the Ceará State Foundation of Meteorology and Water Resources (FUNCEME, 2015). At the end of the experiment, 2.3 L of solution were added to each soil column. Irrigation solutions were prepared similarly to the first experiment.

After irrigation, the leached solution was collected and stored in plastic vials placed below each column. Periodically, vial contents were collected for analyses and the collections were performed until 30 days after maize germination.

The total volume of leached water was measured using a 100 mL graduated cylinder. In the leached material, EC was determined using a conductivity meter with a pipette-type measuring cell and the concentrations of sodium (Na^+) and potassium (K^+) were determined by flame photometry.

Soil moisture was determined by the gravimetric method (Embrapa, 1997) when maize plants were removed from the columns. Soil exchangeable Na^+ and K^+ contents were extracted in Mehlich-1 solution and determined by flame photometry (Teixeira et al., 2017). The EC of the soil saturation extract (ECse) was determined from the saturation paste, as described by Richards (1954), using a conductivity meter with a pipette-type measuring cell.

The shoot and root dry masses of maize were measured. The plant material was ground in a Wiley-type mill, and nitric-perchloric digestion was performed (Teixeira et al., 2017) to determine Na^+ and K^+ contents.

Statistical procedures

Data normality was checked using the Kolmogorov-Smirnov test and subsequently the analysis of variance was performed by the F test ($p < 0.05$). When there was an interaction between factors (salinity and hydrogel), the data were subjected to the regression analysis. Nonlinear models were adopted when the assumptions of linearity and homoscedasticity of the regression were not met. The figures were created using SigmaPlot® and Origin software programs.

Results and Discussion

Hydrogel characterization

The hydrogel spectrum studied is represented in Figure 1. Bands at 3,544 (NH_2 stretching) and 1,670 cm^{-1} (C = O stretching of amide) are characteristics of the acrylamide unit. Bands at 1,567 and 1,408 cm^{-1} are due to carboxylate group stretching of acrylate. The weak band at 1,712 cm^{-1} indicates the presence of a small fraction of the COOH group (acrylic acid). The band at 3,300 cm^{-1} is due to adsorbed water. Groups CH (methinic) and CH_2 (methylenic) appear at 2,943 cm^{-1} (Magalhães et al., 2012).

The acrylate content (Ac %) was calculated based on relative absorbance area of COO^- (carboxylate) band (1,408 cm^{-1}) and the band at 2,943 cm^{-1} (A_{rel} = A1,408/A2,943) as proposed by Magalhães et al. (2012). The hydrogel acrylate content is 36 mol %. Thus, the acrylate/acrylamide molar ratio is 36/64. As the molar masses of K^+ acrylate and acrylamide are 110 and 71 g mol^{-1}, respectively, the gel contains similar mass of K^+ acrylate and acrylamide.

The acrylate can be Na^+ or K^+ salt; thus, the elemental composition was determined by XRF. The gel powder did not contain Na^+; however, 13.8 wt % of K^+ was detected. Therefore, the hydrogel studied is composed of K^+ acrylate and acrylamide as monomers, promoting hydrophilic groups (COOK) along with the carboxyl group (Saha et al., 2020). The XRF analysis also detected aluminum (Al^{3+}) (22.5), sulfur (S) (43.5) and calcium (Ca^{2+}) (20.2), all in relative wt %. The presence of these elements indicates that the hydrogel contains inorganic filler, probably minerals, usually added to the polymer to produce a material of lower cost and supposedly less affected by salinity (Qin et al., 2012; Magalhães et al., 2013).

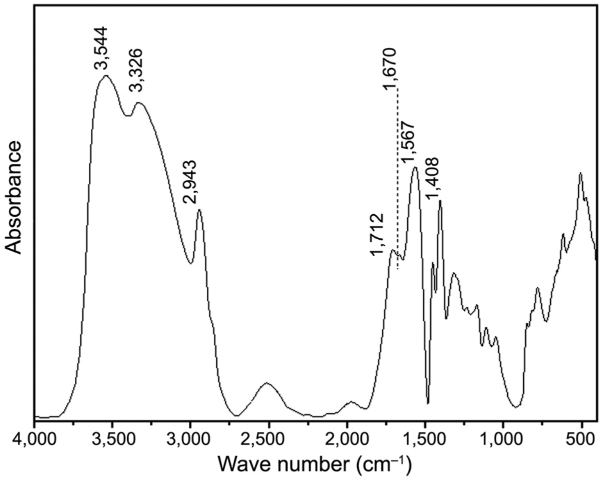

Figure 1 – Fourier Transform Infrared Spectroscopy (FTIR) spectra of hydrogel powder in potassium bromide (KBr) pellet.

The content of inorganic filler (mineral) was obtained by TGA (Figure 2). The TGA curve records the sample residual mass in % as it is heated. The curve starts with 100 % of mass, decreasing as the temperature increases. The material decomposes, producing gases that are released, reducing the residual mass upon heating. All organic matter is decomposed up to 600 °C, mainly if the atmosphere is oxidizing, as is the case of our study. The residual mass at this temperature can be considered as the percentage of inorganic filler, calculated as 40 wt %.

The percentage of mineral found in the hydrogel was high since the improvement in water absorption by the polymer under saline condition reached its maximum level when mineral (Na-bentonite) concentration was 5.0 wt % (Qin et al., 2012). The effects on hydrogel of salinity reduction by the mineral are attributed to its particles acting as cross-linker to interact with carboxylate groups of (poly) acrylate, improving polymer network structure (Pourjavadi et al., 2007; Qin et al., 2012). However, excess of mineral may hinder the increase of polymer chains, limiting the swelling and, consequently, water absorption (Pourjavadi et al., 2007).

The sample water content (moisture) is around 10 %, in agreement with the presence of water detected by FTIR. The high residual mass at 1,000 °C (24.3 %) suggests that the mineral contains sulfate group, probably $CaSO_4$, among other inorganic components. Calcium sulfate is very stable and only a small part was decomposed below 600 °C (Jia et al., 2016).

The hydrogel studied is composed of 10 % of water, 50 % of polymer, and 40 % of inorganic matter (mineral), all in wt %. The polymer is a copolymer of K acrylate and acrylamide. Therefore, the gel contains 10 % moisture, 25 % of K^+ acrylate, 25 % of acrylamide, and 40 % of mineral. Furthermore, the hydrogel capacity to retain distilled water was 444 ± 22 g of water per gram of hydrogel, allowing the product to be considered superabsorbent (Essawy et al., 2016).

Experiments

The first experiment showed a relationship between irrigation water EC and water retention with a difference ($p < 0.01$) in response to the treatments. The amount of water absorbed at the lowest salinity (0.5 dS m^{-1}) was slightly higher than 140 g g^{-1} of hydrogel, representing a reduction when compared to the absorption in distilled water (444 ± 22 g of distilled water per gram of hydrogel). The amount of water absorbed at the highest salinity (4.5 dS m^{-1}) was 70 g g^{-1}, which represents a 50 % reduction compared to the EC of 0.5 dS m^{-1} and 84 % reduction of absorption capacity in distilled water (Figure 3).

Water entrance into ionic hydrogels occurs due to differences in the osmotic pressure between the polymer matrix and external solution. However, salts promote an anion-anion electrostatic repulsion, reducing the osmotic pressure differences between the external solution and the polymer matrix (Saha et al., 2020; Dorraji et al., 2010; Candido et al., 2012; Zhang et al., 2014; Zain et al., 2018). The effects of salts on water absorption by hydrogel is even reduced by polyvalent ions in the irrigation water, as they increase ionic strength (Zhang et al., 2014).

The second experiment showed no effect on the volume of leached solution in response to irrigation water EC (Figure 4A). However, there was a difference (p

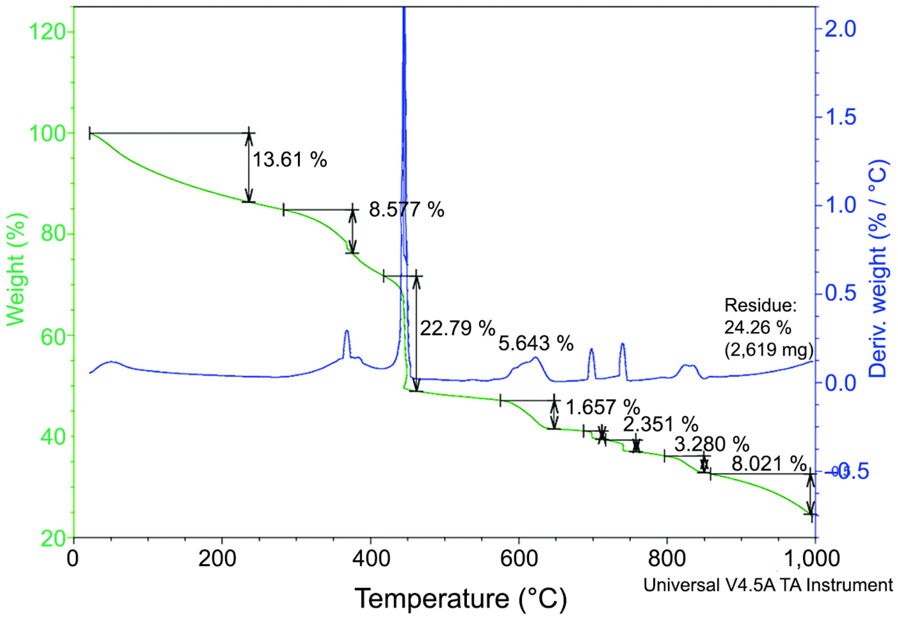

Figure 2 – Thermal Gravimetric Analysis (TGA) and its first derivative (DTG) curves of hydrogel in air atmosphere.

< 0.01) when comparing the volume of leached solution in the treatments with and without hydrogel, in which the treatment with hydrogel resulted in lower volume of leached water (582 mL) compared to the treatment without hydrogel (1,397 mL)

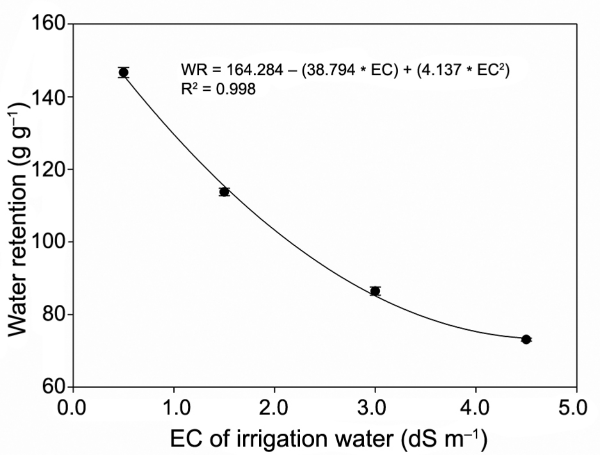

Figure 3 – Water retention by hydrogel (g g^{-1}) in response to increasing electrical conductivity (EC in dS m^{-1}) of irrigation water in laboratory.

The lower volume leached with hydrogel application indicates that the polymer favors water retention in sandy soil, as reported in other studies (Dorraji et al., 2010; Mohawesh and Durner, 2017; Yu et al., 2017). Even at the highest salinity of irrigation water (4.5 dS m^{-1}), the hydrogel absorbed 70 g g^{-1} (Figure 3), enough to contribute to soil water retention. Hydrogel contribution to soil water retention can also occur because of improvement in soil aggregation with the occurrence of bonds between chemical functional groups of the polymer and negative charges of the soil mineral surface (Paluszek et al., 2010). However, in this study, polymer contribution to soil aggregation was not significant because a sandy soil with low charges was used to interact with the polymer.

There was an effect ($p < 0.01$) of irrigation water salinity on the leaching solution EC (Figure 4B). Leachate EC increased by approximately 5 dS m^{-1} with irrigation water salinity (Figure 4B). However, hydrogel application did not reduce leachate EC in comparison to the treatment without polymer (Figure 4B). The

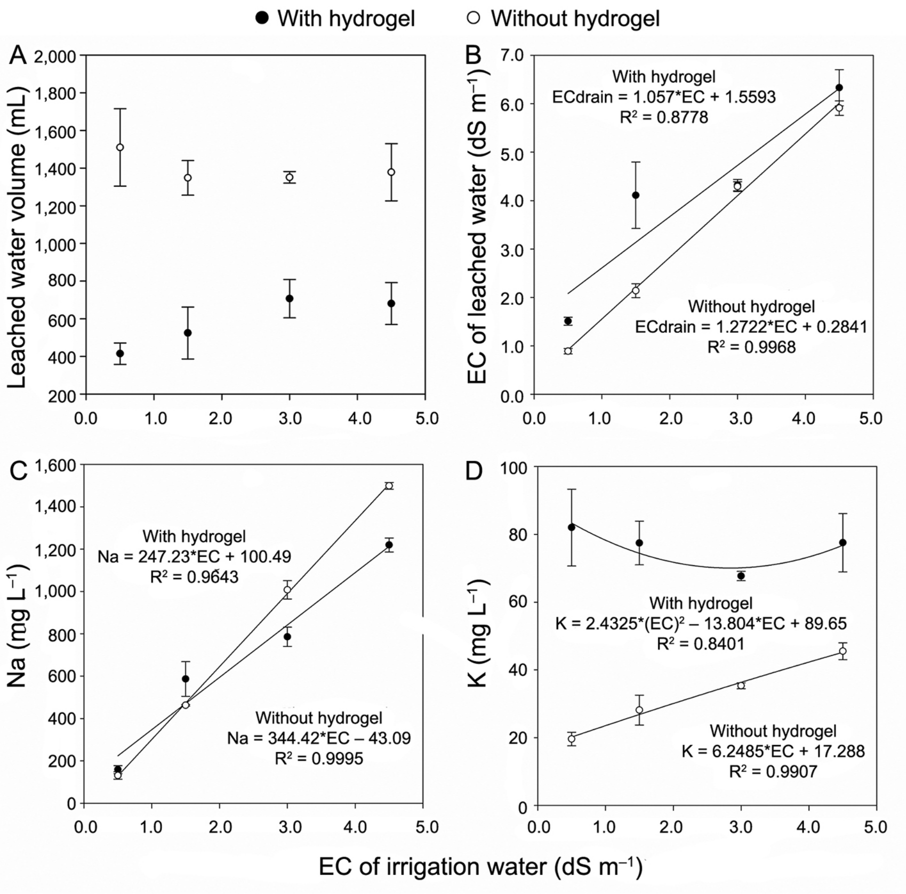

Figure 4 – Attributes evaluated in the leached soil water in response to increasing irrigation water EC (dS m^{-1}). (A) Volume (mL) of leached water along the experimental period; (B) Leaching water EC (dS m^{-1}); (C) Soluble Na^{+} (mg L^{-1}) and (D) Soluble K^{+} (mg L^{-1}) in leached water. Treatments with (●) and without (○) hydrogel.

hydrogel dose of 0.07 % (w/w) was possibly ineffective to decrease salt availability through binding ions in the polymer structure, as observed in studies with a higher hydrogel dose (0.5 % w/w) applied to soils that reduced the salinity effects (Shi et al., 2010; Dehkordi et al., 2017; Saha et al., 2020),

Although Na^+ concentration in the leached solution increased linearly with increased irrigation water salinity, it reached maximum values of 1,499 and 1,219 mg L^{-1} in the treatments without and with hydrogel, respectively, at the highest salinity level (Figure 4C). The decrease in leachate Na^+ concentration promoted by hydrogel was not enough to mitigate the salinity effects on maize development, because 782 mg L^{-1} of Na^+ in irrigation water is enough to reduce maize yield (Isla and Aragüés, 2010).

The treatment with hydrogel had 40 to 60 mg L^{-1} more of K^+ in the leachate when compared to the treatment without hydrogel (Figure 4D). In the treatment without hydrogel, K^+ leaching increased linearly from 20 to 40 mg L^{-1} as the irrigation water salinity increased (Figure 4D). This is because the increase in salinity raises concentration of Na^+ ions, elevating their ionic activity. Subsequently, Na^+ in excess in the soil solution replaces K^+ adsorbed to the soil (Table 1), remaining free until it is leached. Displacement of K^+ from the soil due to excess Na^+, causing K^+ leaching, was observed in a study with sodium-rich saline water applied to the soil (Jalali et al., 2008).

Except for soil moisture (Figure 5A), the other soil variables (EC, Na^+ and K^+ contents) were affected by the hydrogel application ($p < 0.01$) (Figure 5). Soil moisture was approximately 0.10 g g^{-1} (Figure 5A) and did not differ in response to treatments. Soil moisture recorded at the end of the experiment may not have been enough to meet water demand of plants. Soil conditioners improved maize growth, while sandy soil moisture was kept between 0.22 and 0.28 g g^{-1} 5 days after irrigation (Yangyuoru et al., 2006).

The lack of difference between treatments for soil moisture occurred because it was evaluated only at the end of the experiment, when salinity had already damaged hydrogel swelling, reducing the difference in soil moisture with and without the polymer. Other studies observed the reduction of water absorption by hydrogel after the first irrigation and because of the addition of salts (Akhter et al., 2004; Miller and Naeth, 2019).

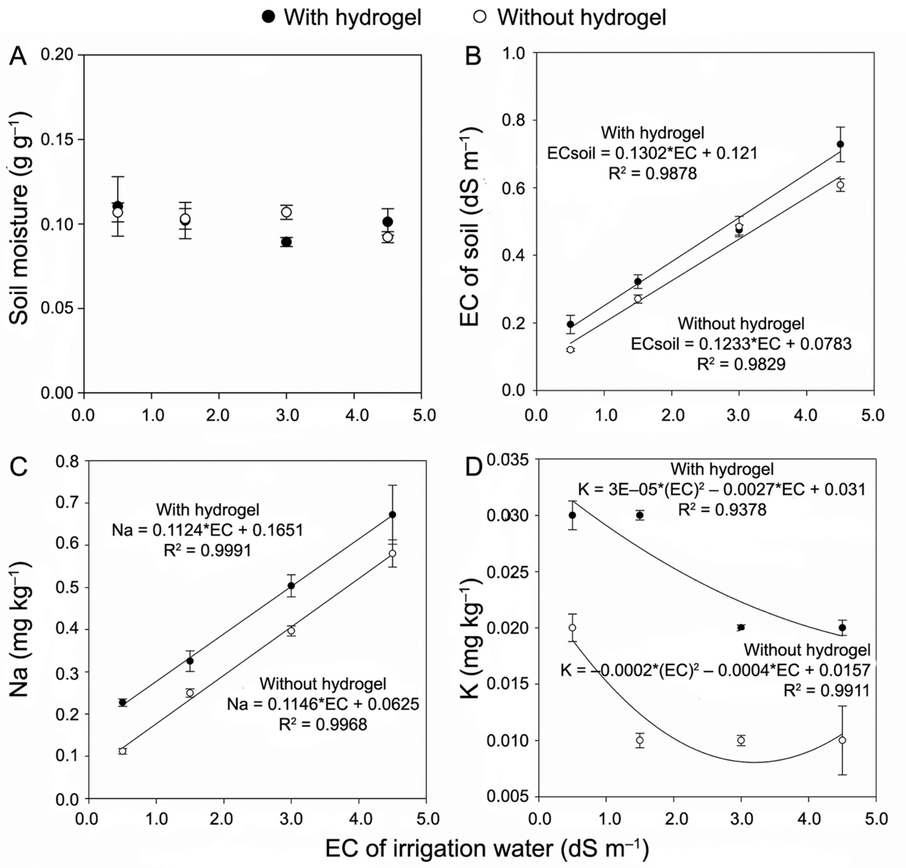

Figure 5 – Attributes evaluated in the soil in response to both irrigation water EC (dS m^{-1}) and hydrogel treatments (with and without). (A) Soil moisture at the end of experimental period (g g^{-1}); (B) Soil solution EC (dS m^{-1}); (C) Exchangeable soil Na^+ content (mg kg^{-1}); and (D) Exchangeable soil K^+ content (mg kg^{-1}).

Regarding soil chemical attributes, both EC and Na^+ contents increased with salinity levels of irrigation water (Figures 5B and 5C). The EC and Na^+ of the soil increased by about 0.5 dS m^{-1} and 0.5 mg kg^{-1}, respectively (Figures 5B and 5C). The higher levels for the treatment with hydrogel than without hydrogel for the variables EC (approximately 0.1 dS m^{-1} higher with hydrogel) and Na^+ (approximately 0.1 mg kg^{-1} higher with hydrogel) in the soil is observed at all salinity levels (Figures 5B and 5C). Bai et al. (2010) observed increase in soil EC with hydrogel application due to the influence of the polymer on soil pH reduction and increase of free ions in the solution. Additionally, the high percentage of mineral containing Ca^{2+} and Al^{3+} identified in the characterization of the hydrogel studied may also have contributed to change soil EC.

The Na^+ contents in the soil were higher with polymer application at all salinity levels (Figure 5C). Although hydrogel retained part of the Na^+ from irrigation water, the salt bound to the polymer was extracted by the Mehlich-1 solution used in this study for the soil analysis, representing the salt content extracted by plants. The extraction of Na^+ from the soil with water could reveal reduction in Na values, according to Chen et al. (2004), in which hydrogel reduced sodium content in salt-affected soil by up to 30 %.

The K^+ contents in the soil (Figure 5D) showed superiority of the treatment with hydrogel at all levels of irrigation water salinity. The K^+ in this treatment, despite more leached, continues to have higher content in the soil, because hydrogel is composed basically of copolymer of K^+ acrylate and acrylamide, acting as a K^+ source for the soil.

As the levels of irrigation water salinity increased, the K^+ content in the soil decreased by about 0.010 mg kg^{-1} in both treatments. Possibly, there was competition between the cations K^+ and Na^+ for the exchange sites of soil particles, increasing the Na^+ contents, leaving K^+ free in the soil solution to be leached (Figure 5D).

The Na^+ content in the plant material increased with irrigation water EC, which was more pronounced with hydrogel (13 mg kg^{-1}) than without hydrogel (8 mg kg^{-1}) (Figure 6A). Although the polymer had retained part of Na^+ from saline irrigation water, decreasing salt concentration in the leached solution, it was not enough to reduce Na^+ soil availability and did not reduce the salt uptake by plants.

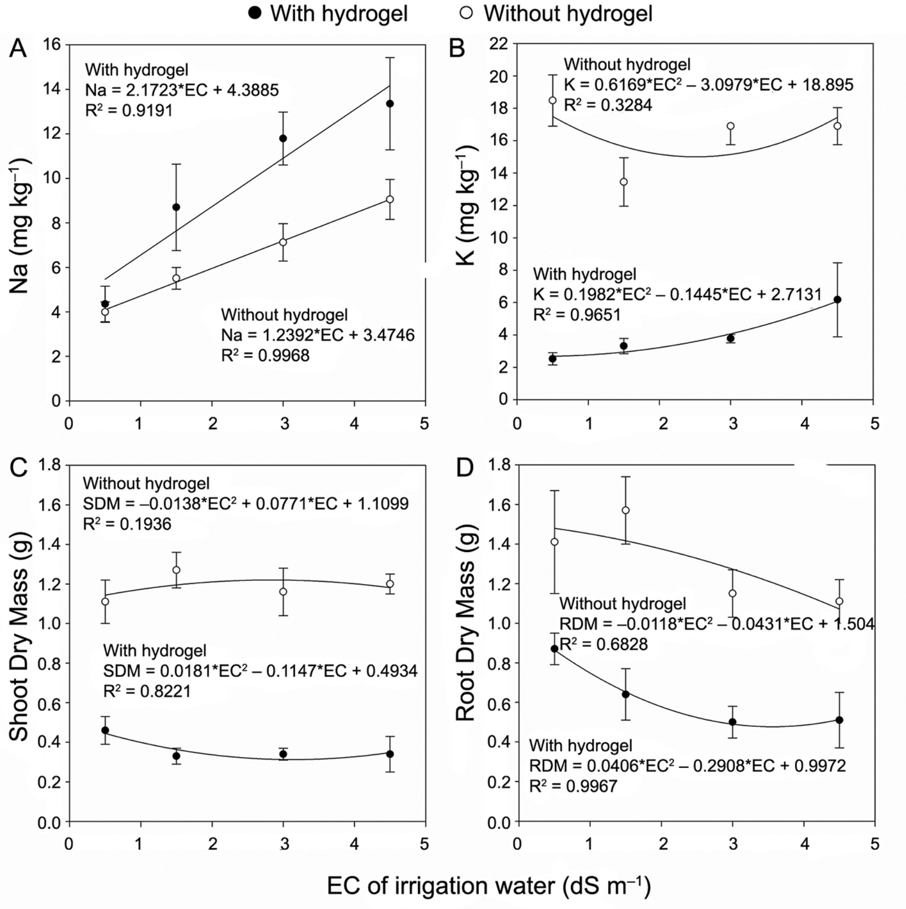

Figure 6 – Attributes evaluated in the plant in response to both irrigation water EC and hydrogel treatments (with and without). (A) Contents of Na^+ (mg kg^{-1}) and (B) K^+ (mg kg^{-1}) in maize plant tissue; (C) Dry mass of maize shoots and (D) roots (g).

Conversely, the K^+ content in plants of the treatment with hydrogel was 10 to 16 mg kg^{-1} lower than that of the treatment without hydrogel (Figure 6B), despite the higher K content in the soil in the treatment with hydrogel (Figure 5D). The available Na^+ content in the soil in which the hydrogel was applied was at least 10 times higher than the K^+ content (Figures 5C and 5D), which contributed for higher absorption of Na^+ than K^+ by plants. Negative correlation between soil EC and K^+ content in maize leaf was observed with EC threshold of 4.4 dS m^{-1} (Isla and Aragüés, 2010).

According to Farooq et al. (2015), Na toxicity in plants is due to the antagonistic effect of Na in K uptake also because Na and Cl influence other essential nutrients, leading to nutritional imbalances. Panuccio et al. (2018) observed in maize plants after 30 days of germination that the Na^+ contents in shoots and roots increased with the presence of 100 mM of NaCl, whereas the K^+ contents decreased by more than 50 %.

Plants cultivated with hydrogel showed lower shoot and root dry masses (Figures 6C and 6D). This result contradicts the study that reported an increase in the shoot and root biomass of maize 30 days after germination due to hydrogel application in saline sandy soil (Dorraji et al., 2010). These authors reported the positive effects of hydrogel on plants for the lowest salinity level (0.5 dS m^{-1}), which corresponds to the lowest salinity level evaluated in the current study. However, the hydrogel dose evaluated by Dorraji et al. (2010) was 0.2 % (w/w), which is 2.8 times higher than the dose evaluated in our study. The hydrogel dose of 0.07 % (w/w) applied to the sandy soil was not enough to mitigate the negative impacts of salinity on the initial development of maize.

Moreover, localized application of the polymer possibly contributed to the negative result in the initial development of maize. In ours study, divalent ions in irrigation water or from correctives and/or fertilizers had no influence. Thus, it is important to conduct studies to assess hydrogel doses, mode of polymer application, and presence of polyvalent ions not only from irrigation water, but also from inputs to the soil.

Conclusions

Increased salinity in irrigation water, promoted by monovalent ions, reduces water absorption by hydrogel composed of potassium acrylate, acrylamide, and mineral. Nevertheless, application of 0.07 % (w/w) of the polymer increases water retention in sandy soil, but effects do not last until 30 days after hydrogel application.

Application of 0.07 % (w/w) of hydrogel composed of potassium acrylate, acrylamide, and mineral in sandy soil did not reduce salts in the leachate or their availability in the soil. Consequently, it does not favor the initial development of maize crop under irrigation with saline water.

The dose and mode of application of the polymer and the presence of polyvalent salts from irrigation water or fertilizers applied to the soil should be further investigated to evaluate the polymer efficiency in agriculture under conditions of water and salt stress.

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Authors' Contributions

Conceptualization: Costa, M.C.G.; Mota, J.C.A. **Data Acquisition:** Lourenço, D.V.; Sousa, R.R. **Data analysis:** Lourenço, D.V.; Sousa, R.R.; Freire, A.G.; Costa, M.C.G. C.; Feitosa, J.P.A.; Mota, J.C.A. **Design of methodology:** Costa, M.C.G.; Feitosa, J.P.A.; Mota, J.C.A. **Writing and editing:** Costa, M.C.G.; Freire, A.G.; Lourenço, D.V.; Feitosa, J.P.A.; Mota, J.C.A.

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