EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2026, 27(1), 143–153
https://doi.org/10.12912/27197050/215138
ISSN 2719–7050, License CC-BY 4.0

Received: 2025.11.22
Accepted: 2025.12.20
Published: 2026.01.01

Effect of *Atriplex halimus* seeds on the electrical conductivity of saline irrigation water during short-term phytopurification (El Oued region, Algeria)

Zid Insaf[1*], Rezkallah Chafika[2]

[1] Laboratory of Biology, Environment and Health, Department of Agronomy, Faculty of Life and Natural Sciences, University of El Oued, 39000 El Oued, Algeria
[2] Laboratory of Applied Chemistry and Environment, Department of Biology, Faculty of Science Exacte and Natural Science and Life, University of Tebessa, Algeria and of Eloued, 39000 El Oued, Algeria
* Corresponding author's e-mail: zid-insaf@univ-eloued.dz

ABSTRACT

Agricultural intensification in the El-Oued region, Algeria, has degraded irrigation water quality due to increasing salinity. This study aims to assess the effectiveness of *Atriplex halimus* seeds for phytopurification, specifically their ability to reduce electrical conductivity (as a proxy for salinity) in irrigation water. A comparative laboratory experiment was conducted using water collected from five representative boreholes in different zones of El-Oued, selected for varying initial salinity levels. The water was treated with *Atriplex halimus* seeds under controlled conditions, and electrical conductivity was monitored regularly over a range of contact times. The results demonstrate that *Atriplex halimus* seeds significantly reduce water salinity during the initial 1 to 6 hours of contact, with the most pronounced decreases observed at higher initial salinities. For example, an immediate reduction was recorded in several zones within 5 to 30 minutes. Stabilization of electrical conductivity occurred from 5 to 6 hours, after which further contact led to a secondary increase in salinity due to ion release from the seeds, indicating saturation. The optimal phytopurification window is therefore within the first 6 hours. Effectiveness is time-dependent and limited by seed saturation; extended exposure beyond 6 hours may reverse the purification effect due to physiological limits of the seeds and the subsequent release of ions. This method offers a cost-effective, sustainable means for reducing irrigation water salinity in arid regions, improving the viability of marginal lands for agriculture. The research is the first to characterize and quantify the phytopurification potential of *Atriplex halimus* seeds in the Saharan context, providing operational recommendations for treatment duration to optimize salinity reduction and avoid undesirable effects.

Keywords: irrigation water, salinity, phytopurification, *Atriplex halimus*, Hassi Khalifa.

INTRODUCTION

Nearly a billion individuals, mostly residing in rural areas, directly depend on agricultural land for their livelihood. However, the global agricultural area, estimated at approximately 3 billion hectares, is undergoing a continuous reduction, mainly due to the increasing salinisation of soils. This issue currently affects between 1 and 10 billion hectares globally, spread across more than a hundred countries, with an annual expansion rate of 10 to 16% (Yensen and Biel, 2006; Qadir and Oster, 2002; Aydemir and Sünger, 2011). In arid and semi-arid regions, soil and irrigation water salinity are one of the main factors limiting plant productivity and agricultural yield, thus posing a major threat to food security (Zid and Grignon, 1991; Kinet and al., 1998; Balkhodja and Bidai, 2004; Ishtiyaq and al., 2023). Agriculture in these areas largely relies on groundwater, which is often mineralised, making it frequently inadequate for direct irrigation. Inadequate management leads to a worsening of soil salinisation (Benbesis and al., 2020). It is estimated that up to 50% of irrigated lands are affected by salinity, thereby compromising their economic profitability (Adams and Hughes, 1990). This salinisation is exacerbated by the intensive exploitation of brackish groundwater and the high evaporation characteristic of arid regions (Radhouane, 2008; Daoud and Halitim, 1994), leading to significant socio-economic losses, including decreased agricultural production and land devaluation (Shahid and Rahman, 2016).

Faced with these challenges, various methods for rehabilitating saline soils have been developed, based on physical, hydraulic, chemical, and biological approaches (Shahid and al., 2010). However, these traditional techniques are frequently limited by their high costs, significant water needs, or the use of chemicals, which reduces their applicability, particularly in arid and semi-arid zones (Kumar and Abrol, 1984; Marlet and al., 2005). A sustainable alternative is emerging with the use of halophytes, naturally salt-tolerant plants capable of thriving in saline environments, sometimes better than in non-saline conditions. These plants represent the adaptive limit of vegetation to salinity (Khan and Duke, 2001; Grigore et al., 2014) and offer valuable potential for enhancing marginal lands that are highly saline and prone to desertification (Nedjimi and Daoud, 2006). Among the plethora of plant species with therapeutic properties, *Atriplex halimus* L., commonly known as "Guetaf," has a long history in traditional Algerian medicine (Taïbi and al., 2020, 2021). Atriplex from the genus Atriplex, belonging to the Amaranthaceae family (Kinet and al., 1998), are halophytes naturally tolerant to soluble salts and thrive equally well in saline environments as in normal conditions (Malcolm et al., 2003). *Atriplex halimus* L., a typical Mediterranean species, is particularly valuable for the ecological and sustainable rehabilitation of degraded lands in coastal environments and arid regions (Walker and Lutts, 2014), as it helps combat erosion and desertification (Marcar and al., 1999).

Halophytes contribute to soil phytoremediation by extracting heavy metals and improving certain soil characteristics, such as fertility and hydraulic conductivity (Qadir and al., 2008; Rabhi and al., 2015). Phytoremediation thus encompasses techniques that use plants to decontaminate and restore polluted environments (Flathman and Lanza, 1998). Moreover, the association of halophyte crops with ecological soil management is recommended for the sustainable restoration of marginal lands (Manouski and al., 2009; Han, RM; Lefèvre and al., 2012).

On the physiological level, halophytes tolerate and accumulate large quantities of salt through mechanisms of osmotic adjustment, vacuolar compartmentalisation, and ionic exclusion, allowing them to maintain their vital functions under saline conditions (Ali et al., 2024; Ahmad et al., 2024). It has been shown that these plants reduce the salinity of water and soil through ionic extraction during active growth and germination phases, while the harvested biomass allows for the export of accumulated salts out of the ecosystem (Ahmadi and al., 2022).

However, the potential of halophyte seeds, especially *Atriplex halimus*, for rapid phytopurification of saline irrigation water has not yet been experimentally evaluated in arid regions such as El Oued.

The present study aims to determine whether seeds of the halophyte *Atriplex halimus* can significantly reduce the electrical conductivity of saline groundwater used for irrigation in the El-Oued region within short contact times (minutes to a few hours), and to quantify how this desalination efficiency depends on the initial salinity level of the water. More specifically, the research seeks to fill the lack of experimental data on the use of *Atriplex halimus* seeds for rapid phytopurification of irrigation water at the seed–water interface, by analysing the dynamics of ion uptake during early imbibition and germination stages. It is hypothesised that *Atriplex halimus* seeds will decrease EC more than the control without seeds, the relative reduction in EC will be greater in more saline waters, and there exists an optimal contact time (approximately 1–6 h) beyond which EC stabilises or increases, reflecting changes in seed–water ionic exchanges.

MATERIALS AND METHODS

Geographical location of the study area

The Hassi Khalifa district is located north of the Eloued province headquarters (30 km), covering an area of 1112 km² (Figure 1), characterised by an arid Saharan climate, with low rainfall that does not exceed 100 mm throughout the year.

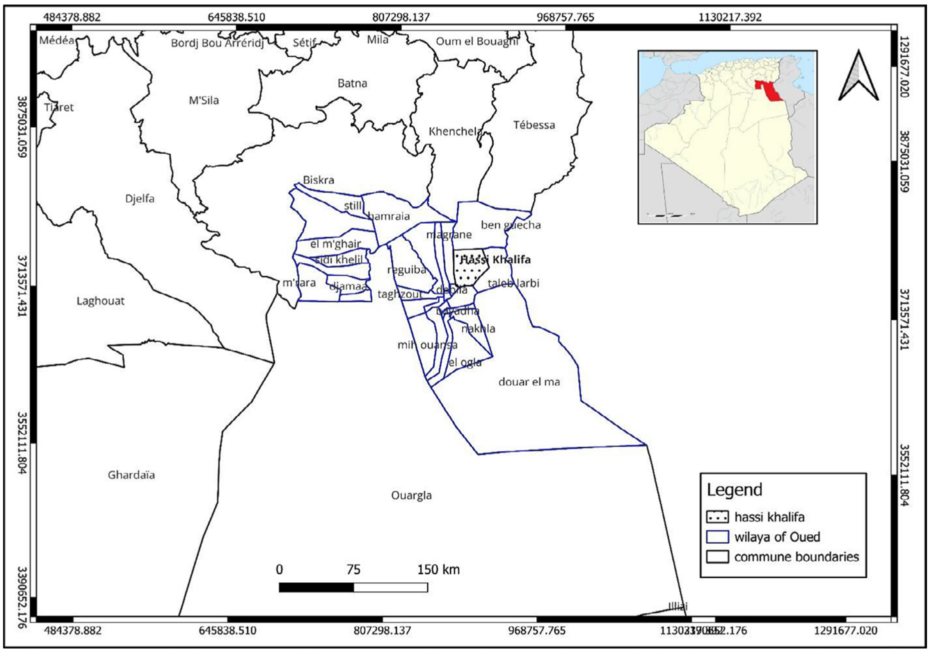

Figure 1. Geographical location of the Hassi Khalifa valley

Sampling method

The experiment was conducted at the laboratory level of the Faculty of Natural and Life Sciences. To assess the salinity of the irrigation water in the region, five water samples were taken at a depth of 25–30 meters from 5 areas with different electrical conductivity (EC). The collected samples were placed in plastic bottles, rinsed with distilled water, and labelled with a capacity of 1 liter and stored in coolers until they reached the laboratory.

The five study zones are distributed as follows (Figure 2):

- Zone 1 (Elaadhal): 1 sample.
- Zone 2 (Shan Elberri): 1 sample.
- Zone 3 (Elmerzaka): 1 sample.
- Zone 4 (Nezla elgherbia): 1 sample.
- Zone 4 (Elmenchia): 1 sample.

The electrical conductivity (EC) of the raw and control water in the different zones (Z1 to Z5) was measured. The results are presented in Table 1.

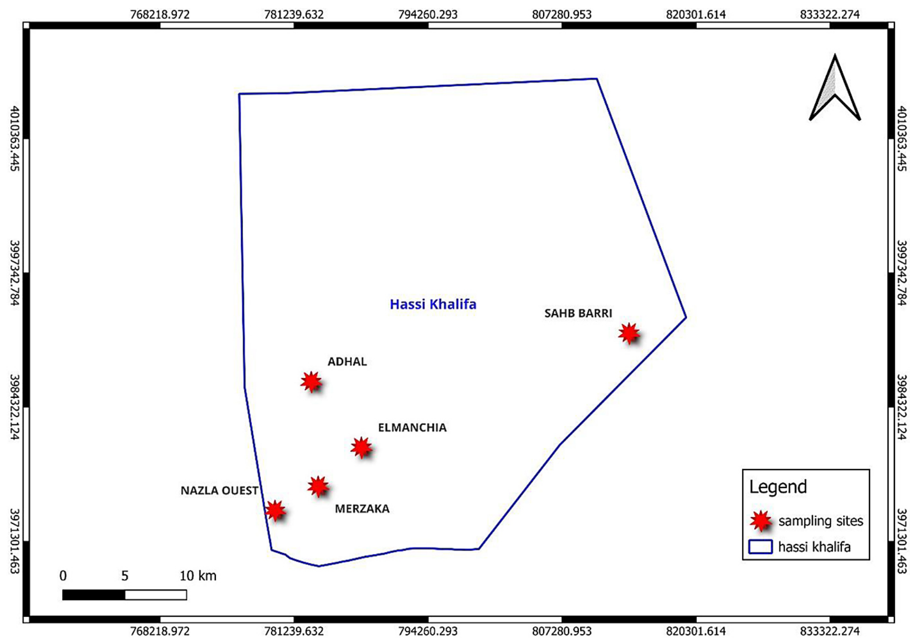

Figure 2. Map of the distribution of sampling sites

Table 1. The EC values of raw-control- waters

ZONES	Z1	Z2	Z3	Z4	Z5
EC ms/cm	5.64	7.73	6.77	10.33	3.38

Conduct of the test

The experiment was conducted in the laboratory of the Faculty of Natural and Life Sciences. Seeds of *Atriplex halimus* were obtained from the High Conservation of Steppe Development (HCDS BARIKA) (Figure 3). No specific pre-treatments were applied to the seeds prior to use. Water samples were first classified by salt concentration levels to create five experimental variations (doses) for seed irrigation. For each variation, 1 g of seeds was weighed using a precision balance. Fifteen perforated plastic cups (three replicates per variation) were prepared, placed inside non-perforated cups, labeled accordingly, filled with seeds, and irrigated with 50 mL of the assigned raw water sample per cup (Figure 3). The value of electrical conductivity EC was measured in situ using a multi-parameter. The Initial electrical conductivity (EC) of the irrigation water was determined by classifying samples according to their salt concentrations prior to use, using standard conductivity measurements. While EC was the primary parameter monitored as a direct indicator of salt ion release from seeds, other factors (e.g., pH, temperature, or seed viability) could influence results but were not measured here to focus on phytoremediation potential via halophyte ion uptake.

After 5 minutes of irrigation, filtered leachate from each cup was analyzed using a conductivity meter. Thirteen EC measurements were recorded per replicate across all doses—from 5 minutes to 48 hours—to track ion release dynamics (Figure 4). This design (5 variations × 3 repetitions) ensures statistical reliability, minimizing random variation through replication

RESULTS AND DISCUSSION

In this section, we present and analyze the evolution of EC across the five experimental zones over the 48-hour incubation period. Our experimental results demonstrate distinct patterns in EC changes across all experimental zones. Figure 5 presents the EC evolution in zone "1" as a baseline reference for subsequent analysis.

The graph shows that the EC varies slightly, with some moderate fluctuations during the first few hours, followed by a decrease below the initial level, then a sharp increase after 9 hours, peaking well above the reference value after 48 hours. The electrical conductivity (EC) of the water increases rapidly upon contact with the seeds, rising from 6.09 ms/cm to 6.7 ms/cm after 2 hours, which is explained by the rapid release of salts and ions by the seeds into the medium (Adjel, 2017). This increase is followed by a sharp drop between 3 and 5 hours, likely due to the absorption or precipitation of ions by the seeds (Soualem, 2014). According to Kahouadji et al. (2022), germination under saline

Figure 3. Plant and instrumental materials

Figure 4. Measurement of the EC value of filtered water

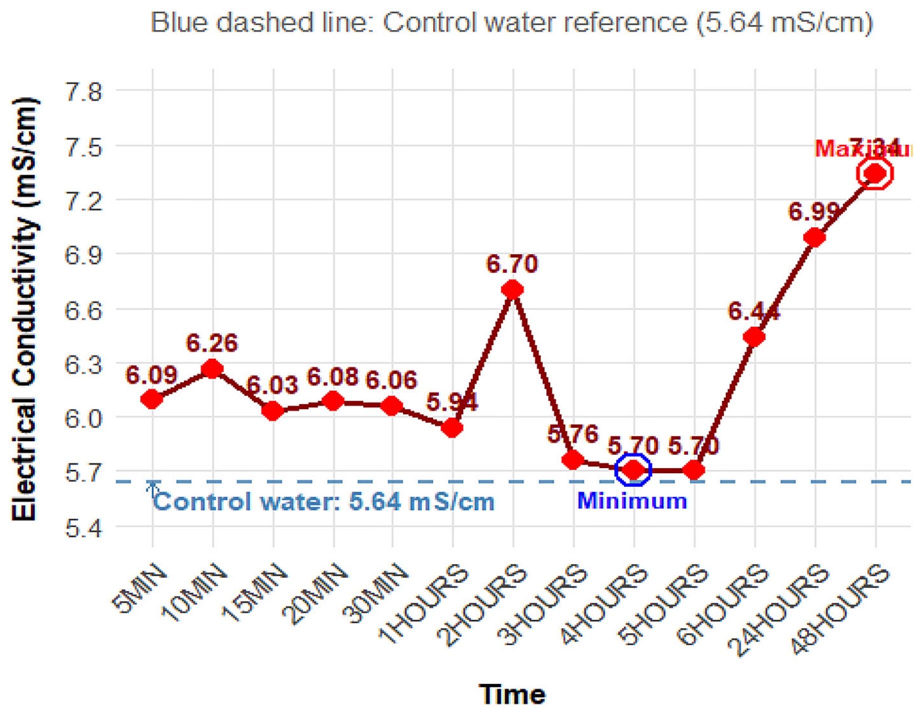

Figure 5. The evolution of electrical conductivity (EC) in Zone "1" as a function of the time of seed-filtered water, in comparison with seed-free water- (red line at 5.64 ms/cm)

stress is always accompanied by a change in EC, illustrating both the initial absorption of ions by the seeds and their subsequent release during the degradation or cell death phase if the saline stress is too strong.

Figure 6 illustrates the biphasic EC patterns observed in zone "2", characterized by an initial decrease followed by a significant increase, highlighting the dynamic ion exchange processes in *Atriplex halimus* seeds.

- Phase 1 – the time might be anything from 5 minutes to 5 hours. The EC value begins at 7.73 ms/cm and drops to roughly 6.15 ms/cm after five hours. The rapid decrease in EC during the first hours supports the hypothesis that Atriplex seeds may absorb saline ions such as sodium (Na^+) and chloride (Cl^-). The study by Kachout et al. (2025) confirms this effect, demonstrating that the growing of Atriplex hortensis on salty soil decreases the EC by 35% after six months. This drop is because plant tissues store salts, seeds take up ions (dissolved salts), or certain biochemical events involving the seeds induce dilution. This phenomenon is often seen in phytoremediation, when plants or seeds absorb certain solutes. The research conducted by Nguyen et al. (2024) and Chourasiya et al. (2024) demonstrates that halophytes efficiently reduce electrical conductivity in laboratory settings. This implies that they may hold the most salt when they are initially exposed to salty circumstances.
- Phase 2 – lasts between 6 and 48 hours – the results gathered over a period of 6 to 48 hours indicate that the water containing *Atriplex halimus* seeds exhibits a greater EC than the reference value for seedless water (7.73 mS).

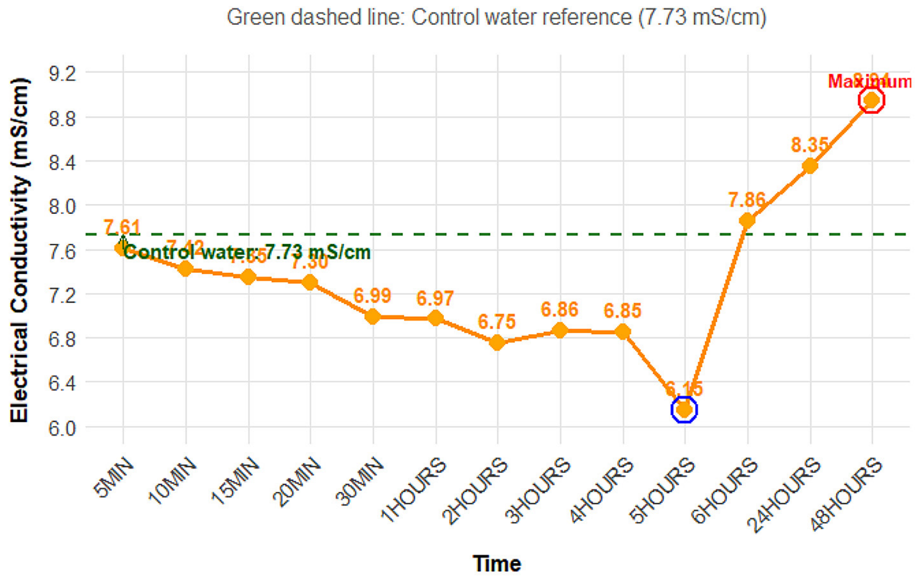

Figure 6. The evolution of electrical conductivity (EC) in Zone "2" as a function of the time of seed-filtered water, in comparison with seed-free water- (red line at 7.73 ms/cm)

At 48 hours, the apex was achieved. This incident illustrates that the ways that seeds may lower salinity are progressively becoming less effective. Recent research shows that this sort of growth signifies the saturation of the seed's absorption and ionic compartmentalisation capacity, leading to the release of sodium and chloride ions, especially upon surpassing the physiological tolerance threshold. (Ehosioke et al., 2025).

Research on *Atriplex halimus* indicates that, contingent upon the starting salinity and duration of exposure, the EC of the substrate may either diminish (attributable to effective ion absorption) or augment (resulting from solute release). (Ahmadi et al., 2022). In zone "3", Figure 7 reveals a similar temporal patterns to zone "2", with early ion absorption followed by later ion release, demonstrating consistent phytopurification behavior across salinity gradients.

The EC value begins at around 6.93 ms/cm, exceeding the control, throughout the first phase lasting from 5 minutes to 5 hours. A gradual decline occurs until about 6.42 ms/cm (the fifth hour). This decline may be attributed to the seeds absorbing ions or to certain dissolved salts

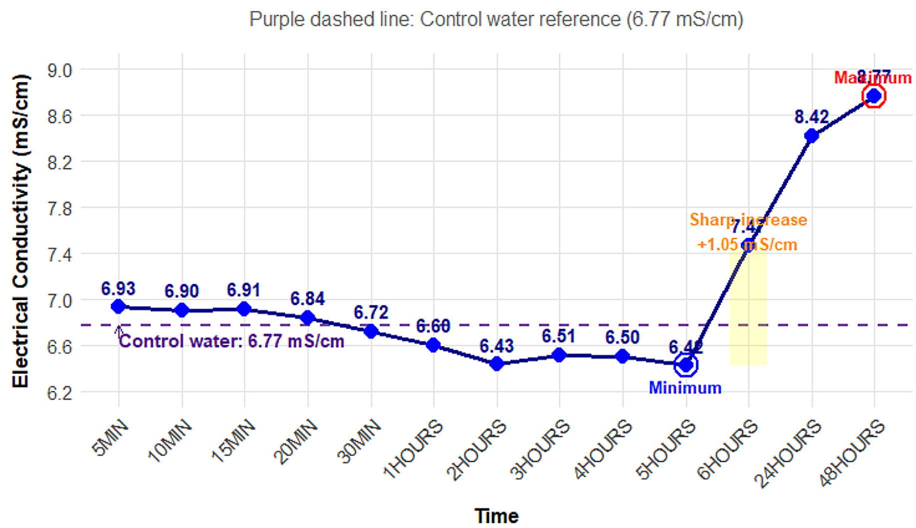

Figure 7. The evolution of electrical conductivity (EC) in Zone "3" as a function of the time of seed-filtered water, in comparison with seed-free water- (red line at 6.77 ms/cm)

undergoing a biochemical transformation. This phase often aligns with the purification effect, whereby plant organic matter either sequesters or metabolises dissolved salts, a phenomenon seen in phytopurification. The EC value increased to 8.77 ms/cm between 6 and 48 hours, surpassing the control value. This indicates that the seeds released ions via exudates and cellular degradation (Benidir et al., 2015).

This result indicates that halophyte seeds may serve to cleanse saline water or soil, since they markedly decreased electrical conductivity within the first hours. The subsequent phase of development necessitates the optimisation of exposure duration and the monitoring of the post-absorption interval to avert re-salination. These results align entirely with contemporary scientific studies on phytopurification in saline conditions (David and Stanley, 2014). Figure 8 from zone "4" (highest salinity) shows the most pronounced EC fluctuations, providing critical insights into the limits of seed-based phytopurification under extreme saline conditions.

After five minutes, the water's conductivity decreases below the control value. After 10 minutes, it increases slightly, and then it keeps dropping for two hours. Conductivity starts to climb after three hours, and by six hours it is higher than the control level. It keeps rising a lot until 24 and 48 hours. This first dip is probably because the seeds are taking in dissolved ions, which lowers the salt levels in the water

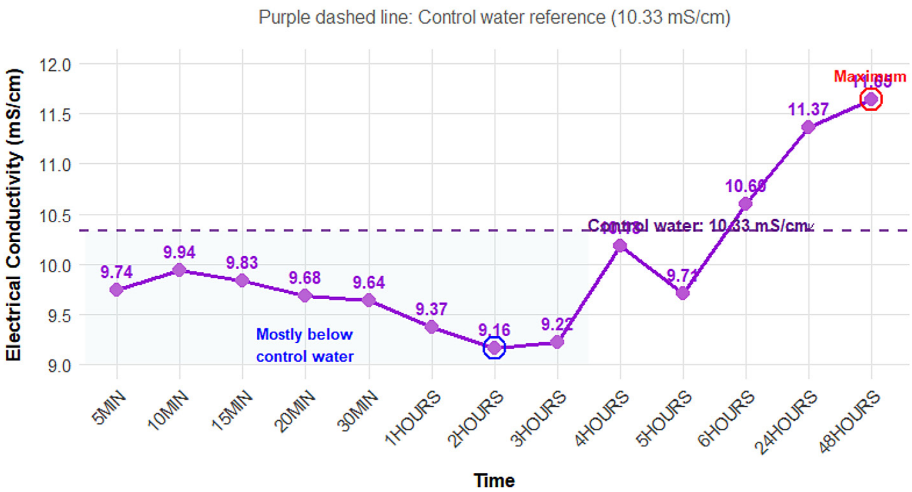

Figure 8. The evolution of electrical conductivity (EC) in Zone "4" as a function of the time of seed-filtered water, in comparison with seed-free water- (red line at 10.33 ms/cm)

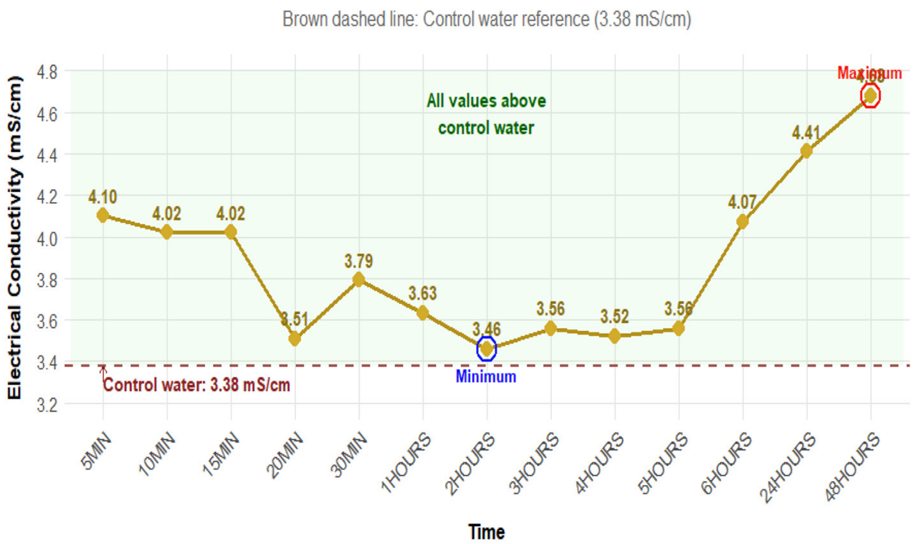

Figure 9. The evolution of electrical conductivity (EC) in Zone "5" as a function of the time of seed-filtered water, in comparison with water without seeds (red line at 3.38 ms/cm)

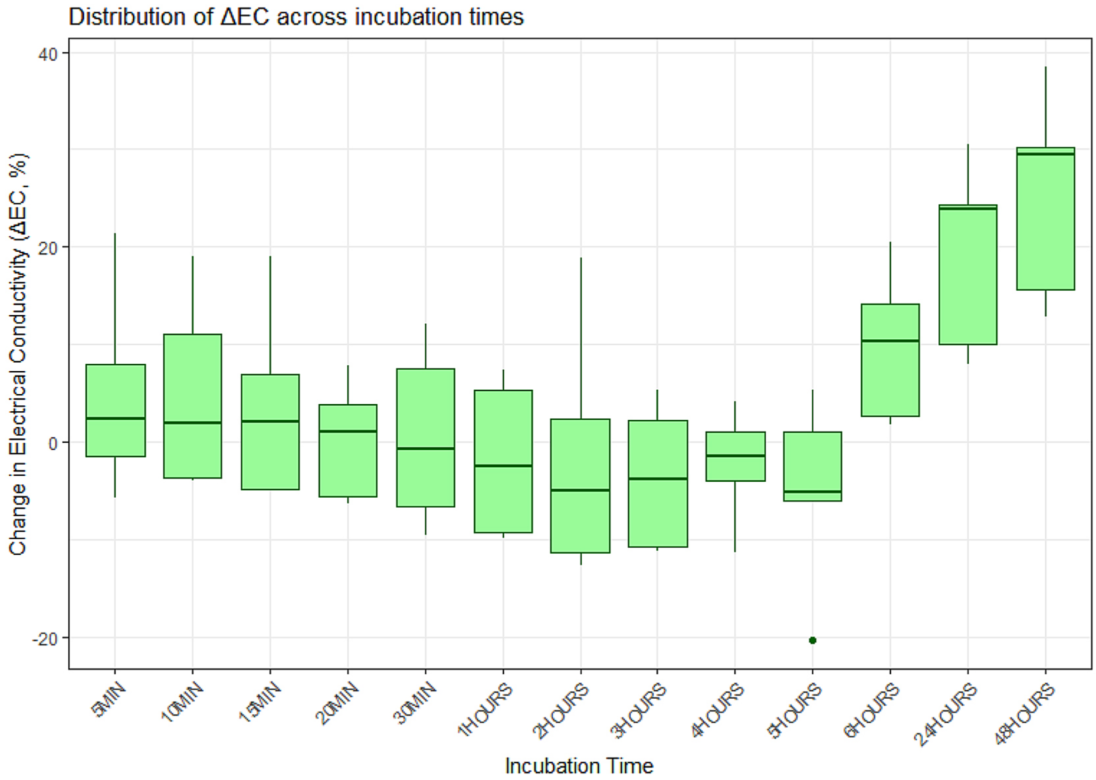

Figure 10. Variation of electrical conductivity during incubation periods

(Razkallah, 2017; Kachout et al., 2025). Seeds absorb ions such as Na+ and Cl−, which lowers electrical conductivity, according to other research (Ehosioke et al., 2025).

After six hours, the conductivity climbs gradually, reaching a peak of 11.65 mS/cm, which is higher than the control. This increase might be caused by the seeds' metabolism, cells breaking down because of salt stress, or the seeds releasing organic chemicals and ions, which makes conductivity go up (Dahaan et al., 2016).

Zone "5" results in Figure 9 contrast with previous zones, showing minimal initial absorption but sustained ion release, indicating salinity-dependent metabolic responses in halophyte seeds.

The EC remains the same at first, but subsequently it goes down a bit. The seeds rapidly absorb water, which makes the ions surrounding them less dense. The steady rise in electrical conductivity from 6 to 48 hours shows that solutes and ions are being released as the germ goes through its metabolic activities. The comparison of control and filtered waters demonstrates that germination alters the ionic composition of the medium by releasing or exchanging ions according to the seeds' requirements (Morteau, 2014). The seeds did not lower salinity; instead, they increased electrical conductivity after an initial absorption impact. This demonstrates the adaptability of halophytes and indicates that seeds alone are insufficient for phytoremediation (Rokbane, 2023).

Statistical analysis of the obtained results

Figure 10 summarizes the statistical analysis of EC variation across all incubation periods, confirming highly significant temporal effects through non-parametric testing (x^2= 85.006, p<0.001). The necessary conditions for the correct application of an ANOVA are not met. The Shapiro-Wilk test indicates a lack of normality in the residuals, while the Levene test reveals heterogeneity of variances between groups. In the face of these violations, a non-parametric Kruskal-Wallis test was used to evaluate the effect of the "Time" factor on the "ΔCE" variable. This test shows a highly significant difference between the values according to the incubation times (χ^2 = 85.006, p = 4.54e-13), suggesting that the electrical conductivity varies considerably over time. The data analysis shows that the conductivity (ΔCE) of *Atriplex halimus* seeds remains low and stable during the first hours of imbibition (5 to 6 h), indicating good membrane integrity and low ionic leakage.

CONCLUSIONS

The study showed that *Atriplex halimus* seeds can reduce the EC of saline irrigation water, indicating a decrease in salinity, mainly during the first 5 hours of contact. This reduction is faster when the initial salt concentration is high, promoting an ionic absorption gradient by the seeds. A stabilisation of the EC is observed between 5 and 6 hours. However, beyond that, between 6 and 48 hours, an increase in the EC indicates a saturation of the seeds' absorption capacities, with a potential release of ions.

These results suggest that the optimal duration for a phytopurification program using these seeds should be between 1 and 6 hours to avoid the re-increase in salinity due to seed saturation. The initial efficiency in salinity reduction opens promising perspectives for the use of halophytes in the bioremediation of saline irrigation water. However, limitations related to the post-absorption phase must be monitored.

In conclusion, phytopurification with *Atriplex halimus* presents an interesting potential for the sustainable management of saline water in agriculture in arid areas, provided that application parameters, particularly the treatment duration, are optimised to maximise the sustainable reduction of dissolved salts in irrigation water.

The exposure time of the seeds should be limited to less than 6 hours if the goal is to reduce the conductivity and thus the salinity of the water.

For effective phytopurification, it would be wise to closely monitor the evolution of conductivity for each zone and adjust the duration of treatments based on the observed results.

It is recommended to supplement these measurements with the analysis of other chemical parameters to understand the mechanisms at play better. A complementary investigation into the types of seeds used and their post-6-hour management would be beneficial in order to optimise the procedure and avoid the undesirable release of ions into the treated water.

REFERENCES

1. Adams, W. M., and Hughes, F. M. R. (1990). *Irrigation Development in Desert Environments.* In Goudi, A. S. (Ed.), Techniques for desert reclamation 135–160. Wiley. New York, 135–160.
2. Ahmadi, F., Mohammadkhani, N., and Servati, M. (2022). Halophytes play important role in phytoremediation of salt-affected soils in the bed of Urmia Lake, Iran. *Scientific Reports, 12*(1), 12223. https://doi.org/10.1038/s41598-022-16694-7
3. Aydemir, S., and Snger, H. (2011). Bioreclamation effect and growth of a leguminous forage plant *Lotus corniculatus* in calcareous saline sodic soil. *African Journal of Biotechnology, 10*, 115571–115577.
4. Balkhodja, M., and Bidai, Y. (2004). La réponse des graines d'*Atriplex halimus* L. à la salinité au stade de la germination. *Science et Changements Planétaires Sécheresse, 15*(4), 331–335.
5. Benbesis, Y., Halilat, M. T., and Salhi, N. (2020). Le chou fourrager Brassica napus L. solution pour la phytoremédiation et la conservation des sols salins. *AFPF, Association Française Pour La Production Fourragère, 243*, 55–61.
6. Benidir, L., Daoui, K., Fatemi, Z. A., Achouak, W., Bouarab, L., and Oufdou, K. (2015). Effet du stress salin sur la germination et le développement des plantules de *Vicia faba* L. *Journal of Materials and Environmental Sciences, 6*(3), 840–851.
7. Daoud, Y., and Halitim, A. (1994). Irrigation et Salinisation Au Sahara Algérien. *Science et Changements Planétaires/Sécheresse 5*(3), 151–60.
8. Dahaan, S., Al-Ansari, N., and Knutsson, S. (2016). Influence of groundwater hypothetical salts on electrical conductivity total dissolved solids. *Engineering, 8*, 823–830. https://doi.org/10.4236/eng.2016.811074
9. Ehosioke, S., Garr, S., Huisman, J. A., Zimmermann, E., Javaux, M., and Nguyen, F. (2025). Technical note Investigating saline water uptake by roots using spectral induced polarization. *Biogeosciences, 22*, 2853–2869. https://doi.org/10.5194/bg-22-2853-2025
10. Flathman, P. E., and Lanza, G. R. (1998). Phytoremediation: Current views on an emerging green technology. *Journal of Soil Contamination, 7*(4), 415–432. https://doi.org/10.1080/15320389809383644
11. Kachout, S. S., Dhane, S., BenYoussef, S., Tlili, A., Douili, M., Guesmi, F., and Zoghlami, A. (2025). Sustainable phytoremediation of saline soils using *Atriplex hortensis* L.: a case study from Bizerte Lagoon, Northern Tunisia. *Frontiers in Plant Science, 16*, 161613594. https://doi.org/10.3389/fpls.2025.1613594
12. Khan, M. A., and Duke, N. C. (2001). Halophytes: A resource for the future. *Wetlands Ecology Management, 6*, 455–456.
13. Kinet, J. M., and Bajji, M. (1998). Salt stress effects on roots and leaves of *Atriplex halimus* and their corresponding callus cultures. Elsevier Louvain, 132–142. https://doi.org/10.1016/S0168-9452(98)00116-2

14. Kumar, A., and Abrol, I. P. (1984). Studies on the reclaiming effect of Karnal-Grass and Para-Grass grown in a highly sodic soil. *Indian Journal of Agricultural Sciences, 54*, 189–192.
15. Marlet, S., and Job, J.-O. (2005). Processus et gestion de la salinité des sols. In J. R. Tiercelin and A. Vidal (Eds.), *Traité d'irrigation*. CIRAD
16. Morteau, B. (2014). *Développement d'un système de traitement des eaux de ruissellement routier par marais purateur adapté et lit filtrant réactif (Thèse de doctorat en génie civil).* Université Laval, Canada.
17. Nedjimi, B., and Daoud, Y. (2006). Effect of Na_2SO_4 on the growth, water relations, proline, total soluble sugars and ion content of *Atriplex halimus* subsp. schweinfurthii through in vitro culture. *Anales de Biologia, 28*, 35–43.
18. Qadir, M., and Oster, J. (2002). Vegetative bioremediation of calcareous sodic soils: History, mechanisms, and evaluation. *Irrigation Science, 21*(3), 91–101. https://doi.org/10.1007/s00271-001-0055-6
19. Qadir, M., Tubeileh, J., Akhtar, J., Larbi, A., Minhas, P. S., and Khan, M. A. (2008). Productivity enhancement of salt-affected environments through crop diversification. *Land Degradation and Development, 19*(4), 429–453.
20. Rabhi, M., Atia, A., Abdelly, C., and Smaoui, A. (2015). New parameters for a better evaluation of vegetative bioremediation, leaching, and phytodesalination. *Journal of Theoretical Biology, 383*, 7–11.
21. Radhouane, L. (2008). Effet du stress salin sur la germination, la croissance et la production en grains chez quelques écotypes de mil Pennisetum glaucum L. R. Br. autochtones de Tunisie. *Comptes Rendus Biologies, 331*(4), 278–286.
22. Shahid, S. A., and Rahman, K. U. (2016). *Soil Salinity Development, Classification, Assessment, and Management in Irrigated Agriculture*. In Handbook of Plant and Crop Stress (3rd ed., 23–39). https://doi.org/10.1201/b10329-4
23. Shahid, S. A., Abdelfattah, M. A., Omar, S. A. S., Harahsheh, H., Othman, Y., and Mahmoudi, H. (2010). Mapping and monitoring of soil salinization: Remote sensing, GIS, modeling, electromagnetic induction and conventional methods – case studies. In *Proceedings of the International Conference on Soils and Groundwater Salinization in Arid Countries* 59–97.
24. Soualem, S. (2014).Thèse.Etude de l'osmoregulation chez une halophyte *Atriplex halimus* L.stressée à la salinité.université d'ORAN.ALGERIIE.138P.
25. Yensen, N.P., and Biel, K.Y. (2006). *Soil remediation via salt-conduction and the hypotheses of halosynthesis and photoprotection ecophysiology of high salinity tolerant plants*. In M. A. Khan and D. J. Weber (Eds.), Tasks for vegetation science, 40, 313–344. Springer Netherlands. https://doi.org/10.1007/1-4020-4018-0_21
26. Zid, E., and Grignon, C. (1991). *Les tests de sélection précoce pour la résistance des plantes aux stress. Cas des stress salin et hydrique*. L'amélioration des plantes pour l'adaptation aux milieux arides. AUPELF-UREF, Jon Libbey Eurotext, Paris, 91–108.
27. Kinet, J.M., Benrebiha, F., Bouzid, S., Lailhacar, S., Dutuit, P. (1998). Le réseau Atriplex. Allier biotechnologies et écologie pour une sécurité alimentaire s'accumulent en régions arides et semi-arides. *Cahiers Agricultures. 7*(6), 505–509.
28. Malcolm, C.V., Lindley, V.A., O'leary, J.W., Runciman, H.V., Barrett-Lennard, E.G, (2003). Tolérance au sel des halophytes et des glycophytes lors de la germination et établissement des arbustes halophytes en milieu salin. *Plant and Soil, 253*(1), 171–185.
29. Walker, D.J., Lutts, S. (2014). La tolérance d' *Atriplex halimus* L. aux stress environnementaux. Emirates Journal of Food and Agriculture. 1081-1090. doi: 10.9755/ejfa.v26i12.19116
30. Marcar, N.E., Ismail, S., Hossain, A.K.M.A., Ahmad, R. (1999). Arbres, arbustes et graminées pour les terres salées : une bibliographie annotée. Monographie ACIAR. 56, 316.
31. Taïbi K., Aït Abderrahim L., Ferhat K., Betta S., Taïbi F., Bouraada F., Boussaid M. (2020,2021). Ethnopharmacological study of natural products used for traditional cancer therapy in Algeria. *Saudi pharmaceutical journal. 28*(11), 1451–1465. https://doi.org/10.1016/j.jsps.2020.09.011
32. Manousaki, E., Kalogerakis, N. Phytoextraction du Pb et du Cd par l'*Atriplex halimus* L. (*Atriplex halimus* L.), (2009) : absorption des métaux en fonction de la salinité. *Environ. Sci. Pollut. Res.* 2009 , *16* , 844–854.
33. Han, R.M., Lefèvre, I., Albacete, A., Pérez-Alfocea, F., Barba-Espín, G., Diaz-Vivancos, P., Quinet, M., Ruan, C.J., Hernández, J.H., Cantero-Navarro, E., et al. (2012). Activités enzymatiques antioxydantes et statut hormonal en réponse au stress cadmium chez l'halophyte des zones humides *Kosteletzkya virginica* dans des conditions salines. *Physiol. Usine. 147*, 352–368.
34. Grigore, M.N., Ivanescu, L., Toma, C. (2014). Halophytes : une étude anatomique intégrative; Springer: New York, NY, États-Unis.
35. Ishtiyaq, S., Kumar, H., D'Souza, R.J., Varun, M., Favas, P.J.C., Paul, M.S. (2023). Réponses physiologiques et adaptations de l'halophyte *Atriplex halimus* à un sol contaminé par le Cd, le Ni et le NaCl. *Soil Systems* , *7*(2), 46. https://doi.org/10.3390/soilsystems7020046
36. Kahouadji, S., Boudghène Stambouli S., Benabadji N. (2021). Etude de la germination des graines de Petit pois (*Pisum arvense* L.P.F.) espèce cultivée soumise aux traitements salés de Chlorure de

sodium (NaCl) et de sulfate de potassium (K_2SO_4). *International Journal Water Sciences and Environment Technologies. VI*(1), April 2021, 30–39. jistee.org/volume-vi-2021

37. Adjel, F. (2017). *Analyse de la tolérance de l'orge (Hordeum vulgare L.) au stress salin*. Université Ferhat Abbas Sétif 1.96p.
38. Rokbane, A. (2023). *Epuration des Eaux Usées par Filtre Planté (Phytoépuration) et Réutilisation pour l'Irrigation.* Application à la Ville d'Ouled Djellal.thèse Doctorat. Université de BISKRA. ALGERIe.182P.
39. Rezkallah, C. (2017). Réhabilitation des sols salés du nord de Tebessa (Morsott-El Aouinet- Boukhadra) par la plantation des plantes halophytes du genre Atriplex (*A.halimus-A.nummularia*). Thèse Doctorat.Université de ANNABA.ALGERIe.219P.
40. Ali H.M., Ibrahim A., Hussain S. (2023). Physiological and biochemical adaptations of halophytes to salt and water stress: recent advances. *Plant Stress 7*, 100147. https://doi.org/10.1016/j.stress.2022.100147
41. Ahmad P., Ahanger M. A., AlYemeni M. N., Wijaya L., Alam P. (2024). Role of osmolytes and antioxidant systems in plant tolerance to salinity and drought stress. *Front. Plant Sci. 15*. https://doi.org/10.3389/fpls.2024.1189012
42. Nguyen N.D., Tran T.T., Le T.M. (2024). Phytoremediation of salt-affected soils using halophytes: potential and application in agriculture. *Sustainability 16*, 1914. https://doi.org/10.3390/su16041914
43. Chourasiya A., Pandey S., Tripathi R.D. (2024). Harnessing halophytes for phytoremediation and sustainable agriculture: current status and future prospects. *Environ. Res. 235*, 117203. https://doi.org/10.1016/j.envres.2024.117203