



(RESEARCH ARTICLE)



EMPLOYING *CYANOBACTERIA* SP. IN BIOREMEDIATION OF SALINE SOILS TO REDUCE WATER POLLUTION

Ameena G Abid, Iman H Gatea *, Qusay A Abdulameer, Adawia B Sabir and Ansam S Sabie

Scientific Research Commission, Baghdad, Iraq.

* Corresponding Authors: eman77aa@yahoo.com, alsudaniameenaghazi@yahoo.com

ORCID Details

Ameena G Abid: <https://orcid.org/0009-0008-1967-8382>

Iman H Gatea: <https://orcid.org/0000-0002-3855-5090>

Qusay A Abdulameer: <https://orcid.org/0009-0002-8600-7440>

Adawia B Sabir: <https://orcid.org/0009-0003-4958-2937>

Ansam S Sabie: <https://orcid.org/0009-0001-2773-2290>

GSC Advanced Research and Reviews, 2026, 29(01), 001–009

Publication history: Received on 22 August 2026; revised on 29 September 2026; accepted on 01 October 2026

Article DOI: <https://doi.org/10.30574/gscarr.2026.29.1.0249>

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

This study evaluated the influence of surface-applied wet algal biomass on key physicochemical properties of saline soil collected from the Abu Ghraib region of central Iraq. The algal mixture, a naturally occurring consortium obtained from a freshwater canal located within the University of Baghdad, was taxonomically identified as belonging to four major algal classes: *Bacillariophyceae*, *Chlorophyceae*, *Cyanophyceae*, and *Zygnemataceae*. These indigenous algae were applied to the soil surface to assess their capacity to modify salinity-related parameters through biological and physicochemical mechanisms. Temporal measurements of electrical conductivity (EC), total dissolved solids (TDS), NaCl percentage, and pH over 24, 48, 72, and 96 hours revealed distinct differences between the Control and algae-amended soils. The untreated Control showed a steady increase in EC, TDS, and NaCl%, indicating progressive dissolution and mobilization of inherent salts within the saline soil matrix. In contrast, soils treated with the algal mixture showed reductions in EC and TDS at most time points, reflecting decreased ionic strength and lower dissolved salt concentrations. NaCl% also declined at later intervals in algae-amended treatments, suggesting effective ion immobilization through biosorption, bioaccumulation, and organic matter interactions associated with the algal biomass. Soil pH remained relatively stable but exhibited slight alkalization in some treatments, consistent with the release of basic cations and the decomposition of algal organic matter. Collectively, these results demonstrate that indigenous freshwater algae possess significant potential for reducing salt mobility and modifying the chemical behavior of saline soils when applied to the soil surface. The findings underscore the value of native algal communities as sustainable, low-cost bioremediation agents for managing salinity in agricultural systems such as those in Abu Ghraib. Furthermore, the study highlights the necessity of employing multiple salinity indicators (EC, TDS, NaCl%, pH) to capture the complex suite of interactions governing soil algae salt dynamics.

Keywords: Algae; Saline Soil; Biosorption, Sustainable soil management

1 INTRODUCTION

Soil salinity is a major global issue owing to its adverse effect on agricultural productivity and sustainability. It also adversely affects plant growth and seed germination, besides influencing the biological activities of plants like respiration, photosynthesis, enzymatic activities, plant metabolism, hormone regulation, etc. (Nainwal *et al.*, 2024).

Nearly 6% of the world's land is affected by salinity. About 20% of irrigated agricultural land and 2.1% of dryland agriculture are exposed to different degrees of salinity (Nisha *et al.*, 2018). Salinity problems occur under all climatic conditions and can result from both natural and human-induced actions (Hardie and Doyle, 2012). The presence of essential dissolved inorganic solutes in the soil aqueous phase is called "Soil salinity". It consists of easily dissolvable and soluble salts, including charged types e.g., K^+ , Mg^{+2} , Ca^{+2} , Cl_2 , NO_2 , HCO_2 , Na^+ , CO_2 , and non-ionic solutes, besides ions that engage to form ion pairs" (Corwin, 2003) .

Many studies have examined the effect of soil salinity on plant yields and growth parameters, which could cause huge losses in plant productivity. Salt accumulation in soils without suitable vegetation can increase wind erosion and cause the surface sediments to form a sleazy texture. Transporting saline sediments with a high concentration of sodium chloride (NaCl) and other potentially fine-grained saline and toxic components could be dangerous for ecological and environmental security, the establishment of vegetation, and human health in arid and semi-arid regions (NainwalChaurasiyaKumarSinghSingh and Tewari, 2024).

Salinization is a more fascinating and vital issue facing world agriculture, particularly in semi-arid and arid regions, which significantly threatens agricultural productivity and sustainability. These salt-affected soils are found around the boundaries of more than 70 countries. These problematic soils also occupy around 20% of irrigated land globally, and in some countries, more than 50% of irrigated land suffers from soil salinization (NainwalChaurasiyaKumarSinghSingh and Tewari, 2024) .

Generally speaking, saline soils occur in arid and semi-arid regions where rainfall is insufficient to meet the water requirements of the crops and leach mineral salts out of the root zone (Zaman *et al.*, 2018). The causes of salinity accumulation in soil are either natural or due to human activities. Soil salinity affects plant growth by many mechanisms: (a) limitation of water uptake by the plant through lowering the osmotic potential of the soil solution, (b) lowering uptake of nutrients, and (c) providing some toxic ions such as chloride, sodium, and boron (Hardie and Doyle, 2012).

The high concentration of Na^+ in the soil may replace cations that are naturally present, such as Mn, K, and Zn; also, it could disperse the colloids of soil, decrease the permeability and aeration of soil, and increase attrition rate and surface runoff. At the same time, high concentrations of Cl^- raise the movement of heavy metals in the soil matrix (Łuczak *et al.*, 2021). This work aims to transform algal biomass from an environmental contaminant into a sustainable resource for saline soil remediation and soil fertility enhancement.

2 MATERIALS AND METHODS

2.1 Sample collection

Soil samples were collected from the Abu-Gareeb region, that experience of high levels of salinity, from different sites at 5 cm depth, then they were mixed well. Algae samples were collected from the Baghdad University channel that contains heavy growth of algae.

2.2 Diagnosis of algal biomass

Upon delivery to the laboratory, algal biomass samples were promptly subjected to microscopic analysis at the Water Research Department.

2.3 Preparing soil samples

Soil samples taken from different sites were mixed well, then distributed into five plastic containers (500 g of soil per container). The saturated soil-water was prepared by adding tap water to the air-dried soil. Then algal biomass was spread on the surface of the soil in the containers. In which the first container represented the control (no algal biomass added), and the remaining containers were supplied with different weights of algal biomass: 2, 10, 20, and 30g. The samples were wetted continuously with tap water for four days.

2.4 EC, TDS, NaCl% and pH measurement

The electrical conductivity (EC) and pH of soil were measured in soil saturated extracts using a pH meter. Soil samples were prepared at a ratio of 1:5 (1 g of soil to 5 mL of distilled water), in which samples were mixed well and incubated in a shaker incubator for one hour at 120rpm. After the incubation, samples were allowed to stand for one hour, then they were centrifuged for 10 minutes at 5000rpm. The supernatant was transferred to a test tube to be prepared for measuring EC, TDS, NaCl%, and pH .

3 RESULTS AND DISCUSSION

The algae used in this study were collected from a freshwater canal located within the University of Baghdad campus. The algal biomass, consisting of species belonging to *Bacillariophyceae*, *Chlorophyceae*, *Cyanophyceae*, and *Zygnemataceae*, was harvested manually using a fine mesh net and immediately transferred into clean plastic containers filled with canal water to preserve cell viability during transport. Upon arrival at the laboratory, the algae were rinsed gently with distilled water to remove debris and sediment, then homogenized into a uniform wet mixture suitable for application. Measured quantities of this wet algal mixture were subsequently applied to 500 g portions of saline soil placed in plastic containers. The algae were distributed evenly across the soil surface to ensure consistent exposure and interaction throughout the experimental period.

The soil used in the experiment was first air-dried and passed through a standard sieve to remove coarse materials and obtain a uniform texture. After sieving, 500-gram portions of the prepared soil were placed into clean plastic containers, which served as experimental units for all treatments. This controlled preparation ensured that each container received soil of identical physical characteristics, allowing any observed changes to be attributed directly to the applied algal treatments.

With the experimental system standardized, the discussion will now focus on interpreting the trends observed in EC, TDS, NaCl%, and pH, and on understanding the mechanisms through which the wet algal mixture influenced salt mobility, ion availability, and overall soil chemical behavior.

The microscopic examination of algal biomass reveals that *Cyanobacteria* sp. was the dominant species in the samples, as shown in Table (1).

Table 1: The diagnosis of algal biomass.

Periphytic algae		planktonic algae	
Class	Species	Class	Species
<i>Cyanophyceae</i>	<i>Anabeana fertilissimb</i>	<i>Cyanophyceae</i>	<i>Aphanocapsa pulchra</i>
	<i>Chroococcus dispersus</i>		<i>Chroococcus uarius</i>
	<i>Lyngbya aestuarii</i>		<i>Oscillatoria tenuis</i>
	<i>Oscillatoria tenuis</i>		<i>Merismopedia punetata</i>
	<i>O. sancata</i>	<i>Bacilariophyceae</i>	<i>Navicula humerosa</i>
	<i>O. princeps</i>		<i>Na. bryophils</i>
	<i>O. imosa</i>		<i>Cymbella turgida</i>
<i>Bacilariophyceae</i>	<i>Cyclotella comta</i>		<i>Tetrademu swisconsincse</i>
	<i>Navicula mutica</i>	<i>Chlorophyceae</i>	<i>Scenedesmus armatus</i>
	<i>Nav. radiosa</i>		<i>Tetradesmus wisconsincse</i>
	<i>Nitzschia inconspicuis</i>		
	<i>Nit.parvula</i>		
	<i>Oedogonium australi</i>		
<i>Chlophyceae</i>	<i>Enotia pectinalis</i>		
	<i>Pediastrum cinctum</i>		
	<i>Ped. Inregrum</i>		

	<i>Scenedesmus abundans</i>		
<i>Zygnemataceaea</i>	<i>Mougeotia abnormis</i>		
	<i>M. scilaris</i>		
	<i>Spirogyra stictica</i>		

In the Control treatment, EC increased steadily over time from 11.346 mS/cm at 24 hours to 23.49 mS/cm at 96 hours, indicating continuous dissolution of inherent salts present in the saline soil. Such upward trends are commonly observed in unmanaged saline soils, where prolonged contact with water promotes ion release into the soil solution (Hillel, 2004).

In contrast, soils amended with wet algae exhibited significantly lower EC values across all time intervals compared to the Control. This reduction was more pronounced at higher algae quantities (10 g, 20 g, and 30 g), demonstrating a dose-dependent mitigation effect. Wet algae contain polysaccharides, proteins, and negatively charged functional groups that facilitate the adsorption of cations such as Na^+ , Ca^{2+} , and Mg^{2+} . This process, known as biosorption, decreases ion mobility and reduces dissolved salt concentrations, thus lowering EC (Volesky, 2007).

A surface layer of moist organic matter may impede salt transport and restrict dissolution. Subsequent decomposition of algal biomass contributes further organic inputs, which improve ion binding capacity and strengthen soil structure (Wong et al., 2010). Although slight increases in EC were observed in algae treatments at 72–96 hours, these values remained far below those of the Control, confirming the persistent salinity-reducing effect of wet algae.

Figure 1 demonstrates that the surface application of wet algae mixture effectively reduces EC by immobilizing ions and suppressing salt release in saline soil. These results highlight the potential of algae-based amendments as environmentally friendly tools for mitigating soil salinity in agricultural systems (Rao et al., 2007).

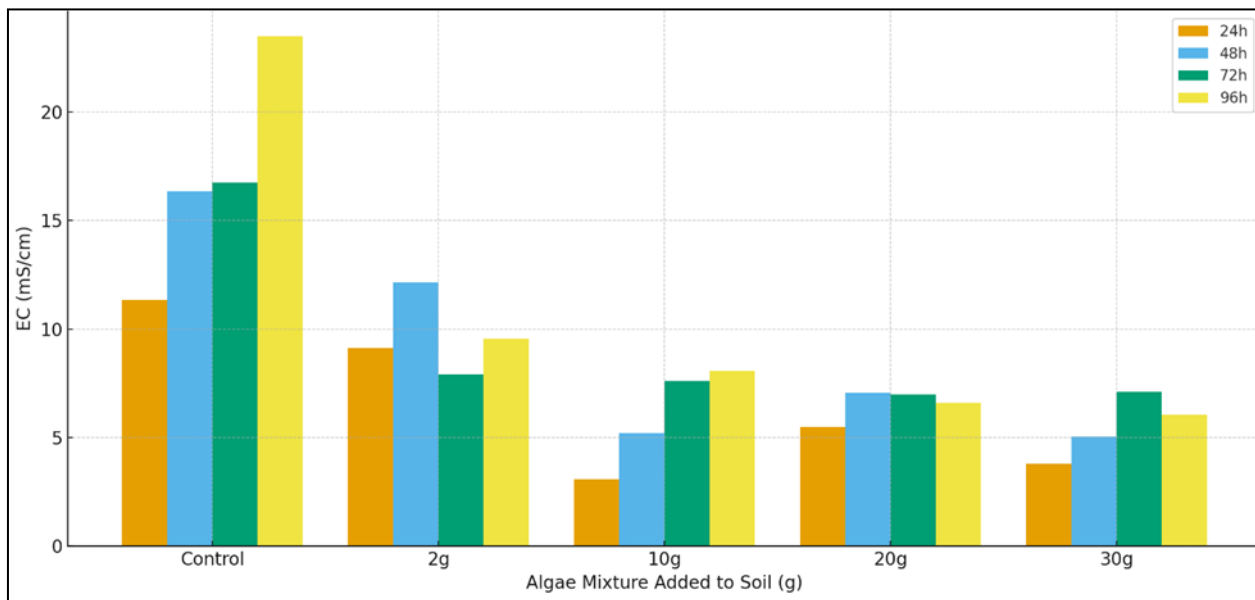


Figure 1: Electrical Conductivity (EC) Response to Different Levels of Wet Algae Mixture Applied on Saline Soil Surface Across Time Intervals

The results show a clear reduction in TDS values in saline soil following the surface application of wet algae mixture, compared with the untreated Control. While the Control exhibited a steady increase in TDS from 5.724 g/L at 24 hours to 11.79 g/L at 96 hours, reflecting continuous dissolution of native salts, the algae-amended treatments demonstrated markedly lower TDS levels across all time intervals, as shown in Figure 2. This indicates that the addition of wet algae significantly reduces the number of dissolved salts in the soil solution. The strong decrease in TDS observed in the 10 g, 20 g, and 30 g treatments, particularly at 72 hours (where TDS values approached ~1.4 g/L), suggests high salt-binding capacity of the algae biomass. Wet algae contain organic compounds, functional groups, and cell walls capable of adsorbing cations and anions from saline soil, a mechanism widely recognized in the literature as *biosorption* (Volesky, 2007).

As these ions bind to algae surfaces, fewer salts remain dissolved in the soil solution, thereby lowering TDS. Additionally, the organic matter released from wet algae can enhance soil structure and increase the adsorption capacity of the soil matrix, further reducing salt mobility (Wong *et al.*, 2010). Over time, microbial activity decomposes the algae, producing organic acids and colloidal materials that promote ion immobilization. This may explain why TDS values remained suppressed throughout the 96 hours, even as the Control continued to show rising salt concentrations. The nonlinear behavior of TDS, especially the sharp drop at 72 hours, may be associated with biological uptake by algal cells, which actively absorb Na^+ , Cl^- , and other ions when hydrated. Such physiological processes are well documented in living algae exposed to saline environments (Rao *et al.*, 2007).

Furthermore, the reduction in TDS with increasing algae quantity (from 2 g to 30 g) demonstrates a dose-dependent effect, consistent with biosorption models where adsorption capacity increases with adsorbent mass. Overall, the results clearly indicate that surface-applied wet algae are effective in reducing dissolved salts in saline soils by combining physical adsorption, biological uptake, and organic matter enhancement. This highlights their potential as a sustainable amendment for mitigating salinity in agriculture.

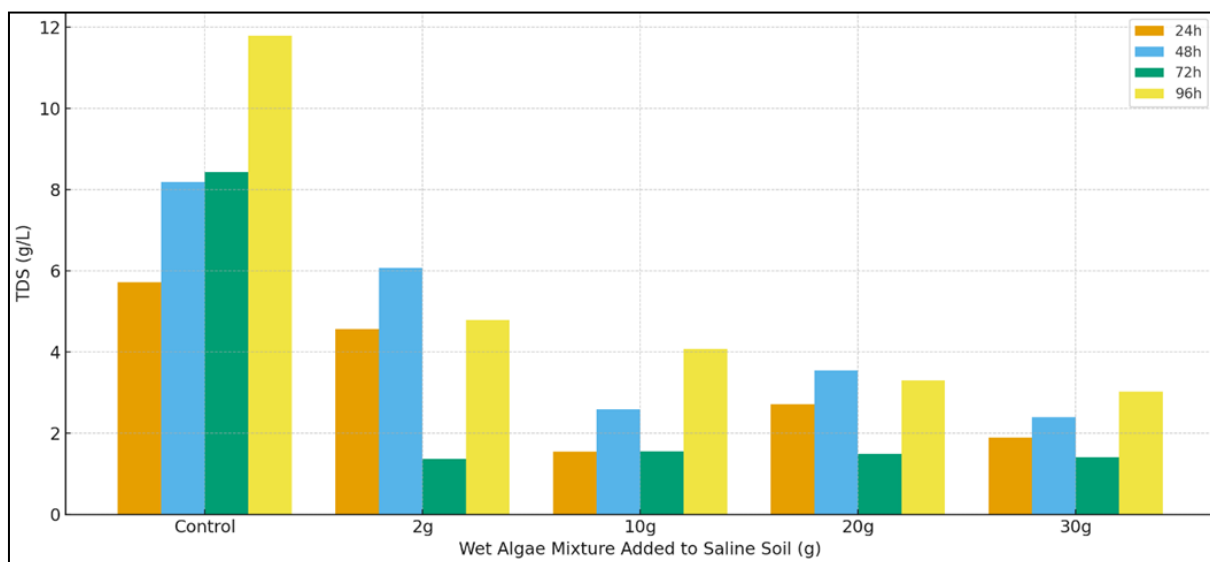


Figure 2: Variation in Soil TDS Across Time After Adding Different

The NaCl% results demonstrate that the surface application of wet algae mixture alters the temporal distribution of salt ions within saline soil. In the control treatment, NaCl% increased from 24 to 72 hours, indicating a progressive release of native salts into the soil solution, followed by a sharp decline at 96 hours. This pattern suggests initial salt mobilization followed by leaching, ion redistribution, or partial adsorption onto soil colloids (TANJI and WALLENDER, 2012). In the algae-amended treatments (2g, 10g, 20g, 30g), NaCl% also generally increased during the early stages, reaching peak values at 72 hours. This rise reflects the temporary liberation of salts into the soil solution following hydration. However, the subsequent decline at 96 hours indicates that the algae mixture contributed to reducing the concentration of free NaCl. Wet algae are known to possess functional groups that bind ions ($-\text{COOH}$, $-\text{OH}$, $-\text{SO}_4$), enabling both adsorption and biological uptake of Na^+ and Cl^- ions (VOLESKY, 2007; WONG *et al.*, 2010). These mechanisms decrease the availability of free salt in solution.

The magnitude of NaCl% reduction at 96 hours was dose-dependent: higher algae quantities resulted in lower NaCl% values, as shown in Figure 3. This trend indicates enhanced biosorption capacity with increasing biomass, consistent with established sorption models and biological ion-uptake behavior in algae (RAO *et al.*, 2007). The algae likely improved soil structure and increased organic matter, promoting further immobilization of salts through enhanced cation exchange and aggregation processes.

Compared with EC and TDS patterns observed in previous figures, NaCl% exhibited similar long-term declines, confirming that wet algae reduce overall salt availability in saline soil. However, NaCl% showed more pronounced fluctuations across time, reflecting the high mobility of Na^+ and Cl^- ions. These ions respond rapidly to moisture changes, algal activity, and surface interactions, which explains the sharp peak at 72 hours followed by stabilization at 96 hours.

Collectively, the NaCl% results indicate that wet algae applied to the soil surface act as an effective amendment for moderating salt concentrations in saline soils. The combined effects of biosorption, bioaccumulation, and organic-matter enrichment contribute to lowering salt levels and improving soil chemical balance.

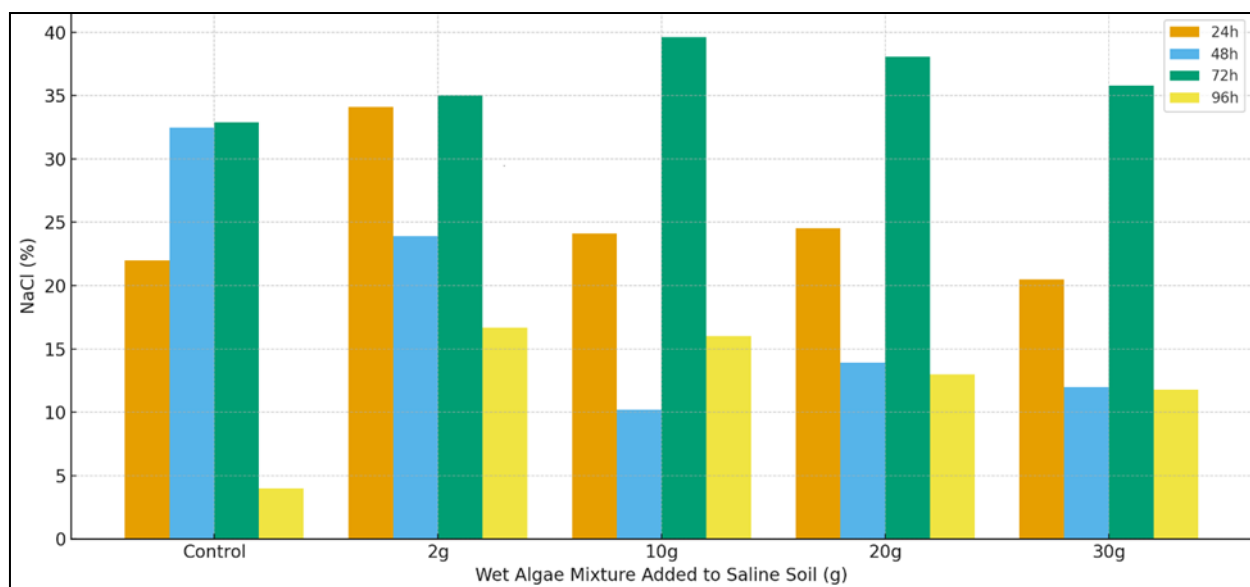


Figure 3: Effect of Surface-Applied Wet Algae Mixture on NaCl% in Saline Soil Over Time.

The combined behavior of NaCl%, EC, and TDS provides an integrated understanding of how the wet algae mixture influences salt dynamics in saline soil. While all three parameters reflect salinity, each responds differently over time due to distinct chemical and biological processes occurring at the soil surface.

EC showed a consistent reduction in algae-amended treatments relative to the Control, indicating decreased ionic strength in the soil solution. This aligns with known effects of organic amendments and algae biomass, which immobilize ions and reduce electrical conductivity through adsorption and enhanced soil aggregation (Wong et al., 2010). Similarly, TDS decreased markedly in algae-treated samples, particularly at 72 hours, reflecting the adsorption and biological uptake of dissolved salts by algae cells, as well as reduced dissolution of soil minerals (Volesky, 2007).

NaCl%, however, displayed a different temporal pattern. Instead of a steady decline, NaCl% increased initially and peaked at 72 hours before decreasing at 96 hours across all treatments. This suggests that Na^+ and Cl^- ions are more mobile and may temporarily accumulate in the soil solution before being adsorbed, metabolized, or redistributed. The later decline indicates the onset of ion immobilization by algae, consistent with documented biosorption and bioaccumulation mechanisms in wet algae (Rao et al., 2007).

A comparison across parameters shows that EC and TDS respond more immediately to the presence of wet algae by decreasing steadily, while NaCl% reflects a more dynamic process influenced by the early dissolution of salts and their subsequent biological or chemical sequestration. This difference underscores the unique behavior of individual ions compared with total ionic strength and total dissolved solids (Tanji and Wallender, 2012).

Overall, the synchronized decline in EC, TDS, and NaCl% at later time intervals confirms that wet algae application effectively mitigates salinity through multiple pathways: ion adsorption, organic matter enrichment, microbial activity, and improved soil structure. These results highlight the natural potential of wet algae as a low-cost, environmentally sustainable amendment for managing saline soils.

Figure 4 illustrates how soil pH responds to the surface application of different quantities of wet algae mixture over a period of 24 to 96 hours. The Control treatment shows relatively stable pH values ranging from 7.30 to 7.53, which is characteristic of saline soils that naturally possess strong buffering capacity due to the presence of carbonates, bicarbonates, and clay minerals (Sparks, 2003).

In contrast, soils amended with wet algae display a gradual increase in pH over time, particularly between 48 and 96 hours, where values rise to approximately 7.9–8.02 in most treatments. This increase can be attributed to several mechanisms associated with algal biomass. Wet algae contain alkaline compounds, including amino groups and mineral ions, which can be released into the soil solution during decomposition. These materials contribute to the displacement of hydrogen ions (H^+) from soil exchange sites, resulting in a measurable rise in pH (Rao et al., 2007). Additionally, the organic matter provided by the algae enhances microbial activity, accelerating the breakdown of algal tissues. Microbial decomposition is known to generate organic ligands that interact with soil minerals, increasing cation exchange and contributing to shifts toward alkalinity. This process aligns with findings that organic amendments often promote increases in soil pH by releasing basic cations such as Ca^{2+} , Mg^{2+} , and Na^+ (Wong et al., 2010). The slight decline in pH

observed in the 30 g treatment at 96 hours may reflect localized microbial acidification or enhanced ion uptake by algae in higher biomass applications. Nevertheless, the overall trend across treatments indicates that wet algae tend to increase soil alkalinity in saline soil. When considered alongside EC, TDS, and NaCl% results, the pH response suggests that algae not only reduce salt mobility but also modulate the chemical environment of the soil solution. The combined reduction in dissolved salts and increase in pH demonstrates the multifaceted role of algae in altering saline soil properties, supporting their potential use as a sustainable soil amendment.

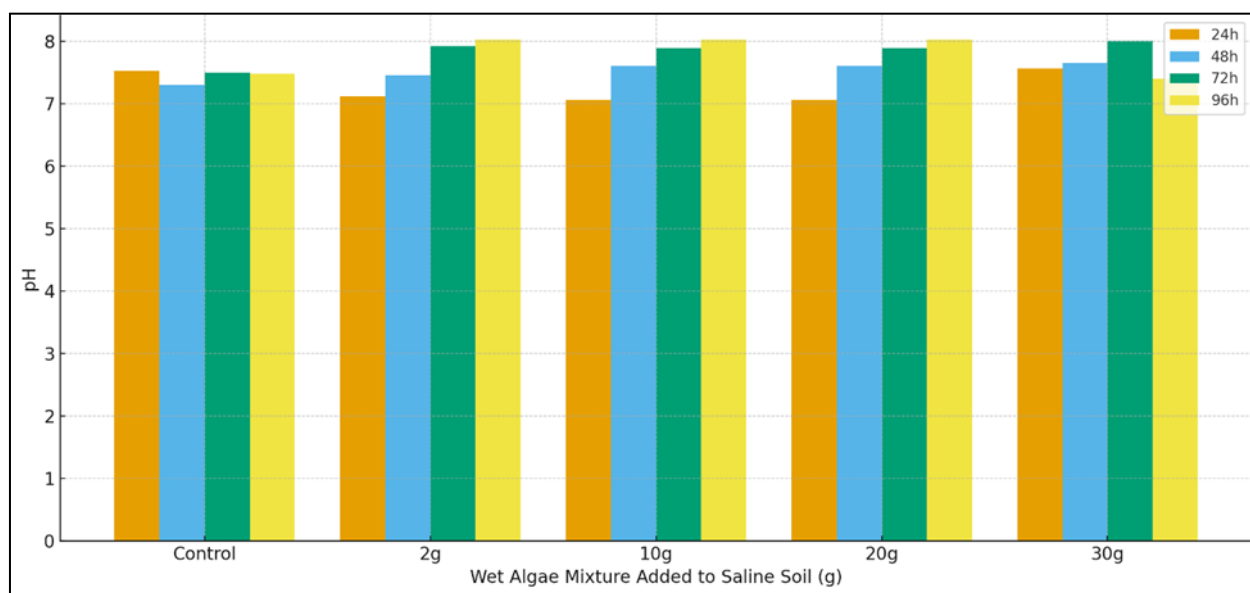


Figure 4: Soil pH Response to Increasing Levels of Wet Algae Mixture Across Time Intervals.

Results of EC, TDS, NaCl%, and pH indicate that the surface application of wet algae mixture effectively improves saline soil properties through multiple interacting mechanisms. EC and TDS declined consistently across all algae treatments compared with the Control, showing reduced ionic strength and lower concentrations of dissolved salts. This reduction is attributed to ion adsorption and biological uptake by the algae biomass.

NaCl% exhibited an initial increase followed by a clear decline at 96 hours, suggesting early salt mobilization before ions were immobilized through biosorption and organic matter interactions. Higher algae quantities produced stronger reductions, confirming a dose-dependent effect. Soil pH increased slightly in most algae treatments, reflecting the release of basic cations and enhanced microbial activity during algae decomposition. In contrast, the Control maintained stable pH, consistent with the buffering nature of saline soils. The integrated assessment of the four parameters reveals that wet algal biomass reduces salinity and modifies soil chemical characteristics, highlighting its suitability as a sustainable strategy for ameliorating saline soils. Figure 5 illustrates the natural temporal behavior of EC, TDS, NaCl%, and pH in untreated saline soil from 0 to 96 hours. The results reflect the intrinsic chemical dynamics of saline soil in the absence of any amendments. Electrical conductivity (EC) increased steadily from 8.240 mS/cm at zero time to 23.49 mS/cm at 96 hours, indicating continuous dissolution of soluble salts into the soil solution. This trend is typical of saline soils where water mobilizes stored salts from soil aggregates and pore spaces over time (Hillel, 2004).

A similar pattern is observed for TDS, which increased from 4.121 g/L at zero time to 11.79 g/L at 96 hours. The parallel rise of EC and TDS confirms the strong relationship between ionic concentration and dissolved solids in saline soils. As more ions enter the soil solution, both parameters increase proportionally, reflecting progressive salt release and a shift toward higher salinity levels (Tanji and Wallender, 2012).

NaCl concentration exhibited a pronounced temporal increase, rising from 16.1% to 46.1% within 96 hours. This substantial elevation reflects the high mobility of sodium and chloride ions in saline soils and their propensity to accumulate in the soil solution in the absence of amendments capable of immobilizing or buffering them. The observed rise in NaCl% parallels the trends in electrical conductivity (EC) and total dissolved solids (TDS), indicating that sodium chloride is a principal contributor to the salinity profile of the control soil.

In contrast, soil pH remained relatively stable, fluctuating only slightly between 7.30 and 8.01 throughout the 96 hours. This stability reflects the strong buffering capacity of saline and alkaline soils, which often contain carbonate and bicarbonate ions capable of resisting changes in hydrogen ion concentration. The minimal shift in pH despite substantial changes in salinity indicates that the soil's mineral composition and buffering systems remained intact and were not significantly altered during the measurement period (Sparks, 2003).

Untreated saline soils naturally accumulate salts over time without significant pH variation, establishing a baseline against which the ameliorative effects of algal amendments on soil chemistry can be assessed. This baseline response provides a critical reference for evaluating the efficacy of algal amendments in modulating salt dynamics, ion mobility, and soil chemical equilibrium, thereby underscoring their potential role in sustainable soil management.

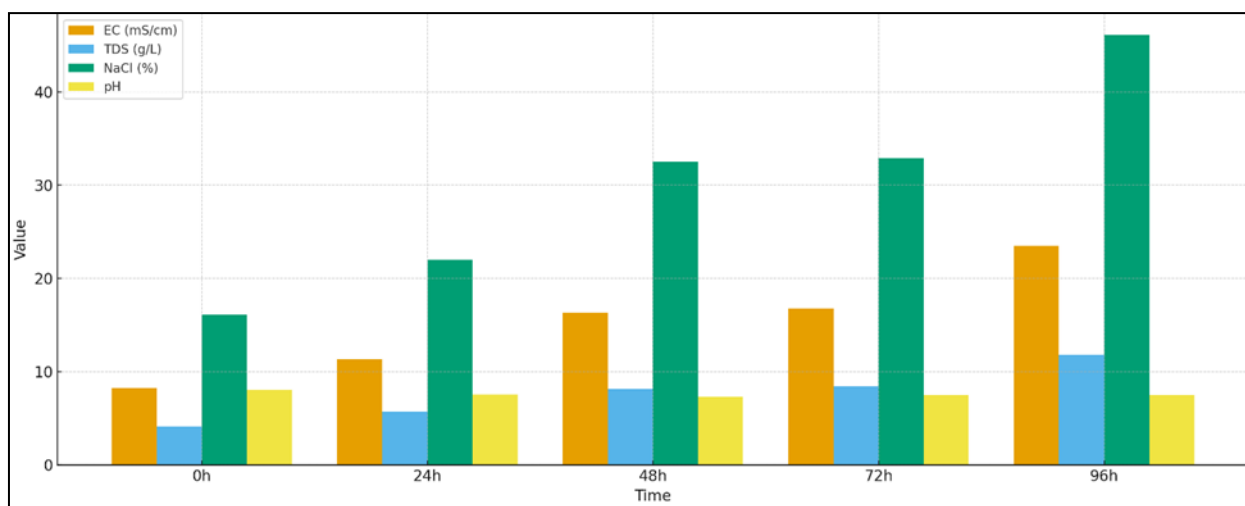


Figure 5: Variation in Soil EC, TDS, NaCl%, and pH Across Five Time Points in the Control Treatment

4 CONCLUSION

The application of a mixed community of wet algae (*Bacillariophyceae*, *Chlorophyceae*, *Cyanophyceae*, and *Zygnemataceae*) markedly reduced salinity in soils from Abu Ghraib. In contrast to the untreated control, which exhibited continuous increases in EC, TDS, and NaCl% due to salt dissolution and mobilization, algae-amended soils consistently showed lower values, attributable to biosorption, bioaccumulation, ion immobilization, and organic matter inputs. Soil pH remained stable in the control but increased slightly under algal treatments, reflecting mild alkalinization from decomposition and cation release. These findings demonstrate that native wet algae can improve the chemical environment of saline soils and reduce salt mobility within short timeframes, highlighting their potential as an eco-friendly, low-cost bioremediation strategy for agricultural systems.

Recommendations

Future research should further investigate the use of locally sourced wet algae as sustainable amendments for saline soils, particularly in contexts where chemical treatments are impractical or environmentally detrimental. Extended monitoring beyond 96 hours and field-scale trials in Abu Ghraib and comparable regions are required to validate laboratory findings under agricultural conditions. Optimization of application rates, comparative studies with other organic amendments (e.g., compost, manure, biochar), and assessments of microbial and plant interactions are recommended to refine efficacy. Moreover, expanding taxonomic screening to additional freshwater algal species may identify candidates with superior salt adsorption and soil improvement potential.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

The authors gratefully acknowledge the **Center for Environmental and Water Technology** for providing laboratory facilities and technical support. Appreciation is also extended to the field teams for their assistance in soil sampling and analytical measurements.

Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

REFERENCES

- [1] Corwin, D. L. (2003). Soil salinity measurement. In B. A. Stewart and T. Howell (Eds.), *Encyclopedia of water science* (pp. 852–860). Marcel Dekker. <https://doi.org/10.1081/E-EWS-120010191>.
- [2] Hardie, M., and Doyle, R. (2012). Measuring soil salinity. In S. Shabala and T. A. Cuin (Eds.), *Plant salt tolerance: Methods and protocols* (pp. 415–425). Springer https://doi.org/10.1007/978-1-61779-986-0_28
- [3] Hillel, D. (2004). *Introduction to environmental soil physics*. Academic Press. <https://doi.org/10.1016/B978-0-12-348655-4.X5000-7>.
- [4] Łuczak, K., Czerniawska-Kusza, I., Rosik-Dulewska, C., and Kusza, G. (2021). Effect of NaCl road salt on the ionic composition of soils and *Aesculus hippocastanum* L. foliage and leaf damage intensity. *Scientific Reports*, 11, 5309. <https://doi.org/10.1038/s41598-021-84541-x>.
- [5] Nainwal, R. C., Chaurasiya, P., Kumar, A., Singh, M., Singh, D., and Tewari, S. K. (2024). Phytoremediation: A sustainable approach to combat soil salinity. *Advances in Environmental and Engineering Research*, 5(2), 1–16. <https://doi.org/10.21926/aeer.2402015>.
- [6] Nisha, R., Kiran, B., Kaushik, A., and Kaushik, C. (2018). Bioremediation of salt affected soils using cyanobacteria in terms of physical structure, nutrient status, and microbial activity. *International Journal of Environmental Science and Technology*, 15(3), 571–580. <https://doi.org/10.1007/s13762-017-1419-7>.
- [7] Rao, C. S., Rao, P. R., and Reddy, R. (2007). Bioremediation of saline soils using algae. *Journal of Environmental Biology*, 28(4), 879–882.
- [8] Singh, V., and Singh, D. (2015). Cyanobacteria modulated changes and their impact on bioremediation of saline-alkaline soils. *Bangladesh Journal of Botany*, 44(4), 653–658. <https://doi.org/10.3329/bjb.v44i4.38646>.
- [9] Sparks, D. L. (2003). *Environmental soil chemistry* (2nd ed.). Academic Press. <https://doi.org/10.1016/B978-012656446-4/50001-3>.
- [10] Tanji, K. K., and Wallender, W. W. (2012). *Agricultural salinity assessment and management* (2nd ed.). American Society of Civil Engineers. <https://doi.org/10.1061/9780784411698>.
- [11] Volesky, B. (2007). Biosorption and me. *Water Research*, 41(18), 4017–4029. <https://doi.org/10.1016/j.watres.2007.05.062>.
- [12] Wong, J. W., Selvam, A., and Chen, G. (2010). Influence of organic amendments on soil structure and ion adsorption. *Bioresource Technology*, 101(23), 8788–8794. <https://doi.org/10.1016/j.biortech.2010.06.051>.
- [13] Zaman, M., Shahid, S. A., and Heng, L. (2018). *Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques*. Springer. <https://doi.org/10.1007/978-3-319-96190-3>.