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Integrated Approaches to Land Rehabilitation and Sustainable Fuel Development under Environmental Stress Conditions

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Abstract

Environmental degradation from soil salinization and pollution remains a major global challenge, particularly in Iraq. This study investigates two approaches to address these issues. First, the biochemical performance of Tamarix spp., a halophytic shrub, was assessed in the highly saline soils of Al-Najaf District. Although Tamarix spp. is adapted to saline environments through specialized salt-excreting glands, findings revealed that extreme salinity levels led to excessive salt accumulation within plant tissues, suggesting a potential limitation of its physiological resilience. Secondly, in response to increasing plastic waste and used oil pollution, the study examined a sustainable fuel alternative by blending plastic-derived fuel (PDF) with waste engine oil (WEO). Through pyrolysis and subsequent blending, the resulting fuel demonstrated improved combustion efficiency and reduced emissions, offering a promising solution for energy recovery and pollution mitigation. The investigations highlight the integrated importance strategies for ecological restoration and the sustainable energy resources development.

Keywords:

Plants, chemical profiling, salinity, ionic buildup, ecological, soil.

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Introduction

Soil saltness is a serious environmental miracle that affects food security and the sustainability of ecosystems, especially in thirsty andsemi-arid regions similar as Iraq (Huang & Leu, 2011). It estimated that further than 30 of agrarian land in Iraq is affected by varying degrees of salinization, leading to dropped soil fertility, deterioration of foliage cover, and reduced agrarian productivity (Alexander et al., 2012). Soil salinization has multiple causes, including the use of poor- quality irrigation water, high groundwater situations, poor agrarian drainage, and harsh climatic conditions similar as high temperatures and evaporation rates (Sredić et al., 2024; Long et al., 2021). All of these factors lead to the accumulation of answerable mariners in the face layers of the soil, creating bibulous pressure that prevents shops from naturally absorbing water and nutrients (Bush et al., 2021; Rao & Menon, 2024). These challenges have contributed to the trend toward the use of shops acclimated to saline conditions, known as halophytes. These shops retain physiological mechanisms that enable them to grow in surroundings with high swab attention, whether in the soil or water (Khatiri et al., 2019). Among these shops, Tamarix spp., which is wide in comeuppance, strands, and wetlands, is used in soil stabilization and desertification control systems (FAO, 1999). The tamarisk factory is characterized by its swab glands on its leaves, which cache redundant mariners outside the apkins, helping to maintain the balance of water and ions within the cells. still, recent studies indicate that the effectiveness of this medium gradationally declines when swab attention exceed a certain limit (Alattabi et al., 2023; Zor & Rahman, 2025). This leads to the accumulation of mariners within the apkins, thereby dismembering the ionic balance and bibulous pressure, affecting the factory's vital processes (Almudhafar, 2020). Consequently, the environmental conditions in Iraq — particularly in areas similar as the center of Najaf District — bear a careful assessment of this factory's capability to acclimatize to high saltness(Min et al., 2025).This study aims to dissect the chemical parcels of tamarisk factory apkins in the field and laboratory, link the results to transnational norms, and give precise scientific recommendations regarding this factory's capability to reclaim the terrain in largely saline surroundings (Long et al., 2021; Kadhim et al., 2023).

Research Problem

Although the Tamarix spp. is classified as a halophyte, tolerant of harsh environmental conditions, the inflexibility of saltness in some areas may exceed the factory's physiological capabilities, dismembering its internal balance mechanisms. Grounded on this, the exploration question is:

Is the Tamarix spp. able to maintain its vital and adaptive functions under the pressure of high salinity in the soil of the Najaf district center?

Research Hypothesis

The study assumes that the Tamarix spp. has the physiological ability to adapt to high salt concentrations through the mechanism of salt glands that secrete excess salts outside the tissues, thus maintaining its internal balance, albeit within a certain limit.

Research Objectives

This study aims to:

- Assess the capacity of *Tamarix spp.* to survive and function under highly saline conditions.
- Determine the concentrations of key chemical elements in the plant tissues.

- Compare the measured values with international standards for halophyte plants.
- Evaluate the ecological viability of *Tamarix spp.* as a sustainable vegetation solution in highly saline areas.
- Propose scientific recommendations regarding its application in reclamation and ecological projects.

Study Area

The study area is located in the center of Najaf District, one of the districts of Najaf Governorate, located in the southern part of Iraq, specifically between latitudes 32°28′ and 33°48′ north, and longitudes 43°28′ and 44°48′ east (Fig. 1). The region is characterized by its arid and semi-arid nature, affected by a desert climate characterized by high temperatures in the summer and low annual rainfall, which does not exceed 120 mm on average (Almudhafar&Alattabi,2019). The center of Najaf District is bordered to the north by Al-Haidariya District, to the south by Al-Shabaka District, to the east by Kufa District, to the southeast by Al-Manathira District, and to the west by the administrative borders of Karbala Governorate (Long et al., 2017). This region is one of the most affected areas in Iraq by salinity, due to the high level of highly saline groundwater, poor irrigation water management, and the absence of modern agricultural drainage systems (Almudhafar & Abboud, 2018b, Almudhafar, 2018a).

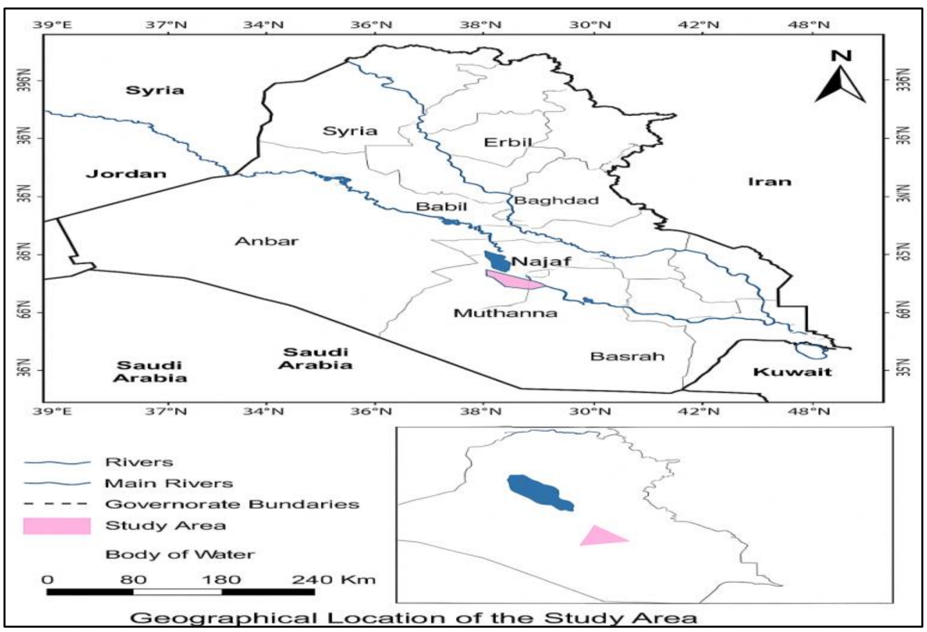

Figure 1. Administrative boundaries of al-najaf district and sampling sites

Figure 2 illustrates the administrative divisions of Al-Najaf district and highlights the three sampling sites selected for this study:

- **Site A**: Near a shallow well with high EC levels,
- **Site B**: A seasonal saltwater accumulation area.
- **Site C**: A naturally salinized dry zone with surface salt crusts.

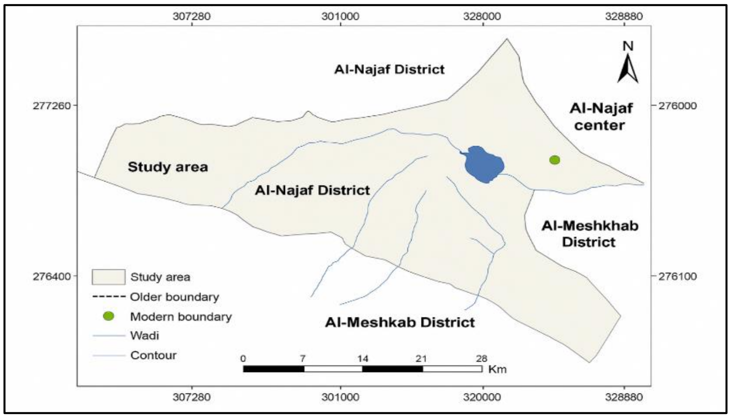

Figure 2. Administrative boundaries of al-najaf district and sampling sites

Figure 2 also indicates water sources, land use types, and key environmental features related to salinization stress.

Geographic and Environmental Context of the Study Area

The exploration was conducted in Al- Najaf District, located in the central region of Iraq within Al- Najaf Governorate. The quarter spans authorizations 32 ° 28 ′ – 33 ° 48 ′ N and longitudes 43 ° 28 ′ – 44 ° 48 ′ E. This area is oppressively impacted by soil and water saltness, primarily due to environmental factors similar as low periodic downfall (lower than 150 mm), high evaporation rates (lesser than 2200 mm/ time), shallow groundwater, and hamstrung agrarian drainage systems. These factors lead to the accumulation of salts in the soil, resulting in vegetation degradation. The soils in the region range from clay loam to silty loam, with high electrical conductivity and visible salt crusts. These conditions make the area an ideal location for studying the salt tolerance of halophytic species like Tamarix spp.

Materials and Methods

Field Design and Sampling Protocol

The fieldwork was conducted in August 2018 during the peak of summer. A semi-experimental field design was adopted to assess the performance of Tamarix spp. under natural salinity stress. Three sampling locations were selected based on preliminary EC readings and visible salt impact:

- **Site A**: Located near a shallow groundwater well with EC ~24 dS/m.
- **Site B**: A lowland area where saline seasonal water accumulates.
- **Site C**: A dry zone with self-salinizing soil and a visible white salt crust.

In each location, five mature Tamarix shrubs (2–3 years old) were randomly selected. From each plant, two samples (leaves and upper stems) were collected using sterile gloves and tools. Each sample was labeled based on its site and plant code (e.g., A1, B2, C3) and stored in ventilated paper bags inside a thermally insulated container for transport to the laboratory within four hours (Figure. 3).

Figure 3. Tamarix spp. growing near saline water in the study area

Sample Preparation and Laboratory Procedures

Preliminary Handling

- Samples were washed three times using double-distilled water to remove surface dust and salts.
- They were oven-dried at 70°C for 72 hours until constant weight was reached.
- Dried materials were ground into fine powder using a stainless-steel grinder (IKA M20) and passed through a 0.5 mm sieve.
- Ground samples were stored in sealed amber glass jars in a cool, dry environment until chemical analysis.

Analytical Methods and Equipment

All analyses were performed at the Soil and Water Science Laboratory, Faculty of Agriculture, University of Kufa, using the following standard methods:

Parameter	**Analytical Method**	**Instrument Used**	**Reference**
EC	1:5 extract (W/V)	HANNA EC Meter – Model HI98331	FAO (1999)
TDS	Calculated from EC × 640	Derived formula	Ryan & Estefan (2003)
Na^+, K^+	Flame photometry	Sherwood Flame Photometer – Model 410	ICARDA Manual
Ca^{2+}, Mg^{2+}	EDTA complexometric titration	Manual volumetric analysis	AOAC (2000)
Cl^-	Argentometric titration ($AgNO_3$ method)	Glass titration flask + potassium chromate	Jackson (1958)
SO_4^{2-}	Spectrophotometry at 420 nm	Shimadzu UV-Vis Spectrophotometer	Allen et al. (1986)

Each measurement was performed in triplicate (n = 3) to ensure reliability and statistical consistency. Mean values and standard deviations were recorded for each ion.

Quality Control and Standardization

- Standard Reference Materials (SRMs) were used for calibration and verification.
- Blank samples were analyzed to account for potential contamination.
- 10% of all samples were randomly re-analyzed to validate accuracy.

- Data were organized and processed using Microsoft Excel and SPSS software for further statistical analysis.

Benchmarking and Literature Comparison

Results were benchmarked against:

- FAO (1999) guidelines for irrigation water quality and plant tolerance levels.
- Ryan & Estefan (2003) ICARDA Soil and Plant Analysis Manual.
- Marschner (2012), Mineral Nutrition of Higher Plants.
- Peer-reviewed studies on ion toxicity and halophyte physiology (e.g., Munns & Tester, 2008; Blumwald, 2000).

Figure 4. Close-up image of Tamarix spp. shrub showing dense green foliage

Results and Discussion

Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

The electrical conductivity (EC) of Tamarix spp. tissue reached 35.8 dS/m, significantly surpassing the international threshold of 22 dS/m (FAO, 1999). This indicates a high osmotic pressure within plant tissues, which may disrupt water absorption and hinder internal physiological processes. The elevated EC reflects the intensity of salt stress the plant is exposed to, potentially leading to reduced metabolic activity and impaired enzyme function (Parida & Das, 2005). Similarly, total dissolved solids (TDS) reached 3150.4 ppm, well above the acceptable limit of 2000 ppm. Such concentrations result in a hyperosmotic environment around root cells, challenging the plant's ability to maintain water balance and increasing the energetic cost of maintaining ion homeostasis (Munns & Tester, 2008).

Sodium (Na^+)

The sodium concentration measured was 1145.6 ppm, exceeding the recommended range of 20–200 ppm. High sodium levels are known to disrupt membrane integrity, leading to leakage of cellular contents and inhibition of vital processes such as potassium uptake (Blumwald, 2000). Excessive Na^+ accumulation can lead to physiological drought conditions despite the presence of moisture in the soil.

Calcium (Ca^{2+})

Calcium levels in the tissues were **1296 ppm**, compared to the standard value of **400 ppm**. Although calcium is essential for cell wall stability and enzyme regulation, excessive amounts can cause nutrient antagonism, particularly reducing the availability and uptake of magnesium, iron, and phosphorus (Marschner, 2012). This may result in metabolic imbalances that affect overall plant performance.

Magnesium (Mg^{2+})

The magnesium concentration was 7776 ppm, whereas the acceptable range is 15–150 ppm, indicating toxic accumulation. Magnesium is vital for chlorophyll structure and ATP utilization, but at toxic levels, it interferes with photosynthetic electron transport and may result in oxidative stress (Epstein & Bloom, 2005). This further compromises plant growth under salinity stress.

Potassium (K^{+})

Potassium levels reached 13962 ppm, which is abnormally high compared to the optimal range of 100–150 ppm. Although potassium helps regulate stomatal function and enzyme activation, its overaccumulation often indicates a compensatory response to sodium toxicity. However, this response may not be beneficial at such extreme levels, potentially disrupting ionic equilibrium and protein synthesis (Marschner, 2012).

Chloride (Cl^{-})

Chloride concentration was recorded at 11340 ppm, whereas the safe threshold is 300 ppm. Elevated chloride levels are associated with leaf margin burn, chlorosis, and inhibited nitrate uptake, affecting nitrogen assimilation and amino acid production (Blumwald, 2000). This level suggests that the plant is suffering from chloride-induced toxicity.

Sulfate (SO_4^{2-})

Sulfate reached 935.6 ppm, surpassing the recommended limit of 200 ppm. High sulfate concentrations may lead to the formation of insoluble salts within tissues and interfere with nitrogen metabolism, resulting in reduced protein biosynthesis and palatability issues for grazing animals (Zahran & Willis, 2009).

Field and laboratory data indicate that the tamarisk plant in the center of Najaf District is operating under high environmental pressures that exceed the capacity of its physiological mechanisms to adapt. Although this plant has active salt glands, the levels of accumulation measured indicate that these glands have reached a stage of stress or functional decline. Therefore, the plant's survival in this environment requires environmental interventions to improve soil quality and reduce salinity, or its use within a mixed plant system with more tolerant species(17)(18).

Conclusions

The study reveals that Tamarix spp. exhibits a remarkable yet limited capability to acclimatize to the largely saline soils of Najaf, Iraq. While the factory survives in extreme conditions (electrical conductivity> 35 dS/m), its physiological functions are significantly strained. Chemical analysis indicates that swab glands, responsible for expelling redundant mariners, come overwhelmed, leading to poisonous accumulations of sodium, chloride, and magnesium. These provide outward signs of stress, as splint yellowing, stunted growth, and decreased photosynthetic efficiency. Over time, the factory’s survival is threatened unless mitigation measures, such as better drainage or soil desalination, are enforced. Also, the high swab content makes Tamarix spp. infelicitous as a beast probe, posing implicit health pitfalls to creatures. These results highlight the vulnerability of factories in the fight against environmental stress and adaptation balance and require additional measures to ensure lifespan under salty conditions.

Future Recommendations

Ameliorate machine oil painting sanctification processes to remove contaminations and heavy essence, which will enhance energy stability and reduce the sharp goods on combustion systems. Conduct detailed profitable feasibility studies to assess product costs, environmental impact, and fiscal returns compared to conventional energies. probe the use of chemical complements that can reduce nitrogen oxide emigrations without negatively affecting thermal effectiveness. Support environmental programs that encourage the use of waste-deduced indispensable energies by furnishing clear impulses and regulations for manufacturers and consumers.

Conflict of Interest

The authors declare that they have no competing interests.

Author Contributions

All authors' contributions are equal for the preparation of research in the manuscript**.**

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