

Blue Regeneration of Salt Affected Lands: Harnessing Aquaculture for Reclamation of Inland Saline and Sodic Soils

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ABSTRACT

Saline and sodic soils represent one of the most serious forms of land degradation affecting agricultural productivity across arid, semi-arid and coastal regions of the world. Conventional reclamation approaches such as chemical amendments, freshwater leaching and drainage are often expensive, water-intensive and slow to deliver visible improvements, particularly in regions facing freshwater scarcity. In recent years, aquaculture has emerged as an innovative and complementary land-use option for salt-affected soils. By converting degraded lands into managed aquatic production systems, aquaculture not only generates economic returns but also initiates gradual physical, chemical and biological improvements in soil quality. This article reviews the concept of aquaculture-based reclamation of saline and sodic soils, examines the underlying mechanisms involved, presents relevant case studies, and discusses

opportunities, constraints and future research needs. The synthesis suggests that aquaculture, when scientifically planned and integrated with conventional reclamation measures, can serve as a sustainable pathway for rehabilitating salt-affected soils while enhancing food security, livelihoods and ecosystem services.

INTRODUCTION

Soil salinity and sodicity have emerged as major threats to global food production and land sustainability. It is estimated that more than 1.38 billion hectares of land worldwide are affected by salinity and sodicity to varying degrees, with large tracts located in Asia, Australia, Africa and the Middle East. In India alone, over 6.74 million hectares are classified as salt-affected, particularly in the Indo-Gangetic plains, arid western states and coastal belts. These soils are characterized by excessive soluble salts, high exchangeable sodium percentage (ESP), poor soil structure, low permeability and reduced biological activity (FAO, 2024).

Traditional reclamation of saline and sodic soils has largely focused on agronomic and chemical interventions, including the application of gypsum, sulfuric acid, organic amendments and prolonged freshwater leaching. While these methods can be effective, they often require significant financial investment, reliable freshwater availability and long-term management. In many regions, particularly inland saline areas, such requirements limit large-scale adoption.

Against this background, aquaculture has gained attention as an alternative land-use system capable of utilizing saline water resources and salt-affected soils productively (FAO, 2011; Qadir *et al.*, 2014). Aquaculture-based reclamation does not aim for immediate conversion of saline soils into crop land; instead, it adopts a phased approach where aquatic farming initiates ecological improvements that gradually enhance soil quality (Qadir *et al.*, 2007). This paradigm

shift aligns well with principles of sustainable land management and climate-resilient agriculture (FAO, 2015).

Saline and Sodic Soils: Characteristics and Constraints

Saline soils are defined by high concentrations of soluble salts, typically reflected by an electrical conductivity (EC) of the saturation extract exceeding 4 dS m⁻¹ (USDA, 2014; FAO, 2015). These soils often maintain relatively neutral pH but impose osmotic stress on plants, reducing water uptake and growth (Munns & Tester, 2008). Sodic soils, in contrast, are dominated by high levels of exchangeable sodium, leading to elevated pH values (often above 8.5), clay dispersion and severe structural degradation (Brady & Weil, 2016).

Saline-sodic soils combine both high salinity and sodicity, making them particularly problematic. Such soils exhibit extremely poor infiltration rates, surface crusting, waterlogging and restricted root development (Qadir & Schubert, 2002). Crop yields on these soils are typically very low or economically unviable (FAO, 2015). Moreover, attempts to reclaim sodic soils without addressing structural problems often result in limited success (Qadir *et al.*, 2007).

From a land-use perspective, many saline and sodic areas remain underutilized or abandoned. However, the presence of shallow saline groundwater and flat topography makes them suitable for pond-based systems, creating opportunities for aquaculture-driven utilization and rehabilitation.



Figure 1. Integrated Strategy for Reclamation of Saline Salt (Source: Smith & Brown, 2022).

Concept of Aquaculture-Based Soil Reclamation

Aquaculture-based reclamation involves the intentional use of saline or sodic lands for fish, shrimp or other aquatic organism culture with the objective of both production and gradual soil improvement (Boyd & Tucker, 1998; Qadir *et al.*, 2014). The approach is particularly suitable for inland saline regions where conventional agriculture is constrained but saline water is available (Allan *et al.*, 2001; FAO, 2011).

The rationale behind this strategy lies in the ability of standing water systems to alter soil processes. Pondered water reduces capillary rise of salts to the surface, promotes sediment deposition (Rengasamy, 2006), and encourages biological activity. Over time, the accumulation of organic residues from feeds, plankton and aquatic organisms contributes to improved soil aggregation and fertility (Boyd, 1995; Qadir & Oster, 2004).

Unlike conventional reclamation, aquaculture does not immediately seek to remove salts entirely. Instead, it manages salt dynamics in a controlled manner while generating economic returns, thereby making land rehabilitation financially attractive to farmers.

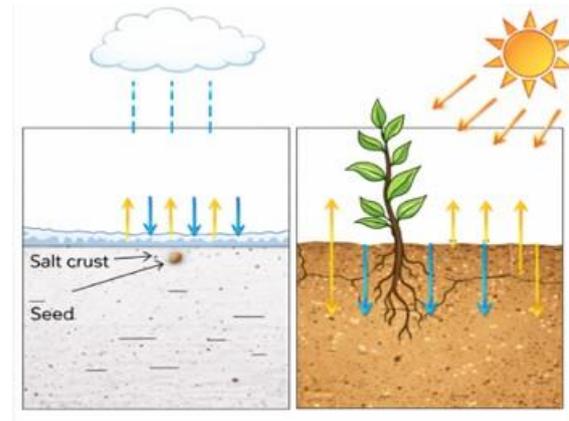


Figure 2. Effect of soil salinity on seed germination and plant growth (Source: Smith & Brown, 2022).

Mechanisms Through Which Aquaculture Improves Salt-Affected Soils

Salt Redistribution and Leaching

Continuous or seasonal ponding of water facilitates downward movement of soluble salts from the surface soil layers. In contrast to bare saline soils, where evaporation concentrates salts at the surface, aquaculture ponds maintain a water column that buffers salt accumulation. Periodic water exchange further removes salts from the system.

Organic Matter Accumulation

Aquaculture ponds receive regular inputs of organic matter in the form of feed, plankton biomass and faecal matter. These inputs settle at the pond bottom, gradually increasing soil organic carbon. Enhanced organic matter improves cation exchange capacity, promotes aggregation and reduces the dispersive effects of sodium.

Biological Activity and Soil Structure

The aquatic environment supports diverse microbial communities that drive nutrient cycling and organic matter decomposition. Microbial by-products such as polysaccharides contribute to soil aggregation, improving permeability and reducing crust formation.

Nutrient Enrichment and Sediment Reuse

Nutrients accumulated in pond sediments can be reused as soil amendments in adjacent agricultural fields. Such sediments are often rich in nitrogen, phosphorus and micronutrients, contributing to improved crop performance once soils are partially reclaimed.

Species Selection and System Design

Selection of suitable species is critical for the success of aquaculture on saline and sodic soils. Euryhaline species such as tilapia (*Oreochromis spp.*), milkfish (*Chanos chanos*), seabass (*Lates calcarifer*) and certain carps have demonstrated tolerance to varying salinity levels. In higher salinity environments, shrimp species such as *Litopenaeus vannamei* are increasingly adopted.

Semi-intensive systems are often preferred in reclamation contexts, as they balance productivity with environmental stability.

Case Studies and Regional Experiences

Inland Saline Aquaculture in India

Inland saline aquaculture initiatives in states such as Haryana, Punjab and Rajasthan have demonstrated the productive use of sodic lands for fish farming (Roy *et al.*, 2007). Studies have reported gradual improvements in soil pH and organic carbon levels after several years of pond operation.

Table 1. Examples of Aquaculture-Based Reclamation Systems

Region / Country	Aquaculture System & Species	Soil / Water Condition	Reclamation & Co-benefits	Citations
Haryana, India	Tilapia, carp, shrimp in ponds	Sodic and inland saline soils	Productive use of saline groundwater; farm income; improved soil structure and adjacent cropping	(Aklakur, 2017), (Yadav <i>et al.</i> , 2024), (Jahan <i>et al.</i> , 2025), (Nagaraja <i>et al.</i> , 2025)

Punjab & Rajasthan, India	Inland saline finfish & shrimp	Saline-sodic, waterlogged	Utilizes degraded land; supports livelihoods; contributes to saline land reclamation	(Pathak <i>et al.</i> , 2013), (Jahan <i>et al.</i> , 2025)
Australia	Barramundi, other finfish	Saline groundwater, salt-affected farmland	Income from salt-affected farms; mitigates saline discharge risk	(Doupé <i>et al.</i> , 2003), (Allan <i>et al.</i> , 2009), (Awal, 2016)
Yellow River, China	Integrated fish-crop/grass/livestock	Low-lying saline-alkali land	Raises soil level, lowers water table, reduces surface salt; higher farm returns	Shu-Yun Liu <i>et al.</i> , 2020
UAE / Desert farms	Tilapia + halophytes (e.g., <i>Salicornia</i>)	Saline water, marginal saline soils	Multiple water use; uses brine/effluent for halophytes; supports land reclamation	(Lyra <i>et al.</i> , 2021), (Ibrahim <i>et al.</i> , 2023)

Integration with Conventional Reclamation Practices

Aquaculture should be viewed as a complementary, not replacement, strategy. Combining aquaculture with gypsum application, organic amendments and controlled drainage can accelerate reclamation outcomes. Integrated farming systems that alternate aquaculture with salt-tolerant crops represent a promising pathway for long-term land restoration.

Environmental and Socio-Economic Benefits

Beyond soil improvement, aquaculture-based reclamation offers multiple co-benefits, including employment generation, diversification of farm income, enhanced food security and improved ecosystem services. These benefits are particularly important in marginal and climate-vulnerable regions.

Challenges and Future Research Needs

Despite its potential, aquaculture-based reclamation faces challenges related to water

quality management, disease risks, initial investment and long-term soil monitoring. Future research should focus on quantifying soil changes over time, optimizing species combinations, and developing policy frameworks that support integrated land-use planning.

CONCLUSION

Aquaculture represents a viable and innovative tool for the reclamation of saline and sodic soils. By aligning economic incentives with ecological processes, it offers a sustainable pathway for rehabilitating degraded lands. When scientifically managed and integrated with conventional soil management practices, aquaculture can transform salt-affected soils into productive and resilient agro-ecosystems.

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