

BIOSALINE AGRICULTURE FOR DRYLAND REHABILITATION

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ABSTRACT

Biosaline agriculture is increasingly recognized as a practical pathway for rehabilitating drylands degraded by salinity, drought and low soil productivity. The approach relies on the use of salt-tolerant crops, halophytes, saline water and soil amendments to sustain biomass production while restoring ecosystem function in marginal lands. Recent studies show that halophytes such as *Suaeda salsa* can contribute both to biomass production and to the remediation of salinized soils, linking agriculture with ecological restoration. Biosaline systems are also expanding through integrated models such as saline aquaculture-agriculture, where fish effluents and intercrops can improve yield and resource-use efficiency under saline conditions. Overall, biosaline agriculture offers a climate-resilient strategy for dryland rehabilitation by combining production, soil recovery and livelihood support in salt-affected areas.

KEYWORDS: Biosaline agriculture, Drylands, Rehabilitation, Sustainable agriculture, Soil Salinity.

1. INTRODUCTION

Drylands are highly vulnerable to salinization, soil erosion, water scarcity and declining fertility, which together reduce agricultural productivity and limit rehabilitation options (Yirdaw et al., 2017; Land salinization, 2021). Biosaline agriculture has emerged as a response to these constraints by shifting production toward salt-tolerant crops, halophytes and saline-resource-based systems that can function in degraded environments (Nikalje et al., 2017; Hameed et al., 2024). This makes it especially relevant for dryland rehabilitation, where restoring land productivity must occur alongside adaptation to scarce and saline water resources (Kramer & Sheil, 2024; Chen, 2022). A core principle of biosaline agriculture is the selection and management of plants that can tolerate high salt levels while still producing useful yields or biomass (Rahman et al., 2021; Egea et al., 2023). Halophytes are central to this strategy because they can survive in saline environments and support land stabilization, forage supply, food production and ecological recovery (Nikalje et al., 2017; Li et al., 2023). In India and other dry regions, halophytic vegetation is also valued for ecological and economic uses, strengthening the case for its inclusion in rehabilitation programs (Vineeth et al., 2020; Hameed et al., 2024). At the same time, biosaline agriculture is not limited to plant tolerance; it also includes soil amendments, compost management and water-quality control to reduce salt stress and rebuild soil health (Bello et al., 2021; Gondek et al., 2020). Soil rehabilitation is a major component of biosaline agriculture because salinity affects soil structure, nutrient availability, microbial activity and crop establishment (Basak et al., 2022; Bello et al., 2021). Some findings show that dryland rehabilitation through biosaline agriculture must be built on site-specific soil and crop management rather than on a single universal solution (Basak et al., 2022; Bouras et al., 2021). Halophytes and salt-tolerant crops can diversify food systems, improve resilience and reduce pressure on freshwater resources in saline landscapes (Rahman et al., 2021; Hameed et al., 2024). Therefore, the scope of biosaline agriculture in dryland rehabilitation includes soil recovery, saline-water use, halophyte-based production, integrated farming and climate adaptation across degraded landscapes.

2. The status of saline land and water

FAO's 2024 assessment says about 1.381 billion hectares of land are salt-affected, equal to 10.7% of global land and another 1 billion hectares are at risk from climate change and poor management (FAO, 2024). The GSAS map also shows more than 424 million hectares of topsoil and 833 million hectares of subsoil are salt-affected, with more than two-thirds of these soils in arid and semi-arid regions (FAO, 2024). Saline water is also a major constraint because increasing groundwater use, poor drainage and seawater intrusion raise salinity in both irrigated and dryland systems (FAO, 2024; USGS, 2018). Salt stress reduces crop growth, water uptake and yield and in the most affected countries it can cause yield losses of up to 70% in crops like rice and beans (FAO, 2024). Recent datasets also show a rising trend in salt-affected land area over time, confirming that the problem is expanding rather than stabilizing (Global Soil Salinity Maps, 2022; FAO, 2024). More than 10 countries account for about 70% of the world's salt-affected soils, so the burden is highly concentrated (FAO,

2024). This means saline land and water are not just local problems; they are major threats to food security, especially in dryland ecosystems (FAO, 2024; Zaman et al., 2025).

3. Soil salinity and sodicity

Soil salinity and sodicity are major constraints in dryland ecosystems because they reduce soil fertility, water uptake and crop productivity, while also accelerating land degradation and desertification (Ivushkin et al., 2021; Basak et al., 2022). The FAO classifies salt-affected topsoil as 85% saline, 10% sodic and 5% saline-sodic, showing that salinity is the dominant form, but sodicity remains a significant problem in drylands (FAO, 2024). These data highlight why salinity and sodicity must be treated together in rehabilitation planning rather than as separate issues (Ivushkin et al., 2021; FAO, 2024). Saline soils are typically identified by high electrical conductivity, while sodic soils are characterized by excessive exchangeable sodium and poor soil structure, reduced infiltration and crusting (UNDRR, 2026; Ivushkin et al., 2021). Salinization and sodification are driven by both natural factors such as climate and pedology and human activities such as irrigated agriculture and poor water management (Ivushkin et al., 2021). High sodium levels disperse soil particles, lower hydraulic conductivity and reduce infiltration, which further limits root development and increases runoff risk (Hailu 2021; UNDRR, 2026). For dryland rehabilitation, several mechanisms are matter because they show that salt problems are not only chemical constraints but also structural and hydrological constraints that require integrated management (Basak et al., 2022; FAO, 2024).

4. Principles of biosaline agriculture

Biosaline agriculture is based on the principle of using salt-tolerant plants and saline resources to maintain production in degraded, water-limited lands (Nikalje et al., 2017; Hameed et al., 2024). It treats salinity as a manageable environmental condition rather than a complete barrier to farming, which makes it useful for dryland rehabilitation (Basak et al., 2022; Li et al., 2023). A major principle is matching the right crop or halophyte to the right site, because performance depends on soil salinity, sodicity, water quality and climate (Rahman et al., 2021; Egea et al., 2023). Another principle is that saline water, brackish water, or marginal-quality water can be used productively if irrigation, drainage and soil management are carefully planned (Bouras et al., 2021; Gondek et al., 2020). Another principle is soil rehabilitation through amendments, organic inputs and improved water management to reduce salt stress and restore soil function (Bello et al., 2021; Basak et al., 2022). Gypsum, compost and bio-organic inputs can improve infiltration, reduce sodium effects and support better root growth in salt-affected soils (Bello et al., 2021; Gondek et al., 2020). Biosaline agriculture also depends on biodiversity-based systems, especially halophytes, salt-tolerant crops and integrated crop-livestock or aquaculture systems that spread risk and improve resource efficiency (Li et al., 2023; Madkour et al., 2025). This is why biosaline agriculture is considered both a production strategy and a restoration strategy for drylands (Hameed et al., 2024; Kramer & Sheil, 2024). The goals of biosaline agriculture were mentioned in the Fig 1.

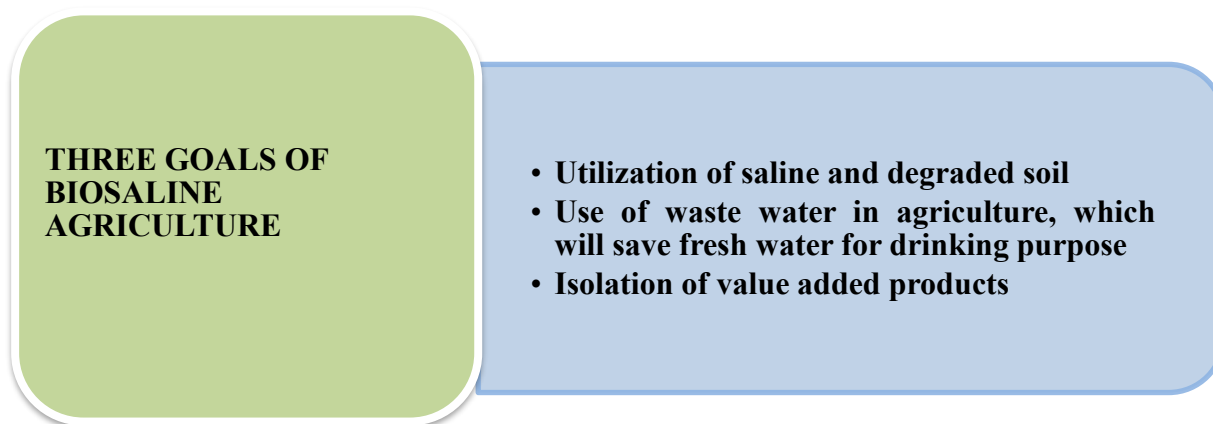


Fig 1. Three goals of biosaline agriculture (Nikalje et al., 2017)

5. Biophysical rehabilitation strategies in dry lands

Biophysical rehabilitation strategies in drylands include water harvesting, soil stabilization, vegetation restoration, biocrust recovery and seed enhancement, all of which aim to improve soil moisture, reduce erosion and rebuild plant cover (ICARDA, 2024; Antoninka et al., 2024). The dryland restoration must be site-specific because climate, soil texture and inoculum traits strongly influence success, especially for rapid biocrust establishment and seedling survival (Antoninka et al., 2024; Pedrini et al., 2023). Seed priming, coating and scarification are increasingly used to improve germination and early establishment under hot, saline and low-moisture conditions common in degraded drylands (Pedrini et al., 2023). Vegetation restoration remains one of the most effective measures and shows improvements in soil organic matter, nutrient cycling and vegetation cover after restoration interventions, particularly when native species and assisted natural regeneration are used (Effects of vegetation restoration, 2023; Yirdaw et al., 2017). The watershed-level soil and water conservation, rangeland management and landscape monitoring as important biophysical tools for land degradation neutrality (ICARDA, 2024). Biocrust acceleration, shading, irrigation and soil stabilization have emerged as promising techniques for restoring bare, erosion-prone surfaces in arid zones (Antoninka et al., 2024). The dryland

rehabilitation is most successful when physical and biological measures are combined rather than applied alone (ICARDA, 2024; Antoninka et al., 2024).

6. Saline water management and revitalization of saline degraded lands

Saline water management means using brackish or saline water carefully so crops can still grow without making the soil too salty (Gawande, 2022; FAO, 2020). The main practices are drainage, leaching of salts below the root zone, blending water sources and using salt-tolerant crops or drip irrigation (Gawande, 2022; FAO, 2020). Subsurface drainage is effective for reclaiming waterlogged saline land and improving soil quality in degraded areas (Singh et al., 2023). The saline water can be used more safely when land is level, irrigation is well managed and crusting and aeration problems are controlled (FAO, 2020). Revitalization of saline-degraded land depends on combining water management with soil amendments, crop choice and proper drainage because salinity is both a water problem and a soil problem (Bello et al., 2021; Basak et al., 2022). The restoring salt-degraded land can improve food production and support climate adaptation in drylands (Negacz et al., 2021; IWMI, 2020). Saline water is not waste if it is managed properly; it can be part of a productive and restoration-based farming system (Gawande, 2022; FAO, 2020).

7. Biosaline technologies for drylands

7.1. Halophytes and salt-tolerant crop plants

Quinoa tolerates salinity up to 51.5 dS m⁻¹, while retaining appreciable seed yield at extreme water salinity levels of 20 dS m⁻¹ (Hirich & Bhargava, 2024). Under low salinity (5 dS m⁻¹), the application of 60 and 70 kg P₂O₅ ha⁻¹ increased seed yield by 29% and 51%, respectively, while at high salinity (17 dS m⁻¹), moderate phosphorus rates still improved yields by 8–13% compared to the control (Bouras et al., 2022).

7.2. Nutrient management under saline conditions

Wang et al. (2022) conducted soil-based experiments with the obligate halophyte *Suaeda salsa* under four salinity levels (0.5-2.0%) combined with three nitrogen treatments. Moderate nitrogen supply at 0.50 g kg⁻¹ soil benefited ion uptake, with sodium and chloride absorption reaching approximately 111 mg and 146 mg per plant at 1.0% salinity, while also enhancing topsoil root elongation by 0.766-1.256 m relative to nitrogen-free controls.

7.3. Salinity-tolerant microbes and microbial bioformulations

An applied field study at Tamil Nadu Agricultural University (TNAU), Coimbatore, evaluated eco-friendly microbial technology for managing dryland saline soils collected from Adivalli village, Udumalpet taluk (EC: 4.03-6.02 dS m⁻¹). Two microbial consortia - a TNAU culture of *Bacillus subtilis* and a CSR-GROW-SURE consortium of *B. licheniformis*, *Lysinibacillus fusiformis* and *Lysinibacillus sphaericus* - were applied at rates of 1, 2 and 3 L ha⁻¹ under field capacity conditions over 90 days. CSR-GROW-SURE at 3 L ha⁻¹ reduced soil EC by 7–9% and the sodium adsorption ratio by 26-27%, with both 75% and 100% field capacity treatments producing comparable amelioration outcomes (Lalitha et al., 2022). The study established that halophilic microbial consortia can serve as a viable, economically accessible biological technology for managing dryland soil salinity without recourse to costly chemical gypsum applications (Lalitha et al., 2022).

7.4. Phytoremediation and agroforestry-based systems

Recommended tree, shrub, and grass species for rehabilitation of salt-affected lands under different salinity stress levels (EC) are mentioned in Table No.1

Table No.1

Stress condition	Suitable trees/shrubs or grasses	Reference
Very high salinity (Ec > 35 dS/m)	Hibiscus sp., Pongamia pinnata, Desmodium umbellatum, Barringtonia asiatica, Manilkara littoralis	(Kumar & Sharma ,2020); (Nainwal et al.,2024)
High salt tolerant (Ec 25–35)	Casuarina, Thespesia populnea, Cocos nucifera (on specific sites)	(Ribeiro-Barros et al., 2022); (Kumar & Sharma 2020)
Tolerant (Ec 15–25)	Casuarina sp., Pongamia pinnata, Eucalyptus camaldulensis, Albizia lebbeck, Ziziphus mauritiana, Parkinsonia aculeata	(Kumar & Sharma ,2020); (Nainwal et al.,2024)

Moderately tolerant (Ec 10–15)	Casuarina, Azadirachta indica, Dendrocalamus strictus, Butea monosperma, Leucaena leucocephala, Tamarindus indica, Balanites roxburghii	(Kumar & Sharma,2020)
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7.5. Technology adoption in coastal and inland dryland systems

For salt-affected vertisols in dryland interior regions, the commercial cultivation of the extreme halophyte *Salvadora* (tolerant to EC up to 50 dS m⁻¹), dill, castor and sunflower on saline fields has proved economically viable and technically accessible to smallholder farmers

7.6. Chemical and physical soil amendments for dryland saline soils

Chemical amendment, particularly gypsum (CaSO₄) application, remains a cornerstone technology for reclaiming alkali and saline-sodic soils in drylands by replacing sodium ions on the soil exchange complex with more favorable calcium ions, following the reaction: Na-clay + CaSO₄ → Ca-clay + Na₂SO₄ (Bello et al., 2021). Gypsum combined with bio-organic amendments has showed a synergistic strategy that accelerates sodic soil rehabilitation while rebuilding soil biological health, microbial diversity and aggregate stability concurrently (Bello et al., 2021).

7.7. Biosaline integrated aquaculture-agriculture systems

A controlled field experiment at the American University in Cairo evaluated the growth performance of Nile tilapia (*Oreochromis niloticus*) and red tilapia (*Oreochromis* sp.) integrated with wheat (*Triticum aestivum* cv. Misr 1) and sugar beet (*Beta vulgaris* cv. Novatelka KWS) crops during the winter season of 2023–2024. Red tilapia reared at 10 ppt salinity achieved the highest final body weight (174.5 g) and weight gain (165.8 g), while a mixed-species culture at 10 ppt yielded the best feed conversion ratio of 1.32 (Madkour et al., 2025). For the associated crops, saline effluent treatments at 5 and 10 ppt reduced wheat growth and yield, with maximum reductions in plant height, leaf area, root biomass and panicle number at the higher salinity level; sugar beet demonstrated greater tolerance and in some treatments at 5 ppt maintained plant height and leaf number comparable to freshwater controls, while also showing a 20-30% increase in total soluble solids under saline conditions (Madkour et al., 2025). An earlier IAAS trial integrating striped catfish with grain sorghum confirmed improved crop yield and fish growth across salinity treatments of 5,000-15,000 ppm, affirming scalability across dryland semi-arid regions (Kimera et al., 2024).

8. CONCLUSION

Biosaline technologies offer a practical way to rehabilitate drylands by turning saline water and salt-affected land into productive resources rather than viewing them only as constraints. The success depends on matching salt-tolerant crops, halophytes, irrigation quality and soil management to local conditions, with case studies demonstrating useful biomass, water savings and land-recovery benefits. These systems are most effective when they combine production with restoration, because dryland rehabilitation requires both immediate livelihood gains and long-term soil improvement. Therefore, biosaline agriculture should be seen as a climate-smart, restoration-oriented strategy for saline and water-limited regions, especially where conventional freshwater farming is no longer sustainable. So, we are not fighting with salinity; but we are adopting agriculture to salinity through biosaline agriculture.

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Authors' contributions

Keerthana Chandra Sekar conceptualized and involved in the literature search and writing the first draft of the manuscript paper. All authors were involved in the revision and approval of the final version of the manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors

Data availability statement

This article is a review of previously published studies; therefore, no new data were generated or analyzed in this study. All data sets supporting the findings of this review are available in the cited literature.

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