BIO SALINE AGRICULTURE: A FEASIBLE SOLUTION FOR SOIL SALINITY CONSTRAINTS

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The slogan *"Halt soil salinization, boost soil productivity"* chosen for the World Soil Day 2021 by the Food and Agriculture Organization underscores the growing severity of soil salination across the globe. According to the Global Map of Salt-Affected Soils (GSASmap v1.0) published by FAO in 2021, about 833 million hectare (Mha) of land worldwide are affected by salinity or sodicity problem (Figure 1) and in India, around 6.74 Mha of land is affected, as reported by CSSRI in 2015.

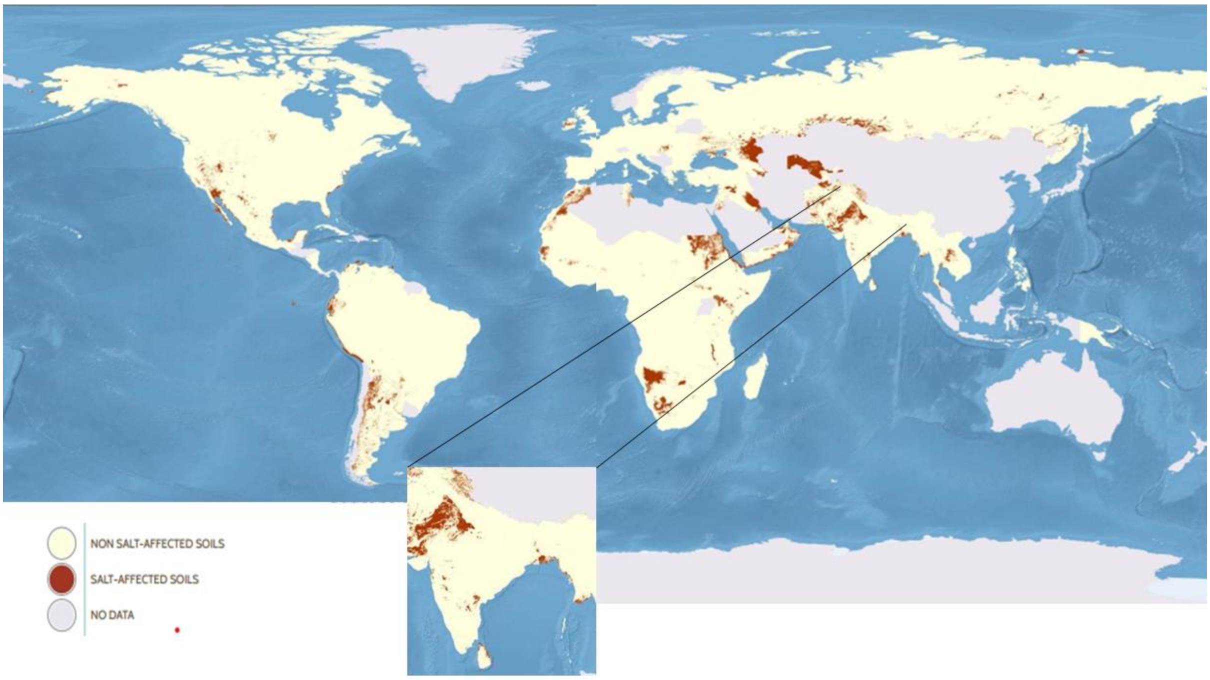

Figure 1. The Global Map of Salt-Affected Soils at 0-30 cm depth (GSASmap V1.0) (Source: FAO, 2021)

A significant portion of our land is already facing serious consequences of soil salinization and if appropriate steps are not taken, this figure will continue to rise, leading to even greater concern. Moreover, other issues such as climate change, urbanization, declining soil fertility, loss of soil carbon are likely to further increase soil salinity. Therefore, it is imperative to explore other alternatives.

One of the feasible options can be bringing more and more salt affected soils into cultivation by considering the saline water and salt affected soils as resource rather than a problem. Most often the agricultural crops are unable to sustain in a saline environment or have very low tolerance to salt. However, there are a special group of plants referred to as halophytes that are biologically engineered to withstand high salt conditions. They not only survive in these conditions, but also produce considerable biomass which can be used for other potential/economic uses in industry, feed, medicine etc.

Therefore, future agricultural production in these saline degraded soils based on salt tolerant crops should be considered as an alternative. Bio saline agriculture is the concept of cultivation of such crops which are able to tide through the harsh salt-based environment and produce biomass which are edible or of economic and ecological significance. Biosaline agriculture offers a dual benefit as it promotes the productive use of saline and degraded soils and promotes the use of wastewater for irrigation, thereby conserving freshwater for essential uses like drinking. Additional benefits of this approach will be discussed later in the article.

CLASSIFICATIONS OF HALOPHYTES

Scientifically, halophytes are defined as plant species that can successfully survive, grow, and reproduce in soils with a salt concentration of > 200 mM of NaCl or an electrical conductivity of saturation extract of > 20 dS m^{-1} (Flowers and Colmer, 2008). Many halophytes and salt tolerant crops have been successfully exploited for desalination process, and a few commercially important halophytes cultivated on degraded lands suggest that these plants are good candidates for bioprospecting. Based on their tolerance to salt concentration in soil solution, halophytes can be further subdivided into mesohalophytes (tolerate 0.5% to 1%), eneuhalophytes (tolerate 1% to 5%) and mesoeuhalophytes (tolerate above 5%). A general classification of halophytes is depicted in Figure 2.

Some halophytes can tolerate high saline condition through salt excretion mechanisms via salt glands and salt hairs located on the leaf cuticle (e.g., *Avicennia officinalis*, *Avicennia alba*, *Avicennia marina*). Others, by virtue of its genetic makeup, can absorb more Na+ and Cl- ions through roots and accumulate in tissue or in the sap of vacuole without any adverse effects on plant metabolism (e.g., *Salvadora persica*, *Sesuvium portulacastrum*, *Suaeda nudiflora*). Salt excluders are another group those prevent or restrict the entry of salt ions into the plant at the root level, thereby minimizing salt interference (e.g. *Rhizophora mucronata, Bruguiera gymnorrhiza*).

Halophytes are also classified based on its ecology as:

- **Obligate Halophytes:** grow only in saline habitats and exhibit satisfactory growth and development under high salinity (e.g. *Salicornia bigelovii*)
- **Facultative Halophytes:** establish themselves on salty soils, but their optimum growth is observed in a salt free or low salt condition. This group includes many Poaceae, Cyperaceae, and Brassicaceae species as well as dicotyledons like *Aster tripolium*, *Glaux maritima*, *Plantago maritima*.
- **Habitat-indifferent Halophytes:** normally grow on non-saline soils but if subjected to saline conditions, they can thrive better than sensitive species (e.g. *Chenopodium glaucum*, *Myosurus min*imus, and *Potentilla anserina*).

Furthermore, based on habitat conditions, halophytes can be classified as:

- **Hydro Halophytes:** adapted to grow in aquatic saline environment (e.g. Mangrove based halophytes) and
- **Xero-Halophytes:** can grow well in dry and saline condition (e.g. desert succulents).

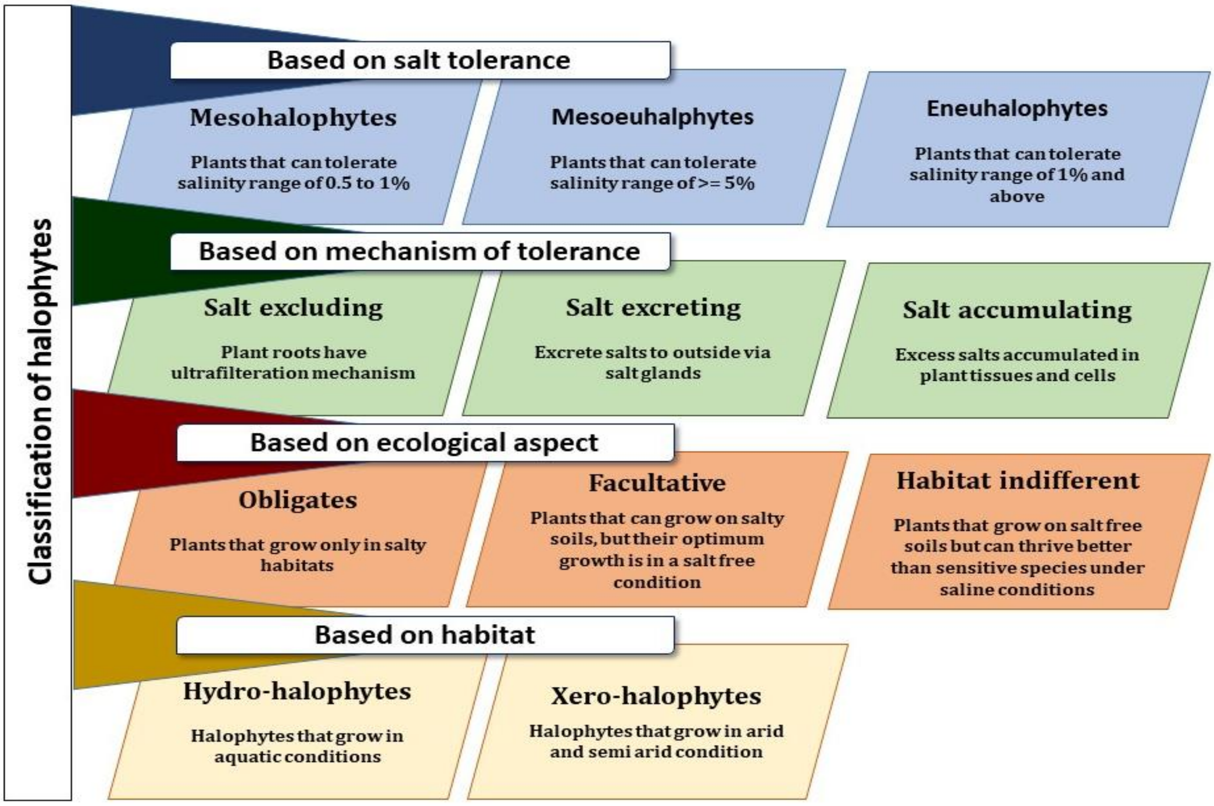

Figure 2. General classification of halophytes

SALT TOLERANCE MECHANISMS IN HALOPHYTES

Over time, halophytes have acquired unique salt tolerance mechanisms. Their adaptation to salt stress is governed by a series of physiological and molecular strategies such as modifications in the rate of photosynthesis and transpiration, accumulation of Na+ into vacuole or outside the cell, stomatal aperture regulation, accumulation and synthesis of phytohormones, and expression of gene associated with these physiological traits. Halophytes adapts to extreme condition through structural as well as biochemical mechanisms viz., formation of salt glands, succulent leaves, accumulation of osmolyte, ion compartmentalization, and antioxidant resistance mechanisms to cope with salt stress (Vineeth et al., 2020).

Some halophytes can tolerate high salinity by maintaining soluble ion concentration in its cells either equal or higher than soil solution around roots so as to continue the process of water absorption. Salinity stress can boost the production of reactive oxygen species, and to counter these, the concentrations of antioxidant enzymes such as catalase ascorbate peroxidase, peroxidase, glutathione reductase, and superoxide dismutase, rise in plants which are responsible for imparting salt tolerance (Berwal et al., 2021). Figure 3 depicts the major mechanisms underlying salt tolerance in halophytes.

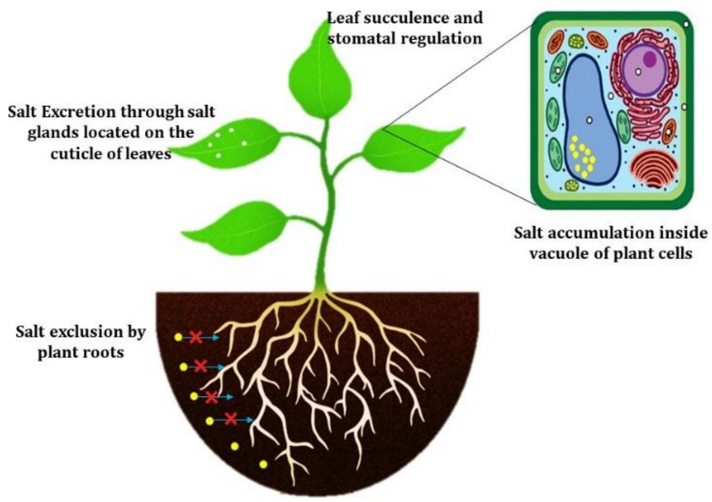

Figure 3. Mechanism of Salt Tolerance in Halophytes

POTENTIAL OF BIO-SALINE AGRICULTURE

Halophytes as Food & Forage: Biosaline agriculture using halophytes is now increasingly being popularized for the cultivation of food and forage crops, medicinal and aromatic plants etc. Certain agricultural crops, such as beetroot (*Beta vulgaris*) and date palm (*Phoenix dactylifera*) are well known for their ability to grow under saline conditions. Fruit bearing trees like gooseberry (*Emblica officinalis*), karonda (*Carissa carandas*), ber (*Ziziphus mauritiana*), and bael (*Aegle marmelos*) tolerate salinity stress and can be irrigated with water up to 12 dS m^{-1}. Among forage crops, *Sporobolus airoides*, *S. marginatus*, *Echinochloa turnerana*, *E. colonum*, *Eragrostis tanella*, *Dichanthium annulatum*, and *Bothriochloa pertusa* are commonly used forages in alkali and saline areas. For halophytes to succeed as irrigated crops, they must have essential criteria: they should have high yield potential; their irrigation water requirement should be less than that of the conventional crops, and the products from halophyte crops must have edible and/or ecological value.

Halophytes as Oilseeds: The seeds of halophytes are a good source of edible oil. High quality oils (70-80% usaturated oil) can be extracted in substantial amount from the seeds of *Suaeda fruticosa, Arthrocnemum macrostachyum, Salicornia bigelovii, S. brachiata* etc. Seeds of *Salvadora oleoides* and *S. persica* contains 40–50% fat and can be considered as substitute of coconut oil having good content of Lauric acid. Other halophytes namely, *Suaeda aralocaspica, Salicornia bigelovii, Crithmum maritimum, Ricinus communis, Euphorbia tirucalli*, and *Descurainaia sophia* can store high concentrations of oils accounting for >20% of the total dry seed weight (Abideen et al., 2014).

Halophytes for Carbon Sequestration and Climate Change Mitigation: Barren lands are highly vulnerable to various forms of degradation, and the absence of vegetation in these lands results significant decline in soil organic matter. Halophytes by virtue of their high biomass producing capacity, can have crucial role in increasing the soil carbon levels and contribute to the carbon sequestration. Halophytes aid in the restoration of barren saline and sodic soils and sequester more and more carbon to our infertile soils. For example, six-year-old *Eucalyptus tereticornis* plantation in sodic land has been reportedly recorded a cumulative carbon stock of approximately 122.6 Mg ha^{-1}, with a CO_2 mitigation capability of 369.2 Mg ha^{-1}.

Halophytes for Bioenergy Production: Production of biofuel from halophytes is yet another opportunity to harness the potential benefits of this unique group of plants. Clean fuel can be produced using the biomass of halophytes as a renewable raw material. In India, the lignocellulosic biomass of four prominent halophytes such as *Pongamia, Jatropha, Panicum virgatum* and *Miscanthus* are widely used for biofuel production This approach of biofuel production not only helps in reducing the carbon footprint but also help in improving the soil health. Among the different types of halophytes, salt excluders are the most suitable for biofuel production. This is because salt-accumulating halophytes tend to cause fouling problems during combustion, as salts are non-combustible and can damage fuel processing equipment (Vineeth et al., 2020).

Halophytes for Phytoremediation: Halophytes have significant potential for phytoremediation, owing to their deep root system and high biomass producing nature. The accumulator group of halophytes not only aid in the phytoremediation of saline heavy metal contaminated soils but also provides additional output in terms of forage. Halophytes have remarkable tolerance to heavy metal toxicity and high ability to uptake and accumulate toxic elements from soil (Liang et al., 2016). Halophytes like *Atriplex halimus, Spartina alterniflora, Sesuvium portulacastrum* and *Tamarix africana* are good for the phytoremediation of heavy metal contaminated saline soils (Vineeth et al., 2020). Moreover, cultivation of *Salicornia sp.* can aid in remediating soil from selenium toxicity, while using the selenium rich biomass in treating selenium deficiency in animals.

Apart from its ecological benefits, bio-saline agriculture can also contribute to improving livelihoods of people living in arid and semi-arid conditions. By enabling cultivation of crops for food, fodder, medicine, and mangrove-based aquaculture, this approach offers sustainable and diverse livelihood opportunities for resource-poor farmers inhabiting saline and degraded lands.

CONCLUSIONS

Halophytes have immense potential in today's scenario, where land degradation due to salinity is becoming increasingly widespread. To address this challenge, biosaline agriculture need to be promoted as an alternative and sustainable cultivation practice to rejuvenate saline and degraded lands. For this, the immediate priority should be to focus on identifying location-specific halophyte species, ensure the large-scale availability of quality seeds, establish efficient nursery systems, and optimize management practices for cultivating halophytic plant populations. Since large-scale adoption of this innovative agriculture method is still in the early stage in the world, many of the challenges associated with biosaline agriculture remain unexplored and will emerge with the advancement of this method. Continued research, policy support, and on-ground implementation will be the key to unlock the full potential of this innovative agricultural approach.

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