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PHYTODESALINIZATION: A BIOLOGICAL RECLAMATION FOR SALINE SOIL

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ABSTRACT

Salinization threatens global agricultural productivity, affecting about 20% of cultivated land. It results from natural processes like weathering and seawater intrusion, as well as human activities such as over-irrigation with poor-quality water. This reduces soil fertility and crop yields. Traditional reclamation methods, like chemical amendments, are costly. Phytodesalinization, an eco-friendly alternative, uses halophytes to extract excess salts through salt exclusion, excretion, and accumulation. Though slow and limited to surface soil, genetically engineered halophytes could enhance its efficiency, making it a sustainable solution for reclaiming salt-affected lands.

KEYWORDS: Agricultural sustainability, climate smart, halophytes, phytodesalinization, salinity

INTRODUCTION

Salinization is the accumulation of salts (cations such as calcium, magnesium, sodium and anions such as chlorides, sulphates, carbonates, bicarbonates) in the rootzone or on the soil surface (Fu et al., 2020, Mohanavelu et al., 2021) rendering large masses of land unproductive. Approximately 835 million hectares (mha) of salt-affected soils (SAS) is distributed in 100 nations across all continents. Currently, 6.73 mha of area in India is saline ranging over 16 states, that is predicted to expand to 16.2 mha by 2050 under the forecasted climate change scenario (ICAR-CSSRI, 2023). Salt affected soils are an important ecological entity majorly in the arid and semiarid regions hampering sustainable agricultural development. The salinization resulting from the parent material during weathering, seawater intrusion and combination of high temperatures, excessive evapotranspiration and deficit rainfall are categorized under primary salinization that is widespread in arid and semi-arid areas of the tropical and subtropical regions. On the other hand, secondary salinization results from faulty agricultural practices like excessive irrigation particularly with poor quality water and lack of drainage facilities and other anthropogenic activities such as deforestation, over exploitation of groundwater, uncontrolled utilization of agrochemicals, utilization of waste effluents, etc (Singh, 2022). Irrigated areas are extremely susceptible to salinization caused land degradation, degrading nearly 14 km2 of fertile areas per day (Zinck and Metternicht, 2009). As per reports, almost 20% of total cultivated and 33% of net irrigated agricultural lands globally are affected by high salinity (Shrivasata and Kumar, 2015)

EFFECTS OF SOIL SALINIZATION ON SOIL AND PLANT SYSTEMS

Irrigation induced soil salinity severely impacts soil and plant system. Among the common visual indicators of soil salinity include white efflorescence on the soil surface (formed from the salt deposition as a result of capillary action of water), inhibited germination, retarded plant growth, patchy crop growth, discolouration and disfiguration of foliage, soil erosion, waterlogging, puddled soil, etc (Mohanavelu et al., 2021). Soil salinity arising particularly due to the excessive salts disturbs affecting root growth, drainage and aeration. However, salinity due to deposition of calcium and magnesium salts improves soil structural stability besides exerting osmotic stress on plants visible from wilting and bluish colouration of the young leaves (due to hindered water uptake and excessive accumulation of salts) (Evelin et al., 2019). Additionally, soil salinity alters electrical conductivity and pH that causes nutritional imbalance and hampered microbial activity. As a result, a decline in organic carbon content, mineralization and enzymatic activity is reported that negatively impacts soil fertility and biomass production.

A salinity level greater than 2 dS/m is associated with a significant decrease in crop output. Salinity levels between 2 and 4 dS/m and above 4 dS/m have been shown to reduce the production of sensitive and tolerant crops, respectively. The majority of crops cannot thrive in soil that has a salt level higher than 16 dS/m. (Singh, 2022). The most common salinity effects on plants are reduced water absorption, nutritional imbalances due to enhanced uptake of toxic ions (like sodium, calcium, magnesium, chloride, sulphates, etc.), reduced turgor pressure and high cystolic Na^+/ K^+ ratio disrupting the rhythmic opening and closing of stomata. As a result of increased sodium ion concentration in relation with potassium ions, the primary effect pertains to reduced turgor potential and hampered photosynthesis. Furthermore, increased sodium ion concentration within the plant system hastens the production of reactive oxygen species (ROS) inhibiting the functioning of photosystem II. The nutritional imbalances within plant system majorly arises from deficiency of phosphorus because of its precipitation as calcium phosphate in soil with increase in pH (Hailu and Mehari, 2021). Such deficiency significantly impacts root development, seed formation, generation of nucleic acid, biological nitrogen fixation, energy generation (like ATP and NADPH) etc.

PHYTODESALINIZATION AS A SOIL SALINITY RECLAMATION MEASURE

Phytodesalinization is a cost effective, green approach for reclaiming salt affected soils by adopting various type of plants capable of removing excessive amount of salts (Srivastava, 2020). Halophytes are highly useful plants adopted for phytodesalinization for its hyperaccumulating capacity of Na+ and Cl- ions. Halophytes are the plants that possesses the ability to grow and reproduce under saline conditions by deploying strategies including avoidance, resistance and tolerance where the salt concentration is nearly 200 mM NaCl or more that is generally detrimental to other plant species known as glycophytes. Some halophytes thrive under harsh climates by restricting salt sensitive phases like germination to a particular season and extends root to non-saline layers of the soil (Nikalje et al., 2019, Saddhe et al., 2020).

Halophytes are classified into three different categories as succulent halophytes (plants that are able to tolerate high salt concentration in their cell sap e.g., Salicornia herbacea), non-succulent halophytes (plants that resist accumulation of high salt concentration by desalinizing their tissues and secretion of excess salts through the salt glands e.g., Spartina alterniflora) and accumulating halophytes (plants that can accumulate excess salts throughout their lifecycle until death e.g., Juncus geradii, Suaeda fruticosa, etc.) (Upadhyay, 2021). Halophytes adopt several adaptive mechanisms for their survival which are mentioned below:

1. AVOIDANCE: It is process in which the salts are kept away from the parts of the plant where they are detrimental.

a. *Salt exclusion mechanism*: it is salt ultrafiltration process at the root surface particular to hydro-halophytes and some phreatophytes. The membranes present in the roots are selectively permeable allowing only water to pass through it. A classic example of salt excluding species is red mangrove (Lee et al., 2013).

b. *Salt excretion/ extrusion mechanisms*: in this process, halophytes specifically recretohalophytes excrete excess salts through epidermal structures called glands (e.g., black and white mangrove) or salt bladders or cuticle present on each leaf (e.g., Tamarix removes salt through cuticle) for maintaining cellular ion homeostasis (Lu et al., 2021).

c. *Salt dilution*: it involves salt dilution present in the tissues of leaves and stems by enhancing succulency by the means of increasing the storage volume and filling the vacuoles of mesophyll cells with water. Succulency is characterized by thick leaves and stems, increased mesophyll cells, smaller intercellular space and higher turgor pressure.

d. *Compartmentation of ions*: it occurs at organ level where salts present are more in roots than inshoot and cellular level where vacuoles accumulate excess salts than cytoplasm protecting the enzymes.

Compartmentalization takes place as a result of presence of ATP dependent vacuolar transporter protein that eventually moves harmful salts ions into the vacuole from the cytoplasm. This acts as osmoticum to maintain favourable water balance.

2. TOLERANCE: it includes osmotic adjustments and synthesis of abscisic acid.

a. *Osmotic adjustment*: plants perform osmotic adjustment either by increased uptake of inorganic ions or by de novo synthesis of organic osmolytes to maintain turgor pressure with plant cells (Zhao et al., 2020). Inorganic ions like Na+, Cl- and K+ ions in the vacuoles and organic molecules like amino acids (proline), soluble sugars, sugar alcohols and glycine betaine are critically important osmoprotectants for osmotic adjustment (Slama et al., 2015).

b. *ROS detoxification*: salt stress cause damage to plant cell organelles due to the generation of ROS. As such, plants possess strict antioxidant defence mechanism that comprises of enzymatic (e.g., superoxide dismutase, glutathione reductase, monodehydroascorbate reductase, etc.) and non-enzymatic antioxidants (e.g., tocopherols, flavonoids, etc.) for scavenging ROS and prevent oxidative damage to the organelles.

Conventional reclamation methods of salt affected areas particularly include utilization of inorganic chemical amendments and leaching. Availability of water and resurgence of salt accumulation on the surface due to capillarity and land smoothing, certainly limits leaching where the salts are moved down beyond the root zone rather than its complete removal. Under such a condition, phytodesalinization is a viable option for remediating saline soils. Also known as vegetative bioremediation or biological reclamation, phytodesalinization is one of the methods of phytoremediation wherein naturally occurring plants or genetically engineered plants are utilized for clearing the environment. Most of these plants absorb and accumulate salts in their above ground parts that are removed completely by harvesting these aerial parts (Manousaki and Kalogerakis, 2011). It has also been reported that, some plant species are effective in reducing the electric conductivity and sodium absorption ratio, providing a congenial microhabitat to the glycophytes for growth and reproduction (Sarkar and Sadhukhan, 2022).

PROS AND CONS OF PHYTODESALINIZATION

The advantages of adopting phytodesalinization extends to reduced dependency on instruments and chemical amendments, preventing surface runoff, retaining topsoil fertility and productivity besides improving soil quality and less capital investment.

However, this approach is time consuming that fails to bring immediate remediation and is restricted only to the soil surface. Moreover, many investigators are of the opinion that it leads to bioaccumulation of heavy metals and harmful salts in the food chain. Hence, genetic engineering or breeding techniques can be formulated for bringing about salt removal within a short span of time with proper disposal methods.

CONCLUSION

Phytodesalinization can be a novel climate smart soil reclamation strategy that eliminates the utilization of chemicals and excessive water for leaching. Halophytes have intricate salt tolerating mechanisms like salt exclusion, salt inclusion and salt accumulation that enables it to thrive under extremely non-congenial environment. It allows successful cultivation of glycophytes paving the way for remediating salt affected soils for normal cultivation. Hence, it can be concluded that phytodesalinization is a less energy demanding, ecofriendly and cost-effective saline soil reclamation measure.

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