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Strategies for Remediation of Marginal Lands and Restoration Technology

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ABSTRACT

Arid and semiarid regions account for almost 40-45% of the Earth's total land surface, and these areas are highly prone to salinization due to low rainfall and improper water management practices. Salinity and drought, two very closely associated abiotic stressors, negatively affect crop productivity (Gamalero, et al. [1]). Almost 20% of the total irrigated land has been degraded due to excess soil salinity [2]. To meet the food, fodder, biomass energy, value-added product and employment requirements of the expanding population, it is critical to developing sustainable agricultural systems under constricted conditions in these marginal lands. Ecological reclamation of the salt-affected areas involves strategic integration and management of the soil, water, forest, and biological-based resources that increase the organic content and microbial activity of the soil and regulate the flow of soil water. Integrating trees with crops and livestock, known as agroforestry, is an optimal practice to restore salt-affected lands [3]. Biosaline agriculture involves the cultivation of salt-tolerant plants, known as halophytes, using seawater and low-quality water for irrigation, thus reducing the reliance on the depleting freshwater resources. Further, halophytes also promote phytoremediation mediated by plant-associated microbiota (Nikalje, et al. [4]). Increased research efforts are required to characterize the physiological, morphological and biochemical stress responses of halophyte species to varying degrees of salinity and water availability and to understand their distinct molecular mechanisms that confer stress tolerance.

Studies are needed to address the knowledge gaps in agroforestry and phytoremediation systems regarding the effects of tree-grass/ crop combinations and plantassociated microbiota on nutrient cycling. The crop diversification and their long-term benefits in soil amelioration and mitigation of climate change are of paramount significance. Keeping in view the importance of restoration of marginal environments, the present review focus on alternative production systems and their management. The overall goal of the study is to identify and develop strategies for sustainable agricultural production systems under saline and arid conditions for field applications. Further, the study also aims to determine the nutrient interaction between leguminous trees, and grass species as part of the saltland restoration practices such as agroforestry. The review also investigates the contribution of native halophytes, grasses, and tree species towards biomass production under different irrigation and salinity conditions.

Keywords: Halophytes; Agroforestry; Legumineous Trees; Salinity; Grasses; Biomass Production

Cultivation in the Saline and Arid Regions of the World

Soil salinity is a key abiotic stressor that negatively impacts plant growth and restricts land use by causing degradation (Gamalero, et al. [1]). Saline and sodic soils are characterized by their high soluble salt content and pH, respectively, which result in imbalances in nutrient cycling and reduced organic content, carbon stocks, and microbial activity in the soil [3]. Globally, approximately 800 million hectares (Mha) of arable land is salt-affected, encompassing 397 Mha of saline soil and 434 Mha of sodic soil (Acosta-Motos, et al. [2,5,6]). Soil salinity is prominent in the arid and semiarid regions of the world due to low rainfall that limits the leaching of salt from the root zone, high evapotranspiration, elevated temperature, and groundwater salinity. The salinization of arid areas is further aggravated by poor water and soil management practices (Qadir, et al. [7,8]). The excessive and improper irrigation in agriculture using poor quality water have mainly contributed to the increasing problems of salinisation, alkalisation and waterlogging (Qadir, et al. [9,10]). Approximately, 20% (45 Mha) of the total irrigated land area (230 Mha) has been subjected to damage by high concentrations of salts [2], and specific studies suggest as high as upto 50% of irrigated land is already salt affected [11]. Climate change is expected to further increase the rate of soil salinization worldwide (Jesus, et al. [12]). Taken together, about 7% of the global land area, 20% of the world's cultivated land area, and half of the irrigated land area are reported to be affected by salinity (Ramachandran Nair, et al. [13]). Salinity-mediated soil degradation poses a severe roadblock for sustainable agriculture. It results in the loss of production of food, fodder, forage and biofuels, which threatens the livelihood of people belonging to marginal lands (Qadir, et al. [9]).

Owing to the expanding population, an estimated 70-100% increase in agricultural production is required to meet the global food demand in 2050 [14]. These reports emphasise the acute and critical need for the development of alternate sustainable agricultural systems in the saltaffected marginal lands by effective management of the soil, water, land and forest resources. Eco-friendly practices such as agroforestry, use of halophytes in biosaline agriculture, agrihorticulture, biodrainage and rhizosphere microbiota-mediated phytoremediation can facilitate desalinisation of the soil and enable the rehabilitation and bioregeneration of the saline lands. Ecofriendly methods for the rehabilitation of saline lands. Soil salinity is a significant environmental challenge, and management strategies that effectively integrate soil, water, forest, and biological-based resources are crucial to the ecological restoration of salt-affected regions. Traditional restoration methods involved chemical and engineering methods such as chemical amendments, tillage operations, cropbased interventions, water-related practices, and electrical currents (Oster, et al. [15]). Since these methods are expensive and not sustainable for the long-term rehabilitation of the saltaffected areas, our current attention is focused on the development of ecosystem-friendly biological reclamation methods.

Crop diversification techniques like agroforestry that promotes the cultivation of trees along with crops, forage grasses, oil-yielding crops, aromatic and medicinal crops, and flower-yielding crops increase the resilience of the marginal lands (Olson, et al. [16]). Agroforestry using biosaline agriculture has emerged as a new frontier in the rehabilitation of marginal areas and in the growth of cash-crops (halophytes). Cultivation of halophytes offers multiple industrial and biotechnological applications in addition to salt remediation of the soils (Nikalje, et al. [4]). Biosaline agroforestry is an innovative methodology that can improve the physicochemical and biological properties of saline and sodic soils. Phytoremediation is a promising and cost-effective biological alternative to the treatment of chemical amendments to accomplish soil amelioration. Furthermore, plant-associated microbiota such as plant growth promoting fungi and bacteria can serve as biofertilisers for degraded lands (Jesus, et al. [12]). The long-term success and stability of these practices depend on the cost benefit ratio of these production systems, nutrient cycling achieved in the soil, and the employment generation and economic development for the people dependent on the resources of these marginal lands. Successful implementation of these practices based on the knowledge from extensive research studies can have long term benefits in climate change and adaptation as well as biodiversity conservation.

Biosaline Agriculture Technology

Fresh water is a very limited natural resource of which only 1% is available in the usable form [2]. Also, freshwater is subjected to salt contamination from erosion of rocks, the intrusion of saltwater into wells in coastal areas and sewage effluent, and leachate infiltration from industrial sites or landfills [2]. These factors limit the availability as well as render contaminated freshwater unsuitable for agricultural use. To overcome this problem, salttolerant plants can be cultivated using saline water, resulting in a sustainable agricultural system referred to as biosaline agriculture that can enrich the soils in the marginal regions. Biosaline agriculture offers multiple benefits such as utilization of salt-affected areas, use of seawater/saline brackish water, and economic development (Nikalje, et al. [17,4]). For the effective cultivation of halophytes in saline agriculture under diverse climate conditions, it is crucial to select an ecologically relevant halophyte having potential for multiple uses based on its salt tolerance mechanisms. Quinoa (Chenopodium quinoa L.) is a promising halophyte of immense agronomic importance. Its advantages include high nutritional value, resistance to drought, wind, and high salt concentrations equivalent to that of seawater (GómezCaravaca, et al. [18,19]). The halophyte Euphorbia tirucalii, which produces high amount of secondary metabolites, has been demonstrated to grow in saline irrigation and is useful for biofuel production (Hastilestari, et al. [20]). Similarly, applications of Salicornia, another desirable halophyte, include use as an animal feed and production of oil for biodiesel and antioxidant compounds such as β-carotene, polyphenols, and ureides (Ventura, et al. [21]). Apart from using low-quality brackish water, seawater can also be a cost-effective irrigation source in biosaline agriculture, provided the crop yield is high enough to compensate for the expenditure of pumping seawater. Further research is required to develop agronomic techniques for growing seawater-irrigated, salt-tolerant crops in a sustainable manner and for the appropriate selection of halophytes with multiple applications capable of growing in various climatic environments.

Role of Agroforestry in Climate Change Mitigation

Carbon sequestration is the process by which carbon is removed from the atmosphere and stored in the form of vegetation (plant biomass) and soil organic matter in the terrestrial ecosystems. In recent years, the pressing issue of an increase in the atmospheric carbon dioxide levels and the resulting climate change has gained a lot of attention. Agroforestry positively contributes to climate change mitigation by both reducing and sequestering the carbon dioxide emission. The sequestration of greenhouse gases is achieved by increasing the soil carbon stocks, creating a positive carbon budget and accumulating carbon in woody biomass (Behera, et al. [3,22]). Agroforestry also promotes adaptation and reduces the risks of climate change by introducing structural and functional diversity in the ecosystem and by reducing the impact of extreme weather conditions. In addition to climate change mitigation, agroforestry-mediated carbon sequestration also contributes to soil enrichment through increased soil water-holding capacity, better soil structure, improved soil quality and nutrient cycling, and reduced soil erosion. Taken together, the advantages of tree plantations and agroforestry systems include habitat expansion, pollination, and seed dispersal; clean water; biodiversity; oxygen production; nutrient cycling; soil fertility enrichment; genetic diversification of crops; carbon sequestration and climate change mitigation and adaptation.

Conclusions & Future Perspectives

In the current scenario, agricultural research is required to focus on the identification and utilization of new crop varieties and other plant species for sustainable agriculture in marginal lands such as saline and sodic soils. Research efforts must be intensified to understand the morphological, physicochemical, genetic and biochemical properties of halophytes that render their successful growth in saline-rich areas under diverse climate conditions (Busby, et al. [23]). Such studies will enable the large-scale cultivation of appropriate halophytes in nonfertile saline and sodic soils, which is yet to be achieved. Various Acacia species found abundantly in Australia, Asia, Africa, and America, are promising salt-tolerant plant candidates for the reclamation of salt-affected barren lands (Abbas, et al. [24-27]). Owing to its high tolerance to salinity, pH, and waterlogging, Acacia species are well acclimatized to the semi-arid and savannah type of climates and grow successfully in diverse environments [28]. A comparative study of five Acacia species: A. ampliceps, A. salicina, *A. ligulata, A. holosericea and A. mangium* revealed that *A. ampliceps* exhibited the highest salt tolerance potential [29]. In another study, *A. ampliceps* showed enhanced salt tolerance compared to *A. nilotica*, which was attributed to the higher K+/Na+ ratio in the tissues of *A. ampliceps* indicating better ion homeostasis (Abbas, et al. [25]). *A. nilotica* tree species has been shown to effectively rehabilitate sodic soils by increasing the organic carbon content, Ca2+ and Mg2+ concentration and availability of nutrients in the soil. In addition, parameters such as soil salinity and soil pH were reduced in *A. nilotica* cultivated sodic lands [27].

Acacia trees are a highly suitable choice for agroforestry as they provide multiple benefits like fodder and shade for livestock, improvement of soil fertility through nitrogen fixation, production of litter and stabilizing soils [16]. Acacia species are also suitable candidates for phytoremediation as they are nitrogen fixing plants and can contribute to rhizosphere acidification and the ensuing cation exchange (Dear, et al. [30-34]). In this study, we aimed to perform the physiological, biochemical characterization of Acacia ampliceps and comparatively evaluate the characteristics. We also conducted an indepth comparative analysis of the phytoremediation potential of the Acacia tree species.

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