Soil Desalination

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Salinity is a major threat that reduces the capacity of all types of terrestrial ecosystems to provide services by threatening biodiversity, lowering agriculture production, degrading the environment, contaminating groundwater below standard levels, increasing flood risks, creating food security concerns, and limiting a community's economic growth.

Keywords: microorganisms ; PGPB ; soil ; salinity

1. Introduction

Among the most important concerns regarding agriculture in the 21st century is soil salinization [1]. According to some recent forecasts, environmental salinization mechanisms will continue to be enhanced as a result of global climate change [2]. The latter is having a significant impact on certain agricultural areas. Its consequences on soil salinity are most severe in arid, semi-arid, and coastal agricultural regions [3]. Salt accumulation in soil is a worldwide issue. Salt-affected soils occur as a result of a variety of processes that can be very localized and complicated in nature. Indicators have been designed to give insight into regions at risk of salinization on a global scale [4]. Increased salinity in agricultural regions is a major environmental hazard that threatens food security [5]. Saline soils are a serious problem for agriculture because they convert agronomically valuable land into unproductive land. According to the United Nations Environment Program, about 20% of agricultural land and 50% of farmland throughout the globe is salt stressed. Soil salinization is limiting the amount of land that can be utilized for agriculture by 1–2% every year, with arid and semi-arid zones being the worst impacted [6]. Soil salinization is expected to damage 1–10 billion hectares globally, posing a danger to the agricultural productivity needed to feed the world's growing population [7], and that salinity stress harms agricultural yield on more than 20% of irrigated land throughout the world [8]. According to assessments, salinity and related issues, such as sodicity, waterlogging, and droughts, cause around 2000 hectares of land to yield reduced agricultural output every day [9].

Salinity is a major threat that reduces the capacity of all types of terrestrial ecosystems to provide services by threatening biodiversity, lowering agriculture production, degrading the environment, contaminating groundwater below standard levels, increasing flood risks, creating food security concerns, and limiting a community's economic growth [10]. Furthermore, salinity is one of nature's most powerful abiotic factors, and it harms both plants and microbes [11]. It can be difficult to distinguish the effects of salinity from those of other factors that may co-vary with salinity when studying the impacts of salinity on soil microbial communities [12]. However, plant life is hampered by high saline levels from germination to the final stage of the plant [13]. High salt intake impairs a variety of physiological and metabolic processes in plants, potentially threatening their viability [14]. Thus, salinity is one of the abiotic factors that has an impact on plant yield; hence, efforts are being undertaken to develop more resistant crops. It has become critical to devise techniques to convert coastal zones and degraded land resources into cultivable land [15]. Various remediation approaches have been successfully implemented and are in use, but there is still no one-size-fits-all technological solution for all circumstances [16]. Scraping, flushing, leaching, and applying an amendment (e.g., gypsum and CaCl2) are common procedures for reclaiming saline soil, although they have limited effectiveness and have negative consequences for agro-ecosystems [14]. An innovative concept known as "biosaline agriculture" has been gaining traction over the last few decades. Different halophytes (salt-tolerant plants) are produced as an alternative for conventional crop plants utilizing saline/brackish water irrigation [17]. The sustainability of agriculture without a compromise of environmental quality, agro-ecosystem functioning, and biodiversity protection are all key challenges in today's agriculture [18]. Thus, the capacity of halotolerant or halophilic PGPB to grow in resistance to high salt levels through the use of osmoregulatory mechanisms to retain regular cell functioning has become crucial [13]. Moreover, for the restoration of saline soils, phytoremediation may be a cost-effective solution [19]. Salt-affected soils can be restored [20] by increasing the nutritional content of the soil and the quantity of soil organisms; an organic amendment to saline–alkali soil can boost the development of salt-tolerant plants directly or indirectly [2]. The ability of biochar–manure compost to relieve salt stress in soils has also been established [21].

Various breeding strategies and genetic engineering technologies are being used in studies to enhance saline-resistant crops [22]. Genetic research might lead to the development of salt-tolerant crops, which could boost agricultural productivity in saline areas and allow agriculture to expand to previously unsuitable areas [23]. In addition, many innovative strategies, such as blending treatment types, mixed plant cultures, and biostimulation, are being employed to increase the efficiency and quality of the restoration of salt-affected soils [16]. However, due to the long-term nature and high cost of such approaches, there is a need to establish simple and low-cost biological solutions that may be applied on a short-term basis [24].

2. Soil Salinization

Salinization occurs when water soluble salts, such as sodium (Na^+), chloride (Cl^-), potassium (K^+), sulfate ($SO4^{2-}$), magnesium (Mg^{2+}), carbonate ($CO3^{2-}$), bicarbonate ($HCO3^-$), and calcium (Ca^{2+}), accumulate in the soil [6]. The most common salt species in saline soils is sodium chloride, which has a negative impact on plant production or causes death. When the electrical conductivity (EC) of the saturation soil paste is 4 dS m^{-1} (about 40 mM NaCl), the soil is categorized as saline [25][26].

The entire amount of salt-affected land on the planet is estimated to be 900 million hectares, or 6% of the total land mass [27]. Soil salinization is limiting the amount of land that can be utilized for agriculture by 1–2% every year, with arid and semi-arid areas being the worst impacted [6]. According to the Food and Agricultural Organization (FAO), the salinization of arable land will lead to 30% land loss over the next 25 years and up to 50% by 2050 if preventive measures are not adopted [28].

In particular, the majority of salt-affected areas are found in arid and semi-arid regions of the globe. The majority of nations impacted by salinity are found in sub-Saharan Africa, and Central and Middle East Asia. Soil salinization is a major problem in developing nations with dry climates (such as India, Bolivia, Pakistan, Egypt, Peru, Tunisia, and Morocco); industrialized nations, however, are less affected by salt but are not insusceptible. Salinization has already harmed crop output in 20–30% of irrigated farmland, with an additional 1.5 million hectares being damaged each year [29].

Soil salinity is becoming more of a concern throughout the world, resulting in soil deterioration and a global yearly agricultural production loss of more than USD 12 billion owing to this phenomenon [30][31].

2.1. Effects of Salinity on Plants

Plant life is hampered by high saline levels from germination to the final stage of the plant. Nutrient absorption, phytohormone production, root and shoot regulation, and the replication of DNA are all hampered as a result [13]. The common consequences of salinity include oxidative stress, which is characterized by the formation of reactive oxygen species that can affect enzymes, bio-membranes, nucleic acids, and proteins [32].

In addition, premature senescence is caused by the toxic effects of Na^+ concentration, which results in a reduction in photosynthetic efficiency and reduced metabolic activities. In membrane transport and enzymatic processes, Na^+ competes with K^+, limiting plant development. The majority of plant cells have strategies to prevent the negative impacts of Na^+ concentration by maintaining K^+ and actively rejecting Na^+ in roots and/or redistributing Na^+ in shoot vacuoles [25][26][27][28][29][30][31][32][33].

2.2. Impacts of Salinity on Soil Microorganisms

Microbial composition, diversity, numbers, and functions are all adversely affected by salinity [33]. It is common to notice a decline in enzymatic activity or microbial biomass [34]. The susceptibility of soil enzyme functions to salt differs; salinity severely decreases the functions of β-glucosidase, alkaline phosphatase, and urease [4]. The dose–response connections between salinity and bacterial growth, as well as quantitative distributions of the trait salt tolerance among populations, have been established. The relationship between community salt tolerance and soil salinity was found to be substantial, suggesting that salinity has a considerable filtering influence on microbial populations [19].

Actinobacteria prevailed in saline soil, whereas Proteobacteria predominated in non-saline soil, according to a biodiversity study of soil microbiome utilizing pyrosequencing of the 16S rRNA gene. *Bacteriodetes*, *Thaumarchaeota*, *Firmicutes*, and *Acidobacteria* were found to be the most common phyla in both saline and non-saline soils, whereas *Cyanobacteria*, *Verrucomicrobia*, and *Gemmatimonadetes* were the least common [12]. In fungi, a low osmolality reduces spore germination and hyphae development, and it affects the morphology [35] and expression of genes [36].

Another negative impact of salt is the disruption of the symbiotic relationship among plants and useful microbes. A disruption in plant–bacteria connections, for example, is induced by changes in proteins implicated in the first adhesion phases (adsorption and anchoring) of bacteria to plant roots in symbiotic relationships, as well as the suppression of nitrogen fixation and nodulation functions [37].

Consequently, the impact is usually more prominent in the rhizosphere due to increased water absorption by plants as a result of transpiration. The basic reason is that living at high salt amounts has a substantial bio-energetic taxation because microbes must preserve osmotic balance between the cytoplasm and the surrounding environment, excluding sodium ions from within the cell. As a consequence, adequate energy for osmoadaptation is necessary [38][39].

3. Impact of Global Climate Change on Soil Salinization

The combined impacts of severe weather events and salinization provide a serious challenge [40]. However, it is difficult to determine the influence of climate change on soil salinization growth [7]. Sea-level rise (SLR) and precipitation changes across wide swaths of coastal areas are both possible consequences of global climate change (GCC). Soil salinization and agricultural productivity will be affected by SLR and precipitation fluctuations. Low-lying coastal locations in South and Southeast Asia, as well as regions in sub-Saharan Africa, are particularly more vulnerable [41]. The salinization of hydromorphic soils will be enhanced by climatic change conditions caused by global warming and an expansion in aridity [42]. Through the physical, chemical, and biological aspects of soil, salinization has the capacity to affect soil health [43].

Because of increased temperature and variations in precipitation (amount and frequency), climate change is projected to have a major effect on soils and ecosystems, changing biogeochemical and hydrological processes [44]. Apparently, increasing groundwater pumping is required to fulfill the growing crop water needs as temperatures rise. Annual precipitation levels in the eastern Mediterranean are expected to decrease by 20% by 2050, increasing the danger of summer droughts [45]. Climate change is anticipated to accelerate the pace of soil salinization over the world. This will result in the use of lower quality water, elevated irrigation-induced salinization, the intensification of dryland salinization (due to the expansion of arid and semi-arid regions and desertification), and sea-level rise, directly contaminating nearby soils or indirectly affecting soils via saline intrusion in aquifers [40].

For example, in Australia, one of the countries most affected by both salinity and climate change, there are an estimated 1.7 million hectares of salinization or at hazard of salinization above the verified 1.047 million ha of salt-affected soils [46]. Thus, inventorying and monitoring climate change impacts on salinity are critical to determine the scope of the problem, identify trends, and develop irrigation and crop management measures that will keep these areas' agricultural production maintained [47].

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