agriculture

Editorial

Fields of the Future: Pivotal Role of Biosaline Agriculture in Farming

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Worldwide, groundwater quality is in decline, growing progressively saltier. This is attributed to seawater incursions in coastal zones and other factors, such as concentration due to evaporation in farming and the introduction of salts due to human activities. Salt-affected soils occupy about 1.0 billion hectares in coastal and continental areas worldwide, and approximately one million hectares per year are added, mainly in arid and semi-arid regions of countries in Asia, Oceania, Europe, North America, and South America. In this context, biosaline agriculture presents a promising solution for utilizing brackish waters and salt-affected soils for productive systems in rural areas.

Biosaline agriculture is a broad term used to describe agriculture under a range of salinity levels in groundwater, soils, or both [1]. This approach aligns with the concept of saline agriculture, which emphasizes profitable and enhanced farming methods on saline lands using saline irrigation water. The goal is to maximize production through the holistic utilization of genetic resources—including plants, animals, fish, insects, and microorganisms—while sidestepping costly soil reclamation techniques [2]. Regardless of the term used (biosaline or saline), this sector can include other types of activities, since salinity is associated with other problems typical of arid and semi-arid regions, including water shortages, which can be intensified due to global climate change.

Advancements in research have made soil restoration in salinized areas not only more achievable but also a promising avenue for sustainable agriculture. Phytoremediation is an efficient technique for the rehabilitation of salt-affected areas, improving the physical, chemical, and biological aspects of soils [3,4]. In this Special Issue, entitled "Biosaline Agriculture and Salt Tolerance of Plants", a study evaluated the potential of the halophyte *Atriplex nummularia* for the reclamation of soils affected by salts, either alone or in association with glycophytes adapted to semi-arid environments, like *Mimosa caesalpiniifolia* Benth, *Leucaena leucocephala* (Lam.) de Wit, and *Azadirachta indica* [4]. The results indicated that *A. nummularia* alone was the most efficient treatment, with reductions of 80%, 63%, and 84%, respectively, in the electrical conductivity and the sodium adsorption ratio of saturation paste extract and the exchangeable sodium percentage of soil after 18 months. Therefore, the use of *A. nummularia* and species adapted to semi-arid regions promoted beneficial effects on the soil quality after the establishment of the plants. According to dos Santos et al. [4], the reclamation of degraded soils with species adapted to semi-arid regions would be suitable agronomic practice to improve soil quality and sustainability, contributing to the increased infiltration of water and carbon sequestration in soil.

The high consumption of water in irrigated agriculture and the scarcity of good-quality (low-salinity) water to meet the multiple growing demands of the population have increased pressure on the sector and have even made the expansion and or implementation of several agricultural enterprises unfeasible. Notably, many plants that thrive in water-limited environments still require significant freshwater resources. But these plants could

Citation: Gheyi, H.R.; Sandhu, D.; de Lacerda, C.F. Fields of the Future: Pivotal Role of Biosaline Agriculture in Farming. *Agriculture* **2023**, *13*, 1774. https://doi.org/10.3390/agriculture13091774

Received: 24 August 2023
Revised: 5 September 2023
Accepted: 6 September 2023
Published: 7 September 2023

be aptly cultivated using brackish water. This realization has amplified the interest in the use of brackish water and wastewater as well as in diversifying water sources in agricultural activities. Sources of brackish and saline water are very common in coastal regions and inland areas, especially in arid and semi-arid regions.

Despite the large number of studies in which brackish water has been used, little is known about the productive potential of these water sources in arid and semi-arid regions. While brackish water is abundant in many of these areas, its exact impact on soil health, crop yield, and overall ecosystem balance is not comprehensively understood. Historically, the primary concern has regarded the potential risks of salinization of soils, which can degrade the soil structure and reduce its agricultural viability. Along these lines, a study conducted by Lessa et al. [5], published in this Special Issue, demonstrated the potential of brackish groundwater in several biosaline agriculture systems. The results demonstrate that the simultaneous use of data from water sources (discharge rate and electrical conductivity) and biosaline systems (water demand and salt tolerance) generates more realistic information related to the potential of brackish water for agricultural purposes, and this type of evaluation should be recommended for semi-arid regions worldwide. The results indicate that the salt tolerance of crops is important, but it is not the only method of addressing salinity problems in the Brazilian semi-arid region. The joint analysis of the data shows that plant production systems with lower water requirements (forage palm, supplementary irrigation, seedling production, hydroponic cultivation, and multiple systems) have greater potential for biosaline agriculture than more salt-tolerant species (such as coconut). The study also indicated the need for diversification and the use of integrated systems as a way of guaranteeing the sustainability of biosaline agriculture in semi-arid regions, especially for small holdings. According to Lessa et al. [5], the data should serve as a basis for formulating public policies aimed at the economic and social sustainability of family farming in tropical drylands.

While the potential of brackish water remains under-explored and its use by farmers is limited [5], it is evident that the use of brackish water depends on management strategies which allow the use of these water sources with little or no impact on crops and soils. In view of the low water discharge rates of most wells with brackish water, there is a need to expand this water supply. Using supplemental irrigation with brackish water has been shown to offer economic benefits, including increased value and farmers' revenues. A paper published in this Special Issue also demonstrated the importance of supplemental irrigation for the sustainability of biosaline agriculture in semi-arid regions [6]. The results suggested that the water stress associated with dry spells is more deleterious to the carbon assimilation and water use efficiency of maize plants compared to the salt stress associated with the use of supplemental irrigation with brackish water. Dry spells compromised the photosynthetic capacity of maize even under the normal water scenario, but the effects became drastic, particularly under drought and severe drought scenarios due to stomatal and nonstomatal effects. The supplemental irrigation of maize with brackish water with electrical conductivity of 4.5 dS m^{-1} reduced water stress and did not result in excessive salt accumulation in sandy loam soil.

In a parallel context, sorghum, despite yield reductions under water stress, remained resilient to saline conditions, tolerating irrigation waters with salinity up to 6 dS m^{-1} [7]. The combined action of osmotic adjustment and stomatal regulation enabled sorghum to thrive in saline environments [8]. The studies presented in this Special Issue [7,8] showed that a concomitant decrease in transpiration rate with a decline in the photosynthesis rate as the soil salinity escalated ensured that the water use efficiency remained constant. This discovery emphasizes the untapped potential of saline waters for irrigating crops like sorghum, especially in water-scarce regions. Furthermore, in a comprehensive study on 'Tahiti' acid lime grafted onto 13 distinct rootstocks, it was observed that water salinity levels of 4.8 dS m^{-1} adversely affected plant performance, primarily through osmotic impacts on photosynthesis, transpiration, and stomatal conductance [9]. However, the core photosynthetic mechanism remained intact. Notably, certain genotypes demonstrated resilience against increased salinity. The authors recommend using water with electrical conductivity of up to 2.4 dS m^{-1} for optimal acid lime cultivation, emphasizing the use of salt-resistant rootstocks and adopting a 0.10 leaching fraction [9]. Hence, the use of brackish water represents an important strategy that can be employed in biosaline agriculture for semi-arid regions, which are increasingly impacted by the shortage of good-quality water. Considering the great spatial variability in rainfall in tropical semi-arid regions and the increase in drought years associated with global climate change scenarios, long-term studies are required to evaluate this strategy in other important crop systems as well as on different soil types [6].

One article featured in this Special Issue investigated the impact of the foliar application of salicylic acid (SA) in mitigating salinity stress in cucumbers cultivated in a hydroponic system [10]. Salicylic acid (SA) is a phytohormone that is crucial in mitigating both biotic and abiotic stresses in plants. It is a phenolic compound that not only regulates plant growth but also manages reactive oxygen species metabolism, contributing to a plant's antioxidant system. Its efficacy varies depending on its concentration, plant species, developmental stage, and application method. In cucumbers, the foliar application of salicylic acid in concentrations between 1.4 and 2.0 mM positively influenced the synthesis of photosynthetic pigments, leaf gas exchange, and the quantum efficiency of photosystem II, in addition to reducing the percentage of electrolyte leakage in the leaf blade, increasing the production, and improving the post-harvest quality (soluble solids, ascorbic acid content, and titratable acidity) of cucumber fruits [10].

A study published in this Special Issue showed that the addition of calcium lignosulfonate significantly enhanced salt tolerance in barley, bolstering its resilience to elevated salt stress levels [11]. Lignosulfonates, byproducts from the paper industry, are complex polymers formed by solubilizing lignin under alkaline conditions, resulting in various chelated forms like Fe-, Ca-, and K-chelated lignosulfonates. These compounds, especially calcium lignosulfonate (Ca-LIGN), have demonstrated positive effects on plant growth, fruit expression, nutrient efficiency, and overall soil health. Physiological parameters analysis revealed that the difference in growth caused by adding Ca-LIGN was primarily due to the higher activity of the antioxidant enzyme peroxidase in the leaves and roots of barley [11]. Furthermore, adding Ca-LIGN to barley plants under various salinity levels boosted the content of chlorophyll *a*, *b*, relative water content, and grain yield production as well as protein content, while the electrolyte leakage was decreased [11].

Inoculation with microorganisms is another strategy that can be used, which can mitigate the effects of salinity, improving the soil microbiota and the absorption of nutrients by plants. Inoculation with microorganisms can accelerate the release of non-available inorganic or organic phosphorus into the rhizosphere and enrich the soil biologically, promoting benefits even in plants under salt stress. In this Special Issue, Castelo Sousa et al. [12] showed that inoculation with *Bacillus aryabhattai*, a plant-growth-promoting rhizobacteria, mitigates the effect of abiotic stress (salt and water) in maize plants, making it an option in regions with a scarcity of low-salinity water. According to the authors, further studies are needed to understand how *B. aryabhattai* acts on morphophysiological and production characteristics under stress conditions to develop efficient strategies to mitigate the harmful effects of salt and water stress [12].

In this Special Issue, a study on a single cultivar of yellow passion fruit (*Passiflora edulis* f. cv flavicarpa) investigated the impact of salinity on leaf antioxidant potential and biomass accumulation in grown plants, correlating these findings to genetic responses [13]. The study showed tissue damage, instances of plant mortality, and a significant reduction in shoot biomass when irrigation water salinity (EC_w) reached 12 dS m^{-1} [13]. Furthermore, by comparing sequences with model plants, homologs of various proteins and cotransporters involved in Na^+ and Cl^- uptake from the soil, their extrusion from roots, and their movement from root to shoot were identified in yellow passion fruit. The gene expression analyses of six genes encoding Na^+ transporters and six genes encoding Cl^- transporters indicated that the efflux of Na^+ from roots to the soil, the loading of Cl^- from root to xylem, and the sequestration of Cl^- into vacuoles of mesophyll cells are vital components of salinity tolerance in passion fruit. The authors concluded that comprehensive insights into the salinity responses of yellow passion fruit would necessitate the exploration of diverse cultivars and the examination of the effects of saline waters rich in either sodium or chloride salts to discern which has the most detrimental impact on the plant [13].

Our understanding of salt tolerance has progressed, revealing intricate genetic mechanisms underlying this trait. These mechanisms, although well understood, present challenges in manipulation. Encouragingly, the genetic underpinnings of salinity tolerance seem conserved across various plant species, a fact evident from the successful gene transfers between Arabidopsis and other species.

In conclusion, faced with growing global challenges, breakthroughs in efficient water management and salt tolerance will be crucial for upholding food security and protecting the environment. It is also important to emphasize that there are great differences in terms of saline resources (plant, soil, and water) in dryland regions around the world, considering quantitative and qualitative aspects. In this sense, applying global knowledge to local realities is a major challenge for biosaline agriculture.

Conflicts of Interest: The authors declare no conflict of interest.

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