International Journal of Sustainable Agricultural Research
2025 Vol. 12, No. 2, pp. 81-97
ISSN(e): 2312-6477
ISSN(p): 2313-0393
DOI: 10.18488/ijsar.v12i2.4167

Achieving sustainable agriculture by application of saline water irrigation

Shifadjzic Khan

Department of Food Security and Agricultural Development, College of Agriculture and Life Science, Kyungpook National University, South Korea.
Email: Shifadjzickhan@gmail.com

Article History
Received: 16 January 2025
Revised: 18 March 2025
Accepted: 10 April 2025
Published: 15 April 2025

Keywords
Environmental resilience
Irrigation
Irrigation water
Saline water
Salt buildup
Salt-tolerant crops
Sustainability.

ABSTRACT

The objective of this study is to investigate the feasibility of saline water irrigation as a potential strategy to mitigate water scarcity in agriculture while promoting sustainable agricultural practices. This study evaluates the efficacy of saline water in irrigation, focusing on its effects on crop yields, soil health, and overall agricultural productivity. The study utilizes a systematic review of current literature. Field experiments assessed the performance of various salt-tolerant crops under saline water irrigation. Soil and water quality parameters were assessed to evaluate the long-term impacts on soil salinity and fertility. Case studies from regions utilizing saline irrigation were analyzed to identify effective practices and mitigation strategies. The findings indicate that appropriate crop selection, soil management practices, and irrigation strategies enable the effective use of saline water for irrigation, maintaining soil health. Improved irrigation methods, including drip irrigation, reduce salt buildup in the root zone. The study highlights the potential of saline water irrigation to mitigate water scarcity, decrease reliance on freshwater resources, and promote sustainable agricultural practices. The adoption of this practice can enhance arable land in saline-affected areas, thereby contributing to food security and environmental resilience.

Contribution/Originality: This work contributes original insights by demonstrating the feasibility of saline water irrigation as a sustainable agricultural practice. It integrates experimental data, soil management strategies, and crop performance analysis to provide actionable guidelines for optimizing saline water use, addressing water scarcity, and enhancing productivity in salt-affected and arid regions.

1. INTRODUCTION

Irrigation is one of the major components in the management practice of agricultural production, which aims to provide moisture to the soil for plant growth. Saline water irrigation refers to the practice of using water with higher levels of dissolved salt to irrigate crops (Rhoades, Kandiah, & Mashali, 1992). Saline irrigation provides soil moisture at the desired level but contains a higher salt content. The application of saline water has both positive and negative effects on plants, crop yield, economic measures, and overall management. The world population continues to increase at an alarming rate, which calls on agricultural stakeholders to come up with a long-term solution for water use. Irrigation water has expanded food security and improved expectations for everyday comforts in many regions of the planet (Tiwari, Mishra, Nishad, & Pandey, 2023). Water shortages have many negative consequences for various socio-ecological systems, including agriculture (Mehrazar, Massah Bavani, Gohari, Mashal, & Rahimikhoob, 2020). Water crises are huge risks to sustainable living frameworks and need immediate attention (Taylor & Sonnenfeld, 2017).

Increasing saltwater intrusion devastates the farmlands and agricultural production.

Salinization events are further exacerbated by climate change, resulting in crop yield reduction and, thereby, high socio-economic losses annually (Deolu-Ajayi & Tran, 2024). The unconventional water resources provide an emerging opportunity to narrow the water demand-supply gap. These include marginal-quality waters, mainly saline ground/drainage and treated effluent (Minhas & Qadir, 2024). The map depicts agricultural distribution over croplands worldwide. Water shortages in cropland hinder agricultural productivity, as seen on the map.

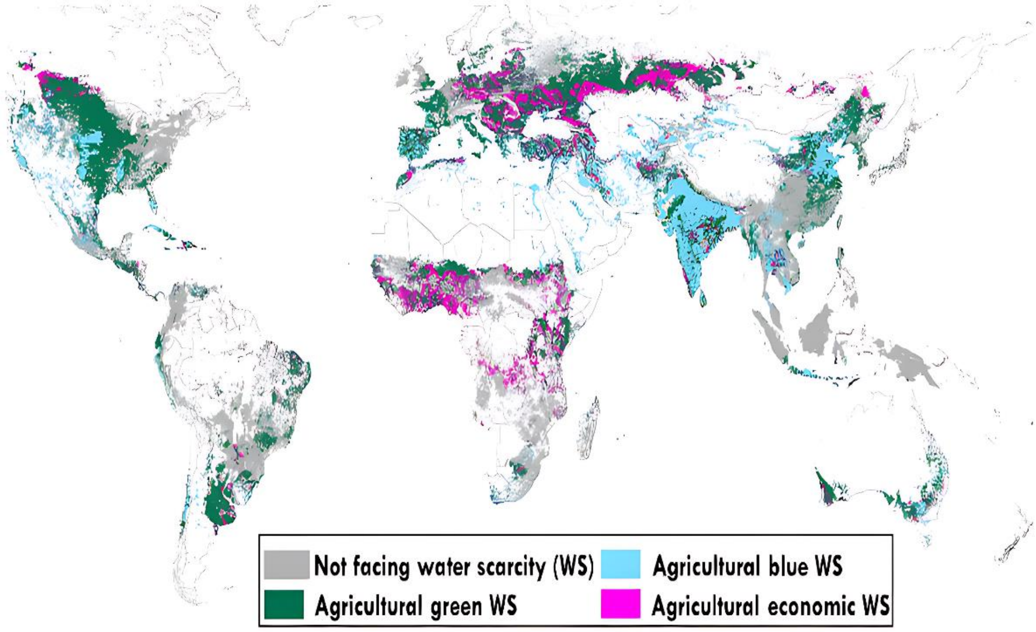

Figure 1. The geography of water shortage in agricultural production across the world.
Source: Rosa, Chiarelli, Rulli, Dell'Angelo, and D'Odorico (2020).

Figure 1 illustrates the water shortage in agricultural production, which is a global issue, particularly affecting regions with arid and semi-arid climates. Areas such as the Middle East, North Africa, South Asia, and parts of Australia are the most vulnerable, where freshwater resources are scarce or mismanaged. In these regions, agriculture heavily relies on irrigation, exacerbating the depletion of water resources. Rapid population growth, coupled with climate change, has further strained water availability, resulting in diminishing crop yields and reduced agricultural sustainability. The competition for water between agriculture, industry, and domestic use is intensifying, making efficient water management crucial. In many countries, the lack of infrastructure and poor water distribution systems further contribute to water scarcity challenges in agriculture.

Sustainable agriculture in saline environments is gaining attention due to increasing food demands and limited freshwater resources (Negacz, Vellinga, Barrett-Lennard, Choukr-Allah, & Elzenga, 2021). Saline agriculture offers a solution for utilizing salt-contaminated lands and water to produce food, fuel, and other valuable products (Ladeiro, 2012). The conjunctive use of saline and fresh water, along with salt-tolerant crop varieties, can improve irrigation water use efficiency while minimizing yield reduction (Hillel, 2000). Proper salinity management strategies, including early warning systems and appropriate drainage, are crucial for maintaining the long-term sustainability of irrigated agriculture (Hillel, 2000). These approaches not only address food security concerns but also contribute to landscape reintegration and soil rehabilitation (Ladeiro, 2012). While some inefficient operations may need to be terminated, irrigated agriculture is expected to adapt and continue playing a vital role in feeding the growing global population (Hillel, 2000; Negacz et al., 2021).

1.1. Global Human Induced Salination Conditions

Freshwater salinization is a growing global issue affecting ecosystems, infrastructure, and human health (Kaushal et al., 2021). It stems from various anthropogenic sources, including agriculture, resource extraction, and road de-icing (Iglesias, 2020). Historically, salinization has impacted civilizations since ancient times, with notable examples in Mesopotamia (Zaman et al., 2018). Current estimates suggest that up to one-third of freshwater bodies may be affected, with potential economic losses of $27 billion annually (Iglesias, 2020; Zaman et al., 2018). Climate change and land use alterations are expected to exacerbate this problem (Iglesias, 2020; Schofield & Kirkby, 2003). The complex interrelationships between salt ions and various environmental parameters, termed Freshwater Salinization Syndrome (FSS), can lead to biodiversity loss, alterations in ecosystem function, and infrastructure corrosion (Kaushal et al., 2021). Addressing this issue requires a comprehensive approach, including improved monitoring, mitigation strategies, and alternative de-icing methods (Iglesias, 2020). Salinization and alkalinization of freshwater are linked global processes driven by human activities like salt pollution, accelerated weathering, and resource extraction (Kaushal et al., 2018).

Expanded salt substances build gravity, thereby adding to the potential for suspended silt. The Food and Agriculture Organization of the United Nations (FAO) has released its first major global assessment of salt-affected soils in 50 years. The report shows that nearly 1.4 billion hectares of land (just over 10 percent of the total global land area) are already impacted by salinity, with an additional one billion hectares at risk due to the climate crisis and human mismanagement (Konyushkova, 2024).

Table 1. Human induced salination conditions in various continents (Million ha).

Continent	Light	Moderate	Strong	Extreme	Total
Africa	4.7	7.7	2.4	-	14.8
Asia	26.8	8.5	17.0	0.4	52.7
South America	1.8	0.3	-	-	2.1
North and Central America	0.3	1.5	0.5	-	2.3
Europe	1.0	2.3	0.5	-	3.8
Australasia	-	0.5	-	0.4	0.9
Total	34.6	20.8	20.4	0.8	76.6

Source: Umali (1993).

Table 1 illustrates the human-induced salinization in various regions of the world. Human-induced salinization is a widespread issue affecting millions of hectares of agricultural land globally, primarily due to improper irrigation practices, overuse of chemical fertilizers, and poor drainage systems. Estimates suggest that approximately 19 million hectares of irrigated land are impacted by salinization. This problem is most prevalent in arid and semi-arid regions where water management practices are insufficient to prevent salt buildup. The accumulation of salt reduces soil fertility, making it increasingly difficult to grow crops and impacting food production. As a result, large areas of farmland, particularly in parts of the Middle East, South Asia, and Australia, are rendered less productive. Effective solutions include improved irrigation techniques, soil management, and the use of salt-tolerant crops to combat the adverse effects of salinization.

1.2. The Drivers of Salinization are Both Natural and Induced by Humans

Climate change is causing aridity and freshwater shortages. Flooding and salinization will threaten over one billion coastal residents by the end of the century due to rising sea levels. Global warming thaws permafrost, adding to salinization. Poor farming techniques also contribute. These include overusing fertilizers, de-icing chemicals, mining, deforestation, and water pumping in maritime and inland regions, irrigating crops with insufficient water, and inadequate drainage. Recently, global freshwater demand has grown six-fold, causing groundwater salinization from aquifer overexploitation for agriculture (Sowers, Vengosh, & Weinthal, 2011).

1.3. Categories of Saline Water

Brackish water is characterized as disagreeably pungent yet less saline than seawater (Buono, Zodrow, Álvarez, & Li, 2016). Notwithstanding certain surface water settings, for example, estuaries, saline water can be found in springs. In certain areas of the country with restricted accessibility to freshwater, desalination of saline groundwater is being utilized as an alternative source. How does salty water contrast with seawater? Seawater generally contains a higher salt content, around 35,000 ppm, when compared to 10,000 ppm or less of saline water.

Table 2 shows the level of salt concentration among various classifications of water.

Table 2. The distinguishes categories of saline water.

Water type	Salt concentration
Fresh water	<1000PPM
Slightly saline	1000-3000PPM
Moderate saline	3000-10,000PPM
Highly saline	10,000-35,000PPM
Ocean water	>35,000PPM

Source: Association (2010).

Table 2 illustrates that saline water can be categorized based on its concentration of dissolved salts, typically measured in terms of electrical conductivity (EC). Saline water can be categorized based on its salt concentration, measured in parts per million (ppm). Freshwater typically has less than 1,000 ppm of dissolved salt. Water with 1,000 to 3,000 ppm is classified as mildly saline, while moderate salinity ranges from 3,000 to 10,000 ppm. High salinity contains between 10,000 and 35,000 ppm, and very high salinity exceeds 35,000 ppm. As salinity increases, water becomes less suitable for most crops, requiring more specialized management techniques for irrigation. Understanding these categories helps determine appropriate irrigation practices and crop selection.

The constructive outcomes of saline water irrigation on sandy soil advancement and the endurance of plants, such as soil nutrient aggregation, have been overlooked for quite a while. The saline irrigation might introduce the nutrient components into the soil. The artificial shelterbelts could be advantageous for soil nutrient collection due to vegetative litter decay, root development, and deterioration, as well as other biogeochemical cycles (Schlesinger, Raikes, Hartley, & Cross, 1996). A lot of the trial work supports the view that standard preparation recommendations for non-saline conditions are also applicable for saline conditions. Furthermore, available data show that the apparent salt tolerance of agricultural crops varies with soil fertility level (Feigin, 1985). Alternate use of water with different salt concentrations results in mixing in the soil, and the yield responds to the mean water salinity (Meiri & Plaut, 1985).

Adverse consequences of inundating with saline water present dangers; for example, salinity perils or salt toxicity for plants, which influence plant development as well as improvement processes including seed germination, seedling development and vigor, vegetative growth, flowering, and fruit set (Sairam & Tyagi, 2004). High salt concentration prevents the movement of water from the soil to the plants by decreasing the water conductivity of roots (Meng, Zhou, & Sui, 2018). Meta-analysis showed that saline irrigation reduced crop yield, Water Productivity (WP), and Irrigation Water Productivity (IWP) by 17.3%, 12.4%, and 10.8%, respectively. This was primarily because saline irrigation resulted in the accumulation of salt particles in the soil (Zhu, Wang, Sun, & Zhang, 2021), which declined the uptake of $K+$ and $Ca2+$ ions (Tester & Davenport, 2003). The higher the soil salinity, the more severe the osmotic stress in the root environment (Karlberg, Rockström, Annandale, & Steyn, 2007). Saline irrigation also decreases the availability of water to plants due to the osmotic pressure at the root zone, thus reducing water available for plant uptake (Wang et al., 2022). A decrease in plant biomass, leaf area, and development has been observed in various vegetable crops under salt stress (Zribi et al., 2009). Salt stress reduces marketable yield due to decreased efficiency and an increased unmarketable yield of organic products, roots, tubers, and leaves without commercial value. Water systems with saline water have been shown to exacerbate the occurrence of blossom end rot in tomatoes, peppers, and eggplants, a nutritional issue associated with Ca2+ deficiency (Kim, Fonseca, Choi, Kubota, & Kwon, 2008). Studies revealed that increased water salinity above 4 dS m-1 affects growth and yield (days to flowering, maturity, leaf area, stem diameter, dry weight, and seed weight), seed weight, and inflorescence length (Abdullah, El Garawany, Badran, & Almadini, 2015).

Visual representation of the ways in which coastal soil salinity is changing because of climate change and how it affects agroecosystem crop yield and food security.

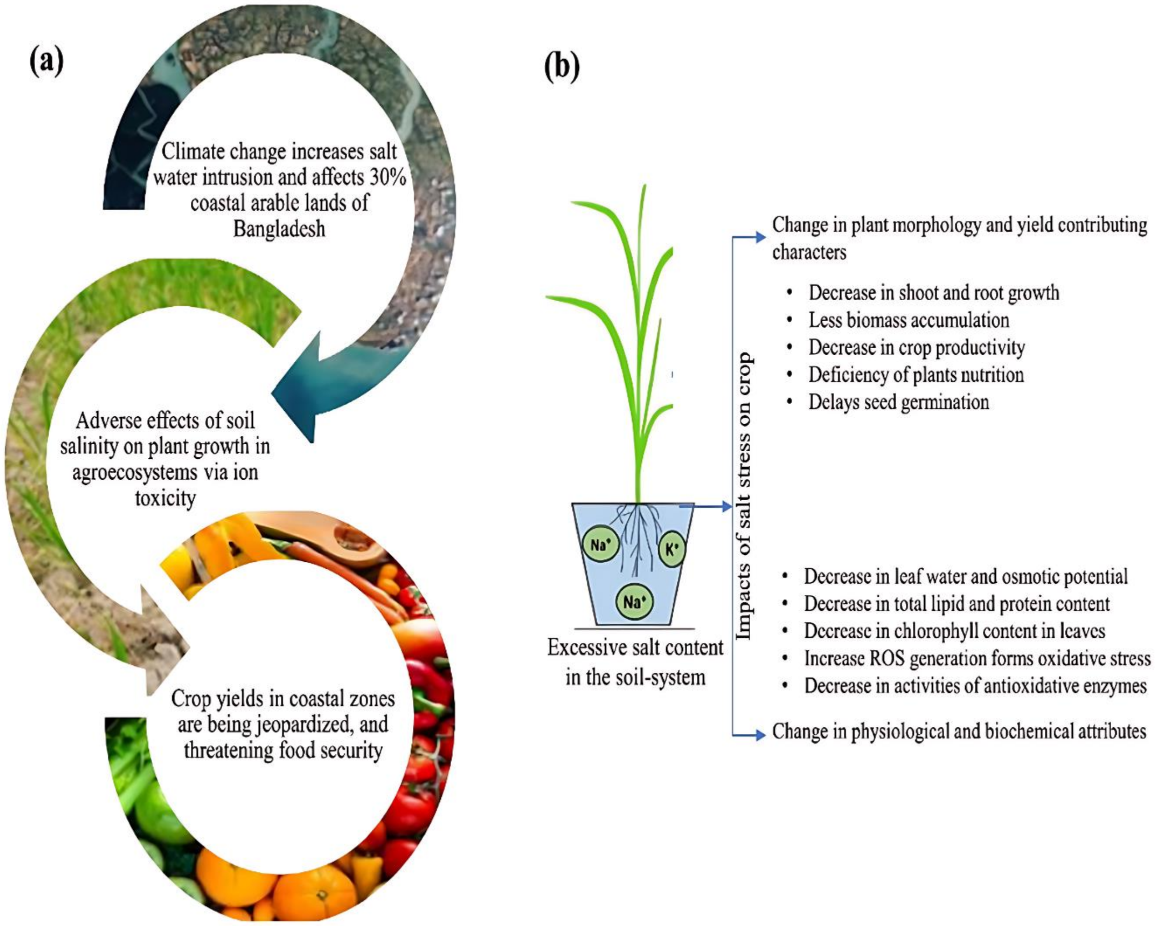

Figure 2. Climate change and saltwater inundation to farmlands are affecting crop growth.
Source: Sultan, Mahmud, and Khan (2023).

Figure 2 demonstrates that climate change is causing rising sea levels, leading to increased saltwater inundation of coastal farmlands. When saltwater enters the soil, it disrupts the water balance, making it harder for crops to absorb fresh water and nutrients. This salt buildup can damage plant roots, stunting growth and lowering crop yields. As salt accumulates over time, the soil becomes less fertile, threatening food security in vulnerable regions. Effective adaptation strategies, such as salt-tolerant crops and improved irrigation systems, are essential to combat these impacts on agriculture.

1.5. Mitigation Strategies

Soil salinity is a global issue affecting crop productivity and food security (Ayub et al., 2020). Plants employ various strategies to mitigate salt stress, including solute accumulation, hormonal signaling, and gene activation for ion homeostasis (Ayub et al., 2020). Exogenous approaches, such as using plant growth-promoting rhizobacteria and organic amendments, can also help manage saline agriculture (Ayub et al., 2020). Irrigation methods and water management strategies significantly impact crop response to saline water. Drip irrigation and blending saline with non-saline water have shown better results for tomato growth and yield compared to furrow irrigation and cyclic water management (Malash & Ali, 2012). Various mitigation approaches include agro-hydrotechnical, biological, chemical, and bio-ecological solutions (Ondrasek et al., 2022). Genetic engineering is becoming a popular strategy for developing salt-tolerant crop varieties with improved ionic homeostasis and yield potential under stressed conditions (Ayub et al., 2020). Soil and water salinity, along with associated problems, are major challenges for global food production. Strategies to cope with salinity include a better understanding of the impacts of temporal and spatial dynamics of salinity on soil water balances vis-à-vis evapotranspiration (ET) and devising optimal irrigation schedules and efficient methods (Minhas & Qadir, 2024).

High-value crops are historically watered with high-quality water. A recent study has revealed that irrigating ornamental horticulture plants and crops with moderately saline water has little negative impact on plant development and quality (Niu & Cabrera, 2011). The salt tolerance of any crop is characterized as the capacity to withstand the effects of excess salt in the root zone. Salt tolerance is described by models that relate the reduction in relative production to the increase in soil salinity (Maas & Hoffman, 1977). Below are some of the mitigation methods that can be implemented to reduce salt accumulation in the root zones of plants while simultaneously achieving greater yield sustainably. To control salinity levels, management should incorporate soil recovery of saline and sodic soils, and the practices of treatment and irrigation should aim to prevent soil salinization and mitigate the impact of soil salinization as well as the use of saline irrigation water in the growth and development of vegetable crops. The use of organic waste on saline-alkali soils is considered a good practice for soil remediation. The effects of applying various organic amendments and earthworm inoculations on saline soils have been studied (Wu, Li, Zhang, Bi, & Sun, 2018).

The scarcity of water and unreliable water quality are significant issues; thus, desalination of saline water is an alternative method to obtain pure water and enhance the quality of life. Seawater encompasses almost 94% of the Earth's surface and facilitates various commercial activities. Saline water derives from several sources, including agriculture, aquaculture, and numerous businesses such as the chemical and pharmaceutical sectors (Ahsan, Qurashi, & Yasmeen, 2022). In water-scarce areas, agricultural irrigation desalination technologies help meet rising water needs. Due to strict ionic concentration criteria for agricultural irrigation water, desalination requires additional energy and post-treatment (Kumar & Meena, 2017).

Saline water irrigation offers a promising solution to water scarcity in arid regions, with potential benefits for agriculture and climate change mitigation. Research indicates that halophytes can be cultivated using saline water, reducing freshwater demand for agriculture by up to 70% (Bushnell, 2024). The conjunctive use of saline and fresh water can improve irrigation efficiency while minimizing yield reduction (Kumar, Mehla, & Kumar, 2020). Halophytes show potential as cash crops and model plants for developing salt-resistant conventional crops (Koyro, Khan, & Lieth, 2011). Subsurface drip irrigation (SDI) has been found to be an effective method for using saline water, resulting in reasonable yields and improved fruit quality in pear orchards (Oron, DeMalach, Gillerman, David, & Lurie, 2002). Additionally, saline water agriculture on deserts and wastelands can contribute to CO2 sequestration and biofuel production (Bushnell, 2024). These findings suggest that saline water irrigation could play a crucial role in addressing water scarcity and climate change challenges.

1.6. Agronomic Practices

It is by and large hard to get adequate quality water, since the possible water sources near the soil to be managed may at this point themselves be particularly saline. If soil leakage is poor and the water table is shallow, a phony waste structure ought to be presented. Sodic soil recovery involves substituting sodium in the soil with calcium particles by applying large amounts of gypsum (Machado & Serralheiro, 2017). The displaced sodium particles are then moved significantly beyond the root zone using overflow water ultimately drained out of the field through waste. Gypsum, when continuously mixed with water, releases calcium particles, which replace sodium particles from the soil into the descending moving water (Machado & Serralheiro, 2017). Beyond excessive enhancement applications should be avoided, and high-quality, chloride-free, low-saline fertilizers should be chosen. In flooded vegetable crops, the yield health requirements should be met by the soil, planning, and the enhancement content in the water system. The water system could contain high enhancement levels (Grattan, 2002) sufficient to partially or completely satisfy crop needs (Grattan, 2002). The use of bio-fertilizers can also alleviate salinity effects on vegetables and reduce soil salinization. A bio-fertilizer could be defined as a formulated product containing at least one microorganism that enhances the nutrient status (Latef & Chaoxing, 2011) of the plants by either replacing soil nutrients, making nutrients more available to plants, and/or increasing plant access to nutrients (Latef & Chaoxing, 2011). Gypsum is the most commonly used amendment for sodic soil recovery and for reducing the harmful effects of high-sodium irrigation waters due to its solubility, low cost, and availability. The effectiveness of an amendment for recovering saline-sodic soils relies primarily on the infiltration characteristics of the soil (Menachem, 1995).

Saline water irrigation poses significant challenges to crop production, particularly for cotton and rice. Agronomic practices can effectively mitigate salinity stress and improve crop productivity in saline environments. For cotton, techniques such as furrow seeding, plastic mulching, increased plant density, and optimized fertilizer management have shown promise in combating salinity effects (Dong, 2012; Zhang, Zhang, Sun, Dai, & Dong, 2023). In rice cultivation, coupled irrigation-drainage management practices, such as changing irrigation water every 3 days while maintaining a 2-5 cm ponding depth, have demonstrated improved growth and yield attributes under saline conditions (Rahman, Ahmed, & Mojid, 2020). Other strategies for managing saline irrigation include adjusting water application modes, irrigation systems, and frequencies, as well as implementing appropriate leaching practices ((Farag, 1993). These agronomic approaches offer practical solutions for farmers to enhance crop performance and resilience in saline soils, ultimately contributing to sustainable agriculture in salt-affected regions. The conjunctive use of saline and fresh water can improve irrigation water use efficiency with minimal yield reduction (Kumar et al., 2020). Crop selection is crucial, with salt-tolerant varieties recommended to minimize salinity impacts (Kumar et al., 2020).

2. IRRIGATION TECHNIQUES

Irrigation system techniques are viewed as a versatile procedure to confront environmental change. Water system procedures aim to save water and boost yield and water efficiency, resulting in increased yield per unit of water utilized in horticulture (El-Nashar & Elyamany, 2023). Irrigation system strategies significantly impacted soil water penetration and salt filtering, and the dirt arrangement concentration was higher in the development period and lower in the neglected period. Under the mulch drip irrigation and shallowly covered drip irrigation conditions, soil water content and salinity were only impacted by irrigation and closely related to precipitation. The long-term utilization of irrigation technology does not cause soil salinization (Jia, Gao, Sun, & Feng, 2023).

Excessive irrigation and unfortunate water management are the two main reasons for water logging and salt accumulation. Poor water management is a chief cause of these issues (Kumar & Meena, 2017). An effective irrigation strategy, along with proper water system planning and drainage, can prevent and mitigate the effects of soil and water salinity by improving water-use efficiency and nutrient use efficiency, as well as managing salt accumulation and drainage. When foliar damage caused by salts in the water system is a concern, water management strategies such as surface drip irrigation, subsurface drip irrigation, furrow irrigation, and low-energy precision application irrigation should be employed. Drip irrigation and surface drip irrigation, along with other water management approaches, can enhance salinity management by increasing water-use capacity and nutrient use efficiency. Proper water system planning and drainage can help mitigate the effects of soil and water salinity by influencing water-use efficiency and nutrient use effectiveness, as well as managing salt accumulation and drainage. When foliar damage caused by salts in the water system is a concern, water management strategies like surface drip irrigation, subsurface drip irrigation, furrow irrigation, and low-energy precision application irrigation should be utilized. Drip and surface irrigation, along with other water management strategies, can improve salinity management by enhancing water-use efficiency and nutrient use efficiency (Hanson & May, 2011; Machado, Do Rosário, Oliveira, & Portas, 2003; Malash, Flowers, & Ragab, 2008). Saline and slightly saline water can be used for farmland irrigation through techniques like drip irrigation and surface mulch (Wang, Xu, Wang, Wang, & Jiang, 2002). According to Gojiya et al. (2023), the paper explores diverse irrigation techniques, including surface, subsurface drip, and sprinkler irrigation, to enhance crop yields in saline soils in the Dwarka region of Gujarat.

3. WATER MANAGEMENT

Sustainable irrigation methods, like trickle water systems, miniature sprinklers, and accurate cultivating, empower exact water conveyance to plants, limiting water loss through evaporation or runoff. By further improving water use efficiency, farmers can maximize crop productivity while minimizing water consumption (Tiwari et al., 2023). The combination of 30% saline water with 70% desalinated water brought Ca, Mg, and S minerals to good levels while creating water with a salinity of EC = 1.35 dS m^{-1}. Examination of relative pepper yields and analysis of replicated results showed that irrigation with mixed water maintained yields greater than 90% compared to irrigation with completely desalinated water (Ben-Gal, Yermiyahu, & Cohen, 2009).

An examination study was directed between two distinct methodologies, in particular cyclic procedure and mixing methodology with various saline water proportions (Daghari, El Zarroug, Muanda, & Shanak, 2020) and non-saline water (Malash et al., 2008) the predominance of the water system with mixing water was noticed both for development and for yield (Daghari et al., 2020). Drip irrigation system is the costliest and least-utilized type, yet offers the best outcomes in conveying water to establish roots with negligible misfortunes the most expensive and least-used type, but offers the best results in delivering water to plant roots with minimal losses (Kumari & Singh, 2016). As a matter of fact, water mixing has been utilized in numerous districts all through the world, including the North China Plain (Sheng & Xiuling, 1997). Water harvesting: Empowering and executing water reaping procedures can give Common an extra wellspring of water. This includes catching water from roofs, streets, and different surfaces, and putting away it for different purposes like water system, arranging, and non-consumable family purposes. Water gathering decreases tension on customary water sources and further develops water accessibility (Qamar & Saleem, n.d.). Groundwater Recharge: Advancing groundwater re-energize techniques renews underground springs. This can be accomplished through strategies like counterfeit re-energize, where abundance surface water is deliberately guided into the ground to renew groundwater holds. Legitimate administration of groundwater assets guarantees their drawn-out supportability (Tiwari et al., 2023). Water conservation Practice: Carrying out water preservation rehearses is vital for maintainable water assets the board. This incorporates bringing issues to light about productive water use, advancing water-saving advancements (Qamar & Saleem, n.d.) and enforcing regulations for water usage. Empowering social changes, like more limited showers, fixing spills quickly, and utilizing water-proficient finishing, can likewise have a massive effect.

4. ROLE OF TECHNOLOGY

There is no more reasonable way to deal with managing the association of freshwater supply than desalting water for all its expected purposes (Ahmadvand et al., 2019). Desalination has acquired a lot of consideration as one of the best ways of managing the issue of freshwater deficiencies (Kabeel et al., 2020). A second possible source of brackish water comes primarily from various underground sources. This kind of water is an option in numerous countries. The typical amount of salt found in one liter of saltwater is 35,000 mg. The degree of salinity in brackish waters is lower (Jones, Qadir, van Vliet, Smakhtin, & Kang, 2019). Studies indicate that reverse osmosis is the most cost-effective method for managing a wide range of salinity (Alsaadi, Francis, Maab, Amy, & Ghaffour, 2015). Electrodialysis and electrodialysis reversal desalination (Buono et al., 2016) are two established procedures that are considered for desalinating low-salinity feeds. Several new methods, such as membrane distillation, forward adsorption desalination, and forward osmosis, are currently in the process of being developed and have the potential to make a significant impact in the future (Alsaadi et al., 2015). One method for overcoming saline conditions is crop-growing with salt-tolerant crops and promoting soil salinity-tolerant plant growth through rhizobacteria. This practice will bring salt-affected soils to a position where we can achieve sustainable production (El-Nashar & Elyamany, 2023). To further improve salinity tolerance of crops, various traits can be integrated, including ion exclusion, osmotic resistance, and tissue tolerance (Roy, Negrão, & Tester, 2014). Tissue tolerance, where high salt concentrations are found in leaves but are compartmentalized at the cellular and intracellular level (Roy et al., 2014), involves ion transporters, proton pumps, and the synthesis of compatible solutes. Desalination of brackish and seawater could be an attractive option to sustain salt-affected agricultural lands in Oman, but challenges include cost and environmental impact (Al-Jabri, Ahmed, & Choudri, 2015). According to Hassan, Yasser, and Elbagoury (2021), combining electrolysis and electromagnetic field technologies with nano-coated electrodes can improve the efficiency of using saline water for irrigation.

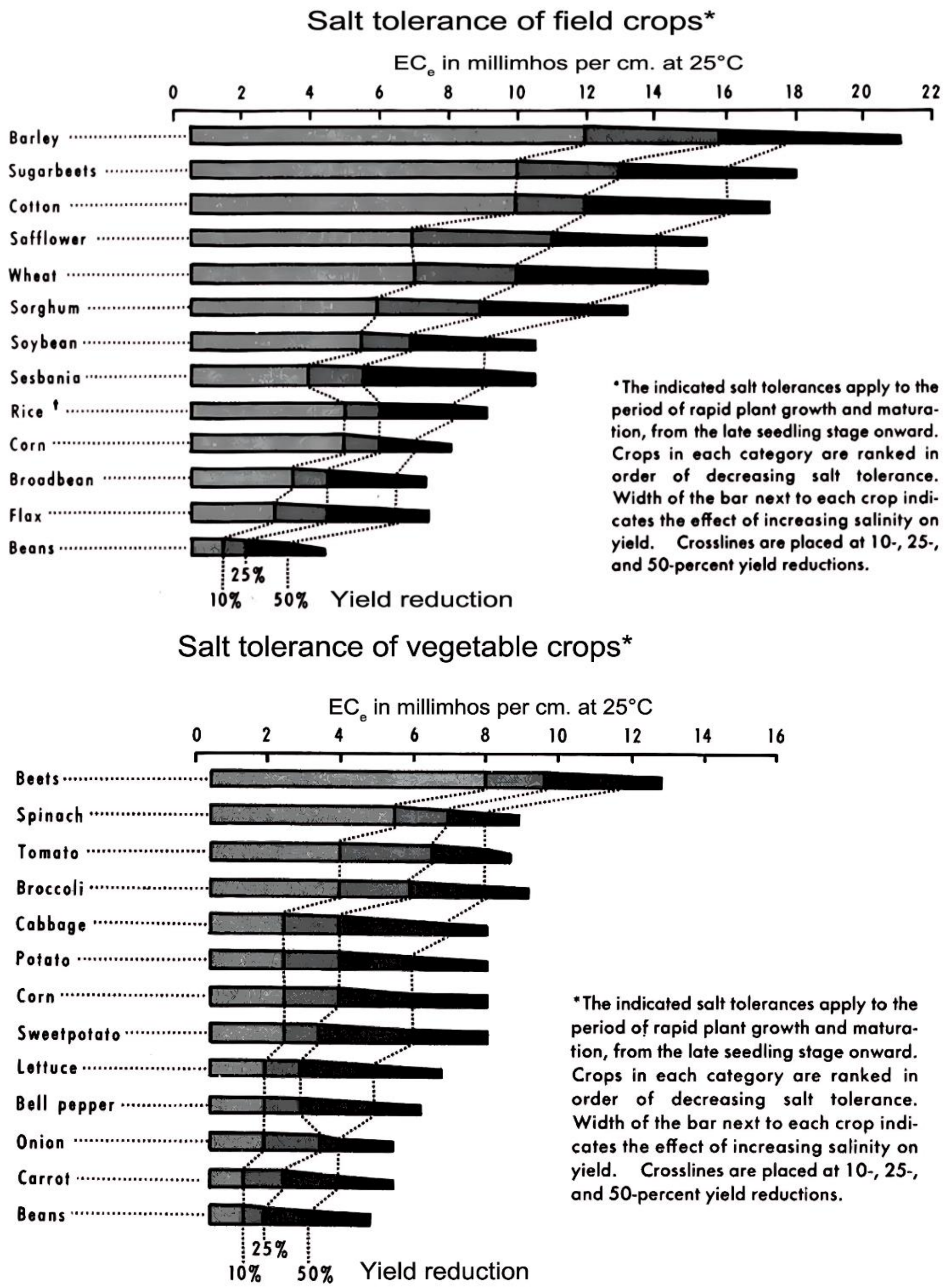

Figure 3. The diagram below depicts the salt tolerance of agricultural field crops and vegetable crops.
Source: Salt tolerance of plants, page 11, Bernstein (1964).

Figure 3 shows that salt tolerance in agricultural crops is crucial, as high salinity levels can significantly reduce the yield of both field crops and vegetables. Crops like barley, sorghum, corn, and beans exhibit varying levels of salt tolerance, with barley generally showing better resistance to salinity compared to sorghum and corn. Similarly, vegetable crops such as beets, cabbage, potatoes, onions, carrots, and beans can also suffer yield reductions due to salt stress. High salinity disrupts water uptake, nutrient absorption, and metabolic processes, which negatively impact growth and development. Understanding and improving salt tolerance in these crops is vital for sustaining agricultural productivity in saline environments.

Sensor-based planning includes utilizing sensors to monitor moisture patterns and using the data for optimal irrigation scheduling. This strategy is especially prevalent in developed countries. Sensor-based planning relies on measurements of soil matric potential and canopy temperature (Vaddula & Singh, 2023). New techniques of molecular breeding, such as advanced molecular tools and CRISPR technology, are now available in economically important vegetables and provide a fair opportunity for the development of genetically modified organisms (Shams & Khadivi, 2023).

5. ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS

Saline water irrigation is a great opportunity for farmers to adopt in their agricultural operations. Nonetheless, a few difficulties that are encountered in carrying out saline water systems include monetary troubles, strict convictions, a deficiency of social capital, and low-level education. Farmers recognize that advanced ways of managing stress — utilizing equipment, chemicals, or compost — are more effective in reducing the impact of environmental threats and in rapidly recovering after a danger; however, some farmers, particularly small-scale farmers, find it challenging to convert their survival strategies. Results show that small-scale farmers are especially becoming vulnerable to climate change and find it hard to handle challenges related to modern agriculture (Liligeto & Nakamura, 2022).

5.1. Case Studies

A review was conducted in a nursery to observe the reaction of lettuce (Uenluekara, Cemek, Karaman, & Erşahin, 2008) to the salinity of irrigation water using a completely randomized block design to assess the response of lettuce (Uenluekara et al., 2008). Results showed that the leaf lettuce plant (L. sativa var. crispa) was notably sensitive to salinity. Instead of yield, the plant dry matter content increased with rising salinity within the examined salinity range. The highest yield was obtained from the control treatment; lettuce yield decreased as soil salinity increased. Lettuce taste was evaluated by 21 testers. There was no significant correlation between taste ratings and the salinity of irrigation water. Plant water consumption decreased significantly with gradually increasing soil salinity, as indicated by a medium negative linear correlation, the Pearson correlation coefficient. Instead of lettuce yield, the dry matter ratio of the plants increased with rising soil salinity. The results further indicated that the flavor of the lettuce, an important quality indicator, was unaffected by the increasing salinity of irrigation water. No obvious symptoms of any nutrient deficiency were identified. Although leaf Na accumulation generally increased with salinity, accumulations of K, Cu, Mn, and Zn were unaffected (Uenluekara et al., 2008). In drought-prone areas, saline irrigation water enhances crop productivity. Alfalfa (Medicago sativa L.), a moderately saline-tolerant legume fodder grass, grows well in irrigated saline–alkali environments and provides significant economic and ecological benefits. A study on alfalfa crops indicated that irrigation with sodium chloride did not affect alfalfa growth and physiology when using NaCl salty water ($EC_{iw} = 4$ mS cm^{-1}). The findings support the safe irrigation of sodium chloride-dominated saline–alkali soils with saline water (Bai et al., 2024). Saline water irrigation is increasingly necessary in arid regions due to freshwater scarcity, but it poses challenges for soil and crop management. Case studies demonstrate that up to 50% of crop water needs can be met with saline drainage water, though high boron levels can be problematic (Ayars, Soppe, & Christen, 2003). In deep groundwater areas, saline irrigation can rapidly increase soil salinity, with accumulation rates of 22.67% and 35.30% for 2 g·L-1 and 5 g·L-1 saline water, respectively (You, Xue, & Huang, 2011). Treated wastewater offers an alternative irrigation source but requires careful regulation to protect water quality (Abou-Hadid, 2003). Management strategies to optimize crop production with saline water include proper drainage system installation, irrigation timing, and consideration of crop salt tolerance, particularly during sensitive growth stages like germination and seedling establishment (Ayars et al., 2003). These approaches can help sustain irrigated agriculture in arid and semi-arid regions despite water quality challenges.

5.2. Challenges and Future Prospects

As farmers are the execution specialists of transformation arrangements and projects, their conduct influences the manners in which these projects are carried out and whether they are successful (Home, Balmer, Jahrl, Stolze, & Pfiffner, 2014). Education plays a very important role as it builds confidence in farmers when trying to adopt new methods and innovations. Prior to identifying those elements, it is vital to determine if farmers are ready to embrace specific adaptive measures. Awareness of environmental change is essential for participating in adaptive behaviors (Mahmood et al., 2020). Subsequently, it improves the economic resilience of farming communities (Amir et al., 2020).

Saline water irrigation faces significant challenges but also offers promising prospects for future agriculture. Salinity adversely affects crop growth, yield, and soil productivity, particularly in arid and semi-arid regions (Sharma & Singh, 2015). However, innovative approaches are emerging to address these issues. Developing salt-tolerant crop varieties, implementing soil amendment techniques, and integrating precision agriculture can mitigate salinity's impact on cotton cultivation (Baig et al., 2023). Desalination of brackish and seawater presents an attractive option for sustaining agriculture in salt-affected lands, although high costs and environmental concerns regarding water disposal remain challenges (Al-Jabri et al., 2015). Utilizing halophytes for food, forage, and oilseed production in saline environments offers another promising avenue (Gul & Khan, 2003). Sustainable management of saline soils requires a holistic approach, combining technological innovations, policy support, and ongoing research to ensure food security and agricultural productivity in salt-affected regions.

All around the world, salinization is viewed as one of the most pervasive soil degradation processes, to which one can adapt by the utilization of suitable methods. One of them is saline agriculture, characterized as "beneficial and further developed agricultural practices utilizing saline land and saline irrigation water to achieve improved production through the sustainable and integrated use of genetic resources (Aslam, Awan, Rizwan, Gulnaz, & Chaghtai, 2009), avoiding costly soil recovery measures (Aslam et al., 2009). Saline groundwater issues are closely related, as these may occur when irrigation wastewater permeates to a spring or when the groundwater table rises. Moreover, lacking coastal protection measures might lead to seawater intrusion, which in turn leads to various long-term issues (Food and Agriculture Organization (FAO) & United Nations Environment Programme (UNEP), 2011). By utilizing saline irrigation in agriculture, it not only improves sustainability with better soil salinity management but also aims to achieve Sustainable Development Goals (SDGs) objectives, such as 2, 6, 13, and 15 (Nations, 2017; Singh, 2021).

6. CONCLUSION

Climate change threatens agriculture globally. Water shortages must be addressed with saline irrigation. Saline water irrigation benefits and harms plant growth. Agronomic methods can mitigate climate change's effects on water shortages and agriculture's high irrigation needs. Soil management and additives can turn saline soil into arable land. Drainage methods reduce soil salinity. The costliest and least-used approach is drip irrigation, which delivers water to plant roots with low losses and minimizes soil salinity, according to research. Mixing salty and non-saline water makes it suitable for irrigation. Technology has improved desalination, but it's expensive. Plants can survive in salty conditions thanks to genetic engineering and biotechnology. To adapt to changing climates and saline circumstances, salt-tolerant cultivars have been developed. The Fiji Islands are affected by ocean inundation, coastal floods, drought, and poor agricultural soil. However, agricultural stakeholders must plan and analyze saline water irrigation immediately to reduce freshwater strain and increase water availability in dry regions. Farmers drive creativity and initiative; thus, comprehensive planning and policy must be devised to involve and educate them about saline water irrigation and its environmental impacts. Saline water irrigation is a long-term solution to water shortages and climate change. Innovative salinity reduction approaches are needed since conventional ones fail. Recent endophytic bacteria-assisted phytoremediation and climate-smart agriculture have presented potential in improving salt stress reduction and boosting plant growth and nutrient uptake.

7. RECOMMENDATION

1. Choosing and growing salt-tolerant crops or genetically engineered plants that can survive in salty circumstances is essential. Barley, quinoa, and other halophytes are salt-tolerant, making these plants ideal for saline irrigation.
2. Use advanced partial root-zone drying or drip irrigation to reduce soil salt formation and efficiently use saline water. These strategies keep crops wet and control root zone salts.
3. Manage and leach soil to reduce salinity by adding organic matter, gypsum, or other amendments. Where possible, regular freshwater leaching can drain surplus salts from the soil profile, sustaining production. Using these tactics, saline water may be used efficiently without harming agricultural systems.

Funding: This study received no specific financial support.
Institutional Review Board Statement: Not applicable.
Transparency: The author states that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

REFERENCES

Abdullah, A., El Garawany, M., Badran, A., & Almadini, A. M. (2015). Effect of irrigation water salinity on the growth of quinoa plant seedlings. *Journal of Agricultural Science*, *7*(8), 205. https://doi.org/10.5539/jas.v7n8p205

Abou-Hadid, A. F. (2003). The use of saline water in agriculture in the Near East and North Africa Region: Present and future. *Journal of Crop Production*, *7*(1-2), 299-323.

Ahmadvand, S., Abbasi, B., Azarfar, B., Elhashimi, M., Zhang, X., & Abbasi, B. (2019). Looking beyond energy efficiency: An applied review of water desalination technologies and an introduction to capillary-driven desalination. *Water*, *11*(4), 696. https://doi.org/10.3390/w11040696

Ahsan, Y., Qurashi, A. W., & Yasmeen, R. (2022). Desalination of saline water: A review: Desalination of saline water. *MARKHOR (The Journal of Zoology)*, *3*(1), 08-12. https://doi.org/10.54393/mjz.v3i1.36

Al-Jabri, S. A., Ahmed, M., & Choudri, B. S. (2015). Prospects of desalination for irrigation water in the Sultanate of Oman. *Journal of Water Reuse and Desalination*, *5*(4), 430-436. https://doi.org/10.2166/wrd.2015.059

Alsaadi, A. S., Francis, L., Maab, H., Amy, G. L., & Ghaffour, N. (2015). Evaluation of air gap membrane distillation process running under sub-atmospheric conditions: Experimental and simulation studies. *Journal of Membrane Science*, *489*, 73-80. https://doi.org/10.1016/j.memsci.2015.03.029

Amir, S., Saqib, Z., Khan, M. I., Ali, A., Khan, M. A., & Bokhari, S. A. (2020). Determinants of farmers' adaptation to climate change in rain-fed agriculture of Pakistan. *Arabian Journal of Geosciences*, *13*(9), 1-19. https://doi.org/10.1007/s12517-020-06019-w

Aslam, Z., Awan, A., Rizwan, M., Gulnaz, A., & Chaghtai, M. (2009). *Saline agriculture farmer participatory development project in Pakistan: Punjab component (Technical report, 2002–2008)*. Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan.

Association, N. G. W. (2010). *Brackish groundwater national ground water association*. Westerville, OH: Information Brief.

Ayars, J. E., Soppe, R., & Christen, E. W. (2003). Managing salinity for sustainability of irrigation in areas with shallow saline ground water.

Ayub, M. A., Ahmad, H. R., Ali, M., Rizwan, M., Ali, S., Ur Rehman, M. Z., & Waris, A. A. (2020). Salinity and its tolerance strategies in plants. In Plant life under changing environment In (pp. 47-76): Academic Press.

Bai, G., He, F., Shan, G., Wang, Y., Tong, Z., Cao, Y., & Yuan, Q. (2024). Effect of saline irrigation water on alfalfa growth and development in saline–alkali soils. *Agronomy, 14*(12), 2790. https://doi.org/10.3390/agronomy14122790

Baig, K., Ali, Z., Warraich, I., Khan, S., Kausar, R., Kashaf, A., & Ahmad, H. (2023). Sustainable cotton cultivation in saline soils: Challenges, innovations, and future prospects. *Biological and Clinical Sciences Research Journal, 2023*, 584. https://doi.org/10.54112/bcsrj.v2023i1.584

Ben-Gal, A., Yermiyahu, U., & Cohen, S. (2009). Fertilization and blending alternatives for irrigation with desalinated water. *Journal of Environmental Quality, 38*(2), 529-536. https://doi.org/10.2134/jeq2008.0199

Bernstein, L. (1964). *Salt tolerance of plants agricultural information bulletin No. 283*. Washington, D.C: U.S. Department of Agriculture.

Buono, R. M., Zodrow, K. R., Álvarez, P. J. J., & Li, Q. (2016). Brackish groundwater: Current status and potential benefits for water management. *Issue Brief, 4*, 11-16. https://doi.org/10.25613/hn6h-7e11

Bushnell, D. M. (2024). Halophytes/saline water/deserts/wastelands nexus as a scalable climate mitigation including freshwater impacts. *Water, 16*(3), 373. https://doi.org/10.3390/w16030373

Daghari, I., El Zarroug, M. R., Muanda, C., & Shanak, N. (2020). Best irrigation scheduling way with saline water and desalinated water: Field experiments. *La Houille Blanche, 106*(4), 72–74. https://doi.org/10.1051/lhb/2020037

Deolu-Ajayi, A. O., & Tran, B. T. N. (2024). Adapting crop production to increasing salinity in the Vietnamese Mekong Delta: Thoughts on stakeholders and roles in a potential transition process.

Dong, H. (2012). Combating salinity stress effects on cotton with agronomic practices. *African Journal of Agricultural Research, 7*(34), 4708-4715. https://doi.org/10.5897/ajar12.501

El-Nashar, W., & Elyamany, A. (2023). Adapting irrigation strategies to mitigate climate change impacts: A value engineering approach. *Water Resources Management, 37*(6), 2369-2386. https://doi.org/10.1007/s11269-022-03353-4

Farag, A. H. (1993). Saline irrigation practices and management. *Towards the Rational Use of High Salinity Tolerant Plants: Vol. 2 Agriculture and Forestry Under Marginal Soil Water Conditions*, 353-370.

Feigin, A. (1985). Fertilization management of crops irrigated with saline water. In D. Pasternak & A. San Pietro (Eds.), Biosalinity in Action: Bioproduction with Saline Water. In (pp. 285-299). Dordrecht: Springer Netherlands.

Food and Agriculture Organization (FAO) & United Nations Environment Programme (UNEP). (2011). *The state of the world's land and water resources for food and agriculture: Managing systems at risk*. Earthscan: Food and Agriculture Organization (FAO) & United Nations Environment Programme (UNEP).

Gojiya, K., Karangiya, B., Chavda, S., Bandhiya, R., Pampaniya, N., Gaadhe, S., . . . Chavda, D. (2023). Enhancing crop yields in saline soils: Progressive irrigation strategies for different crops in Dwarka region of Saurashtra, Gujarat. *International Research Journal of Modernization in Engineering Technology and Science, 5*(8), 1749-1756.

Grattan, S. (2002). Irrigation water salinity and crop production. In (Vol. 9). Oakland: Ucanr Publications.

Gul, B., & Khan, M. A. (2003). Saline agriculture: Promises and prospects for future agriculture in degraded saline lands.

Hanson, B., & May, D. (2011). *Drip irrigation salinity management for row crops*. University of California Agriculture and Natural Resources. Publication No. 8447.

Hassan, M., Yasser, A. E., & Elbagoury, K. F. (2021). Effect of electrolysis technology on saline water under utilize nano-coated electrodes. *Arab Universities Journal of Agricultural Sciences, 29*(2), 519-533. https://doi.org/10.21608/ajs.2021.81485.1394

Hillel, D. (2000). *Salinity management for sustainable irrigation: Integrating science, environment, and economics*. Washington DC: World Bank Publications.

Home, R., Balmer, O., Jahrl, I., Stolze, M., & Pfiffner, L. (2014). Motivations for implementation of ecological compensation areas on Swiss lowland farms. *Journal of Rural Studies, 34*, 26-36. https://doi.org/10.1016/j.jrurstud.2014.01.004

Iglesias, M. C.-A. (2020). A review of recent advances and future challenges in freshwater salinization. *Limnetica, 39*(1), 185-211. https://doi.org/10.23818/limn.39.13

Jia, Y., Gao, W., Sun, X., & Feng, Y. (2023). Simulation of soil water and salt balance in three water-saving irrigation technologies with HYDRUS-2D. *Agronomy, 13*(1), 164. https://doi.org/10.3390/agronomy13010164

Jones, E., Qadir, M., van Vliet, M. T., Smakhtin, V., & Kang, S.-M. (2019). The state of desalination and brine production: A global outlook. *Science of the Total Environment, 657*, 1343-1356. https://doi.org/10.1016/j.scitotenv.2018.12.076

Kabeel, A., Sathyamurthy, R., Manokar, A. M., Sharshir, S. W., Essa, F., & Elshiekh, A. H. (2020). Experimental study on tubular solar still using graphene oxide nano particles in phase change material (NPCM's) for fresh water production. *Journal of Energy Storage, 28*, 101204. https://doi.org/10.1016/j.est.2020.101204

Karlberg, L., Rockström, J., Annandale, J. G., & Steyn, J. M. (2007). Low-cost drip irrigation—A suitable technology for southern Africa?: An example with tomatoes using saline irrigation water. *Agricultural Water Management, 89*(1-2), 59-70. https://doi.org/10.1016/j.agwat.2006.12.011

Kaushal, S. S., Likens, G. E., Pace, M. L., Reimer, J. E., Maas, C. M., Galella, J. G., . . . Yaculak, A. M. (2021). Freshwater salinization syndrome: From emerging global problem to managing risks. *Biogeochemistry, 154*, 255-292.

Kaushal, S. S., Likens, G. E., Pace, M. L., Utz, R. M., Haq, S., Gorman, J., & Grese, M. (2018). Freshwater salinization syndrome on a continental scale. *Proceedings of the National Academy of Sciences, 115*(4), E574-E583.

Kim, H.-J., Fonseca, J. M., Choi, J.-H., Kubota, C., & Kwon, D. Y. (2008). Salt in irrigation water affects the nutritional and visual properties of romaine lettuce (Lactuca sativa L.). *Journal of Agricultural and Food Chemistry, 56*(10), 3772-3776. https://doi.org/10.1021/jf0733719

Konyushkova, M. (2024). *FAO launches first major global assessment of salt-affected soils in 50 years (Global Status of Salt-Affected Soils, Issue.* Retrieved from https://www.fao.org/newsroom/detail/fao-launches-first-major-global-assessment-of-salt-affected-soils-in-50-years/en

Koyro, H.-W., Khan, M. A., & Lieth, H. (2011). Halophytic crops: A resource for the future to reduce the water crisis. *Emirates Journal of Food and Agriculture, 23*(1), 1-16. https://doi.org/10.9755/ejfa.v23i1.5308

Kumar, A., Mehla, M. K., & Kumar, S. (2020). A review: use of saline water in irrigation for agriculture. *International Journal of Pure & Applied Bioscience, 8*(1), 262-271.

Kumar, R., & Meena, R. (2017). Water Management for problem soils. In sustainable management of soil and environment. In (pp. 1–15): Springer. https://doi.org/10.1007/978-981-13-8831-8_1.

Kumari, M., & Singh, J. (2016). Water conservation: Strategies and solutions. *International Journal of Advanced Research and Review, 1*(4), 75-79.

Ladeiro, B. (2012). Saline agriculture in the 21st century: Using salt contaminated resources to cope food requirements. *Journal of Botany, 2012*(1), 310705. https://doi.org/10.1155/2012/310705

Latef, A. A. H. A., & Chaoxing, H. (2011). Effect of arbuscular mycorrhizal fungi on growth, mineral nutrition, antioxidant enzymes activity and fruit yield of tomato grown under salinity stress. *Scientia Horticulturae, 127*(3), 228-233. https://doi.org/10.1016/j.scienta.2010.10.010

Liligeto, S., & Nakamura, N. (2022). Farmers' perceptions of climate hazards and coping mechanisms in Fiji. In V. Ongoma & H. Tabari (Eds.), Climate impacts on extreme weather. In (pp. 235–252): Elsevier. https://doi.org/10.1016/B978-0-323-88456-3.00016-2.

Maas, E. V., & Hoffman, G. J. (1977). Crop salt tolerance—current assessment. *Journal of the Irrigation and Drainage Division, 103*(2), 115-134.

Machado, R. M. A., Do Rosário, M., Oliveira, G., & Portas, C. A. M. (2003). Tomato root distribution, yield and fruit quality under subsurface drip irrigation. In J. Abe (Ed.), Roots: The Dynamic Interface between Plants and the Earth: The 6th

Symposium of the International Society of Root Research, 11–15 November 2001, Nagoya, Japan. In (pp. 333-341). Dordrecht: Springer Netherlands.

Machado, R. M. A., & Serralheiro, R. P. (2017). Soil salinity: Effect on vegetable crop growth management practices to prevent and mitigate soil salinization. *Horticulturae, 3*(2), 30. https://doi.org/10.3390/horticulturae3020030

Mahmood, N., Arshad, M., Kaechele, H., Shahzad, M. F., Ullah, A., & Mueller, K. (2020). Fatalism, climate resiliency training and farmers' adaptation responses: Implications for sustainable rainfed-wheat production in Pakistan. *Sustainability, 12*(4), 1650. https://doi.org/10.3390/su12041650

Malash, N., Flowers, T., & Ragab, R. (2008). Effect of irrigation methods, management and salinity of irrigation water on tomato yield, soil moisture and salinity distribution. *Irrigation Science, 26*(4), 313-323. https://doi.org/10.1007/s00271-007-0095-7

Malash, N. M., & Ali, F. A. (2012). Response of tomato to irrigation with saline water applied by different irrigation methods and water management strategies. *International Journal of Plant Production, 2*.

Mehrazar, A., Massah Bavani, A. R., Gohari, A., Mashal, M., & Rahimikhoob, H. (2020). Adaptation of water resources system to water scarcity and climate change in the suburb area of megacities. *Water Resources Management, 34*(12), 3855-3877. https://doi.org/10.1007/s11269-020-02648-8

Meiri, A., & Plaut, Z. (1985). Crop production and management under saline conditions. In D. Pasternak & A. San Pietro (Eds.), Biosalinity in action: Bioproduction with saline water. In (pp. 253-271). Dordrecht: Springer Netherlands.

Menachem, A. (1995). *Soil erosion, conservation and rehabilittaion* (1st ed.). Boca Raton: CRC Press.

Meng, X., Zhou, J., & Sui, N. (2018). Mechanisms of salt tolerance in halophytes: Current understanding and recent advances. *Open Life Sciences, 13*(1), 149-154. https://doi.org/10.1515/biol-2018-0018

Minhas, P., & Qadir, M. (2024). Promoting irrigation sustainability with saline water: The way forward. In irrigation sustainability with saline and alkali waters: Extent, impacts and management guidelines. In (pp. 295–304). Singapore: Springer

Nations, U. (2017). *Sustainable development-knowledge platform: United nations.* Retrieved from https://sustainabledevelopment.un.org/

Negacz, K., Vellinga, P., Barrett-Lennard, E., Choukr-Allah, R., & Elzenga, T. (2021). Future of sustainable agriculture in saline environments. In (pp. 541): Taylor & Francis.

Niu, G., & Cabrera, R. I. (2011). Irrigating ornamental horticultural plants and crops with saline and alternative water sources in ornamental plants: Types, cultivation and nutrition. In (pp. 161–178): Nova Science Publishers.

Ondrasek, G., Rathod, S., Manohara, K. K., Gireesh, C., Anantha, M. S., Sakhare, A. S., . . . Raihan, F. (2022). Salt stress in plants and mitigation approaches. *Plants, 11*(6), 717.

Oron, G., DeMalach, Y., Gillerman, L., David, I., & Lurie, S. (2002). SW—soil and water: Effect of water salinity and irrigation technology on yield and quality of pears. *Biosystems Engineering, 81*(2), 237-247. https://doi.org/10.56093/jsswq.v16i1.152187

Qamar, N., & Saleem, S. (n.d.). Long-term water availability by sustainably using water resources through water storage and water conservation.

Rahman, M. A., Ahmed, T., & Mojid, M. A. (2020). Coupled irrigation–drainage management practice for HYV rice cultivation with saline-irrigation water: Evidence from lysimeter experiment. *Agricultural Science, 2*(1), p95-p95. https://doi.org/10.30560/as.v2n1p95

Rhoades, J., Kandiah, A., & Mashali, A. (1992). The use of saline waters for crop production-FAO irrigation and drainage paper 48. In (pp. 133). Rome: FAO.

Rosa, L., Chiarelli, D. D., Rulli, M. C., Dell'Angelo, J., & D'Odorico, P. (2020). Global agricultural economic water scarcity. *Science Advances, 6*(18), eaaz6031. https://doi.org/10.1126/sciadv.aaz6031

Roy, S. J., Negrão, S., & Tester, M. (2014). Salt resistant crop plants. *Current opinion in Biotechnology, 26*, 115-124. https://doi.org/10.1016/j.copbio.2013.12.004

Sairam, R. K., & Tyagi, A. (2004). Physiology and molecular biology of salinity stress tolerance in plants. *Current Science, 86*(3), 407–421.

Schlesinger, W. H., Raikes, J. A., Hartley, A. E., & Cross, A. F. (1996). On the spatial pattern of soil nutrients in desert ecosystems. *Ecology, 77*(2), 364–374. https://doi.org/10.2307/2265615

Schofield, R. V., & Kirkby, M. V. (2003). Application of salinization indicators and initial development of potential global soil salinization scenario under climatic change. *Global Biogeochemical Cycles, 17*(3), 4.1-4.13. https://doi.org/10.1029/2002gb001935

Shams, M., & Khadivi, A. (2023). Mechanisms of salinity tolerance and their possible application in the breeding of vegetables. *BMC Plant Biology, 23*(1), 139. https://doi.org/10.1186/s12870-023-04152-8

Sharma, D., & Singh, A. (2015). Salinity research in India-achievements, challenges and future prospects. *Water and Energy International, 58*(6), 35-45.

Sheng, F., & Xiuling, C. (1997). Using shallow saline groundwater for irrigation and regulating for soil salt-water regime. *Irrigation and Drainage Systems, 11*(1), 1-14. https://doi.org/10.1023/A:1005736708632

Singh, A. (2021). Soil salinization management for sustainable development: A review. *Journal of Environmental Management, 277*, 111383. https://doi.org/10.1016/j.jenvman.2020.111383

Sowers, J., Vengosh, A., & Weinthal, E. (2011). Climate change, water resources, and the politics of adaptation in the Middle East and North Africa. *Climatic Change, 104*(3), 599-627. https://doi.org/10.1007/s10584-010-9835-4

Sultan, M. T., Mahmud, U., & Khan, M. Z. (2023). Addressing soil salinity for sustainable agriculture and food security: Innovations and challenges in coastal regions of Bangladesh. In (pp. 100260): Elsevier.

Taylor, P. L., & Sonnenfeld, D. A. (2017). Water crises and institutions: Inventing and reinventing governance in an era of uncertainty. *Society & Natural Resources, 30*(4), 395-403. https://doi.org/10.1080/08941920.2017.1274208

Tester, M., & Davenport, R. (2003). Na+ tolerance and Na+ transport in higher plants. *Annals of Botany, 91*(5), 503-527. https://doi.org/10.1093/aob/mcg058

Tiwari, A. K., Mishra, H., Nishad, D. C., & Pandey, A. (2023). Sustainable water management in agriculture: Irrigation techniques and water conservation. *Dr. Ajay B. Jadhao, 53*.

Uenluekara, A., Cemek, B., Karaman, S., & Erşahin, S. (2008). Response of lettuce (Lactuca sativa var. crispa) to salinity of irrigation water. *New Zealand Journal of Crop and Horticultural Science, 36*(4), 265-273. https://doi.org/10.1080/01140670809510243

Umali, D. L. (1993). Irrigation-induced salinity: A growing problem for development and the environment. In (pp. 215): World Bank Publications.

Vaddula, Y., & Singh, K. (2023). Progression of drip irrigation and fertigation in cotton across the globe and its future perspectives for sustainable agriculture: An overview. *Applied Water Science, 13*(9), 177. https://doi.org/10.1007/s13201-023-01986-3

Wang, H., Feng, D., Zhang, A., Zheng, C., Li, K., Ning, S., . . . Sun, C. (2022). Effects of saline water mulched drip irrigation on cotton yield and soil quality in the North China Plain. *Agricultural Water Management, 262*, 107405. https://doi.org/10.1016/j.agwat.2021.107405

Wang, Q. J., Xu, Y. M., Wang, J. D., Wang, Y. P., & Jiang, Q. H. (2002). Application of saline and slight saline water for farmland irrigation. *Irrigation and Drainage, 21*(4), 73-77.

Wu, Y., Li, Y., Zhang, Y., Bi, Y., & Sun, Z. (2018). Responses of saline soil properties and cotton growth to different organic amendments. *Pedosphere, 28*(3), 521-529. https://doi.org/10.1016/S1002-0160(17)60464-8

You, Q.-G., Xue, X., & Huang, C.-H. (2011). Preliminary study on the effects of saline water irrigation on soil salinization in deep groundwater area: A case study of Minqin oasis. *Journal of Desert Research, 31*(2), 302-308.

Zaman, M., Shahid, S. A., Heng, L., Shahid, S. A., Zaman, M., & Heng, L. (2018). Soil salinity: Historical perspectives and a world overview of the problem. *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*, 43-53. https://doi.org/10.1007/978-3-319-96190-3_2

Zhang, D., Zhang, Y., Sun, L., Dai, J., & Dong, H. (2023). Mitigating salinity stress and improving cotton productivity with agronomic practices. *Agronomy, 13*(10), 2486. https://doi.org/10.3390/agronomy13102486

Zhu, M., Wang, Q., Sun, Y., & Zhang, J. (2021). Effects of oxygenated brackish water on germination and growth characteristics of wheat. *Agricultural Water Management, 245*, 106520. https://doi.org/10.1016/j.agwat.2020.106520

Zribi, L., Fatma, G., Fatma, R., Salwa, R., Hassan, N., & Néjib, R. M. (2009). Application of chlorophyll fluorescence for the diagnosis of salt stress in tomato "Solanum lycopersicum (Variety Rio Grande)". *Scientia Horticulturae, 120*(3), 367-372. https://doi.org/10.1016/j.scienta.2008.10.010