9 Innovations of the 21st Century in the Management of Iranian Salt-Affected Lands

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CONTENTS

9.1	Introduction	147
9.2	Salt-Affected Regions in Iran	148
9.3	Management Strategies for Salt-Affected Area.....	150
9.3.1	Utilization of Floodwaters	151
9.3.2	Leaching	151
9.3.3	Reusing Drainage Waters	152
9.3.4	Dry Drainage	153
9.3.5	Saline Aquaculture	154
9.3.6	Halophytes as Salt-Tolerant Crops	155
9.3.7	Saline Agriculture.....	156
9.3.8	Executive Operations around Lake Urmia	159
9.4	Conclusion	162
	Acknowledgments.....	165
	References.....	165

9.1 INTRODUCTION

All life on Earth is anchored by soil and sustained by water. The European Commission (EC 2006) has highlighted seven functions of soil including biomass production (viz., agriculture and forestry), the storing, filtering and transforming of nutrients, substances and water, as a pool for biodiversity (such as in habitats, species and genes), a physical and cultural environment for humans and human activities, a source of raw material, acting as a carbon pool and as an archive of geological and archaeological heritage. Water is the most widespread substance that plays a crucial role both for the environment and in human life (Stec 2020). However, a range of natural and human-based factors are affecting soil and water functions (Sadeghi et al. 2019; Hazbavi et al. 2020), making them saline in many parts of the world. About 1125 Mha of the Earth's surface in more than 100 countries is affected by salinity, and these numbers are continually growing (Ivushkin et al. 2019). The salinity

problem has been threatening sustainable land development and is one of the significant causes of land degradation from ancient times until now. Salinity is a universal concern for the 21st century because of its accelerating impact on the quality of life, particularly food security. The Middle East, including Iran (i.e., the Islamic Republic of Iran), has significant areas of salt-affected soils (Ivushkin et al. 2019). After India and Pakistan, Iran is one of the most vulnerable countries to salinity (Moameni 2011). Numerous studies have been done to assess, monitor, evaluate, map and combat the salinity of soil and water resources in Iran (e.g., Tavousi et al. 2018; Hazbavi et al. 2019; Salehi and Dehghani 2019; Bagheri 2019; Fathizad et al. 2020; Mahmoodi-Eshkaftaki and Rafiee 2020). The present review summarizes Iranian activities in the salinity area over the first two decades of the 21st century. This research presents a useful road map for future policy making at regional, national and global levels.

9.2 SALT-AFFECTED REGIONS IN IRAN

Iran is located in West Asia; it has an area of 164.8×10^6 ha (163.6×10^6 ha land and 1.2×10^6 ha water bodies) (Qadir et al. 2008). Iran is home to several salt diapirs, lakes and marshes, including Lake Urmia, one of the largest hypersaline lakes in the world. The main soil types of Iran are Xerosols, Arenosols, Regosols, Soloncharks and Lithosols (Siadat 1998). The mass of saline waters in the country is also significant. Shiati (1998) reported that of the country's 100 billion m^3 of water resources, about 11 billion m^3 have a salinity of over 1500 mg L^{-1} . Several rivers of the south, southwest and central parts of the country are saline (Ranjbar and Pirasteh-Anosheh 2015).

Figure 9.1 shows the spatial variation of soil salinity in Iran (Banie 2001). Soil salinity hotspots occur on the Khuzestan Plain, central plateau, southern coastal plain and in the inter-mountain valleys. In addition, about 50% of irrigated lands fall into different categories of salt-affected soils. The salinization of land and water resources in Iran has been the result of natural and anthropogenic conditions. The arable soils of Iran show some evidence of a long history of anthropological interference. Around 11% of Iran is cultivated land, which also includes 8.1 Mha of irrigated agriculture (ICID 2002; Qadir et al. 2008). The latest assessments have shown a 6% increase in the total cultivated area since the late 1990s (Qadir et al. 2008). Average crop yields are higher with irrigation than under dry-farming conditions, and this has led to a 3.8% expansion of irrigated farming systems between the 1980s and early 1990s. During the second national development plan (1993–98), there was an increase of 0.5×10^6 ha in irrigated land which had consequences for salinization. The nonexistence of appropriate water management tools resulted in the low effectiveness of water use; the overall efficiency was ~30%. The level of land affected by salinity also varies in the different provinces of the country. In Khuzestan and Fars provinces, salinity accounts for 32.9 and 16.4% of the land area, respectively; but in East Azarbaijan Province, only 1.36% is affected. Figure 9.2 shows a general view of the soil salinity status in irrigated lands of Iran. Soils with EC_e values of 0–4, 4–8, 8–16, 16–32 and more than 32 dS m^{-1} are, respectively, designated as soils with no salinity, slight, moderate, strong and very strong salinity (World Bank 2005).

FIGURE 9.1 Spatial variation of salinity in Iran. (Source: Banie 2001.)

The oldest report on salinity in Iran comes from Dewan and Famouri (1964) who indicated that saline and alkaline soils accounted for about 12.5% of the country's total area. Other reports have referred to salinity accounting for 25–27 Mha (15–17% of total land area) (Sayyari and Mahmoodi 2002) and 34 Mha (20.6% of the total land area), including 25.5 Mha of low to medium salinity and 8.5 Mha of high salinity (Moameni et al. 1999). Of the total of 6.8 Mha of salt-affected agricultural land, about 4.3 Mha have only salinity limitations whereas the other 2.5 Mha have other additional limitations including a susceptibility to erosion and a shallow depth to water table. In most salt-affected soils in agricultural areas, the depth to the water table is deeper than the root zone. (Areas in which the depth to water-table falls within the root zone are only ~8.4% of the total salt-affected

FIGURE 9.2 Soil salinity levels of irrigated lands of Iran. (Source: World Bank 2005.)

agricultural lands). This suggests that the reclamation of salt-affected lands is technically practical and economically viable (Moameni 2011). In another study, the total area of irrigated land in Iran was 7.3 Mha, and the total area of arable land with varying degrees of salinity of the soil, water, or both was estimated to be 3.3 Mha (Banaei et al. 2004).

Most recently, Moameni (2011) has assessed the geographical distribution and salinity levels of Iran's soils. The results showed that 6.8 Mha of agricultural land have soils with different salinity levels. Of this, about 3.4 Mha have no restrictions other than salinity, and about 2.5 Mha also have additional restrictions caused by variation in texture, depth, drainage coefficient, poor permeability and high risk of erosion; about 0.5 Mha (8.4%) have shallow groundwater problems in the root zone (Moameni 2011). The salinization of land resources in Iran has been the consequence of both natural and human activities (Siadat et al. 1997; FAO 2000; Qadir et al. 2008).

9.3 MANAGEMENT STRATEGIES FOR SALT-AFFECTED AREA

Different research institutes and universities have conducted research on the management of soil and water salinity in Iran for more than half a century. There are many effective ways for improving salt-affected lands, such as water leaching, drainage water management, soil management, chemical remediation, phytoremediation, growth and genetic improvement of salt-tolerant crops and use of irrigation scheduling practices. The first field works to evaluate different techniques for improving salt-affected soils were started in the 1970s by the Soil and Water Research Institute (SWRI; www.swri.ir). The Agriculture Biotechnology Research Institute of Iran (ABRII) was established in 1999 to develop and use modern agricultural technologies to solve agricultural problems, improve food security and community nutritional health and protect essential resources and environmental substrates for sustainable development. This institute carried out a comprehensive project on *Salicornia* to produce forage, oil and other biological sub-products and mitigate

against dust storms. In addition, numerous soil and water scientists, conservationists and ecologists were engaged in projects focused on salinity mitigation, control and management. In 2000, the National Salinity Research Center (NSRC; www.nsrc.areeo.ac.ir) was established to focus on all research activities in the field of salinity. This center now tackles diverse aspects of soil and water salinity problems in different agro-ecological regions. The main areas included in salinity management projects have been in Yazd, Golestan, Fars, Khurasan, Khuzestan, Markazi, Hormozgan (Bushehr), Moghan, Azerbaijan, Esfahan and Qom provinces (Heydari 2019).

9.3.1 UTILIZATION OF FLOODWATERS

The use of seasonal floods in agriculture and horticulture has a long history in Iran and elsewhere in the world. Sabzevar and Khosroshahi (2010) investigated the effects of low-quality floodwater on the desert area of the KaleShoor River, Sabzevar. They concluded that flood irrigation was able to leach gypsum from the root zone into deeper soil layers. This approach was also of benefit in restoring and improving pastures in different areas. By creating a diversion bar on the margin of the BarAbad Desert in Sabzevar, rier, seasonal floods of the KaleShoor River with a salinity of 7–14 dS m⁻¹ were used to revitalize and modify pastures revegetated with *Atriplex canescens* through irrigation once a year. With this treatment, forage production increased from 10 to more than 700 kg ha⁻¹. This practice allowed for the development of dairy farming and decreased rural migration. Though droughts and environmental conditions have caused some parts to be dry in some years, the projected area was increased by more than 3000 ha over 10 years, and species such as *Nitraria schoberi*, *Seidlitzia rosmarinus* and *Haloxylon* spp. were cultivated (Filehkesh and Hashemi Nezhad 2017). Floodwater spreading and floodwater farming have also improved crop production in Africa (Asch and Woperei 2001), America (Nabhan 1979), China (Guo et al. 2008; Seydehmet et al. 2019) and Spain (Hooke and Mant 2002).

9.3.2 LEACHING

The use of soil leaching can decrease the adverse effects of salt on crop establishment (Heydari 2019). This approach is especially relevant to soils with high levels of clay or hardpans in the Khuzestan, Isfahan and Tabriz plains. Khoshgoftarmanesh and Shariatmadari (2002) did a ground survey to explore the leachability of saline soils in Qom Province. Soils initially had EC_e values of 67.1 and 54.7 dS m⁻¹ in the surface and sub-surface layers; leaching water came from rainfall and snowmelt. With leaching after one year, EC_e values in soil were less than EC_w of the irrigation water. Severe symptoms of delayed germination and the burning of leaf margins were observed in control plots without leaching, whilst improved crop yields were reported for plots treated with salt leaching.

Moameni and Stein (2002) and Qadir et al. (2008) concluded that incorporating leaching with an improved drainage system could sustainably ameliorate most of the soils of Iran. Azadegan (2008) noted the benefits of leaching, drainage and sulfur application in improving the quality of *pistachio* orchards growing on saline soils in Garmsar County, Semnan Province. Bazzaneh and Rezaei (2017) evaluated

the leaching of saline-sodic soils using different levels of pure and acidic water in some parts of the Mahabad Plain (West Azerbaijan Province) irrigation and drainage network. In this study, to evaluate the possibility of modification of saline-sodic soils, different treatments with pure and acidified waters at three levels of application (25, 50 and 75 cm) were repeated in a randomized complete block design in three days. The results showed that the lowest and highest percentages of salinity and alkalinity improvement were related to the application of 25 cm pure water or 75 cm acidic water with 24.7 and 41.2% decreases in mean values of exchangeable sodium and 25.9 and 69.0% decreases in EC_e values compared to initial soil conditions, respectively.

The international scientific literature suggests that the leaching requirement varies with the level of salinity in the irrigation water and with crop salt tolerance (Kolahchi and Jalali 2007; Mostafazadeh-Fard et al. 2009; Heydari 2019). In other regions of the world, this technique has been studied and applied to achieve varying target outcomes. For instance, Corwin et al. (2007) described the use of steady-state and transient models to characterize leaching requirements for soil salinity control. Ning et al. (2020) evaluated the irrigation water salinity and leaching fraction on the water productivity of barley, bean, wheat and maize crops in China. The required leaching fraction depended on the salt tolerance of the crop and the salinity of the irrigation water. Despite the advantages of leaching, its application has not always been successful or accepted by decision-makers. Ning et al. (2020) noted that the risk of environmental contamination might be increased due to the leaching of pesticides, nutrients and trace elements. Furthermore, it is worth noting that drought and water crises exist in many regions because there is limited access to freshwater. Using this method for salinity abatement may, therefore, gain less attention in the future.

9.3.3 REUSING DRAINAGE WATERS

The use of drainage and saline waters for agricultural irrigation or other objectives involves several management methods (Nasrollahi et al. 2017). Choosing the appropriate method for releasing or reusing drainage waters mainly depends on the quality of the water concerned. Water with an EC_w of up to 8 dS m^{-1} can be used for the irrigation of salt-resistant crops such as barley, sugarbeet, rapeseed and cotton (Homaei 2003). Nasrollahi et al. (2017) examined the effects of drip irrigation using saline water on corn crops at the research farm-scale, at Shahid Chamran University in Khuzestan Province. Drip irrigation with proper management appeared suited to the reuse of vast quantities of drainage water. Sharifipour et al. (2017) investigated the reuse of saline drainage water using a system dynamics analysis tool (Vensim) in the western part of the Karun River, a region where the land is ~99% saline. Their results showed that, for at least the next 20 years, the quality of drainage water released from south Karkhe and west Karun River Basins will not be suitable for the cultivation of saline resistant crops except for sugarcane. However, the drainage effluent from these areas will be suitable for developing vegetation in rangelands. The most critical challenge in controlling dust production in the south of Khuzestan Province is the supply of water to these areas; vegetation development with these effluents will be possible shortly.

Rhoades and Dinar (1991) conducted a study in the United States on the reuse of agricultural drainage water to increase water supplies for irrigation. They first intercepted and isolated the drainage water from the good-quality water; this water was then reused for the irrigation of suitably salt-tolerant crops, decreasing the volume of secondary drainage water that needed to be disposed of. Hussain et al. (2019) have reviewed the use and management of non-conventional water resources such as saline water, wastewater and graywater for the rehabilitation of the arid and semi-arid MENA (the Middle East and North Africa) regions. They concluded that the recovery of marginal and saline degraded lands via appropriate planning and the sustainable use of different sources of non-conventional water could be an economic and environmental investment.

9.3.4 DRY DRAINAGE

Dry drainage refers to the planting of irrigated crops in slightly higher areas adjacent to lower fallow land. “Drainage” can occur if the irrigation results in the development of a shallow water-table, but the water actually evaporates from the adjacent fallow area (Figure 9.3). This method, initially introduced by Gowing and Wyseure (1992) can contribute to the removal of excess water and salt from irrigated land and control soil salinity (Wu et al. 2009; Mostafazadeh-fard and Ghasemi 2016). Dry drainage is an appropriate alternative management tool where artificial drainage is not applicable (Wu et al. 2009). Dry drainage has been recently introduced into some regions of Iran such as Tehran and Isfahan as a novel method for the drainage of agricultural areas. This method has potential for arid and semi-arid areas with a shallow water-table and high potentials for evaporation

FIGURE 9.3 Diagram of the dry drainage simulation model. (Source: Ansari et al. 2017.)

and capillary rise (Soltani et al. 2017; Ansari et al. 2017, 2019). Mostafazadeh-Fard and Ghasemi (2016) tested the effects on dry drainage of depth to water-table, irrigation water salinity, groundwater salinity and soil salinity. Their results indicated a significant reduction in soil salinity in a study area without polluting surface or underground water. This technology has potential for areas that have an impermeable layer near the soil surface and a hydraulic gradient between the irrigated and non-irrigated (fallow) fields.

In China Wang et al. (2019) also investigated the efficiency of the dry drainage method for soil salinity control at a field location over five years (2007–2011). The established dry drainage system played an important role in draining excess water and salt. Konukcu et al. (2006) evaluated the application of dry drainage in the Lower Indus Basin in Pakistan. This area was characterized by shallow saline groundwater, intensive irrigation and high evaporation. The results showed a satisfying balance between water and salt when the cropped area and sink area were approximately equal, and the water-table depth was around 1.5 m.

9.3.5 SALINE AQUACULTURE

Nakhaei et al. (2018) conducted a project to use brackish and saline water resources in Kerman Province from 2008 to 2009 in the city of Ravar-Shahrbabak-Sirjan-Zarand and Rafsanjan. They concluded that the culture of rainbow trout, sturgeon, seabream, milkfish, carp, tilapia and artemia are feasible. Typical pictures of the artemia ponds established during the project are shown in [Figure 9.4](#). In the study region, there are many saline water sources which are not suitable for agriculture, drinking or industry. In addition, with the movement of salty water towards freshwaters, the volume of freshwater has also been reduced. The results of this research showed that the salinity of these waters varies from 5.12 to 96 dS m⁻¹. Regardless of source, the water ranged in temperature (lowest to highest) from 13.5 to 24.5°C, and the pH varied from 6.8 to 8.6. Manaffar et al. (2020) studied the reproduction and life span characterization of *Artemia urmiana* in Lake Urmia at five sampling stations of Heydarabad, Golmankhaneh, Bari, Kabodan and Eslami. The different environmental conditions at the various locations in the lake caused differences in the growth, survival and reproduction of the fish; best reproduction and life span occurred at the Bari, Golmankhaneh and Heydarabad locations.

At a global level, aquaculture provides more than 50% of food needs, and is estimated to expand to about 93.2×10^9 kg by 2030; aquaculture will therefore be a leading food supply source (Hawrot-Paw et al. 2020). To this end, several technologies are developing to increase saline aquaculture production. For instance, in Poland Hawrot-Paw et al. (2020) used a growth medium containing *Chlorella minutissima* and verified its efficiency in saline aquaculture. In India Debroy et al. (2020) cultured shrimp (*Litopenaeus vannamei*) as a potential species for sustainable production in inland saline waters. High growth rate, tolerance to high stocking density, tolerance to fluctuations in temperature and salinity, utilization of a low protein diet, a high meat yield, easy spawning and high disease resistance were noted as advantages of this shrimp for saline aquaculture.

FIGURE 9.4 *Artemia* culture using saltwater (a) and a sample of the cultured *artemia* (b). (Source: Nakhaei et al. 2018.)

9.3.6 HALOPHYTES AS SALT-TOLERANT CROPS

The importance of salt-tolerant plant species for the restoration of salt-affected soils has been evaluated in several parts of the country (Koocheki 1996). Halophytes are important species in the rangeland communities of salt-affected areas. While close interactions have been recognized between livestock and halophytic communities as forages, these linkages have not been sufficiently employed at scale. Utilizing halophytes for various goals (e.g., for fodder, manufacturing and domestic applications) has been well-received by indigenous people. Qadir et al. (2008) reported that 16 halophytic plant families contain 92% of the halophytic species identified in the country. *Atriplex* is a prospective and economic forage source and is an agent in combating desertification in arid lands (Koocheki 1996; 2000).

The physiological characteristics of nine halophytic forage plants were evaluated at the Research Station of Chah Afzal, Yazd in 2011–2012. There were significant physiological differences between species, which may be related to their ability to produce forage. Amongst the species studied, *Kochia indica*, *Sesbania aculeata* and

Atriplex halimus were selected as superior species due to their higher forage production and low ash, sodium and chloride concentrations (Banakar et al. 2012). Soleimani and Najafifar (2017) investigated the effects of several hand-planted halophytes on the salinity and sodium in soils in southeastern Fars Province. Their results showed that regardless of the depth and distance apart of the plant species, the EC_e of the soil in the shade of plants was significantly higher than outside the shade. The effects were more significant at 0–10 cm than at 10–40 cm depth. Various research has also been conducted on the nutritional value of halophytes, including *Gamanthus gamocarpus*, *Petrosimonia glauca*, *Salsola crassa*, *Halotis occulta*, *Halocaris sulphurea*, *Alhagi* sp., *Gundelia tournefortii* and *Kochia prostrata*. Because of their valuable nutrients, and chemical composition, in arid and semi-arid regions they can act as alternatives to wheat straw and dry hybrid straw and help maintain livestock, such as *Baluchi* sheep (Bashtani 2017). To feed the increasing nourishment needs of the world, different actions are adapted in various countries, e.g., India (Kashyap et al. 2020), Vietnam (Paik et al. 2020), China (Nadeem et al. 2020), Italy (Incrocci et al. 2020), Tunisia (Bani et al. 2020) and Oman (Al-Farsi et al. 2020) to find novel solutions to manage, adapt and improve tolerance of various crops against salinity conditions.

9.3.7 SALINE AGRICULTURE

Saline soils and water are being used in Iran for saline agriculture (Khorsandi 2016). This concept and related techniques such as biosaline agriculture, seawater agriculture, haloculture, haloengineering and halophyte farming, are also being increasingly adopted in Iran. These, along with other methods to combat salinity, offer a range of benefits such as producing sustainable and economic products, erosion control, land reclamation, environmental quality improvement and improving the socio-economic status of local communities; they are in line with the objectives of the Water-Energy-Food Nexus concept, and take into consideration basic human needs (Khorsandi and Siadati 2017).

The feasibility of halophytic plants as new crops was examined for the first time in Iran through the international project (i.e., INT/5/144 “Sustainable Utilization of Saline Groundwater and Wastelands for Plant Production”) (Khorsandi and Siadati 2017). The foundations of haloculture were initiated with the first “biosaline agriculture” research project in Iran (Pedraza 2009). The general principles of haloculture according to the capacities, conditions and needs of Iran are summarized in Figure 9.5.

Because of its range of agro-climatic environments, Iran has a rich genetic diversity of flora, fauna and microorganisms for economic haloculture under different saline situations in a diversity of geographical settings. One example is a successful program of halophytic tree cultivation in the highly saline lands of the Chah Afzal Area, Yazd Province (Khorsandi 2016; shown in Figure 9.6). The generation of energy and management of water are two of the critical activities that occur with haloengineering. Reducing dependency on fossil fuels and on the limited freshwater resources of the country are two goals that could be achieved (Khorsandi 2016; Khorsandi and Siadati 2017).

FIGURE 9.5 General view of haloculture principles and objectives. (Source: Khorsandi 2016.)

A review of literature (Ranjbar and Pirasteh-Anosheh 2015) has shown that halophytes studies began in the last half-century but have substantially increased since 2001. The research focus has been mainly on *Kochia scoparia*, *Portulaca oleracea*, *Chenopodium album*, *Chenopodium quinoa* and *Salicornia* spp.

Quinoa (*Chenopodium quinoa*) from the Amaranthaceae family is a discretionary halophyte and is classified as a pseudo-cereal. The cultivation and growth of

FIGURE 9.6 Haloculture services: (a) bare salty land, and (b) restored salty land using halophytes. (Source: Yazd Province, Iran; Khorsandi 2016.)

quinoa under different conditions has occurred in European countries, the United States, Canada, Morocco, Pakistan and India. Quinoa has different mechanisms to survive salt stress. One of the exciting adaptations of this plant is the presence of salt bladder cells on leaf surfaces and panicles, which can absorb excess salt from the plant cells (Salehi and Dehghani 2019). Quinoa is currently cultivated in many parts of the world because of the value of quinoa seed and its high production potential in harsh environments (Khalili et al. 2019).

The cultivation of quinoa has been considered in Iran in recent years (Figure 9.7), where it is promising and resistant to saline conditions (Salehi and Dehghani 2019; Tavousi et al. 2018). This plant is cultivated in Iran in Sistan and Baluchestan, Khuzestan, South Kerman and Karaj provinces, which showed adaptation in November, late October, early October and the Middle of August, respectively (Tavousi et al. 2018). The main factors of this sound adaptation could be attributed to the appropriateness of temperature and precedent soil moisture. Seed yields of quinoa of 3 t ha⁻¹ have been obtained under irrigation with saline water (EC_w 14 dS m⁻¹) in Iran. Important selection issues for quinoa are photoperiod sensitivity, and salinity and drought tolerance, but the selection of better genotypes for different climates may be possible depending on the availability of sufficient genetic diversity. Quinoa genotypes have produced 4 t ha⁻¹ under rainfed conditions (200 mm rainfall) (Salehi et al. 2018).

The initial establishment of quinoa is affected by irrigation water salinity, initial soil salinity, air temperature, soil oxygen and soil moisture. It is highly tolerant of salinity during germination and can germinate at EC_e values up to 40 dS m⁻¹. However, its susceptibility or tolerance to salinity depends strongly on cultivar.

FIGURE 9.7 Quinoa at the pollination period. (Source: Tavousi et al. 2018.)

Researchers have suggested suitable quinoa cultivars and appropriate areas for quinoa cultivation in the country (Tavousi et al. 2018; Salehi and Dehghan 2019; Bagheri 2019).

In order to examine the effect of electrical conductivity of water (EC_w) and phosphorus levels on some of the characteristics of quinoa plant in greenhouse conditions, a factorial experiment was conducted by Khalili et al. (2019) in a completely randomized design with three replications. The results showed that increasing EC_w to 15 dS m^{-1} (equivalent to EC_e 30.4 dS m^{-1}), decreased plant height by 18.65% and decreased panicle length by 52.4%. When EC_e values reached 183 dS m^{-1} , the sodium concentration in the plants increased by 18.5% compared with the control. Increasing phosphorus application to the soil to 100 kg ha^{-1} increased plant height by 12.3%, increased panicle length by 8.8%, and increased phosphorus concentration in shoots by 12.5%, compared to the control. A comparison of the average interactions between salinity of irrigation water and phosphorus on plant height showed that a salinity of 3 dS m^{-1} increased plant height by 15.1%, compared with the control. Adding phosphorus (100 kg per hectare triple-super phosphate) reduced the effect of salinity stress on the plant (Khalili et al. 2019).

Talebnejad and Sepaskhah (2018) conducted experiments over three years under greenhouse conditions with shallow saline groundwater in Fars Province, to determine the phenology, and responses of quinoa ("Titicaca, no. 5206") to salinity and water stress. Their findings suggested that quinoa could complete its growth cycle and generate a seed yield under Iranian conditions. With full irrigation (800 mm) there was a seed yield of 2.21 Mg ha^{-1} ; with a 70% decline in irrigation there was a 40% decrease in seed yield (to 1.16 kg m^{-3}).

Akhani et al. (2003) described the *Salicornia persica* AKHANI sp. novo (Chenopodiaceae) from the central inland salt marshes of Iran in Esfahan, Fars and Yazd provinces. Zare and Keshavarzi (2007) conducted other research to identify the morphological characteristics of the Salicornieae (Chenopodiaceae) tribe native to Iran.

The Nanobiotechnology Research Institute has conducted a comprehensive plan on the ability of agricultural halophytes to produce forage, oil and other biological sub-products and prevent dust storms. Some important characteristics mentioned for the Salicornieae are including the possibility of irrigation with unconventional saline water and seawater (with a concentration of $27.734\text{--}33.281 \text{ dS m}^{-1}$) producing at least 15 t ha^{-1} dry fodder, a potential yield of 1.5 t ha^{-1} of high-quality edible oil, and a potential yield of $700\text{--}1800 \text{ L ha}^{-1}$ biofuel, application as a meal in poultry nutrition, productive employment creation, high salt storage capacity in aerial parts, saline soils emendation and potential application in bioremediation of heavy metals and petroleum contaminants from soil. Figure 9.8 shows some views of the Salicornieae produced in this project (<http://www.abrii.ac.ir/en/>).

9.3.8 EXECUTIVE OPERATIONS AROUND LAKE URMIA

Lake Urmia (LU) is the one of the largest salt lakes in the world, and is located in northwestern Iran. The Lake Urmia Basin (LUB) has an area of 520 Mha , or 3.15% of the country, and supports a population of more than three million people.

FIGURE 9.8 Implantation of superior *Salicornia* genotypes at the Nanobiotechnology Research Institute. (Source: <http://www.abrii.ac.ir/en/>.)

Fourteen permanent rivers provide the water (3.1 billion m³ annually) needed to maintain LU's water balance. Over the past two decades, unsustainable human activities have put increasing pressure on the natural resources of the LUB and the lake has decreased in size. Intensification of agricultural activities, the development of water resources and the destruction of natural resources, have increased salinity in the water to more than 300 g L⁻¹; recent droughts have worsened the situation (Fanni and Maroofi 2017). The Urmia Lake Restoration National Committee (ULRNC; www.ulrp.ir) was founded in July 2013. It implemented measures during the years 2014 and 2015 to reclaim saline land and control the saline dust blowing off the lake. These measures have included the allocation of 55 billion Rials for

FIGURE 9.9 Production of *Atriplex*, *Nitraria* and *Tamarix* seedlings for planting in the areas around Lake Urmia. (Source: www.ulrp.ir.)

FIGURE 9.10 Surface runoff and sewage control operations in saline lands around Lake Urmia. (Source: www.ulrp.ir.)

FIGURE 9.11 Construction of a quantification station of wind erosion and salt dust events. (Source: www.ulrp.ir.)

LUB restoration objectives, identifying critical areas and sites for geology and soil profiling operations on 7600 ha, combating desertification on 3200 ha using native species (*Atriplex*, *Nitraria*, *Tamarix*; Figure 9.9), improving surface runoff and sewage control operations (Figure 9.10). Land restoration processes and processes to increase plant cover have included the use of curved pits (150 ha), contour furrows (1450 ha) and pitting (1000 ha), seeding (2600 ha) and drainage channels (7500 m), the construction of windbreaks using *Tamarix* planting (528 ha), fence building (3200 ha), grazing management (200,000 ha) and the conservation of forests (300 ha). In addition, a new station to quantify wind erosion and salt dust events has recently been created. This station is equipped with sediment traps (set of three centralized and 64 decentralized traps) and can collect wind deposits at different altitudes (Figure 9.11).

9.4 CONCLUSION

We have discussed some of the crucial research conducted on the management of salt-affected lands in Iran. Table 9.1 summarizes the most important studies. The widely used management activities during the two last decades in Iran were leaching, drainage and irrigation water management, soil amendments application, haloculture, dry drainage, crop rotation systems and saline aquaculture. Use of best management practices (BMPs) in the management of salt-affected areas will be essential in ensuring sustainability and food security without compromising soil and water quality. The key to salinity management centers on assessing, managing and monitoring, whereby the efficiency of management options is monitored and assessed, and modifications are made consequently. Rational salinity management practices must allow for both environmentally and economically sustainable yields and for the restoration of soil and water health. The poor management of salt-affected resources in low-income countries is intrinsically linked to financial and managerial limitations and poor practices in situations of a changing climate, poor infrastructure and poor marketing arrangements.

TABLE 9.1**Summary of Research Done on the Management of Saline Soil and Water Resources of Iran during the Period 2001–2020**

Year	Researcher/s	Approach	Case Study	Land Use	Texture	EC (dS m ⁻¹)	Experiment Type
2002	Khoshgofarmanesh and Shariatmadari	<i>Leaching</i>	Qom Province	Agriculture	-	67.1	Field
2008	Azadegan	Drainage and sulfur application	Garmsar region, Semnan Province	Orchards	Loam-Clay Loam	8.9	Field
2010	Feizi et al.	Leaching	Isfahan Province	Agriculture	Clay	7.7	Field
2011	Yazdanpanah and Mahmoodabadi	Amendments application and leaching	Kerman Province	Agriculture	Sandy Silty	19/81	Laboratory-Soil column
2012	Yazdanpanah et al.	<i>Soil amendments</i>	Kerman Province	Agriculture	Loam	19.81	Laboratory-Soil column
2015	Feizi and Saadat	Irrigation management with salt water	Isfahan Province	Agriculture	Clay	6.8	Field
2015	Saghafi et al.	Rhizobacteria and saline water application	Karaj, Alborz Province	Agriculture	Loam	1.28	Pot
2016	Boostani et al.	Rhizobacteria (PGPR) and Arbuscular mycorrhizae fungi (AMF) application	North of Khuzestan Province	Agriculture	Silty Clay Loam	2	Greenhouse
2016	Khorsandi	Haloculture	Chah Afzal, Yazd Province	Agriculture	-	-	Field
2016	Mostafazadeh-fard and Ghasemi	Dry drainage	Isfahan Province	Agriculture	Sandy Loam Clay	3 and 7	Laboratory
2017	Ansari et al.	Dry drainage	Isfahan Province	Agriculture	Loam	3	Laboratory
2017	Bazzaneh and Rezaie	Leaching	Mahabad, West Azerbaijan Province	Agriculture	Silty Clay	8.4 38.9	Field
2017	Asadi Kapourchal and Homae	Crop rotation and leaching	Ramhormoz, Khuzestan Province	Agriculture	Silty Clay – Clay	44–45	Field

(Continued)

TABLE 9.1 (Continued)**Summary of Research Done on the Management of Saline Soil and Water Resources of Iran during the Period 2001–2020**

Year	Researcher/s	Approach	Case Study	Land Use	Texture	EC (dS m⁻¹)	Experiment Type
2017	Nasrollahi et al.	Drip irrigation with saline water	Ahwaz, Khuzestan Province	Agriculture	Silty Loam	2.5	Experimental site
2017	Soltani et al.	Dry drainage	Aburaihan Faculty, University of Tehran	Agriculture	Loam	5.1–7.4	Farm
2018	Nakhaei et al.	Saline aquaculture	Kerman Province	Water resources close to agriculture and orchards	Different mainly with high sand	7.3–147.2	Field
2018	Hassantabar Shobi et al.	Dissolved organic carbon application	Mazandaran Province	Agriculture	Clay	13.85	Incubation
2018	Talebnejad and Sepaskhah	Quinoa cultivation	Fars Province	Agriculture	-	20	Greenhouse
2018	Ansari et al.	Dry drainage	Isfahan Province	Agriculture	Loam	3	Laboratory
2019	Rousta et al.	Humic Acid compounds application	Yazd Province	Agriculture	Sandy Clay Loam	15.24	Field
2019	Moradi et al.	Organic carbon application	Urmia, West Azerbaijan Province	Agriculture	Sandy Loam	0.58	Pot
2019a	Sharifipour et al.	Leaching and water and drainage water application	South of Khuzestan Province	Agriculture	Clay	-	Field
2019b	Sharifipour et al.	<i>Drainage water management</i>	South of Khuzestan Province	Agriculture	Clay	-	Field

Challenges in salinity research in Iran, include the absence of critical managerial initiatives such as a well-cleared strategic blueprint, a sound research foundation and a lack of teamwork. There will be an increased focus on “precision agricultural” approaches in the future.

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