Chapter 17
Management of Saline Lands in Oman: Learning to Live with Salinity

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Abstract Low rainfall, high temperature, and the past human activities resulted serious salinity problems in today's agriculture in the Sultanate of Oman. Secondary soil salinity has increased rapidly due to the persistent use of saline groundwater, and the extent is increasing due to increased pumping in Batinah region. The balance existing between total pumping and annual recharge before the 1990s has been disturbed that has resulted in the reduction of crop yields and gradual abandoning of lands for agriculture. In addition, seawater intrusion due to overpumping also occurs. In the year 2005, about 18.9–36.0 $\times 10^6$ US$ was lost due to salinity. To tackle salinity problem, a project was undertaken at Sultan Qaboos University to mitigate soil and water salinity. The project focused on four approaches: soil rehabilitation, biosaline agriculture, fodder production, and integration of fish culture into crop production. The project was initiated with the objectives to develop scientifically sound and environment-friendly guidelines for farmers (a) to sustain cost-effective agricultural production in saline agriculture lands irrigated with saline groundwater, (b) to improve food security of Oman, and (c) to combat desertification in agricultural lands to avoid abandonment. The salt-tolerant varieties of tomatoes, barley, sorghum, and pearl millet have shown promising results for successful cultivation in saline soils. Surface mulching with a thin layer of shredded date palm residues resulted in lesser salt accumulation and more crop yield than other methods. The fodder grown in saline soils using saline irrigation water did not affect growth and meat quality of sheep fed with this fodder. The incorporation of aquaculture in saline areas was proven feasible and profitable.

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17.1 Introduction

Soil salinity has emerged the most significant problem of present-day irrigated agriculture in the Sultanate of Oman. Due to hyperarid conditions, scanty rainfall and high temperature caused the soils to become saline. The past human activities of using saline groundwater in agriculture proved driving factor to form secondary soil salinity, which is persistently increasing at an alarming rate due to increased pumping in Batinah region. The region is the main focus for agriculture encompassing 80,000 ha (Cookson and Lepiece 2001), where salinity is seriously threatening sustainable agriculture. General soil survey of the region also indicated the severity and extent of the problem (MAF 1990).

The balance between the annual pumping and recharge before 1990s has significantly been disturbed, which has initially reduced the ultimate crop yields and gradually led to abandoning lands for agriculture. Seawater intrusion due to consistent overpumping also influenced agriculture in near sea areas, and good productive lands are desertified. Currently, 44% of the total geographical area is affected to varying degrees of salinity, which accounts to 70% of area suitable for agriculture. Recently, Hussain (2005) has reported 18.9–36.0 million US$ annual losses due to only salinity. The abandoning of land for agriculture increases unemployment and hence disturbed the socioeconomic status of the society. It is now obvious that salinity mitigation is a prerequisite to keep agriculture alive in Oman.

The integrated study of North Batinah indicated the upward trends of salinity buildup in agriculture areas. The study recommended ways to tackle salinity problem through creating balance between groundwater pumping and annual recharge. A shift in cropping strategy was also emphasized through replacing perennial grasses by seasonal fodders and farm crops (MAF 1993). The importance of the problem has been highlighted from time to time (Qureshi 1995). A comprehensive review (Ahmed et al. 2004) also enlightened the salinity problem and indicated the prospects of biosaline agriculture in Oman. Follow-up to this review, a 10-year (2005–2015) strategic salinity management plan was prepared (Hussain 2005). This plan identified short-, medium-, and long-term salinity management strategies for the stakeholders such as government, farmers, extension workers, and the researchers. The plan also pointed out that past efforts were inadequate to successfully address the problem.

Realizing the problem of salinity increase in Oman, a budget of 95,000 Omani rials (1 OR = 2.58US$) was allocated from HM Fund to implement a project on "Management of Salt-Affected Soils and Water for Sustainable Agriculture" during 2006–2009. The project was started with the objectives (1) to conduct research and evolve techniques to mitigate soil and water salinity (Ahmed et al. 2010; Al-Rawahy et al. 2010) and (2) to identify and promote of appropriate solutions which are environmentally sustainable. Such an important project was necessary due to the need to utilize marginal lands. To achieve the objectives, the project was focused on four approaches: soil reclamation, biosaline agriculture, fodder production, and integration of fish culture into crop production to explore compensatory economic returns to the farmers.

17.1.1 Climate, Soils, and Water of Oman

The Sultanate of Oman is located in the southeast corner of the Arabian Peninsula. It is an arid country with a mean annual rainfall of less than 100 mm. Rainfall is irregular from year to year, and most of the months around the year can be totally dry. Groundwater is the main water resource of the country. The net annual natural recharge to the groundwater has been estimated to be around 1,260 million cubic meters (MCM). The total water demand is around 1,650 MCM of which 90% is used for agriculture. The deficit of 390 MCM is drawn from the groundwater reserves (Abdel Rahman and Abdel-Majid 1993). In Al-Batinah, the main agriculture zone of Oman, the mean annual temperature is 28.6 °C, relative humidity is 58%, wind speed is 221 km day^{-1}, and sunshine hours are 9.7 h day^{-1}.

The land resources suitable for agriculture are limited, as only 7.07% of the soils are suitable for agriculture, equaling to 2.22 million ha of the total land of Oman, which is not insufficient for the population of the country, with the condition that sufficient water is available and all the land is exploited for agriculture; however, this is not the current situation, and hence, Oman has to import food to meet its food demand. The Al-Batinah plain is formed from very thick alluvial, marine, and aeolian sediments (MAF 1993). In the last three decades, there has been tremendous growth in agriculture; as a consequence of this growth, excessive pumping of groundwater resulted in seawater intrusion into the coastal aquifers and has caused the problem of soil salinity in many parts of the Al-Batinah plain. Major crops grown in this area include date palm, lime, alfalfa, vegetables, fruits, Rhodes grass, and other fodder crops. According to a study conducted by MAF (1993), 50% of the agricultural area in the South Al-Batinah is reported to be affected from slight to moderate salinity ($EC_e > 4$ dS m^{-1}) levels, and the major part of the salt-affected soils is Gypsiorthids (gypsiferous). In Oman, salt-affected soils belong to two soil orders (Aridisols and Entisols), and four suborders – Salids, Psamments, Fluvents, and Orthents (Hussain et al. 2006). The soils of South Al-Batinah are mostly moderately alkaline (pH 7.9–8.4). Calcium and magnesium are the main cations saturating the soil exchange complex. Organic carbon and nitrogen contents are usually low (less than 1%). The average topsoil calcium carbonate equivalents are about 37% in Barka and 26% in Masanaa and Suwayq areas (Qureshi 1995). In the North Al-Batinah, about 50% of the total cultivated land is irrigated with water of EC more than 3 dS m^{-1}, and approximately 38% is irrigated with water of $EC > 5$ dS m^{-1} (MAF 1997).

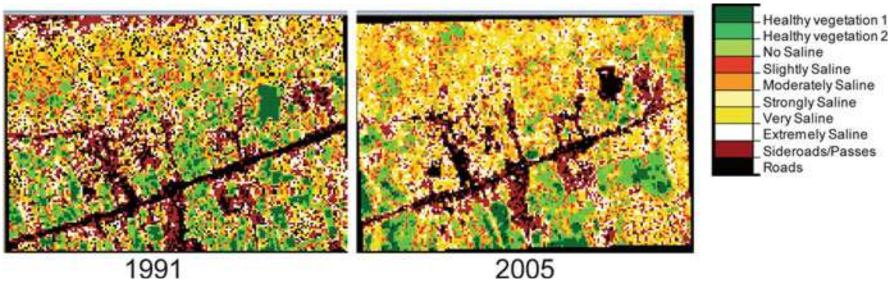

Fig. 17.1 NDSI analyses on 1991 and 2005 satellite image show clearly how soil salinity increased in 2005 (Adopted from Al-Mulla and Al-Adawi (2009))

17.1.2 Losses Due to Salinity

The salinity problem was timely highlighted in the integrated study of the Batinah area; however, necessary actions were not taken to address this menace. Resultantly, the problem has aggravated further in Al-Batinah. Recent study (Al-Mulla and Al-Adawi 2009) has indicated significant expansion of salt-affected soils in Al-Batinah area (Fig. 17.1), and as a consequence of this, many date palm farms have been abandoned. Thus, the earning source and the livelihood of the farmers were taken off by the salinity, and many become jobless. In other farms which are presently under cultivation, yield is gradually decreasing, leading to uneconomical farming. In 2005, it was realized that current estimates on the extent of salinity and its affect on the losses do not exist; therefore, some estimates were made by Hussain (2005). To estimate the losses, some assumptions were made, e.g., 25 and 50% yield losses and the gross margins are coming from crops/trees which could be grown on the abandoned lands due to salinity. The area under different land utilization types and the gross margin values were taken from the Integrated Studies of Batinah (1993–1997). It was estimated that in Oman, annual losses due to soil salinity are from 6.7 to 13.3 million Omani rials. If the losses from abandoned date palm farms are also included, then the losses range between 7.3 and 14.0 million OR per annum.

17.1.3 Salinity Research in Oman

17.1.3.1 Basic Principles

The following principles for future research in Oman are suggested as a guide to all researchers and managers of the related fields:

- The techniques to be evolved should be cost-effective and acceptable to the farmers. The concept of applied research should remain the main focus. Basic

research should only be undertaken when it is essentially required to understand or verify certain concepts and phenomena under prevailing conditions of Oman.
- All future research concepts should be central to water-saving strategies.
- All modern technologies including but not limited to tissue culture and manipulation of DNA should be adapted in addition to conventional methodologies.
- Duplicity of research with respect to time and space must be avoided.
- Multidisciplinary and integrated approach to be used to address complex salinity problem.

17.1.3.2 Future Research Priorities

The short-, medium-, and long-term strategies devised by Hussain (2005) and modified to fit Omani conditions, to effectively achieve the future goals of salinity research should be considered and undertaken stepwise.

Short-term research priorities (*1–3 years*)

- Assessment, mapping, and monitoring of soil and water salinities to understand the changing trends for better resource use and management.
- Evolving of economically sound, socially accepted, and easily adaptable management practices to utilize saline waters.
- Understanding of nutrient dynamics for crops grown in saline environments.
- Management and revegetation of saline soils using salt-tolerant crops/plants.

Medium-term research priorities (*1–5 years*)

- Establish leaching requirements/leaching fraction of saline waters for important crops and fruit trees grown in Oman.
- Conduct salt tolerance studies involving major crops, bushes, and fruit plants grown in Oman.
- Establish fertilizer requirements of fruit trees in saline environment.
- Monitoring and management of salt accumulation in plant root zone when using drip and bubbler irrigation systems.
- Evaluate critical limits of water EC on different crops to establish salt burn effects under sprinkler irrigation.
- Conduct research on the reuse of saline drainage water from agricultural fields.

Long-term research priorities (*more than 5 years*)

- Identification, screening, and domestication of natural and exotic salt-tolerant genetic material, and testing of new plants capable of withstanding seawater salinity and are of economic importance.
- Conduct breeding/grafting experiments (using salt-tolerant root stock) for salt tolerance.
- Conduct multidisciplinary and integrated long-term research trials.

17.2 Recent Research Findings

17.2.1 Effect of Mulching

Surface mulching has significantly reduced water losses through evaporation. Mulching has conserved moisture in the root zone and decreased salt accumulation. This study was conducted to compare the effects of two different mulching materials (date palm leaves and black plastic in addition to control without any mulch) and resultant growth of sorghum (Al-Dhuhli et al. 2010). There were two levels of water salinity (3 and 6 dS m^{-1}) and three levels of water application rates (ETc., 1.2 ETc., and 1.4 ETc.). The study revealed that date palm leaf mulch was more effective in conserving soil water content, reducing salt accumulation in the soil, reducing soil temperature, and resulting in higher yield of sorghum compared to the plastic mulch that was successful to maintain moisture at even higher level than date palm mulch, but use of plastic cover raised soil temperature that resulted in lowering the yield of sorghum.

17.2.2 Leaching Requirements

A field experiment was conducted to investigate the effect of saline water irrigation and leaching fraction on barley (*Hordeum vulgare* L.) growth (Al-Busaidi et al. 2010a). For this purpose, highly saline water was diluted to the salinity levels of 3, 6, and 9 dS m^{-1} and applied by drip irrigation at 0.0, 0.15, 0.20, and 0.25 leaching fractions (LF). The results of the experiment showed that both quantity and quality of water regulated salt distribution within the soil. The salts were found higher near or immediately below the soil surface. An enhanced LF carried more salts down the soil horizon, but there was no significant difference in plant yield between different treatments of leaching fractions; however, the saline water significantly impaired barley growth. The good drainage of sandy soil enhanced leaching process and minimized the differences between leaching fractions. The increment of salts in irrigation water treatments added more salts and stressed the plant growth. It is visualized that the conjunctive use of marginal water at appropriate LF could be effective to enhance the yield potential of crops in water-scarce areas.

17.2.3 Crop Selection: Tomato

Pot experiments were conducted to evaluate the effects of saline water irrigations on five varieties of tomato (4, 22, 38, 46, and 54) (Al-Busaidi et al. 2010b). These varieties are commercially available in Thailand and Pakistan but have not been specifically tested for salinity tolerance. Plants were irrigated with diluted seawater adjusted to three levels of electrical conductivity: freshwater (control) and 3 and

6 dS m^{-1}. The results of the experiment showed that saline waters remarkably affected the evapotranspiration rate, soil moisture, salts accumulation, and plant biomass production. Saline irrigation had the ability to keep much water in the soil with higher level of salt content. Low-salinity treatment exhibited highest plant growth and lowest soil moisture and salt deposition. The difference in soil moisture is due to higher water uptake by plants in low salinity condition as well as reduction of evaporation for saline water. Variety numbers 38 and 46 gave the highest values for fruits number and weight. Whereas, variety number 22 got the lowest values. However, variety number 4 was the tallest and had the highest value for green matter even under high-salinity treatment. Overall, under saline conditions, it was observed that all plant parameters of different varieties were reduced compared to the control except for the number of fruits of some varieties such as 38, 46, and 54. However, fruit weight for variety number 38 was enhanced by saline irrigation which could be a good sign for salt tolerance in saline conditions.

Growing tomatoes using saline water and in conditions where soil has low nitrogen and other essential nutrient contents is of great challenge. A field experiment was conducted on using different levels of saline water and fertilizer for growing tomatoes (Al-Yahyai et al. 2010). The objectives of this work were (1) to examine the yield and quality of tomato (*Lycopersicon esculentum* L.) grown under three levels of saline water and (2) to study the effect of different types of fertilizers on the yield and fruit quality of tomatoes grown under saline conditions. A two-factor completely randomized design experimental plot was set up at the Agricultural Research Station, Rumais, Oman. Tomatoes were grown in sandy soil and irrigated with three levels of saline water ($EC_w = 3$, 6, and 9 dS m^{-1}). Three types of fertilizers were applied including: inorganic NPK, organic (cow manure), and a mixed fertilizer of both. Tomato plants were grown during the months from November to April and for two consecutive seasons. Total fruit number and weight of harvested tomatoes were determined. Results indicated that growing tomatoes under 3 and 6 dS m^{-1} irrigation water produced the highest yield, whereas irrigating with 9 dS m^{-1} significantly reduced the final fruit number and fruit weight. Tomatoes grown using cow manure produced the least amount of yield compared to those fertilized with inorganic and mixed fertilizers. Measured fruit quality attributes were not significantly affected by salinity or fertilizer treatments. The data on fruit quality and yield suggest that the best growing conditions for tomatoes were in plots irrigated with 6 dS m^{-1} water and with mixed fertilizer.

17.2.4 Crop Selection: Pearl Millet

Five genotypes of pearl millet (*Pennisetum americanum* L. Leerke), namely, IP 19586, Sudan Pop III, IP 6104, IP 6112, and IP 3616, proven superior in performance against salinity were subjected to study their response to four levels of irrigation water salinity, namely, control (1 dS m^{-1}), 3, 6, and 9 dS m^{-1}, consecutively, during summer seasons of 2007 and 2008 (March–April to May–June) under field conditions

(Nadaf et al. 2010). The results indicated that the effects of years and salinity were significant ($p<0.05$) to highly significant ($p<0.01$) for plant height, number of tillers, leaf length, chlorophyll content, green matter, and dry matter yields. The main effect of years was found to be highly significant ($p<0.01$) for number of leaves, leaf width, and % dry matter. Besides, interaction effect of years x salinity was significant ($p<0.05$) to highly significant in respect of plant height, leaf width, chlorophyll content, and % dry matter, whereas interaction effect of genotypes x salinity was significant ($p<0.05$) only for chlorophyll content. However, main effect of genotypes and other interaction effects were found to be nonsignificant ($p>0.05$).

Salinity tolerance of pearl millet genotypes was assessed using the concepts of both stress susceptibility index at each higher salinity level in relation to control and mean value over the salinity treatments with respect to each character. The most tolerant genotypes were selected considering the information of all the characters under study. Mean values across the salinity treatments could discern the general ability of salinity tolerance of these genotypes, as these were originally selected for their superior performance under irrigation water salinity ranging from 5 to 11 dS m^{-1}. Hence, their mean performance over tested salinity levels was found to be insignificant ($p>0.05$) in respect of each character. However, salinity tolerance of the genotypes for each salinity level in comparison with their performance at control could be accessed through their stress susceptible index (SSI) values. Among all the genotypes tested at 3 dS m^{-1}, salinity tolerance of IP 3616 was of higher degree and more consistent as it scored low SSI values in respect of four characters, namely, plant height, number of leaves, leaf width, and chlorophyll content, out of eight characters studied. At 6 dS m^{-1}, salinity tolerance of IP 6104 was of higher degree and more consistent as it scored low SSI values in respect of five characters, namely, plant height, number of tillers, leaf width, green, and dry matter yields, out of eight characters studied whereas at 9 dS m^{-1}, salinity tolerance of IP 3616 was of higher degree and more consistent as it scored low SSI values in respect of four characters, namely, plant height, leaf length, leaf width, and chlorophyll content, out of eight characters studied. However, IP 6112 was also found to possess higher degree of tolerance because of its low SSI values for both green and dry matter yields. All other genotypes, however, responded differentially to different levels of salinity for different characters.

17.2.5 Salinity and Soil Microbiology

A study was conducted to investigate the effect of salinity on growth, reproduction, and production of pectolytic enzymes by *P. aphanidermatum*, the main causal agent of damping-off and wilt diseases of many vegetable crops in Oman (Al-Sadi et al. 2010). A survey in 129 greenhouses from different districts in Oman showed that the salinity level of irrigation water in greenhouses varies from 0.41 to 7.7, with an average of 1.47 dS m^{-1}. About 26% of greenhouses in Oman were found to be irrigated with water having an EC above 1.7 dS m^{-1}. Increasing irrigation water salinity from 0.01 to 50 dS m^{-1} showed negligible effects on growth of *Pythium* in sand culture. There was no effect of salinity on the growth of *Pythium* at salinity levels between 0.02 and 5 dS m^{-1}. In addition, oospore production by *Pythium* was not affected at salinity levels below 5 dS m^{-1}, but no oospores were produced above 20 dS m^{-1}. The activity of pectolytic enzymes produced by *P. aphanidermatum* is decreased but not prevented at high salinity levels. Findings from this study show limited effects of salinity on growth, reproduction, and pectolytic enzyme production by *P. aphanidermatum*.

17.2.6 Fodder Production Under Saline Conditions

Alfalfa is one of the major crops grown in the Batinah region. However, current high water salinity presents a challenging situation to grow this crop especially if we consider efficient water use in forage production. A study was conducted to evaluate the performance of alfalfa in terms of productivity and water-use efficiency (WUE) under different regimes of water salinity levels and irrigation levels (Al-Lawati et al. 2010). Three levels of water salinity were applied: 1, 3, and 6 dS m^{-1}. Three levels of irrigation were applied: 125% (125ETc), 100% (100ETc), and 75% (75ETc) of actual evapotranspiration (ETc.). Split-plot design was used, where water salinity level was the main plot and irrigation level was the sub-plot factor. Results showed that productivity of alfalfa of cumulative fresh biomass yield was significantly ($p \leq 0.05$) higher for the treatment of irrigation levels of 125ETc (13.90 kg m^{-2}) compared to 100ETc (12.45 kg m^{-2}) and 75ETc (10.90 kg m^{-2}) at salinity level of 1 dS m^{-1}. Productivity decreased with increasing water salinity, and the differences in productivity among irrigation levels were diminished. Water-use efficiencies were higher at 1 dS m^{-1} across the irrigation levels and generally decreased with increasing water salinity levels. Water-use efficiency was significantly ($p \leq 0.01$) higher for irrigation level of 75ETc than 100ETc and 125ETc across all salinity levels. The highest WUE was for the treatment of 75ETc and salinity level of 3 dS m^{-1} (0.804 kg of dry matter m^{-3}), and the lowest was for the treatment of 125ETc and salinity level of 6 dS m^{-1} (0.407 kg of dry matter m^{-3}). These results suggest that increasing irrigation water level up to 125% of ETc. for low water quality of 6 dS m^{-1} will not perform well either for increasing alfalfa productivity or WUE. Efficient water use for such water quality may reach within the range of 75ETc and 100ETc.

17.2.7 Effect of Feeding Fodder Grown in Saline Lands on Animals

This study was conducted to use salt-tolerant sorghum (*Sorghum vulgare*, *S. bicolor* L.) that has a potential to use saline soil and provide a good source of roughage for livestock feeding in Oman (Al-Khalasi et al. 2010). Sorghum variety Super Dan was planted and irrigated with three levels of saline waters: S3 (3 dS m^{-1}), S6 (6 dS m^{-1}), and S9 (9 dS m^{-1}). Sorghum was manually harvested, dried, chopped, and fed to experimental animals. Thirty-two, 3-month-old male Omani lambs were randomly distributed according to body weight (BW) into four groups of eight lambs each. The first group was fed a control diet of Rhodes grass hay (RGH) plus a commercial concentrate. The other groups were given sorghum hay irrigated with the three different levels of water salinity (3, 6, 9 dS m^{-1}) each. Daily feed intakes and weekly body weights were determined. A digestibility trial was carried out on 12 animals (three sheep per diet) consisting of 10 days of adaptation and a subsequent 10 days collection period for feces and urine. Blood samples were drawn three times during the experiment and analyzed for hematological and serum biochemistry levels. At the end of the trial, the animals were slaughtered. Chemical analyses indicated that RGH had higher mineral content than sorghum forage grown under various levels of salinity. Animals fed with sorghum-based diets did not show signs of ill-health. Hematological and biochemistry investigations showed no treatment effects on blood parameters. There were no differences ($p > 0.05$) in digestibility coefficients of acid detergent fiber and neutral detergent fiber and ether extract between RGH, S1, S2, and S3 diets. However, the S1 diet had lower DM, Ca, CP, P, and energy digestibilities but higher ash content. There were no treatment effects on hay, concentrate, or total feed intake; total body weight gain; or gain per kg per body weight of experimental animals. Sheep fed with RGH, S1, S2, and S3 diets had average daily body weight gains of 96, 84, 82, and 68 g day^{-1}, respectively. There was no diet effect on rumen condition except that RGH-fed animals had lower N-ammonia and butyric acid concentration. Also there were no significant differences on body composition, carcass characteristics, and meat quality or minerals contents. However, the RGH-fed animals had higher S and Zn contents in feces and S content in their meat. The heart weights were significant with S2 group having the highest. Transmission electron microscopy for sheep kidneys and livers showed no morphological and pathogenic problems for all animals at different treatments. This study indicated that sorghum forage grown under high salinity levels may be used for feeding Omani sheep without adverse effects on health, performance, or carcass and meat quality characteristics.

17.2.8 Fish Farming in Salt-Affected Farms

Since 2003, integrated tilapia culture has been introduced at a number of sites in the Sultanate of Oman. Nile tilapia (*Oreochromis niloticus*) and red hybrid tilapia (*Oreochromis* sp.) have been grown successfully across a range of salinities (0–20 ppt) confirming previous studies on optimal salinities for growth conducted elsewhere. In order to study the mineral cycle, the mineral content of commercial fish feed and effluent from experimental fish production tanks was determined (Goddard et al. 2010). The tanks were supplied with brackish groundwater at 3 and 6 ppt and stocked with red hybrid tilapia (initial stocking density 100 kg m^{-3}). When tilapia were cultured intensively in tank systems, with low daily water exchange, some dissolved nutrients including magnesium, calcium, sulfur, and boron accumulated to approach or exceed levels suitable for fertilizing vegetable crops. Some key nutrients, including nitrogen, potassium, and phosphorus were deficient. In a preliminary trial, low-salinity, tilapia effluent was shown to support the early growth of tomato plants in a hydroponic culture system.

17.2.9 Salinity Monitoring

Al-Mulla and Al-Adawi (2009) worked on mapping changes in soil salinity with time in Al-Rumais (near Barka) using remote sensing analysis (Al-Mulla 2010). They used two satellite images, a 1991 Landsat (TM) and a 2005 Landsat (ETM+) (Fig. 17.1). They performed different image enhancements on the two satellite images in order to separate between the features in these images to assist in delineating salt-affected soils. They included the use of different spectral indices like NDVI, II, SAVI, and Normalized Difference Salinity Index (NDSI) in addition to detection of temporal changes in soil salinity using change analysis techniques.

17.2.10 Socioeconomic Impacts of Salinity

The farming in Batinah region has deteriorated to a significant extent during the last two decades. Besides the technical reasons like salinization of lands, seawater intrusion in the area, and worsening of groundwater quality that affected crop yields adversely, there have been socioeconomic considerations that have contributed toward this deterioration. Therefore, it was warranted that such socioeconomic reasons and background facts must be investigated, identified, and enlisted for future accurate planning so that these are properly addressed. For this purpose, a socioeconomic survey was undertaken (Zekri et al. 2010). Sixty-one sample farms spread throughout in the Batinah region were randomly selected for this study with the help of local agricultural extension workers. All the socioeconomic data were collected through interviews, while soil and water samples were collected and analyzed with the help of technical personnel.

The collected data indicated that farmers of age 25–80 years were engaged in farming with an average family size of 13 members. None of the farmers is merely and solely dependent upon farm income only. Rather, most of them are farming partially because either they are retired from jobs or still in government or private job. Single ownership is about 69%, while the rest is combined with brothers, sisters, and other relatives. Majority of farms (61%) are less than 4.2 ha in size. The number of workers per farm varies from 2 to 6 with 113–164 working days per cropped ha and having salaries of 62–77 OR per month. The affected area from salinity was found mainly (60%) in small farms of less than 2.1 ha, while it was 23% in farms of size over 4.2 ha. All the Willayat were affected from salinity problem, but Shinas was the worst (47% area) in this regard followed by Musanaa (35%) and Barka (30%), respectively, while Suwaik was relatively better (7%) in this regard. The total area under perennials (date palms, mango, lemon, banana, and fodder crops) and seasonal vegetables was almost equal (51:49), but bigger farms were growing seasonal crops on more areas (58%) than medium (43%) or small farms (12%) because highly saline (>7,040 mg l^{-1}) water was more on small farms (15% out of 21% for the area). Potato was the crop giving the highest gross margin (OR 2519) followed by mango (OR 1395) and water melon (water melon OR 1031 and melon OR 1010) when the irrigation water was of low salinity (<3,840 mg l^{-1}). The gross margin decreased significantly with increasing salinity of irrigation water, especially for seasonal crops.

17.3 Salinity Management

Soil and water salinity will remain as a serious problem in the Sultanate of Oman as long as the highly saline water is going to be utilized for irrigation by the farmers. Farmers are forced to use this water due to severe scarcity of good-quality water. As stated earlier, unplanned pumping of good-quality groundwater in the Batinah plain created a large deficit between annual recharge and utilization. This not only increased the usage of highly saline groundwater, but also seawater intrusions have occurred. As a result, land degradation, salinization, desertification, abandoning of fertile date palm orchards, and significant losses in yield of crops are clearly visible. This situation demands clear policy decision by the government and framing of laws to implement such decisions. The farmers, researchers, and agricultural extension workers have to work together rigorously to formulate techniques for the management of saline waters and lands in such a way that not only no further losses should occur to the natural resource base but also gradual improvement and reversion to the original level should be encouraged. Some of such policy decisions, activities, techniques, and strategies (short, medium, and long term) have been suggested in this chapter.

17.3.1 National Policy Issues

There are certain policy issues and actions essential for tackling soil salinity problem. However, these can only be considered by the government for implementation:

- Construction of recharge dams and dikes at all potential sites to collect rainwater. Recharge of aquifer through rain water will keep the groundwater quality reasonable. It is only possible if recharge is regularly and consistently occurring.
- Banning of farming and pumping of groundwater for lands upstream declared unsuitable for agriculture in National Soil Survey, 1990.
- Establishing a net balance between annual total pumping and recharge should be the ultimate target. Regulations are needed to be prepared and implemented for

the replacement of Rhodes grass with seasonal fodders like pearl millet and sorghum that have been proved to be relatively salt tolerant but require far lesser water than Rhodes grass.

- Subsidies should be provided to rehabilitate abandoned saline lands that were originally having good potential. If a farmer wants to sell his saline land at all or change its use from agriculture to nonagriculture, his land may be acquired by the government, and he may be compensated with alternate land that has been declared unsuitable for agriculture due to different limitations but can be used for nonagricultural purposes. The agricultural lands were developed over thousands of years and must be protected and quality preserved as a national nonrenewable resource for the future generation. In this regard, necessary regulations can be formulated and implemented by the government, especially the Ministry of Agriculture (MoA).
- It is strongly recommended to establish an independent National Soil Salinity Research Institute in Oman to address all salinity-related issues and research activities and provide technical support. As a beginning, a specialized soil salinity unit should be established within MoA, which has all essential resources (infrastructure, equipment, and manpower) to address salinity issues from assessment, mapping, and monitoring to modeling and conducting salinity-focused research.
- Special budget allocation for salinity research should be earmarked, and multidisciplinary projects addressing all aspects of salinity should be prepared and implemented.
- Separate training programs for researchers, extension workers, and farmers regarding management of soil and water salinity should be implemented.
- A gradual change in cropping system must be encouraged and implemented at government level. Perennial crops and grasses should be replaced by annual crops and vegetables to save the excessive pumping of water. A law should also be framed and implemented to control unlimited and unnecessary pumping of groundwater.

17.3.2 Proposed Soil Salinity-Related Activities for the Agricultural Extension Staff

Continuous, collaborative, and concerted joint efforts of all stakeholders are required to deal the soil salinity problem in the country. Agricultural extension workers have to play a key role in minimizing soil salinity effects through technology transfer from research institutes to the end users (the farmers and owners of salt-affected lands) in the following ways:

- Document the extent and temporal variation of soil salinity in the respective area of each worker. The cumulated values will ultimately give the accurate estimate for the region and the country. Thus, the extent and location of the affected area will become available.

- Inventory of farmers who have abandoned their lands due to salinity problem.
- Learn the new techniques evolved by research organizations to use and manage saline lands and waters and the research organizations to conduct specialized training programs to educate farmers about new technologies and also to conduct field days to demonstrate the success stories.
- Transfer the established technologies through farmer meetings, training programs, radio and TV talks, and distribution of brochures and pamphlets.
- Render advisory service to farmers through relevant organizations. Soil and water testing from farmers' fields should be completed and based to formulate appropriate recommendations and their implementation at farmers' field through relevant research organizations and agricultural extension workers in a close and collaborative manner.

Guidelines for the farmers

- Close contact of extension and research workers with farmers to learn site-specific problems and seeking solutions.
- Provide recommendations to farmers based on soil and water testing results.
- Convince farmers for gradual replacement of Rhodes grass with seasonal fodders like sorghum, barley, wheat, oats, and fodder beet.
- Guide the farmers for successful shifting from conventional to modern irrigation systems.
- Guide the farmers in water-saving techniques to avoid wastage and for optimum water use for crops.
- Lobby the farmers to avoid the change of land use and selling lands for nonagricultural uses.

17.3.3 General Recommendations for the Management of Saline Lands and Water

The following techniques and options can be adopted for the management of saline water and land by the farmers and land owners to use these marginal resources effectively to avoid further degradation (Hussain et al. 2010):

- Farmers should make soil and water testing on a regular basis to understand the changing faces of soil and water salinity in their farms.
- Where salinity is showing effects, it is recommended to grow only salt-tolerant crops like date palm, sorghum, pearl millet (ICBA varieties; IP 3616, IP 6104 and IP 6112) wheat, barley, tomato, spinach, and alfalfa, matching the salinity level of soil and water for the specific farm.
- The integrated and mixed farming comprising of arable crops, livestock, cow and goats, and fish ponds can be adopted to increase income and employment. Sorghum irrigated with water up to EC 9 dS m^{-1} may be used safely as a feed for Omani sheep because no health problems such as diarrhea, constipation, or anorexia was observed in experiment on animals.

- Saline water should be used 20–30% more than the crop requirements (to meet leaching requirements) to flush salts from root zone to minimize harmful effects on plants. However, when the water is highly saline (EC > 9 dS m^{-1}), this strategy may not work, and some other nonconventional plants have to be grown.
- Application of organic matter or organic fertilizers are recommended to improve physical properties of sandy soils (to improve water- and nutrient-holding capacity), to provide to some extent the essential nutrients, and to mitigate the adverse effects of saline water. In heavy soils, these organic materials improve soil structure and increase soil permeability and help leaching salts below root zone through improving drainage conditions.
- Using the date palm leaves as mulch for growing tomato and sorghum proved useful. It reduces evaporation, decreases accumulation of salts, saves water and keeps the soil moist for longer time, and keeps the root zone cool.
- Modern irrigation system like drip or bubbler can save water, but sprinkling of highly saline water should be avoided, as it may cause salt injury to leaves.
- Lands should be kept leveled for uniform water distribution.
- Deep plowing should be used where dense or harder layer exists to improve drainage to avoid salt buildup.
- Root zone should be washed prior to sowing to leach the salts. Frequent irrigations during growth of crops will be helpful to avoid harmful effects of salts.
- High seeding rate, more number of seedlings per unit area, and soaking of seed in saline water (to be used for irrigation subsequently) for 6–8 h is a useful practice and can easily be adopted by the farmers.
- Transplantation of nursery of comparatively more age often is useful because seedlings become somewhat hardier.
- Sowing of seed on the shoulder of ridges-furrow irrigation (the zone comparatively low in salts) has often been found conducive for good results.
- Higher rates of fertilizer as compared with normal soils are generally required when crops are grown in salty lands or irrigated with saline water. Band placement of fertilizers such a phosphorous may be adopted for highly calcareous soils to reduce P-fixation.
- Fields should be kept plowed, especially where soils are loamy and clayey. Field boundaries should be kept strong, in particular before seasonal rains, so that useful rainwater capable of carrying salts to down profile may not be wasted as runoff.
- Scraping of salts (3–5 cm) is often recommended where the surface salinity is very high; the salts should be disposed safely. The remaining soil will become low in salinity that can be used for sowing of crops. This is a temporary solution; salts may build up at surface if site is not properly managed.

17.3.4 Conclusions

In spite of concerted efforts made to combat salinization, in many countries including Oman, the problem remained fully unresolved and persistent. This is due to poor understanding of salinity process and limited resources to combat salinization on a permanent basis. This suggests that learning as how to live with the salinity rather than abandoning agricultural areas may be a better strategy. This requires developing careful policies for implementation in the country. The results and outcomes of recent investigations have showed new ways to tackle soil and water salinity in Oman. The socioeconomic study has confirmed that salinity is a serious social problem because farmers are facing great crop yield decline, culminating into income decreases manifold when farmers use moderately or highly saline water for irrigation. However, some of the results are highly encouraging. These results showed the way forward and direction of future policies for the government, new horizons for the salinity researchers, and modified tasks of the agricultural extension workers in the national interest and helped to formulate guidelines for the farmers for crop yield improvements.

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