IAEA TECDOC SERIES

IAEA-TECDOC-1841

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Challenges and Opportunities for Crop Production in Dry and Saline Environments in ARASIA Member States

IAEA

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

IAEA
International Atomic Energy Agency

CHALLENGES AND OPPORTUNITIES FOR CROP PRODUCTION IN DRY AND SALINE ENVIRONMENTS IN ARASIA MEMBER STATES

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2018

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Printed by the IAEA in Austria
May 2018

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Challenges and opportunities for crop production in dry and saline environments in ARASIA member states / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2018. | Series: IAEA TECDOC series, ISSN 1011–4289 ; no. 1841 | Includes bibliographical references.
Identifiers: IAEAL 18-01156 | ISBN 978–92–0–101918–9 (paperback : alk. paper)
Subjects: LCSH: Soil salinization — Control. | Arid regions agriculture. | Soils, Salts in.

FOREWORD

The IAEA and the Food and Agriculture Organization of the United Nations (FAO), through the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, and the Division for Asia and the Pacific, assist scientists, policy makers and farmers worldwide to ensure food security and to promote sustainable agricultural resources. The Joint Division's programme and activities are demand driven and focus on developing and transferring technologies in response to real and practical needs. This programme provides assistance to Member States in the implementation of suitable nuclear and related techniques to enhance agricultural production.

This publication provides information on salt affected agricultural lands and the use of isotopes techniques in dealing with salinity and droughts condition in States Parties to the Co-operative Agreement for Arab States in Asia for Research, Development and Training related to Nuclear Science and Technology (ARASIA). The information is based on successful and sound practices that have been used for sustainable cropping of salt affected soils. This publication also presents existing knowledge of salt affected soils and possible ways to overcome the problem.

The IAEA is grateful to all the contributors to the preparation of this publication. The IAEA officers responsible for this publication were A. Wahbi of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and P. Salame of the Division for Asia and the Pacific.

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CHAPTER 1. INTRODUCTION

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1.1. BACKGROUND

In the arid and semi-arid regions of the world, soil salinity is a primary constraint of successful agriculture and food production [1.1]. It has been reported that approximately 6% of all arable land is affected by salinity [1.2] which translates to more than 800 million hectares spread across 100 countries located in mostly arid regions. Salinization of soils of arid environments is usually caused by improper irrigation methods, intensive cropping, and using poor quality irrigation water [1.3]. Salts dissolved in irrigation water eventually concentrate themselves in cultivated soil via evaporation depending on climatic conditions [1.4].

Irrigation is inevitable in crop production and agricultural development in arid and semi-arid regions. Competition for freshwater resources among municipal, industrial, environmental, and agricultural sectors is likely to increase in the coming decades. This will lead to a gradual decrease in fresh water availability for agricultural purposes. Therefore, water resources of marginal quality – such as saline water generated by agriculture drainage systems or pumped from saline aquifers- will likely be used to reduce the gap between demand and supply [1.5]. However, using saline ground water in agriculture without suitable management of soil and crop poses high risks for land degradation through the concentration of salts, sodicity, and nutrient imbalances in soils.

Therefore, the IAEA launched a Technical cooperation project for ARASIA Member States to develop effective packages of technology for efficient and proper management of salt affected land (TC RAS 5072). A technical workshop was held for all participants and IAEA officers in which a practical frame work for efficient utilization of abandoned salt affected waste land was developed. In this endeavour, counterparts were given a general road map of strategies to be implemented according to soil, plant and climatic conditions of their respective countries. Through close and continuous communication among IAEA officers and Counterparts, a substantial and large body of scientific data concerning cropping of such abandoned waste lands utilizing saline ground water were obtained. As such, it was necessary to arrange and compile an instructional document to be used as a guide for efficient management of this land.

1.2. STRUCTURE

This publication includes information from nine Member States, namely; Iraq, Jordan, Kuwait, Lebanon, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, and Yemen. The information within contains past and present information about the saline and dry areas of the aforementioned nations and ways to cope with these constraints.

1.3. OBJECTIVES

The main objective of this publication is to help scientists and farmers select management alternatives most efficient for agriculture in saline environments within their own countries. These management alternatives may include:

1. Leaching.
2. Amendments (kind and rate of application).
3. Crop selection.
4. Cultural practices (e.g. tillage and irrigation method and irrigation scheduling).

1.4. SCOPE

This publication was designed to serve as specific guide for each participant country and as a general guide for whom soil salinity is a problem. An overview of the process and causes of soil salinization, and an exploration of general measures for sustainable cropping of such waste lands are given in the first paragraph. Each of the nine Chapters (starting from Chapter 3) was designated to one participating country. All Chapters share the same format which includes;

- Salt affected soils in the country (area, type of salts, and impact).
- Main causes of salinity in each country.
- Crops grown in the area.
- Adaptation measures to live with salinity.
- Gap analysis.
- Details of progress made and successful management practices introduced through the entire ongoing ARASIA project.
- Nuclear and isotopic techniques used.
- National and international references were given at the end of each Chapter for other scientist to evaluate their work against them.

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CHAPTER 2. SOIL SALINITY: CURRENT STATUS AND IN DEPTH ANALYSES FOR SUSTAINABLE USE

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2.1. BACKGROUND

Salt-affected soils occupy more than 930 million ha of land worldwide equivalent to more than 6% of the world's total land area [2.1] and 20% of the total irrigated area [2.2] including the ARASIA partner countries, although their exact extent is not well defined. Table 2.1 summarises estimates of salt-affected land in ARASIA countries based on the FAO/UNESCO Soil Map of the World [2.3, 2.4]. A total of about 15 million ha are designated as salt-affected of various salinity levels. Data for Yemen (37 100 ha) are given in Chapter 11, but these are only for salt-affected agricultural land and do not include salt-affected land in desert areas. However, as the information presented in subsequent Chapters demonstrates, these estimated areas were determined before the expansion of agricultural production and irrigated areas of the last 40 years. So, they are probably underestimates of the area now.

TABLE 2.1. ESTIMATED AREAS OF SALT-AFFECTED SOILS IN ARASIA COUNTRIES. DATA FROM [2.4]

Country	Salt-affected soils (000, ha)
Iraq	6 726
Jordan	180
Kuwait	209
Lebanon	na
Qatar	225
Saudi Arabia	6 002
Syrian Arab Republic	532
United Arab Emirates	1 089
Yemen	na
Total	14 963

na; not available

Weathered rocks and minerals are the source of all salts, but salt-affected soils are rarely formed from *in situ* accumulation of salts. Rather they are the result of salts received from other areas, principally via water, and especially when irrigated crop production is introduced. Although there is a large range of salt-affected soils, two main groups have been distinguished in ARASIA countries. These are: i) saline soils (sometimes called solonchak) containing chiefly sodium chloride and sodium sulphate, together with appreciable quantities of calcium and magnesium chloride and sulphate; and ii) sodic soils (sometimes called solonetz) containing sodium salts capable of alkaline hydrolysis, mainly sodium carbonate. The classifications in this and other Chapters are based on United States Department of Agriculture (USDA) standard soil salinity classification. Saline soils are defined as soils in which the electrical conductivity of a saturated paste extract electrical conductivity (EC_e) exceeds 4 dS/m, while sodic soils are defined as soils in which the exchangeable sodium percentage exceeds 15% (although the EC_e may be <4 dS/m).

The purpose of this overview is to briefly summarize the main features described in the subsequent individual Chapters with particular emphasis on the scientific strengths that are evident, together with gaps in knowledge and the areas that require more attention in the future.

2.2. SCIENTIFIC STRENGTHS IN THE ARASIA PARTNERSHIP

The partnership constitutes a diverse geographical region with expertise focussed on the issues of greatest relevance to the sub-regions within the different countries. The individual country Chapters present accounts of the knowledge currently available and demonstrate the competencies that exist in aspects of soil, water and crop sciences.

Table 2.2 presents a semi-quantitative assessment of the scientific strengths that are employed within each country to manage soil salinity. In using the table, it is important to bear in mind that this assessment is partial. It is based only on what is presented in the country Chapters, not on the full scientific resources employed in each country. Nevertheless, the table highlights some important strength. Firstly, nearly all countries have a soil map and a database indicating the major areas of salt-affected soils. These maps, together with locally available data and information of water sources and irrigation practices, can be used as a basis to indicate areas where future salinity problems might be anticipated. However, the reliability of the data is problematic both as regards to its age and spatial accuracy. There is a big overlap between data for land degradation, desertification and salinization, which makes it difficult for countries to strategize their future land use planning. It is widely recognised, though, that this strength is dissipating with time because the data available are not keeping pace with the changes in the areas and techniques of crop production. Secondly, many countries either have, or are developing, capacities to monitor water quality and the quantity extracted from rivers, reservoirs and aquifers. This strength is allied to many recognised problems, especially the fact that over extractions are occurring, particularly from aquifers. Intensive extraction of water without knowing the regeneration rate may lead to depleted water sources, increased pumping costs for irrigation, and rapid seepage of sea water into coastal water bodies. Thirdly, some countries are building expertise in selecting plants and crop genotypes that can cope with saline conditions. Selection of salt-tolerant plants, biosaline agriculture, sustainable cropping of salt affected soils, and better understanding of crop water requirements as a basis for water applications to crops are all elements of this strength. Finally, there is limited strength in translating the research knowledge available on salt-affected soils and their amelioration to land users and farmers. There are several reasons as to why this potential strength is limited, not least the institutional arrangements within countries that divide research and extension services.

TABLE 2.2. SUMMARY OF COUNTRY DATA ON SALINITY RESEARCH FOR UTILIZATION OF SALT-AFFECTED LANDS

Yes = clear evidence presented in country paper. Some = aspects of the topic presented in the country papers; Limited = little evidence presented; No = no evidence presented in country Chapter

Country	National soil data and map	Information on local causes of salinity	Human capacity available for water monitoring and modelling	Breeding programmes on evaluation of salt-tolerant genotypes	Biosaline agriculture practices in national plan	Participation with farmers
Iraq	Some	Yes	Some	Limited	No	Limited
Jordan	Yes	Some	Some	Some	No	Some
Kuwait	Yes	Limited	Limited	No	No	Limited
Lebanon	Yes	Yes	Some	Limited	Limited	No
Qatar	Some	Limited	Limited	Limited	Some	Limited
Saudi Arabia	Yes	Limited	yes	Limited	Limited	Limited
Syrian Arab Republic	Limited	Limited	Limited	Some	No	Some
United Arab Emirates	Yes	Limited	Yes	Some	Yes	Limited
Yemen	Yes	Yes	No	Limited	No	Limited

2.3. TOPICS IDENTIFIED AS REQUIRING MORE ATTENTION

As for the research strengths and weaknesses, different countries have identified different aspects of salinity management that require more attention. In part the topics identified reflect analysis of the weaknesses in present approaches, and in part they look forward to how things might be approached differently (and better).

Most of the Chapters identify a range of common topics but not all are identified by each country and some are very specific to particular countries or regions within countries. Table 2.3 is an attempt to summarize the relative priorities of each country for six of the most commonly identified topics. A high priority is given by many countries to the need for updating their soils information to reflect the changed and increased areas of salinization and/or agricultural production in the last 40 years. Many countries in the ARASIA partnership have used their limited crop-bearing land to expand production of high-value horticultural fruits and vegetables using modern and improved irrigation systems. Many of the crops grown are sensitive to salt so that soil salinity information on farm level, if possible, is essential for appropriate management and sustainability of production.

Many countries see the need to build on their currently limited strengths in crop improvement and breeding to develop plants and genotypes that are able to tolerate and grow well in salt-affected soils. The gradual development and adoption of biosaline agriculture and sustainable agriculture in several countries is one indication of this, with concomitant selection of plant species that will grow on very saline soils for food, feed, fuel and fibre. Many countries are still reliant on the general crop tolerance data available from FAO, but several appreciate that specific genotypes have significantly improved salt-tolerance (for different traits). Although breeding and selection within the ARASIA states is currently limited, several countries are in the preliminary stages of research and introduction of these improved salt-tolerant crops to farmer's fields. This work is mainly restricted to research institutes and universities but a few countries have national plans to develop these plant materials more widely. In the majority of countries, though, the issue is not included in their national strategic plan and they do not have the technical and financial resources to address it as part of improved agricultural production, environmental concerns, poverty alleviation or any of the sustainable development goals (SDG's). Many rely on import of food from outside rather than expand agriculture on salt-affected lands.

There is also a growing recognition by countries that it is necessary to integrate scientific knowledge from several disciplines in order to improve policies for agriculture and water use. The main issue lies the way the Ministries of agriculture, livestock, fisheries, environment, and water resources/management operate separately so that an integrated approach is frequently lacking. Finally, the researchers' desire to see their achievements and knowledge translated into practice means that improved mechanisms for communication with farmers and shapers of land use policy are highlighted in several Chapters. Poor extension services in many countries limit this ambition.

TABLE 2.3. COMMON ISSUES IDENTIFIED BY ARASIA COUNTRIES REQUIRING MORE ATTENTION

The relative priority of the different country for the topic is indicated as follows: *** clear priority in country paper; **few aspects covered in the country paper; * few components presented; - no evidence presented in country Chapter

Country	Causes of increasing soil salinity	Updated information on soils (including instrumentation)	Development /Adaptation of salt-tolerant crops and varieties	Development of policies for sustainable water use (in Last 5 years)	Integration of soil, water and crop production expertise	Improve communication to farmers
Iraq	***	***	***	**	*	-
Jordan	-	***	***	-	-	***
Kuwait	***	***	*	-	-	-
Lebanon	**	-	***	***	*	***
Qatar	**	***	***	-	-	***
Saudi Arabia	*	***	**	***	-	*
Syrian Arab Republic	***	***	*	*	***	-
United Arab Emirates	***	***	***	**	***	**
Yemen	***	***	**	*	**	***

2.4. THE ROLE OF NUCLEAR AND ISOTOPIC TECHNIQUES

Salinity is exacerbated by the application of excessive irrigation and the inefficient irrigation systems used. To irrigate with the right amount of water it is necessary to measure the soil water content. A reliable technique for this is the neutron soil moisture probe which measures water in a limited volume of soil. This technique employs a radioactive source and has proved suitable in almost all soil types including saline soil where other devices failed. If it is desired to know the soil water content of a wide area, then a Cosmic Ray Neutron Sensor (CRNS) could be used. CRNS is a passive sensor that measures soil water content in a circle of about 20 ha.

Carbon isotope discrimination (CID; $^{13}C/^{12}C$) could be used as a guide for salinity and drought tolerance and as a tool for breeding cultivars tolerate to salinity or drought conditions.

The negative consequences of salinity on crop growth can be ameliorated to some degree in some circumstances by improving soil fertility through biological nitrogen fixation and the application of the right amount of nitrogen fertilizers. To investigate these factors, Nitrogen-15 can be used to measure nitrogen fixation and nitrogen use efficiency. Nitrogen-15 is a stable isotope and can be used without any hazard to trace the movement of nitrogen within the soil/plant system and to check for nitrate pollution.
Isotopes and radiation techniques offer a precise estimate of salt displacement. Stable and radioactive isotopes can be used as tracers to investigate salt distribution in soils and their movement. Sodium-22 (stable isotope) and Chlorine-36 (with a gamma activity scanner) can be used in such studies.

2.5. GAPS IN KNOWLEDGE AND INFRASTRUCTURE

The topics identified in paragraph 2.3 form the foundation of the gaps in knowledge. Among the most commonly identified gaps are:

(a) Updated quantitative information about the current rate of increase of salt-affected soils as a consequence of irrigated agricultural production. Some case studies exist but integrated assessments for whole countries are rare.

(b) Quantitative information about the medium- and long-term availability of irrigation water (good quality and others).

(c) Within the region, specific breeding programmes for crop genotypes tolerant from moderate to high salt levels in soils.

(d) Lack of national plans to combat desertification and salinization in addition to coordination between national stakeholders.

Coupled with these scientific gaps was an appreciation that research infrastructure and links to extension services are not good enough. This manifest itself in several ways, but most evidently in the lack of modern instrumentation available to researchers to monitor salts in soils and water bodies. However, salinity monitoring does not necessarily require modern equipment but dedicated human skills and efficient field monitoring systems that are lacking in the partner countries.

Generally, the lack of clear technological packages to be transferred to farmers is also challenging, and translation of research into practice appears to be limited. Different areas need different packages to deal with salinity problems, and long-term national programmes are needed to ameliorate the large areas of salt-affected soil. Participatory approaches require developments that enable farmers to see and modify research-based solutions into practices that will work on their fields. Farmers need to gain confidence in the techniques and establish good, trusting, relations with the researchers and extension services. Socio-economic research can accompany the technological enquiries and be factored into the adoption and impact studies since that is the main way to convince policy makers and end users of the technology benefits.

In summary, there exists a body of knowledge about salt-affected soils in the partnership countries and the amelioration and coping practices that might be possible. However, this knowledge is not being widely translated into on-farm practices, and is in danger of being lost because of a lack of investment in infrastructure (including instruments) that will permit its being kept current.

A big challenge is the lack of channel of communication between the researchers, farmers and extension workers on the one hand, and with policy makers on the other, to develop efficient and modular policies. In general policies do exist for water management (mainly focusing on dams, sanitation, etc.) and land use, but proper mechanisms to translate research findings into national policies are lacking but urgently needed. In addition, regional collaboration is very important for transfer of technology, new plant genetic material, human expertise and regional interaction.

Suggestions:

1. Bring on board the senior government functionaries (National Liaison Officer (NLO) and others) to realize the severity of the emerging problem of salinity, now and in coming years. It is also imperative that the partner country government make sure of a national task force with key Research and Development (R&D) institutions that work together. Many of the current projects and/or partner countries lack this initiative.

2. Integrate and update information on land and water degradation processes in partner countries and share through ARASIA or other platforms in Member States.

3. The role of salt affected land in increasing crop productivity can be included as a measure to meet the increasing food demand in the national plan of member countries. This would take time but it will make sure that human and budget resources are available for future food security plans in member countries.

4. Monitoring and evaluation programmes can be updated annually and implemented to ensure that appropriate technologies on biosaline and sustainable agriculture are adopted and implemented by farmers.

5. Seed production programmes can be supervised by national R&D programmes to make sure that sufficient seeds are available locally for scaling up.

6. Small or Medium Enterprise (SME's) and Entrepreneurship programmes can be gradually injected in the whole value chain, especially with young graduates and through participation of women.

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CHAPTER 3. IRAQ

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3.1. INTRODUCTION

Iraq has a total area of 444 000 km^2 (44.4 million ha). In general, of the total land area, 78% is suitable for agricultural use. However, only 27% of the total area is actually cultivated for agriculture. The country is divided into a rain-fed northern winter grain-producing zone and a central-southern irrigated zone that produces vegetables and fruit as well as rice and cereals.

Agriculture used to occupy a key position in the economy of the country and provided employment for a relatively high percentage of the working population. Agricultural production is based principally on irrigation; the basins of the Tigris and Euphrates are the major crop-producing areas and irrigated farming has been practiced for many millennia. Soil formation in Iraq is quite diverse and therefore the soils are unique in their characteristic development. In the central and southern part of the country, salinity has long been identified as a major threat to agriculture and has led in the past to policies aimed at improving irrigation and drainage practices, but these were halted in the early 1980s. Since then, Iraq's extensive irrigation infrastructure has fallen into disrepair and soil salinity has spread across many of the irrigated areas of central and southern Iraq (authors un-published data). According to the FAO estimates, more than two million hectares are irrigated, and it is estimated that approximately 75% are moderately saline and another 25% have levels of salinity that prevent farming. It is estimated that Iraq is losing about 25 000 ha per year of agricultural cropping land as a result of salinity.

Salinization of soils in Iraq is usually caused by mismanagement, water shortages and by the increasing levels of salinity in the irrigation water from both the Euphrates and Tigris rivers due to changed water regimes. These changes are a combination of upstream damming of the rivers and tributaries in Turkey and Syrian Arab Republic, and recent events of climate change/variability. Another important cause of salinity is the lack of efficient drainage systems [3.1].

Based on topography, morphology, and climate, the territory of Iraq can be divided into five broad physiographic units [3.2]. Each unit (region) has its specific geological, hydrogeological, and climatological conditions and consequently specific soil conditions as well. The regions are: the mountains, the foothills, Aljezera, the Lower Mesopotamian Plain and the desert.

3.2. SALT-AFFECTED LAND IN THE COUNTRY AND IN DIFFERENT REGIONS

3.2.1. Lower Mesopotamian plain

Iraq's Lower Mesopotamian Plain (LMP) is one of the most extensive river plains in the world. It extends across an area of approximately 600 x 200 km in the central and southern part of the country. The alluvial material found here is predominantly derived from the flow and flooding of the Tigris and Euphrates Rivers [3.1].

The groundwater level contours for the Mesopotamian Plain, emphasising the semi-enclosed nature of the Plain, and in particular, the very flat hydraulic gradient along the length of the Plain to the southeast [3.1].

The Plain itself is very arid, with little rainfall (less than 200 mm/year). It has grown in size over recent geological time towards the southeast. Current surface water flow, and consumption of that flow, means that little river water entering the floodplain leaves by surface flow. Groundwater also flows towards this area of Iraq, from all sides. All the major aquifer systems drain into the topographic low under the plains, the aquifers of which in turn drain slowly into the Gulf. The aquifers of the floodplain are also connected to the surface water in the rivers and exchange flows, depending on the relative hydraulic gradients. The low rainfall, the very low topographic gradient towards the coast and the movement of saline groundwater flow into the floodplain from the areas immediately adjacent mean that there has been little opportunity for flushing of salts out from the landscape. The sediments of the underlying geological basin also contain major evaporitic layers (gypsum and other salts), and these naturally high levels of salt, together with the lack of flushing efficiency, contribute to the high salinity levels of the very shallow groundwater under much of the plain. This salinity is also manifested as widely distributed gypsiferous and saline soils.

3.2.2. Salinity: past and present

The salinization and accumulation of salt in the soils of the Lower Mesopotamian Plain (LMP) have a long history. Recognition of salinization as a serious problem in the history of Iraq was first mentioned by Russell [3.3]. The prolonged irrigation of agricultural lands, and the introduction of canals and new irrigation techniques, have resulted in soil salinity and abandoned land [3.3, 3.4].

Three major occurrences of salinity have been established from ancient records [3.5]. The earliest and most serious of these affected southern Iraq from 2400 B.C. until at least 1700 B.C. A milder phase is attested to in documents from central Iraq written between 1300 and 900 B.C.

The Nahrawan area situated north-east of Baghdad became salty only after A.D. 1200. Jacobsen and Adams [3.5] concluded that: firstly, salinity was not as severe a problem in ancient times as it is in the present; secondly, no traces or records of artificial drainage were found; thirdly, the first salinity records encountered (about 2400 B.C.), relate to the present area of Gharraf (some 300 km south of Baghdad). The area did not recover from the onset of salinity, and this phenomenon may have contributed to the decay of the Sumerian Empire. Fourthly, there was an onset of salinity in northern Babylonia around 100 B.C.; and finally, although there may be some fossil marine salt deposits, the genesis of soil salinity in Iraq as a whole could be attributed to the salt content of the irrigation water.

Numerous field and laboratory studies have been carried out to characterize the salt-affected soils of LMP [3.2, 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, and 3.12], including a comparative characterization of soils taken from various locations in the country [3.9]. Investigation of the Sabakh and Shura soils (the local names of the two most widely salt-affected soils in Iraq) for their nature, salt regime, and their interrelationship during the process of salinization found that the two groups of soils did not differ in the source of salinity, but in some chemical properties and in the stage of the salinization process [3.13]. Studies of salinity indicated that more than

70% of the soils of the LMP are salt-affected [3.14]. The present salinity of the LMP stems from a number of natural and economic reasons. It was reported that each year of irrigation water adds 3 million tons of salt to the irrigated soils of Iraq [3.1]. This amount of salts increased to approximately 26 million tons in 1975 and 75 million tons in 1995.

The main chemical characteristics of the Shura and Sabakh soils of the Dujaila project (200 km south-east of Baghdad) are summarized in Table 2.1. [3.10, 3.13]. Obviously, sodium is the dominant cation in the surface horizons of Shura soils, whereas calcium and magnesium are the dominant cations in the salt crust and Ap horizon of Sabakh soils. It is further concluded that $NaCl+Na_2SO_4$ or $MgCl_2$ are the dominant salts in the upper horizons of the soil profile of Shura soils, and $CaCl_2$ and $MgCl_2$ are the dominant salts in the upper horizons (particularly in the crust) of Sabakh soils.

TABLE 3.1. CHEMICAL CHARACTERISTICS OF SHURA AND SABAKH SOILS AT THE DUJAILA PROJECT
(200 km south-east of Baghdad); from [3.13]

Horizon and depth (cm)	Soluble ions ($cmol_c\ kg^{-1}$)								
	EC dS/m	pH	Ca	Mg	Na	Cl	SO_4	HCO_3	NO_3
Shura Soil									
AP (0-10)	330	7.8	2.0	1.2	125.4	21.3	114.5	0.8	0.28
C1-C3 (10-145)	27	8.0	0.7	0.2	11.16	2.6	9.7	0.1	0.04
GW^+ ($meq\ l^{-1}$)	32	8.1	15.61	49.2	290.4	31.0	310	5.5	0.4
Sabakh Soil									
Crust (0-0.5)	445	5.1	94.7	71.3	50.1	214	0.01	0.16	316
AP (0.5-11)	246	6.6	24.2	6.9	55.6	81	0.57	0.13	7.5
C1-C3 (11-145)	18.5	8.0	0.9	0.7	7.5	8.4	0.34	0.54	0.17
GW^+ ($meq\ l^{-1}$)	11.3	8.2	18.28	21.88	70.64	93.53	10.56	2.6	0.52

+ GW= Ground water

Both soils contain a high percentage of lime and a considerable amount of gypsum. Another feature of the Sabakh soils is the surface crust (< 0.5 cm) which consists of Na-organic molecules soluble in water. This high solubility makes the N-organic molecules behave like water-soluble salt [3.15].

3.2.3. Irrigation and salinity

For productive irrigation farming to continue, adequate leaching and drainage needs to be available to remove salt left in the root zone after uptake of water by the crop. The volumes of water infiltrated in excess of crop requirements can be very large (200–300%) which is in excess of the natural drainage capacity of the soil. Consequently, the water tables rise. Therefore, engineered drains are often necessary to prevent waterlogging and salinization of the crop root zone [3.16]

The salinity of surface water was also assessed in terms of the spatial distribution of salinity throughout the river system, as a guide to understanding the salinization process and to provide guidance as to where effort might be invested to reduce salinity in the system [3.1, 3.17].

3.2.4. Changes in salinity

Useful information about the behaviour of a river system and the processes that might be operating can be gained by analyzing the spatial trends in river salinity for a particular sampling date/period within the river. Little data exists on the pre-1973 salinity status of the Tigris–Euphrates river system but Figures 3.2, 3.3 and 3.4 show longitudinal trends in river salinity for the Euphrates River [3.17].

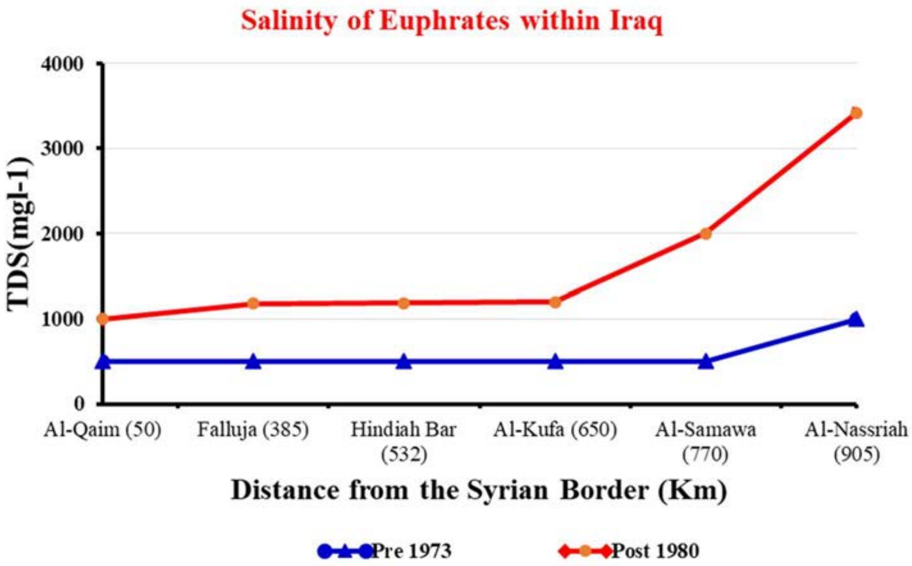

FIG. 3.1. Salinity of the Euphrates within Iraq; reproduced from [3.17].

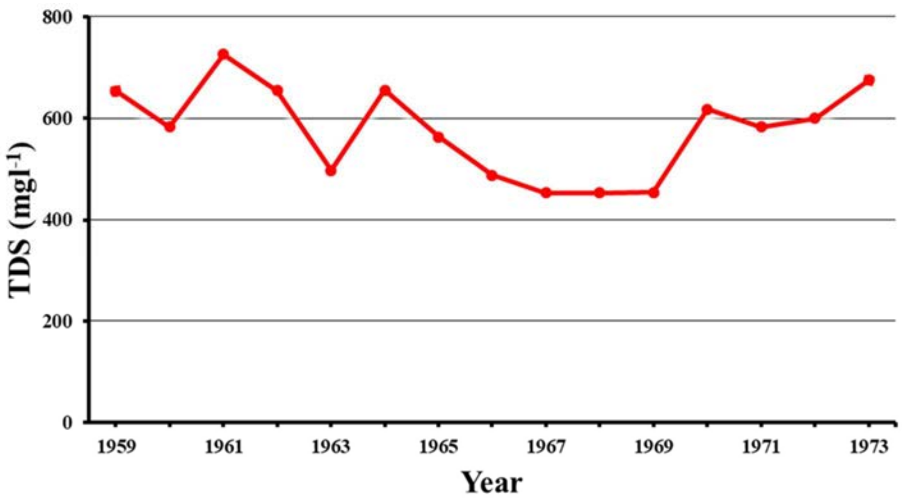

FIG. 3.2. Mean annual total dissolved salts (TDS) at Falluja Gauging Station; reproduced from [3.17].

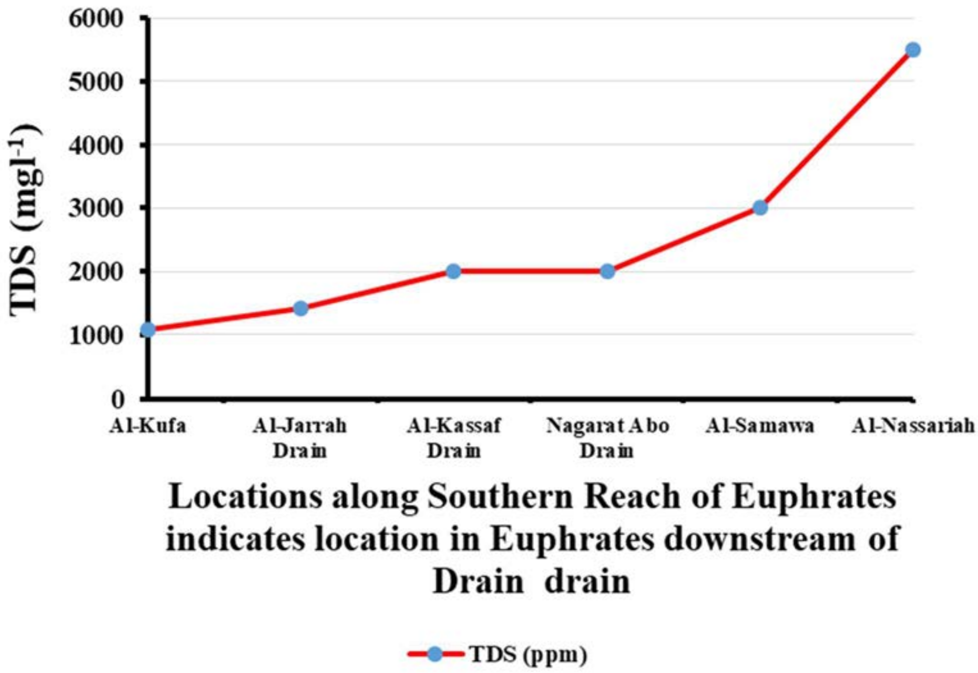

FIG. 3.3. Total dissolved salts (TDS) in Euphrates River in 2002; reproduced from [3.17].

Figure 3.1 shows that the salinity of the Euphrates River at the Syrian Arab Republic border apparently doubled between 1973 and late 1989. The salinity of the river more than doubled at Nassariyah (located towards the end of the system). Several processes may have caused this, with the most likely assumed to be increased return flows from irrigation development as a proportion of total flow in the river. This could be brought about by either a reduction in flow, causing less dilution of a static irrigation return, or by an increase in salinity in the drainage water. Suggesting that groundwater intrusion could be an important factor. The correct explanation is probably a combination of all of these.

Figure 3.2 shows that for the period of record at Falluja, the salinity of the river was essentially constant at about 600 mg/l total dissolved salts (TDS). Finally, Figure 3.3 shows that, for the year 2002, the salinity of the Euphrates River increased from about 1000 mg/l TDS at the Syrian Arab Republic border to well over 5000 mg/l TDS at Nassariyah.

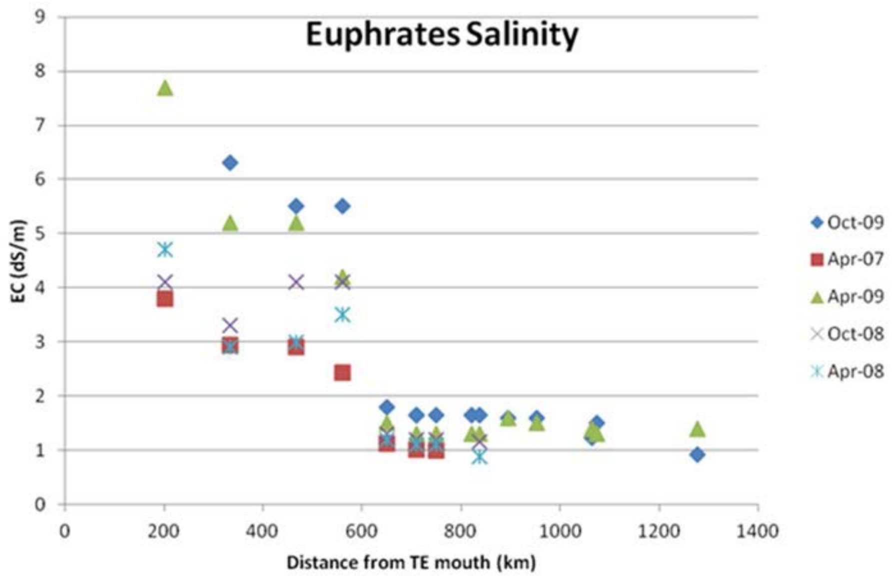

FIG. 3.4. Salinity of the Euphrates; reproduced from [3.1].

Data collected during the study were organised and plotted to provide further information about the behaviour of the system. Figure 3.4 shows salinity data for the Euphrates River for various times over a two-year period, as longitudinal profiles along the river length from the mouth of the system (at the Gulf). The data showed the same increasing downstream trend as depicted in many publications, essentially increasing from about 1 dS/m (electrical conductivity) at the Syrian Arab Republic border to about 5 dS/m at the end of the system; these data were from Gurna, as opposed to the previous data which were from Nassariyah. Interestingly, even though the trend is almost identical, the absolute salinity is lower than those published in [3.17] (note: 1 dS/m is about 700 mg/l TDS).

3.2.5. Salinity and drainage

One of the first steps taken to remove drainage water from irrigated lands was to build surface drains of relatively shallow depth. Besides drainage water removal, it was intended also to remove surface water in flood periods. This work was started before 1958, and several open drains were built. Later, drainage systems with a sparse network of surface collectors were built in the period from 1958 to 1968.

Since 1968 field drains have been installed in some irrigation systems. The existing drainage systems with surface collectors cover an area of more than 500 000 ha. Field drainage exists on about 400 000 ha. Most of the work was in the form of projects managed by foreign companies and distributed in the central and southern parts of the country.

Before 1993, the Tigris and Euphrates rivers, the main outfall drains, lakes (e.g. Hammar) and local depressions (e.g. Dalmaj) were used as drainage water receivers. In mid-1993, construction of the main drain was started and in 1994, the main drain was put into operation for the disposal of drainage water from the major drainage system of the LMP to the sea. The total length of the main drain is 565 km, designed to discharge 200 m^3/s at the terminal point. The main drain starts at the Ishaki drain in north-west Baghdad between the Tigris and

Euphrates rivers. It continues to Nassiriyah and runs parallel to the Euphrates River until it connects with the Shat-Al-Basrah River (north of Basrah city) before flowing into the Gulf at Khur-Abdulla. The main drain is designed to transport nearly 50 million tons of salts per year from the LMP to the sea.

3.3. MAJOR CAUSES OF SALINITY

The major causes of soil salinity in Iraq include:

(a) Imbalance between irrigation and drainage caused by long-term practice over thousands of years of irrigation without sufficient drainage.

(b) Poor natural drainage of irrigated lands and occurrence of groundwater with high salt concentration (3–10 g/l) and limited lateral movement.

(c) Pronounced aridity of the climate with evaporation exceeding precipitation.

(d) Heavy texture soils with low permeability.

(e) The application of water to land for irrigation, and the leakage of water from the associated network of water storage coupled with the absence of efficient drainage systems, are the main reasons for groundwater to rise close to the soil surface. This has resulted in continuous accumulation of salts in the upper 20–30 cm of the soil.

(f) Inappropriate interventions by farmers cause major problems in the water allocation system, resulting in water scarcity in many parts of the LMP. Farmers do not follow the rationing system and use larger amounts of water than they should, by installing irregular irrigation intakes and water pumps on all levels of irrigation canals. Other mismanagement includes intentional or unintentional damage to the distributor canals' head regulators through private use, irrigating areas outside the planned agricultural areas, and constructing unauthorized fish farms. These are key deficiencies in the system, which contribute to land degradation, waterlogging, salinity and poor productivity.

(g) The existing status of irrigation and drainage infrastructure, current operations and maintenance set-up, and on-farm irrigation practices are all directly responsible for increasing soil salinization.

3.4. EFFECTS OF SALINITY ON CROP PRODUCTIVITY IN IRAQ

Agricultural production in Iraq has been variable over time (Figure 3.5). Based on the FAO crop database for the whole of Iraq, rice yield has slightly declined from the end of the 1960s to the 2010s, while maize yield appears level from the late 1970s to the 2010s. Wheat yield has increased from the late 1970s, while barley appears to be declining.

Generally, productivity for the four crops is very low compared to those from more intensive cropping systems world-wide. The yields of these crops are only about a quarter of what could be expected from irrigated agriculture on non-saline soils with modern management systems and full availability of inputs. Based on the available information, it appears that agriculture in Iraq is at a very low point.

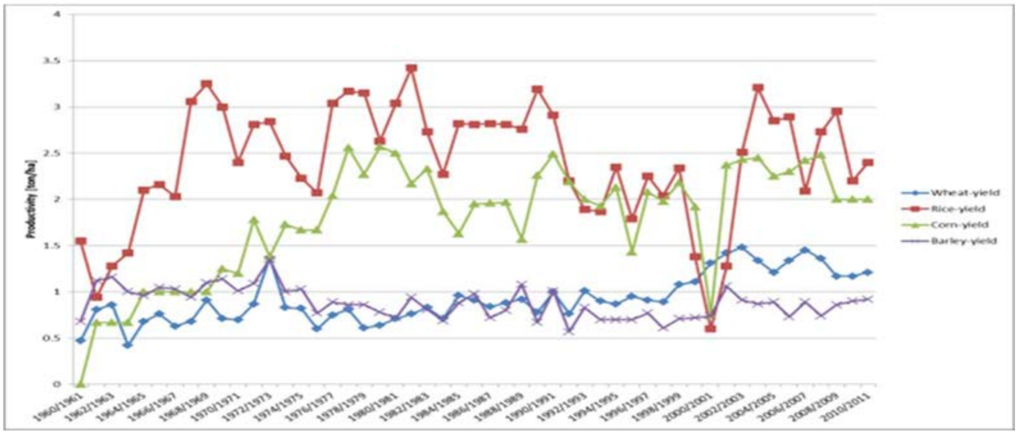

FIG. 3.5. Productivity for wheat, barley, rice and corn from 1961–2010 for Iraq; reproduced from [3.1].

An analysis of spatially averaged annual Normalised Difference Vegetation Index (NDVI) values for the Mesopotamian Plain show year-to-year variability, strongly related to the availability of water (Figure 3.6). The dry period between 2000 and 2002 resulted in small areas of rice cultivation around Najaf, while 1999 and 2004 saw a large area of rice cultivated.

3.5. CROPS GROWN BY FARMERS IN SALT-AFFECTED AREAS

Crop productivity has decreased linearly with the increase of salt content in soils. Most common crops grown in the country are grown in arable land irrespective of salt content. Some of the main crops are given in Table 3.2 below.

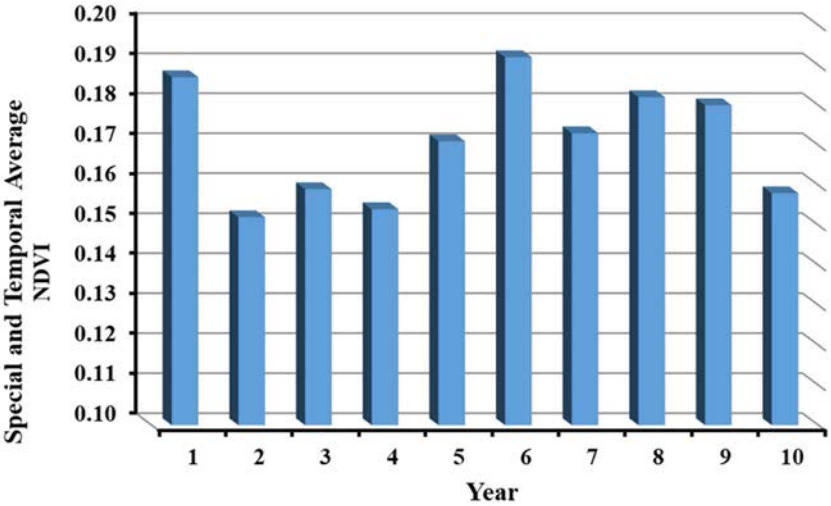

Figure 3.6. Average Normalised Difference Vegetation Index (NDVI) for Mesopotamian plain from 1999–2008; reproduced from [3.1].

3.6. FARMER KNOWLEDGE OF SALINITY AND ADAPTATION MEASURES

3.6.1. Fallowing

Fallow is a very old practice in Iraq. The oldest known written document on agriculture is 3000 years old. It is a clay tablet with cuneiform script found at Nippur contains instructions for sowing and irrigation [3.18]. This system of farming was based on centuries of practical experience under specific Mesopotamian conditions. Fifty percent of the cultivated land has a winter cereal crop (mainly barley and wheat) from October to April, followed by an eighteen-month fallow period without irrigation and ploughing for two summers. Ploughing the root zone is done to minimize the capillary rise of saline soil solution. Typically, soil moisture content drops from 34% at the end of the growing season to 10% at the beginning of the new crop season [3.18]. The common irrigation method for winter crops was the border method, consisting of plots of approximately 15 x 30 meters on both sides of the irrigation ditch. Cotton and most vegetables were grown by applying water from furrows every two or three weeks. The irrigation system was rather primitive and often there were large water losses.

TABLE 3.2. COMMON CROPS GROWN IN SALT-AFFECTED AREAS IN IRAQ

Crops	Trees	Grasses and weeds
Alfalfa	Acacia	*Alhagi morurum*
Barley	Buckthorn	*Atriplex leococlada*
Celery	Date palm	*Atriplex numularia*
Cotton	Olives	*Atriplex hortensis*
Cowpea	Pomegranate	*Atriplex tartarica*
Melon	Sesbania	*Arundo donax*
Mung bean	Fig	*Chenopodium album*
Okra	Casuarina	*Cressa cretica*
Faba bean		*Cynodon dactylon*
Sorghum		*Frankenia pulverulenta*
Wheat		*Glycyrrhiza glabra*
Millet		*Juncus acutus*
Sunflower		*Juncus arabicus*
Sugar beet		*Juncus martitimus*
Tomato		*Peganum harmala*
Egg plant		*Phragmites australis*
		Prosopis farcta
		Suaeda vera
		Tamarix spp
		Typh domingensis
		Pimpinella anisum
		Chenopodium album

The uncultivated areas were usually used as pasture for animals, whose urine and manure served as a source of nutrients and organic carbon to the soil. Nothing was done to control the principal weeds Shok *(Prosopis Stepheniana)* and Agul or camelthorn *(Alhagi maurorum).* These two weeds, deep-rooted perennials, were salt-tolerant and grew rapidly after the crop harvest. They used up the water left in the soil, lowered the perched groundwater table and dried out the soil and substratum. At the end of the eighteen months' fallow period, the soil was dry to a depth of at least 2–3 m. As a consequence, there was no accumulation of salt in the crop rooting zone. The legumes accumulated nitrogen and were used for fuel at the end of the fallow period. This very old practice is still used by a number of farmers in Iraq cultivating a variety of crops (see Table 3.2).

Floods, which occur on the flood plain every few years, have a similar effect. Flood water leaches the upper part of the dry soil and 'pushes' the salts down to deeper layers so that the fallow system enabled farmers to use land for about 450 or 500 years [3.3].

3.6.2. Leaching of soils and drainage of the land

Desalinization is an essential step in the reclamation of salt-affected soils to reduce salinity levels and improve the root environment. The principle is very simple: salts need to be washed downwards by means of water leaching either continuously or intermittently. This series of processes is called reclamation. From a technical point of view, it is often possible to reclaim salt-affected soils, provided that they can be effectively drained and sufficient fresh water is available for washing and irrigation. It is, however, not always economic to reclaim some salt-affected soils, particularly those with poor physical conditions. The most important necessity in reclaiming salt-affected lands is a good drainage system. Soil drainage is the most important technical problem in agriculture in Iraq. Numerous small and large field experiments as well as laboratory work have been conducted on desalinization of the soils of Iraq during the last 50 years [3.9, 3.19, 3.20, 3.21, 3.22, 3.23] These experiments included many different soil and water conditions.

3.6.3. Growing vegetables under salinity stress

Vegetables, particularly tomatoes, are grown on small plots during the summer. Farmers usually dig irrigation furrows about 2 m apart, about 30 cm deep and 30 cm wide with a flat bottom and erect sides. Tomatoes are grown on a small shelf, half way up the northern side of the furrow, and the furrows are filled with water up to the level of the tomatoes. Salts in the soil near the tomato plants are pushed to the upper part of the furrow wall and to the strip in between the two furrows. Later on, the salt-free strip of soil half way up the southern side of the furrow is added to the plants on the northern side. These methods of farming on salt-affected land are of fundamental importance for Iraq.

3.6.4. Irrigation with saline groundwater

This practice was based on the well-known positive interactions between biological, chemical and physical factors and their effects on the removal and redistribution of salts in soils. The technology was developed on ten hectares of abandoned salt-affected wasteland [3.24, 3.25]. Two wells of 30-m depth were drilled in the area; each was supplied with a 15 HP submersible pump. Soil salinity in most of the area was > 80 dS/m and the salinity of the groundwater was 4.0 to 5.8 dS/m. At the start, 40-cm depth of groundwater was applied to the surface of the entire area, after it had been ploughed and levelled. This was done to flush the excess water-soluble salts out of the rooting zone. Salt-resistant shrubs and trees were planted parallel to the irrigation channels, to ensure uniform root distribution for intercepting seepage water and to prevent raising of the water table. As a result of leaching and green-manuring, the salt levels of the entire area were reduced to 61% of their original content, and soluble sodium was reduced to 30%; organic matter content, on the other hand, was increased by 12.5%. Yields of sugar beet and barley linearly increased with cropping time (34.8% and 32.4% respectively), which confirmed the considerable improvement of the soil conditions, and consequently the success of this package of technology in rehabilitating salt-affected wasteland. Chemical amendments like gypsum, phosphogypsum, and elemental sulphur, applied at levels determined experimentally, were found to be effective in reducing the sodium adsorption ratio (SAR) of the soil and in turn improving soil tilth. It was therefore concluded that crop residue, farm waste and green manuring can have a substantial positive impact in improving soil conditions [3.26].

This technology is adopted at present by some farmers, although it is fully adopted by the Government. However, the lack of security across the country is the main reason for not being able to implement it over the entire affected area.

3.6.5. Chemical and organic amendments

Use of saline water to irrigate crops and tolerant plants in salt-affected soils creates a complicated environment. Increasing soil salinity enhances the opportunity for sodium to be adsorbed by clay colloids. Consequently, there is significant dispersion of soil aggregates, which in turn causes loss of soil porosity, so that percolation of water and solutes is reduced. Accordingly, chemical amendment is essential to release calcium from calcium carbonate in order to replace sodium at the exchange sites of the soils. Organic amendments are usually added at different levels to increase the aggregate stability of the soil.

Field experiments have been carried out to investigate the role of organic matter in enhancing soil productivity irrigated by different types of water [3.27]. Three types of organic matter, i.e. ground corn cobs, compost and sheep manure, were separately mixed with the soil surface at a rate of 0.0, 0.5%, 1.0%, and 2.0% by weight to soil, equivalent to 0.0, 13, 26, and 52 Mg ha^{-1}. Both fresh and saline water were added to each treatment at a depth of 10 cm. The results showed that the biomass of sorghum was significantly increased for all levels and types of organic matter. An application rate of 2% of either compost or sheep manure increased the biomass of sorghum to 119.0% and 92.4 % upon leaching with fresh water, whereas the biomass increased by 246.6% and 268.7% upon leaching with saline water for the two types of organic matter.

Another study, concerning the use of sulfuric acid as an indirect source of calcium ions in the reclamation of calcareous salt-affected soils, was evaluated in terms of the increase removal of sodium [3.28, 3.29]. The results showed that sodium removal was increased by 73–77%. An acid concentration of 0.5 N was the most effective in terms of total sodium removal and maintaining the hydraulic conductivity of the soil. Biological evaluation showed that leaching with sulfuric acid increased the dry matter yield of corn by 49% in comparison with the soil leached with river water.

Phosphogypsum (PG) and sulphur as chemical amendments were also investigated in a field experiment to reduce the negative effect of saline water on soil conditions and on barley [3.30]. Gypsum was applied at 50%, 75%, 100%, and 125% of the total gypsum requirement. The results indicated that dry matter and seed yield increased with the level of PG added. The highest seed and dry matter yield were found when 75% PG was added. Seed and dry matter yield at this level of PG increased by 96.6% and 30.49% compared to the control. Also, electrical conductivity at all depths was found to be lowest when 75% PG was added. Electric Conductivity (EC) was reduced by 41.10%, 34.12%, 24.89%, and 14.64% compared to the control as the quantity of PG applied increased. EC was reduced by 59.36%, 51.31% and 37.21% averaged across all application rates after 45, 90 and 150 days of growth respectively. By contrast, the concentration of sodium remaining in the rhizosphere was found to decrease as the rate of PG application increased.

3.6.6. Phytoremediation

Iraq's soils are of low organic carbon content, which is the main constraint regarding removing excess salts and restoration of soil productivity. A successful phytoremediation programme to enhance the productivity of degraded and salt-affected lands has recently commenced. Sesbania, alfalfa, and barley were cultivated, ploughed and mixed with soil, as organic amendments. The experiment was conducted with bioremediation using organic matter, mycorrhiza and salt-tolerant crops (sorghum, alfalfa and millet). Table 3.3 shows the role of organic matter added at 1.5% of soil by dry weight basis in reducing the hazardous effects of salinity on biomass yield of various crop. Results clearly showed that there is a significant effect of organic matter (OM) addition in increasing biomass yield. However, the effect of OM addition was found to decrease with the increase of level of soil salinity. This is also true for applying arbuscular mycorrhizae to the soil; see Table 3.4 [3.31].

TABLE 3.3. ROLE OF ORGANIC MATTER (OM) IN REDUCING EFFECTS OF SALINITY ON BIOMASS YIELD OF FIELD CROPS
The levels of soil salinity were 8.0, 11.5, 16.1 and 24.0 dS/m for L1, L2, L3 and L4 respectively [3.31]

Plant type	L1		L2		L3		L4	
	-O.M	+O.M	-O.M	+O.M	-O.M	+O.M	-O.M	+O.M
	gm/pot							
Sorghum	46.77	66.76	33.69	47.85	22.15	31.10	10.63	14.68
Millet	28.44	41.45	20.01	29.11	12.21	17.50	6.82	9.76
Sorghum + Millet	48.72	72.15	36.45	53.15	24.70	35.64	13.25	18.55

L.S.D. 0.05=7.4050

TABLE: 3.4. ROLE OF ARBUSCULAR MYCORRHIZA (*GLOMUS LEPTOTICUM* AND *GLOMUS MOSSEAE*) (A.M) IN REDUCING EFFECTS OF SALINITY ON BIOMASS YIELD OF SPECIFIED CROP YIELDS
The levels of soil salinity were 8.0, 11.5, 16.1 and 24.0 dS/m for L1, L2, L3 and L4 respectively [3.31]

Plant type	L1		L2		L3		L4	
	-A.M	+A.M	-A.M	+A.M	-A.M	+A.M	-A.M	+A.M
	gm/pot							
Sorghum	47.16	66.37	34.44	47.10	22.75	30.50	11.09	14.21
Millet	29.10	40.79	20.75	28.37	12.81	17.15	7.22	9.36
Sorghum + Millet	49.67	71.25	37.25	52.35	25.25	35.09	13.55	18.25

L.S.D. 0.05=8.1145

3.7. MAJOR GAPS

The main objective regarding efficient utilization of salt-affected and saline groundwater is to develop baseline data and information for central and southern Iraq, in order to provide a robust framework for the development of long-term sustainable salinity management strategies. Iraqi farmers' livelihoods, food supplies and environmental outcomes will be improved through the sustainable use of available water and soil resources in central and southern Iraq. To assist this, the following gaps have been identified:

3.7.1. Availability of data on soil and water quality

A large body of data is available on soil, water and plants which have been collected during the last four decades through the activities of surveying groups and researchers. The data were generated by the Ministry of Agriculture, the Ministry of Water Resources, Soil Science Departments in the universities of Iraq and the Agricultural Directorate of the Ministry of

Science and Technology. A large body of data was also generated by foreign companies contracted to build irrigation and drainage systems across the country during the 1970s; this information is now largely out of date.

3.7.2. Availability of salt tolerant crops and varieties

Salinity has invaded the agricultural lands of Iraq for thousands of years; consequently, several types of natural vegetation palatable to animals exist in salt-affected areas. Unfortunately, these natural plants are not fully described due to the security problems in our country.

Camels, goats, sheep and some cows and buffalo feed on the natural vegetation in salt-affected areas. Farmers have begun to cultivate salt-tolerant crops, and research has recently begun to identify other salt-tolerant crops. These include cereal crops such as wheat and barley, cotton, alfalfa, and others.

3.7.3. Availability of tools, knowledge and expertise

Since salinity is the most serious constraint inhibiting agricultural development, huge amounts of knowledge and research are available, as well as tools and expertise. However, poor agricultural policies which have halted all land reclamation projects are the main reason for the low productivity of the agricultural system in Iraq.

3.7.4. Soil management factors affecting salinity

As mentioned above, mismanagement of soil and water is one important cause of salinity. The problem of mismanagement of these natural resources is severely aggravated by the conversion to an intensive agricultural system. The increasing levels of salinity in the irrigation water from both the Euphrates and Tigris rivers is due to changed water regimes, which are a combination of upstream damming of the rivers and subsidiaries in Turkey and Syrian Arab Republic, and recent events of climate change/variability. International intervention is essential to ensure Iraq shares in the benefits of the transboundary rivers of Turkey, Syrian Arab Republic, and Iran.

3.8. THE USE OF NUCLEAR AND ISOTOPIC TECHNIQUES

Radioactive Isotopes have been used as a tracer to investigate salt distribution in soils and their movement under different leaching methods. Under these studies ^{22}Na and ^{36}Cl were used to find the most efficient leaching practices under soil and environmental conditions of Iraq. Other radio isotopes like ^{65}Zn, ^{54}Mn, and ^{59}Fe were used as tracers to evaluate forms of the availability of Zn, Mn and Fe to plant in Iraqi calcareous soils. All these isotopes are gamma emitters which made it easy to be followed and determined in all soil constituents. Results of such studies were used to evaluate amount of each element to be applied to secure crop sufficiency.

^{32}P labelled fertilizer we also used to evaluate efficiency of conventional phosphate fertilizers under various agricultural practices.

Gamma emitting radioisotopes, ^{60}Co, ^{65}Zn and several other radioactive isotopes were used to study fate and bio-removal of such radioisotopes by successive cropping or appropriate extracting solutions. These kinds of study were of considerable importance for environmental evaluation of residual radioactivity in soils under accidental release, fall out and fission products.

Stable Isotopes like ^{15}N was used to evaluate efficiency of nitrogen fertilizer under agricultural practices in Iraq and to develop most efficient bio-fertilizers.

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CHAPTER 4. JORDAN

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4.1. INTRODUCTION

The main causes of soil problems in Jordan are: (1) improper farming practices, such as failure to use contour ploughing, or over-cultivation of the land; (2) overgrazing; (3) the conversion of rangelands to croplands in marginal areas where rainfall is insufficient to support crops in the long term; and (4) uncontrolled expansion of urban and rural settlement at the expense of cultivable land. Local soil conditions can worsen the situation. For example, in the southern part of the Jordan Valley, the soil is characterized by high salt content, poor permeability and high gypsum content. The degradation is worse when low quality irrigation water, for example treated wastewater, replaces fresh water.

Patterns of water use in some cases in Jordan are inappropriate due to water pricing policies, and centralized management systems mean that water is seldom used efficiently. Significant economic and environmental externalities have arisen through excessive utilization of non-recharged aquifers, such as salinization of aquifer water. In irrigated areas in Jordan, especially the Jordan valley and highlands, the excessive application of irrigation water has resulted in soil salinization.

According to Miyamoto *et al.* [4.1], changes in soil salinity cannot be assessed based on water quality data alone. Therefore, improved understanding of soil salinity status and its major chemical components would be helpful for assessing the soil salinization potential associated with irrigation water and land management to help ensure more sustainable food and animal feed production in the Jordan Valley. Reclaimed water contains salts, either from geological layers and groundwater, or human actions such as industrial disposal, household waste disposal and the use of fertilizers. Salts are dissolved in water in the form of cations (positively charged particles) or anions (negatively charged particles). The main cations in reclaimed water are sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). The main anions in reclaimed water are chloride (Cl^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3), and sulfate (SO_4^{2-}). Furthermore, reclaimed water contains various trace elements, such as boron (B), and metals such as iron (Fe), aluminium (Al), cadmium (Cd) and lead (Pb).

The leaching requirement is defined as the amount of irrigation water that has to pass effectively through the root zone to leach salts beyond it, thus preventing salinity build-up. The leaching requirement is usually given in the form of irrigation depth (mm). This requirement, which leaches salts beyond the root zone, has to be added to the total crop water requirement and thus is defined as the leaching fraction.

The effects of soil salinity on plant functioning are similar to those caused by soil drought. As soil salinity increases, soil water available to the plants decreases as a result of the reduction in osmotic potential. Accordingly, this may cause short-term disturbance in plant water status and gas exchange and long-term disturbance in growth and productivity.

The excess accumulation of salts can result in salt-affected soils. Salts may rise to the soil surface by capillary transport from a salt-laden water table and then accumulate due to evaporation. They can also become concentrated in soils due to human activity, for example the use of potassium as fertilizer, which can form sulfate, a naturally occurring salt. As soil salinity increases, salt effects can result in degradation of soils and vegetation.

4.2. SALT-AFFECTED LAND IN THE COUNTRY AND IN DIFFERENT REGIONS

In Jordan, the flat topography (<8%) and low annual rainfall (< 200 mm) are responsible for active and strong winds carrying sediments. The severity of wind erosion is considered to be a major cause of soil degradation in the north-western part of Jordan [4.2]. In Jordan land degradation caused by water erosion is 330000 ha while the amount of soil degraded by wind erosion is some 3 million ha. Land sales also play an important role in the decline in the area of productive lands. In Jordan, the agricultural sector lost about 24.3% of its land during the period from 1997 to 2007. Rain-fed cultivation, which represented 89% of total cultivated land in 1983, had lost 22.6% of its area by 1997.

In the Jordan Valley soil salinity is distributed as follows: about 6500 ha is affected by salinity – 1400 ha slightly, 1600 ha moderately, and the rest severely. In the Jordanian Desert, soils contain a level of salt ranging from 1–10% in the area where the rainfall is less than 200 mm and there is sandy soil (more than 90% of the total area). In other parts of Jordan where the rainfall is more than 200 mm, soil salinity is less than 1.0 dS/m and the soil texture is dominated by clay (less than 8% of the total area). Water resources consist primarily of surface and groundwater, with treated wastewater increasingly being used for irrigation, mostly in the Jordan Valley. Renewable water resources are estimated to be about 780 million cubic meters (MCM) per year, including underground water with a safe yield of 275MCM/year (distributed among eleven catchment basins) and surface water of 505 MCM/year (distributed among fifteen catchments). These figures have been calculated by many studies [4.3, 4.4, and 4.5]; see Table 4.1. An additional 143 MCM/year are estimated to be available from fossil aquifers [4.6] and about 50 MCM/year from brackish aquifers after desalination [4.4]. The use of treated wastewater has become common for irrigated agriculture, especially in the Jordan Valley, with an annual amount of treated wastewater reuse of about 103 MCM in 2010.

TABLE 4.1. GROUNDWATER BASINS AND THEIR EXPLOITATION IN 2010
Data from [4.3] and [4.5]

	Annual Abstractions (MCM/year)		Rate (%) (over-pumping)	No. of operating wells
	Safe Yield	Current Abstraction		
Yarmouk Basin	40.0	49.0	125.0	166.0
Jordan Riverside Wadis	15.0	27.7	185.0	98
Jordan Valley Basin	21.0	27.0	128.0	539
Amman–Zarqa Basin	87.5	158.4	181.0	867
Dead Sea Basin	57.0	90.0	158.0	327
Disi	0	63.2	Fossil	85
Wadi Araba North Basin	3.5	7.1	205.0	34
Red Sea Basin	5.5	6.8	125.0	58
Jafer Basin	9.0	32.6	362.0	213
Azraq Basin	24.0	53.2	222.0	560
Wadi Sirhan Basin	5.0	1.4	29.0	26
Hammad Basin	8.0	1.1	15.0	5
Total	275.5	518.4	188%	3098

Only 8% of the country's land area is arable; rain-fed agriculture occupies some 450 000 ha; in 2015 the irrigated agriculture area was estimated to cover 30 000 ha in the Jordan Valley and 66 000 ha in the Highlands [4.7]. The Jordan Valley (JV), mostly located to the north of the Dead Sea, is the main agricultural region, with a cultivated area of about 35 000 ha [4.8]. Over 60% of Jordan's agricultural produce is grown in the JV. Within the JV there are different soils, annual precipitation, cropping patterns, and agricultural operations. The salinity of irrigated soils along the JV is changing because natural floods are no longer available to flush the irrigated land and leach salts. In addition, high evaporative conditions and insufficient rainfall for adequate leaching contribute to additional salt accumulation.

4.2.1. Brackish water resources in Jordan

4.2.1.1. Renewable brackish groundwater

It is estimated that the amount of renewable brackish water is 50 MCM/year. Most of this is located in the JV, where part of it is used for irrigation where the salinity levels range from 2000 to 5000 mg/l (Table 4.2).

TABLE 4.2. SOURCES OF BRACKISH WATER WHICH CAN BE UTILIZED FROM DIFFERENT GROUNDWATER BASINS
Data from [4.9]

Groundwater basin	Storage amount of non-renewable groundwater (billion m^3)	Safe yield of renewable groundwater (MCM/year)	Salinity range (Total dissolved salts) (mg/l)
Azraq	88	10 to 12	1000 to 3000
Jordan Valley		6	1350 to 2500
Dead Sea		9 to 12	1000 to 1700
Wadi Araba		8	1000 to 7000
Jafr	101.7		1000 to 10 000
Sirhan	32	5	1000 to 7000
Hammad	16	7	1000 to 3200
Total	237.7	55 to 60	

4.2.1.2. *Non-renewable brackish groundwater*

This is located in the following water layers: AL-Khreem, Al-Zarqa and Sandy Al-Kurnub, as well as in the layers of (B2/A7) in the Al-Azraq basin, Al-Hammad basin, Al-Sirhan basin and Al-Jafr basin. It is also located in layers (B4/B5) in some locations in Al-Azraq, Al-Hammad and Al-Sirhan.

The amount of non-renewable brackish water is estimated (at all levels, including the whole depth/thickness) at 240 billion m^3. Only 10% of that can be used, which equates to about 24 billion m^3 (Table 4.3).

TABLE 4.3. WATER RESOURCES USED IN 2010 (MCM)

Source	Domestic	Industrial	Irrigation	Livestock	Total Uses
North Ghors & KAC	53.6		77.3		130.9
South Ghors (Sweimah)	46.5		4.7		51. 2
Springs for drinking water	19.8		0.3		20.1
Reusable water			55.3		55.3
Springs			37.2		37.2
Base flow and flood flow			40.4	7.0	47.4
Reusable water	1.5		46.2		47.7
Surface water (subtotal)	121.4	6.5	256 .3	7.0	391.2
Renewable	203.9	22.0	201.0	0.3	427.2
Non-renewable	27.8	11.9	44.0		83.7
Groundwater(subtotal)	231.7	33.9	245.0	0.3	510.9
Grand Total	351.7	40.4	501.3	7.3	902.2

4.2.1.3. *Inflow water*

The groundwater basin is located in the area that extends from the Dead Sea to the western part of Amman (Al-Zarqa groundwater basin). The amount that is usable is estimated to be 365–

300 MCM per year. Given the fact that this layer includes the northern and southern Dead Sea, the salinity levels range from 5000 to 9000 mg/l.

4.3. MAJOR CAUSES OF SALINITY

Over-pumping of groundwater leads to lowering of the water table and increases the salinity of the water. Several brackish springs have been identified in various parts of the country. The stored volume of brackish groundwater for the major aquifers suggests immense resources; however, not all of these quantities are feasible for utilization. Water levels in the main aquifers are declining due to this over-exploitation, with some aquifers showing considerable deterioration of their water quality due to salinity.

In Jordan the brackish groundwater is generally stored in deep aquifers except in the southwest, where Disi formations or Precambrian complex outcrops are found. The quality of the brackish groundwater ranges from 1000–2000 mg of total dissolved salts (TDS) per litre to 5000–10 000 mg/l, which is good neither for domestic use nor irrigation. Brackish groundwater with salinity of less than 2000–3000 mg/l can be used directly for some crop irrigation, depending on pervious or sandy soil conditions. Another potential use for brackish groundwater is for specific purposes in the mining industry, for example for washing water. In general, brackish groundwater can be safely used after desalination or mixing with very fresh water.

There are two major sources for desalination: the first is the brackish water available throughout the country, and the second is seawater at the Gulf of Aqaba. One source is the brackish water in the South of Ghors between Dier Alla town and the Dead Sea, with salinity of about 5000–7500 mg/l and a yield of about 60 Mm^3/year. Other sources are the saline springs east and west of the Jordan Valley with a capacity of about 10 Mm^3/year, and the brackish water that is distributed all over the country, estimated at hundreds of millions of cubic meters. However, it is very difficult to exploit these resources due to the topography of the country, the distance between these scattered resources, and the need for special treatment to remove some chemicals such as manganese, sulfates and iron, as well as gases such as hydrogen sulfide. Finally, the main problem is the disposal of brine, which can cause environmental problems. These scattered resources, however, can supply desalinated water for small communities by using solar energy or/and wind power.

4.4. EFFECT OF SALINITY ON MAJOR CROP PRODUCTIVITY

The water balance in the Jordan Valley leads to continuing salinization of agricultural land. High-efficiency localized irrigation systems reduce water use, but concentrate salts in and around the roots of the crops. Reduced upstream flows are increasing in salinity because of upstream salt loading, increases in salinity of base flows into wadis and springs, and the increase in the salinity of reclaimed wastewater flows from Amman. These salts end up in the Valley soils and need to be leached regularly because they threaten crop production and yields. Leaching occurs through rainfall (but not on land that is covered with plastic greenhouses and tunnels) during the autumn and winter rains and when high rainfall and flood flows through the King Abdullah Canal. These events permit higher doses of freshwater irrigation to be applied to move salts down through the soil beyond the rooting zone and eventually to drains (although this has the resulting effect of increasing the salt loading of the Jordan River).

The cropping mix of the Jordan Valley has been shifting for three decades as increasing salinity levels and reduced freshwater flows have progressively reduced the area that can sustain salt-sensitive citrus in the middle region of the Valley. When summer crop production in the Jordan Valley was banned, the Jordan Valley Authority decreased areas planted with vegetables under irrigation such as tomatoes, potatoes, and eggplants to provide freshwater flows for drinking water in Amman, which also caused complications in land management. Farmers have had to invest in individual on-farm holding tanks to enable them to blend lower- and higher-grade (generally reclaimed) saline water to grow vegetable and fruit crops in the autumn, winter and spring months. The on-farm reservoir investments are combined with small diesel or electric pressurization pumps, filters, and fertilizer injectors to permit the use of high-efficiency micro-irrigation equipment.

The water allocation assumes that the quantity of water delivered matches the full crop water requirement – that is, the water quality in terms of salinity is constant throughout the cropping season, and the average water quality available does not restrict crop selection. If the effect of reductions in water availability reduces farmers' ability to leach salts from soils, it would drive the Valley's cropping pattern to a narrower range of more drought- and salt-tolerant crops, eliminating higher value crops that are currently exported or bring high prices on domestic markets, such as strawberry and cucumber. This concentration of production against a smaller range of crops would reduce the attractiveness of the Valley for continued investment by agribusinesses that currently contract for export and domestic production.

Because the government has yielded to pressure from the powerful agricultural lobby, the irrigated area in the groundwater-dependent Highlands increased from about 31 000 ha to 42 000 ha between 1996 and 2000, with most of this growth – 8900 ha – coming from tree crops such as olive, cherry, almond, and pears, which have a higher priority water allocation (see Tables 4.4, 4.5, and 4.6).

4.5. CROPS AND VARIETIES GROWN BY FARMERS IN SALT-AFFECTED AREAS

There has been a shift towards non-traditional water resources to alleviate the shrinking in agricultural production in Jordan. Both treated wastewater and saline water are being used more frequently, introducing salt- and drought-tolerant crops to currently uncultivated areas to provide local residents with an economic base while reducing land degradation.

Not all plants respond to salinity in the same way. Some crops can produce acceptable yields at a much higher level of soil salinity than others. This is because some crops are better able to make the needed osmotic adjustments, enabling them to extract more water from a saline soil. In areas where a build-up of soil salinity cannot be controlled at an acceptable concentration for the crop being grown, an alternative crop can be selected that is both more tolerant of the expected soil salinity and able to produce economic yields. There is an 8–10-fold range in the salt tolerance of agricultural crops. This wide range in tolerance allows for greater use of moderately saline water, much of which was previously thought to be unusable. It also greatly expands the acceptable range of water salinity considered suitable for irrigation.

The relative salt tolerance of most agricultural crops is sufficiently well known to make it possible to give general salt tolerance guidelines. Tables 4.4, 4.5, and 4.6 give a list of crops classified according to their tolerance and sensitivity to salinity. The following general conclusions can be drawn from these data:

(a) Full yield potential should be achievable with nearly all crops when using water with salinity less than 0.7 dS/m.

(b) When using irrigation water of slight to moderate salinity (i.e. 0.7–3.0 dS/m), full yield potential is still possible, but care needs to be taken to achieve the required leaching fraction in order to maintain soil salinity within the tolerance of the crops. Treated sewage effluent will normally fall within this group.

(c) For higher salinity water (more than 3.0 dS/m) and sensitive crops, increasing leaching to satisfy a leaching requirement greater than 0.25–0.30 might not be practicable because of the excessive amount of water required. In such cases, consideration needs to be given to changing to a more tolerant crop that will require less leaching, to control salts within crop tolerance levels. As water salinity increases within the slight to moderate range, production of more sensitive crops may be restricted due to crop tolerance level and inability to achieve the high leaching fraction needed, especially when grown on heavier, more clayey soil types.

TABLE 4.4. MODERATELY SALT-TOLERANT AGRICULTURAL CROPS
Data from [4.10]

Moderately tolerant	
Fibre, Seed and Sugar Crops	
Cowpea	*Vigna unguiculata*
Oats	*Avena sativa*
Rye	*Secale cereal*
Safflower	*Carthamu stinctorius*
Sorghum	*Sorghum bicolor*
Soybean	*Glycine max*
Triticale	*X Tritico secale*
Wheat	*Triticum aestivum*
Wheat, Durum	*Triticum turgidum*
Grasses and Forage Crops	
Barley (forage)	*Hordeum vulgare*
Bromus , mountain	*Bromus marginatus*
Canary grass, reed	*Phalaris arundinacea*
Clover, Hubam	*Melilotus alba*
Clover, sweet	*Melilotus*
Fescue, meadow	*Festuca pratensis*
Fescue, tall	*Festuca elatior*
Harding grass	*Phalaris tuberosa*
Panic grass, blue	*Panicum antidotale*
Rape	*Brassica napus*
Rescue grass	*Bromus unioloides*
Rhodes grass	*Chloris gayana*
Grasses and Forage Crops	
Ryegrass, Italian	*Lolium italicum multiflorum*
Ryegrass, perennial	*Lolium perenne*
Sudan grass	*Sorghum sudanense*
Trefoil, narrow leaf bird’s foot	*Lotus cornicula tustenuifolium*
Trefoil, broadleaf	*L. corniculatu sarvenis*
Wheat (forage)	*Triticumae stivum*
Wheatgrass, standard crested	*Agropyron sibiricum*
Wheatgrass, intermediate	*Agropyron intermedium*
Wheatgrass, slender	*Agropyron trachycaulum*
Wheatgrass, western	*Agropyron smithii*
Wild rye, beardless	*Elymus triticoides*
Wild rye, Canadian	*Elymus Canadensis*
Vegetable Crops	
Artichoke	*Helianthus tuberosus*
Beet, red	*Beta vulgaris*
Squash, zucchini	*Cucurbita pepo melopepo*
Fruit and Nut Crops	
Fig	*Ficuscarica*
Jujube	*Ziziphysjujuba*
Olive	*Oleae uropaea*
Papaya	*Carica papaya*
Pineapple	*Ananascomosus*
Pomegranate	*Punicagranatum*

TABLE 4.5. MODERATELY SALT-SENSITIVE AGRICULTURAL CROPS
Data from [4.10]

Moderately sensitive	
Fibre, Seed and Sugar Crops	
Broad bean	*Vicia faba*
Castor bean	*Ricinus communis*
Maize	*Zea mays*
Flax	*Linum usitatissimum*
Millet, foxtail	*Setaria italica*
Groundnut/peanut	*Arachis hypogaea*
Rice, paddy	*Oryza sativa*
Sugarcane	*Saccarum officinarum*
Sunflower	*Helianthus annuus palustris*
Grasses and Forage Crops	
Alfalfa	*Medicago sativa*
Bentgrass	*Agrostis stoloniferapalustris*
Bluestem, Angleton	*Dichanthium aristatum*
Brome, smooth	*Bromus inermis*
Buffel grass	*Cenchrusciliaris*
Burnet	*Poterium sanguisorba*
Grasses and Forage Crops	
Clover, berseem	*Trifolium alexandrinum*
Clover, ladino	*Trifolium repens*
Clover, red	*Trifolium pratense*
Clover, strawberry	*Trifolium fragiferum*
Clover, white Dutch	*Trifolium repens*
Corn (forage) (maize)	*Zea maize*
Cowpea (forage)	*Vigna unguiculata*
Dallis grass	*Paspalum dilatatum*
Foxtail, meadow	*Alopecurus pratensis*
Vegetable Crops	
Broccoli	*Brassica oleracea botrytis*
Brussel sprouts	*B. oleracea gemmifera*
Cabbage	*B. oleracea capitata*
Cauliflower	*B. oleracea botrytis*
Cucumber	*Cucumis sativus*
Eggplant	*Solanum melongenaesculentum*
Kale	*Brassica oleraceaa cephala*
Kohlrabi	*B. oleracea gongylode*
Lettuce	*Latuca sativa*
Muskmelon	*Cucumis melon*
Pepper	*Capsicum annum*
Potato	*Solanum tuberosum*
Pumpkin	*Cucurbita pepo pepo*
Radish	*Raphanus sativus*
Spinach	*Spinacia oleracea*
Fruit and Nut Crops	
Grape	*Vitis* sp.

TABLE 4.6. SALT-SENSITIVE AGRICULTURAL CROPS
Data from [4.10]

Sensitive	
Fibre, Seed and Sugar Crops	
Bean	*Phaseolus vulgaris*
Guayule	*Parthenium argentatum*
Sesame	*Sesam umindicum*
Vegetable Crops	
Bean	*Phaseolus vulgaris*
Carrot	*Daucus carota*
Fruit and Nut Crops	
Almond	*Prunus dulcis*
Apple	*Malus sylvestris*
Apricot	*Prunus armeniaca*
Avocado	*Persea americana*
Blackberry	*Rubus*
Mango	*Mangifera indica*
Orange	*Citrus sinensis*
Passion fruit	*Passiflora edulis*
Peach	*Prunus persica*
Pear	*Pyrus communis*
Strawberry	*Fragaria*
Persimmon	*Diospyros virginiana*
Plum: Prune	*Prunus domestica*
Raspberry	*Rubus idaeus*

TABLE 4.7. LAND USE IN JORDAN ACCORDING TO AGRO-ECOLOGICAL ZONES
Data from [4.11]

Ecological zone	Crops	Uses
Semi-desert (badiah)	Pastoralism	100% in <100 mm rainfall areas
		50% in 100–200 mm rainfall areas
	Rain-fed crops	40% in 100–200 mm rainfall areas
	Irrigated crops	10% in 100–200 mm rainfall areas
Arid	Barley growing	50% in 200–250 mm rainfall areas
	Cereals/fruit trees	25% in 300–350 mm rainfall areas
	Pastoralism	25% stubble grazing
Semi-arid	Cereals	40%
	Vegetables	30%
	Fruit trees	10%
	Forestry	5%
	Pastoralism	5%
Humid	Cereals	50% (Wheat)
	Fruit trees	30%
	Forestry	15%
	Pastoralism	5%
Ghors (Rift Valley)	Vegetables (irrigated)	85%
	Fruit trees (irrigated)	10%
	Forage cultivation	5%

4.6. MEASURES IMPLEMENTED TO ADDRESS SALINITY AT FARM LEVEL

Farmers in the Jordan Valley have a good level of knowledge about salinity because they live in an area of saline soil. They use large amounts of irrigation water to combat the salinity on their farms, or select crops that have high tolerance to saline soil (see Table 4.7). Unfortunately, these activities push the salt into the groundwater, thus increasing the salinity of several wells in the region and rendering the water less suitable for human and plant use. To avoid future problems good salinity management can be applied in every farm. The adoption of new highly salt-tolerant crops, such as date palm, can help in combating the salinity build-up in the soil and the deterioration of groundwater quality caused by over-pumping and using treated wastewater in irrigation.

4.7. MAJOR GAPS TO IMPROVEMENTS

4.7.1. Availability of data on soil and water quality

A soil order map is available and based on soil analysis and field survey at a scale of 1:50 000 [4.12]. The soil information for Jordan is restricted to the soil orders with a dominance of Aridic soils. A more recent soil map of Jordan showed the extensive distribution of gypsic soils [4.13].

4.7.2. Availability of salt-tolerant crops and varieties

Many genotypes with high yield potential (grain or forage) suitable for growing in saline conditions with treated wastewater irrigation are available in Jordan. These include: quinoa, triticale, Sudan grass, pigeon pea, oats, canola, sesbania, *Medicago arborea*, pearl millet, and atriplex. These genotypes are available to be included in future studies of soil salinity with farmers. Promising barley and triticale genotypes were produced at the Al-Khalediyah saline agriculture research station and in farmers' fields respectively.

4.7.3. Availability of tools, knowledge and expertise

(a) Expert staff is available who are trained in dealing with salinity.
(b) There are well furnished laboratories with modern technology for soil, water, and plant analysis.
(c) There is a need for field devices to measure water and soil salinity.

4.7.4. Any other soil and management factors affecting salinity

Other factors affecting soil salinity include the climatic conditions in Jordan. Soil electrical conductivity is also affected by cropping, irrigation, land use, and applications of fertilizer, manure, and compost.

4.8. THE USE OF NUCLEAR AND ISOTOPIC TECHNIQUES

Jordan with cooperation and support from the International Atomic Energy Agency (IAEA) has used the ^{15}N and neutron probe in their research for years. Jordanian researchers have utilized the neutron probe for the scheduling of irrigation for a variety of field crops (such as barley, tomatoes, and potatoes) and orchards (such as citrus fruits in the Jordan Valley). The neutron probe technique has also been used to determine the crop coefficient of the aforementioned crops. Over the last decade, ^{15}N was used to determine the nitrogen use efficiency (NUE) from different fertilizer sources (urea or ammonium sulfate) on vegetable crops (such as potatoes and tomatoes) in the Jordan Valley under irrigation and on field crops under rainfed conditions such as lentil and chickpea. Recently, ^{15}N was used to determine the NUE for irrigated maize in the Jordan Valley with varying levels of soil organic matter. Future work will evaluate NUE using ^{15}N from ammonium sulfate sources in an updated experiment. Data is currently being examined for forage crops (barley, vetch, and sunflower) under saline water and soil conditions. Additionally, the NUE will be evaluated for okra using ^{15}N ammonium sulfate under saline soil and water conditions to evaluate quality and yield. Some of these data were published in an international academic journal and new data is being analysed for further publication.

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CHAPTER 5. KUWAIT

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5.1. INTRODUCTION

Soil and water salinity is a global crisis which has serious implications for crop production, the ecosystem and the livelihoods of farmers worldwide. According to a report by the FAO Land and Plant Nutrition Management Service, more than 6% of the world's land area is affected by salinity or sodicity [5.1]. The area and extent of soil and water salinization depends upon geographical and climatic conditions, in addition to the agricultural, irrigation and land management practices followed in the region. Very limited research has been done on the salt-affected soils of Kuwait, and the current extent and status of soil salinity in Kuwait is largely unknown. Salinization has been addressed only recently as an early warning of land degradation and desertification in Kuwait [5.2]. Soil problems in Kuwait can be classified into three major groups:

(a) Physical – compaction and hard-setting, wind and water erosion.
(b) Chemical – fertility depletion, oil contamination, salinization and sodification.
(c) Biological – decline in soil organic matter, macro and micro fauna and biodiversity.

5.2. DATA ON SALT-AFFECTED LAND IN THE COUNTRY AND DIFFERENT REGIONS

Soil salinity is common in the agricultural and coastal areas. Hamadallah [5.3] reported that 209 000 hectares, comprising 11.7% of the entire area of Kuwait, are affected to varying degrees by salinity and sodicity. There is therefore great concern about the current situation and the limits that this might impose on agricultural expansion in Kuwait. In Kuwait, agricultural production is concentrated in three main areas: Al-Abdaly (in the north), Kabd (central) and Al-Wafra (in the south), with estimated crop production areas of 10 000, 20 000 and 37 500 ha respectively. The effects of salinity are evident where salts can be seen on the soil surface in the farming areas in the north (Al-Abdally) and south (Al-Wafra) of Kuwait.

Kuwait's soils are divided into four groups ([5.4, 5.5]):

(a) Desert soils: generally saline with low water holding capacity. These cover 75% of the land area.
(b) Desert-regosol intergrades: slightly saline with low water holding capacity. Mostly found in irrigated agriculture.
(c) Lithosol: found on sloping land. Cover 1% of the total area.
(d) Alluvial soils: sandy or clay soils with high salt accumulation formed from marine sedimentation in coastal regions.

Water is an invaluable natural resource, and the agricultural sector consumes nearly 70% of the country's freshwater resources. The aquastat survey conducted in 2008 points out that nearly 913.2 million m^3 water is abstracted every year in Kuwait, which includes irrigation and livestock (54%), municipalities (44%), and industry (2%). Of the 54% of water used for agriculture, 80% is for productive agriculture, 9% for landscape features and 11% for garden watering [5.6].

In Kuwait, good quality water is limited and the seasonal water balance, i.e. the difference between rainfall and evaporation, is invariably negative and imposes severe demands on the availability of water for agriculture. The groundwater in Kuwait is mostly saline, with limited amounts of fresh and brackish water [5.7]. The quantity and quality of groundwater is deteriorating due to the continuous pumping of water. Irrigation water contains soluble salts which accumulate on the soil surface and in the root zone on application, so that poor water quality is one of the major factors affecting soil salinity [8]. Based on its soluble salt content, groundwater is divided into fresh groundwater (<1000 mg/l), brackish groundwater (1000 to 7000 mg/l) and saline groundwater (7000 to 12 000 mg/l). Fresh groundwater and saline groundwater are not used for agricultural purposes, as the former is stored in freshwater reservoirs for drinking water, and the latter contains an excessive concentration of soluble salts [5.6]. As a result, brackish groundwater is used for agricultural and domestic purposes and when not properly managed, may exacerbate salinity, and hence further degrade land resources. Other non-conventional sources of water are produced such as wastewater, treated waste water, reused treated waste water, and desalinated water; these are reused together with agricultural drainage water.

5.3. MAJOR CAUSES OF SALINITY

Kuwait is a desert country with an average temperature of 45ºC during the long hot dry summer season and falling to below 4ºC in winter. The annual precipitation is very low and ranges between 106 and 134 mm [5.6]. The extremely arid climate and low annual precipitation leads to low soil water content and high evaporation that eventually increases soil salinity. Primary salinization occurs in soils naturally rich in soluble salts, and is prevalent in areas with a shallow saline groundwater table. Secondary salinization occurs when low quality brackish or saline irrigation water is used without adopting adequate leaching and drainage measures in the irrigation system. Deforestation and overgrazing also contribute greatly to soil salinity [5.8].Waterlogging is observed upon leaching with inadequate drainage systems. Thus excess leaching with insufficient drainage, insufficient application of water, poor land levelling, inappropriate crop rotation systems, chemical contamination from excessive use of fertilizers, dry season fallow practices with a shallow water table, misuse of heavy machinery resulting in soil compaction and inadequate drainage, and inefficient irrigation all significantly increase soil salinity.

5.4. EFFECT OF SALINITY ON CROP PRODUCTION

Salt-affected soils are characterized by the formation of salt crusts on the soil surface and are classified into saline, saline-sodic and sodic soils based on the content and concentration of the salt present [5.8]. Increased soil salinity reduces the availability of water and nutrients in the root zone of plants. Plants undergo water stress, oxidative stress, ion toxicity, genotoxicity, hormonal imbalances, membrane disorganization, reduced cell expansion and division, all of which significantly reduce overall growth and productivity. Plants exhibit poor growth patterns with delayed germination and foliar damage. In addition, salinity affects water quality, causing serious social, economic and environmental issues. Bio-saline agriculture has gained momentum in this scenario, where crops tolerant of salinity are cultivated in the salt-affected areas through improved soil and water management techniques.

Several studies have been conducted in Kuwait to ascertain the effects of brackish water irrigation on plant growth and productivity. Various crop genotypes have been classified as tolerant, moderately tolerant, semi-sensitive and sensitive based on their yield potential in soil with different levels of electrical conductivity and exchangeable sodium percentage. The performance evaluation of mutant barley genotypes under a brackish water irrigation system has identified number of salt-tolerant varieties for cultivation in Kuwait's harsh environmental conditions [5.9]. Introduction of a farming approach with improved soil, water and nutrient management practices in the crop production system could significantly reduce soil salinization and sodification.

5.5. RANGE OF CROPS GROWN BY FARMERS IN SALT-AFFECTED AREAS

Kuwait's arable land is characterized by sandy soil with low water retention capacity, poor organic matter content and low nutrient content. All these factors have negative impacts on the healthy growth of plants. Out of the total harvested irrigated cropped area of 8055 hectares, wheat, barley, potatoes, vegetables, dates, and other annual and perennial crops constitute about 290, 1263, 760, 3660, 390, 1589 and 103 hectares respectively [5.6]. About 45% of the agricultural land is devoted to vegetable production - mainly tomatoes, eggplants, cucumbers and sweet peppers - and 19% is used to cultivate cereals such as barley and wheat. Date palm trees are the most important fruit trees grown, and occupy about 20% of the cultivated land. In 2003, agricultural production included 207 000 tons of vegetables, 18 000 tons of fruits and about 3300 tons of cereals [5.10].

5.6. MEASURES IMPLEMENTED TO ADDRESS SALINITY

Recently several projects have been initiated as coordinated research projects and technical cooperation programmes in cooperation with the International Atomic Energy Agency (IAEA) aimed at the enhancement of use of salt affected soils and saline water. This will be achieved by the introduction of alternative sources of irrigation water, such as treated wastewater and brackish water, optimization of water and fertilizer use efficiency and development of genotypes with desirable traits through mutation breeding.

To manage the salinity problem, research needs to be undertaken to determine the best practices of soil reclamation and management, such as the best mix of plants and possibly sub-surface drainage to achieve salinity control. Al-Menaie [5.11] suggested the following as pre-requisites for research on salt-affected soils in Kuwait:

(a) Identification, mapping and characterization of salt-affected soils.

(b) Identification of the causes and sources of salinity.

(c) Corrective measures.

Several corrective measures such as physical methods (sanding, subsoiling, scraping, land levelling), biological methods (organic manure application, blue-green algae, saline agriculture, crop rotation, mulching), chemical methods (amendment, soil conditioning, mineral fertilizer) and hydraulic methods (leaching, irrigation, drainage, safe disposal of saline waters) are advocated to reclaim salt affected soils by removing excess salts from the root zone [5.12]. Continuous cropping assists the sustainability of crop production in reclaimed land by maintaining the organic carbon content of the soil. Incorporation of legumes in the cropping system with minimal tillage is a sustainable approach to improving physical soil conditions and crop yield, by increasing nitrogen content in the soil, pore space, air holding capacity, organic matter content and microbial activity. Thus, an integrated approach of physical, chemical, and biological reclamation approaches is necessary to turn barren salt-affected areas into productive land.

5.7. MAJOR GAPS TO FURTHER IMPROVEMENTS

The major gaps are:

(a) Insufficient desalinated freshwater for agricultural purposes and poor quality groundwater.
(b) Nuclear-isotopic techniques not introduced in soil-water-crop management systems and plant breeding in Kuwait.
(c) Unavailability of suitable equipment for mutation breeding and soil and water management using nuclear-isotopic techniques.
(d) Lack of qualified staff in mutation breeding, soil and water management using nuclear-isotopic techniques and crop simulation models.
(e) Lack of local crop genotypes with high water use efficiency, crop water productivity, and improved yield adaptable to Kuwait's environmental conditions.

5.8. THE USE OF NUCLEAR AND ISOTOPIC TECHNIQUES

No nuclear or isotopic techniques are currently in use in Kuwait. However, the use of ^{15}N for the estimation of nitrogen use efficiency as well as the Cosmic Ray Neutron Sensor for soil moisture estimation will be incorporated in the near future. These techniques will help determine irrigation scheduling and fertilizer precision application.

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CHAPTER 6. LEBANON

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6.1 INTRODUCTION

Land degradation in Lebanon has expanded and intensified due to soil salinity and deterioration of soil and water quality. Intensive agriculture and mismanaged irrigation including unregistered water abstraction have all contributed to this situation. Current practices of water management lead to the deterioration of water quality and exacerbate the impacts of climate change, human pressure and water scarcity. Excessive pumping from wells has resulted in a decline of groundwater quality in the coastal area caused by seawater intrusion [6.1] and a drop in groundwater level in the Bekaa plain [6.2]. Therefore, controlling water abstraction and ensuring efficient water use, including utilizing non-conventional water resources, are prerequisites for the sustainable management and use of water resources in the country. The map of the main driving forces causing land degradation in Lebanon shows soil salinity to be more acute in the coastal area with its large quantity of greenhouses, and in the north eastern part of Lebanon.

6.2 SALT-AFFECTED LAND IN THE COUNTRY AND DIFFERENT REGIONS

Lebanon has five major agro-ecological zones: 1. the coastal area, 2. the mountains, 3. North-east Bekaa, 4. Central and West Bekaa and 5. the southern plateau. The prevailing climate is dry Mediterranean on the coastal area and inland, dry sub-humid in the mountains and semi-arid in North-east Bekaa, with annual rainfall varying between 700 mm, 1200 mm and <300 mm, respectively.

Studies from Central Bekaa using a chlorine tracer technique in different cropping patterns (permanent grape and fruit trees, vegetable monoculture and wheat-potato rotation) has shown that soluble salts and pollutants can penetrate to the groundwater table in less than one year, notably in areas of vegetable production [6.3]. Therefore, the soil-groundwater system is highly vulnerable to pollution and salinity build-up.

Almost half of Lebanon's total surface area could potentially be cultivated, although with different levels of productivity [6.4]. The main crop production regions are distributed as follows [6.5]:

(a) Coastal strip: citrus fruits, bananas, and vegetables (predominantly grown in plastic greenhouses).

(b) Akkar Plain: cereals, potatoes, grapes and vegetables.

(c) Bekaa Plain: potatoes, vegetables, grapes, stone fruits and grains.

(d) Mountainous region: fruit orchards and vegetables.

(e) Western slopes of Mount Hermon and the eastern mountain chain: grapes, olives and cherries.

(f) Hills in the South: olives, grains, tobacco and almonds.

The majority of agricultural production is concentrated in the Bekaa Plain, which encompasses about 42% of the total area of cultivated land in Lebanon. It also represents the highest percentages of essential crop types such as cereals and vegetables [6.4]. The most important cereals cultivated are wheat, barley and maize, which play an important role in food self-sufficiency. Production of cereals reached 394.400 tons in 2005 with a total value of LBP 92.9 billion [6.6].

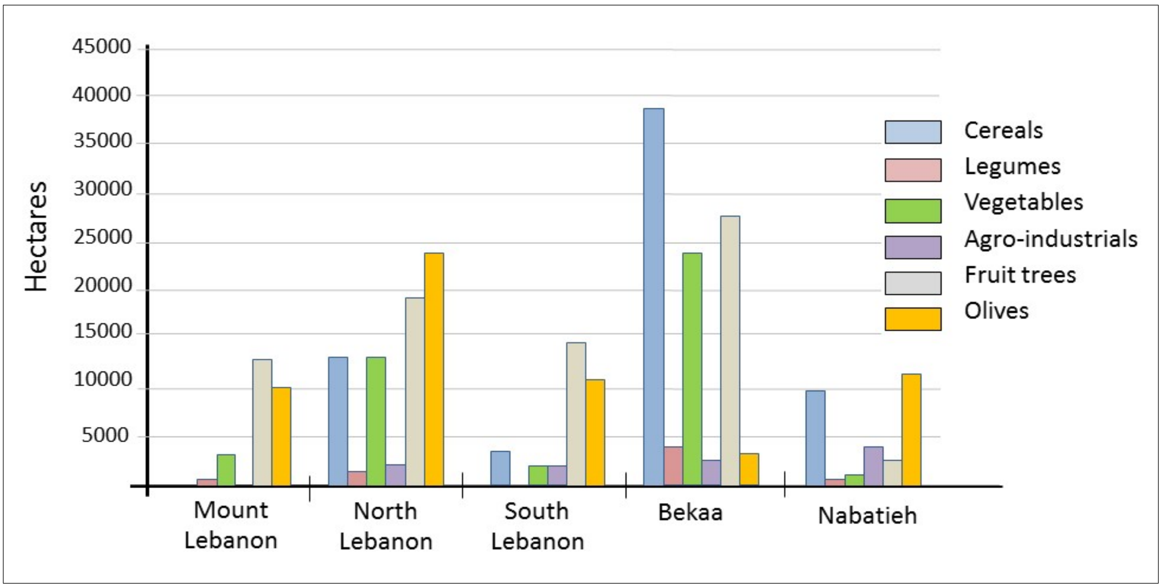

FIG. 6.1. Distribution of crop area by governorate [data from 6.6]

The main irrigated field crops are potatoes, vegetables, wheat, tobacco, pulses, bananas, grapes, and tomatoes, in addition to irrigated fruit trees such as citrus, apples and bananas. A census comparing old and new agricultural practices undertaken by the Ministry of Agriculture of Lebanon (MoA) and Food and Agricultural Organization (FAO) in1999 and 2010 showed a slight increase (by 11%) in the area of wheat from 16 940 ha to 18 760 ha and a significant decrease in the area of barley from 5140 ha to 3060 ha and maize from 3490 ha to 1400 ha, corresponding to 40% and 60% respectively [6.7]. Meanwhile, the area of potatoes and subsidized tobacco was reduced from 19 170 ha to 15 860 ha and from 8980 ha to 2890 ha, corresponding to 20% and 67% respectively (Figure 6.1).

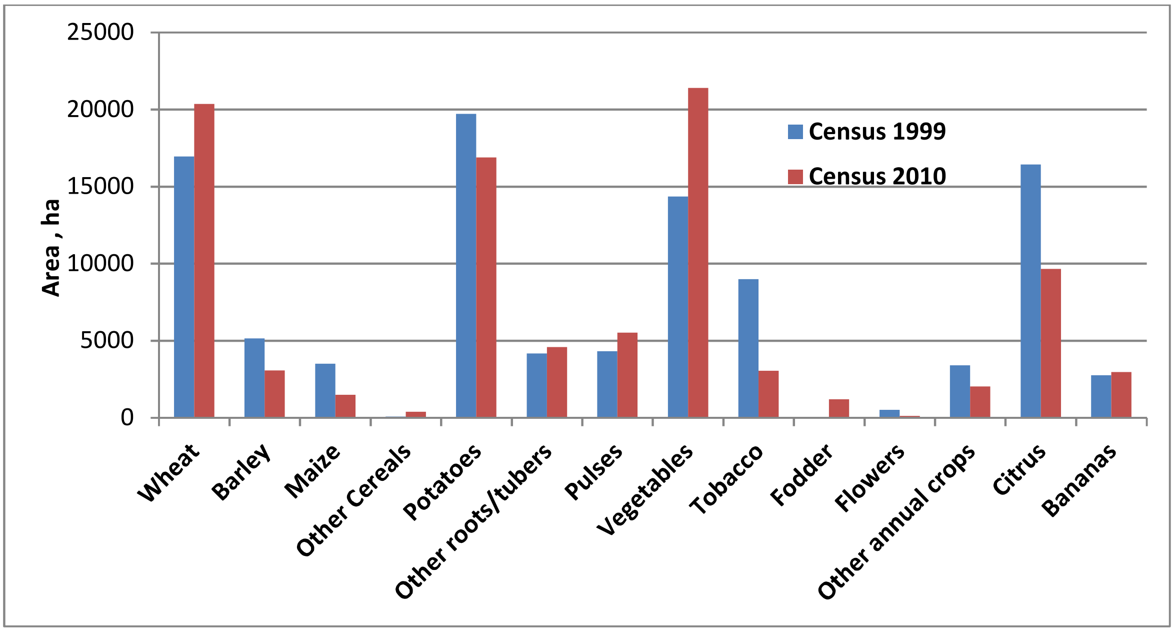

FIG. 6.2. Comparative agricultural census implemented by the MoA and FAO in 1999 and 2010 [data from 6.7]

The reduction in the area of some strategic crops was associated with a simultaneous increase of vegetable-growing areas from 14 340 ha to 19 690 ha; an expansion equivalent to 37% in a ten-year period.

6.2.1. Salinity and protected agriculture in the coastal area

In greenhouses with a total area of 5000 ha (FAO, 2000), 90% of Lebanese farmers practice excessive application of animal manure (3500–100 000 tons/ha) and 15% of them still use low solubility, complex Nitrogen, Phosphorous and Potassium (NPK) fertilizers as a starter fertilizing system [6.8, 6.9]. In orchards (citrus, apples, and olives) more than 75% of farmers apply equal NPK recipes in combination either with ammonium sulfate or Patentkali.

Even in the absence of a relationship between soil salinity and water salinity [6.10], excessive fertilizing during the 1980s caused some increase of soil salinity problems in greenhouse production in Lebanon (Table 6.1). Improved land levelling and leaching management were advised as a way of significantly reducing the risk of soil salinization, despite the decrease in the quality of groundwater along the Lebanese coastal area.

The improvement of soil management via the yearly leaching of salts has become a generally accepted practice. However, our survey proved that, as a result of poor fertilizing and irrigation scheduling, the gradient of yearly soil salinity increase inside the greenhouses in comparison with the outside soil is in the range of 1.4–6.5-fold [6.8]. The improved management of existing modern irrigation systems, at farm level, coupled with higher fertilizer use efficiency, could substantially improve the quality of the soil and groundwater.

TABLE 6.1. RANGE AND MEAN VALUES OF GREENHOUSE SOIL AND WATER SALINITY

Component	Beirut-Jbail area [6.10]	Beirut-Jbail-Batroun Area [6.8]
Soil	1.0- 17.8 (4.7)*	0.64-8.56 (3.36)*
Irrigation water	0.26-1.96 (0.39)*	0.17-4.5 (0.52)*

* Mean value

In the greenhouses, vegetables and ornamentals are the major crops, of which tomato and cucumber occupy the largest surface area [6.8]. Cucumbers are grown in spring, following an autumn tomato crop. Intensive agricultural practices in these protected plastic houses require excessive nutrient input, causing soil salinity which is probably responsible for the significant decrease in yield [6.11].

Observations in greenhouses located in the southern coastal area (Jieh town) showed that they had high salinity conditions (28.3 dS/m) with negative crop performance, and small tomato fruits were produced, resembling “cherry tomatoes” in size [6.12]. This could be related to irrigation with saline groundwater, caused by seawater intrusion [6.13]. But the monthly water input does not exceed 75 mm, so that soil salinity might be influenced by additional factors, such as crop evapotranspiration and high doses of fertilizer application. In fact, the Electrical Conductivity (ECe) values to a depth of 40 cm showed a significant linear relationship with the soil chloride content present as a byproduct in complex fertilizers (15% of each of N, P_2O_5 and K_2O) containing potassium chloride as a source of potassium (Figure 6.3). Chloride accumulation in the soil exchange complex explained 61 % of the soil salinity [6.14].

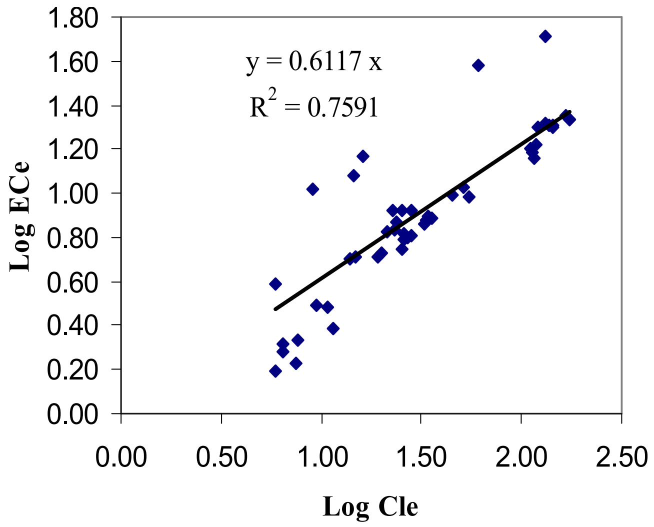

FIG. 6.3. Relationship between the chloride content (Cle) and the electrical conductivities (ECe) of soil extracts in soil samples between 0 and 40 cm in depth; reproduced from [6.14].

Soil samples from the northern coastal area (Beirut-Batroun region) up to an altitude of 450 m showed various levels of ECe (Table 6.2), with the largest number in the moderate salinity class (4–8 dS/m). Comparison of two soil samples taken at different times showed an increasing trend of salinity, although there was an absence of excessively saline samples (>16 dS/m). The recorded means of soil salinity were close and in the same class (moderate salinity) at both sampling times (Table 6.2). The origin of this salinity build-up was investigated with reference to the irrigation water used.

The majority of water samples taken from the Nahr-Ibrahim River were of good quality (ECw 0.3 dS/m). Only 15% of the water samples had EC_w> 0.75 dS/m, i.e. an increasing risk of salinity according to the FAO recommendations [6.15]. This was relevant to the coastal Batroun area, not covered by the earlier study [6.10], which gave the highest ECw readings (>3 dS/m). Linking soil salinity levels to the agricultural practices required a search for a correlation with the various causes of soil salinity. Surprisingly, no correlation was found between the salinity of the soil and that of the irrigation water.

TABLE 6.2. COMPARATIVE VALUES OF SOIL AND IRRIGATION WATER SALINITY IN GREENHOUSE PRODUCTION IN THE NORTHERN COASTAL AREA

Area		Beirut-Jbail	Beirut-Jbail-Batroun
Range of irrigation water salinity (dS/m)		0.26-1.96 (0.39)*	0.17-4.5 (0.52)*
Range of soil salinity (dS/m)		1.0- 17.8 (4.7)*	1.06-13.7 (5.4)*
Distribution of soil salinity (dS/m)	0-2	15.7 %	9.8 %
	2-4	46.1 %	27.9 %
	4-8	21.9 %	44.3 %
	8-16	11.4 %	18.0 %
	>16	4.9 %	0
Source		[6.10]	[6.8]

*Mean values are shown in brackets

The quality of irrigation water explained 29% of the variation in soil salinity in the greenhouses of the northern coastal area; the remaining variation might be linked to other factors. One possible explanation is the excessive fertilization practiced in greenhouse production. As a result of using a poor fertilizing and irrigation schedule, up to a 6.5-fold increase of soil salinity inside the greenhouses was observed in comparison with that of the outside soil [6.16].

Since the introduction of greenhouse production in Lebanon in the early 1980s, some practices have in fact improved production conditions. Land levelling and the yearly leaching of salts have resulted in significant reduction of salinity hazards. However, the adequate monitoring of the existing modern irrigation system, at the farmer level, coupled with higher fertilizer use efficiency, could substantially improve the situation. This is particularly relevant to the increasing use of saline irrigation water in the region.

6.2.2. Salinity development in open fields

Intensive agriculture with a large fertilizer input is one of the major sources of soil and groundwater contamination with nitrates [6.17]. This trend is enhanced by mismanaged irrigation practices and induced groundwater recharge [6.18]. The threat is particularly associated with cash crops that require high inputs. The loss of water quality with the reported increase of the content of nitrates and soluble salts in the ground water could be linked to agricultural activities, in particular to fertilization and irrigation management [6.19].

Surface water resources in the area are limited and thus farmers rely mainly on deep wells. The electrical conductivity of this water was found to be of good or medium quality [6.20], ranging between 0.7 and 0.9 dS/m. The empirical agricultural practices and intensive input of chemicals employed in a fragile semi-arid area in an attempt to reach early crop targets have caused the deterioration of the fragile soil quality, which is known for having low resilience [6.21]. After removal of the shallow petrocalcic layer, farmers intensively cultivate the soil material underneath. A very low organic matter content ($<1.0\%$) together with weak non-developed structure is characteristic of this soil, which has a massive or single grain and fine to very fine size structure. Water quality, fertilization and mismanagement of drip irrigation are probable causes of a build-up of salinity in the soil. As a result, soil resilience to salt accumulation and surface layer coherence to erosion are altered. Crop yields are eventually reduced in the absence of adequate soil conservation measures, leading to detrimental economic and environmental consequences.

Monoculture of high water and nitrogen demanding crops is usual for this area. The high prices of watermelon and vegetables are the reason for the adoption of intensive practices. Farmers rely mostly on their own skills in the choice of crops. Rotation is rare or absent, a fact that creates possible problems of soil depletion, unbalanced removal and accumulation of applied nutrients (Table 6.3).

TABLE 6.3. MODERN AND TRADITIONAL CROPPING PATTERN AND DOMINANT IRRIGATION SYSTEMS IN NORTH-EAST BEKAA, LEBANON

Crop pattern and agricultural practices			
Crop Rotation	Crop cultivated in monoculture	Production	Irrigation Technique
Watermelon-legume-tomato-lettuce-eggplant-barley	Stone fruit trees between tree rows.	Open field	Surface, drip
	Vegetables	Greenhouse, small tunnels and open field	Drip
	Wheat	Open field	Supplementary irrigation by sprinkler
	Barley		

Various different irrigation techniques are used in the area. Observations showed no salinity hazards when farmers applied flooding, furrow irrigation or macro sprinklers [6.22]. However, water shortages impose a shift to localized systems which have been adopted primarily for vegetable production, both in the open field and in plastic greenhouses. However, mismanagement of cultivation elements in a vulnerable area results in a slight rise in soil salinity and negative crop response to inappropriate practices.

Traditionally, farmers apply manure as well as different types of low-solubility and soluble fertilizers with different ratios of N, P and K (Table 6.4). Analysis of applied fertilizers showed an extreme disproportion of nitrogen in relation to phosphorus and potassium. Watermelon is less demanding than tomato for P_2O_5 and K_2O considering the recommended ratios of 1: 0.13:0.93 and 1:0.47:1.25 for watermelon and tomato respectively [6.23].

The assessment of the effect of agricultural practices on soil salinity revealed no significant correlation between the amount of added manure and observed soil salinity. However, farmers apply fertilizers with a high salinity index. This, in addition to the mismanagement of irrigation and the absence of leaching fraction and drainage canals, increases soil salinity. Monitoring of the electrical conductivity of soil samples (Figure 6.4) undertaken in 2000 indicated an expansion of salt-affected soils in comparison with a previous field sampling done in 1997 [6.22].

TABLE 6.4. UNBALANCED NUTRIENT APPLICATION IN BAALBECK-HERMEL AREA, LEBANON

Crop	ECe dS/m	Poultry manure Kg/ha	Ratio N: P_2O_5: K_2O			Recommended ratio
Watermelon	0.6	6000	1	4.3	1.8	1:0.13:0.93
Melon	3.1	6000	1	1.14	3.1	1:0.3:0.6
Tomato	8.6	8000	1	2.1	0.7	1:0.47:1.25

Salt-affected soils had a pH value of 8.2±0.2. The cation exchange capacity (CEC) value varied between 21 and 42 cmol/kg. However, the sodium absorption ratio did not exceed 1%. Therefore, these soils were classified as Solonchaks. Mismanagement of localized irrigation systems influenced the concentration of soluble salts in the soil solution. The comparative impact of different irrigation systems on salinity build-up in the Baalbeck-Hermel area showed that, regardless of the crop system, the highest EC value (6.8 dS/m) was under drip irrigation and monoculture (Table 6.5). The smallest ECe (0.7 dS/m) was under rain-fed conditions, whereas soils under flooding, and alternation of drip and sprinkler irrigation systems, were very slightly saline (1.4 to 1.7 dS/m).

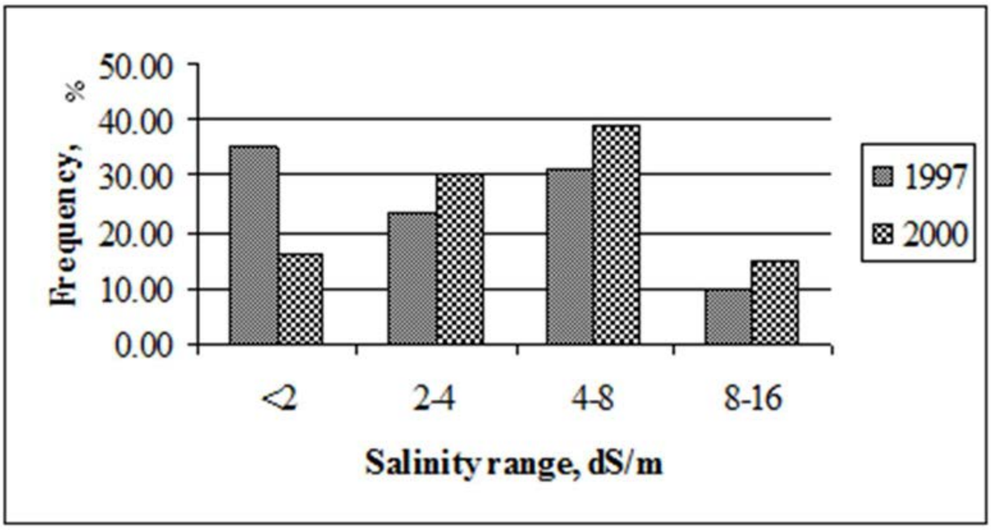

FIG. 6.4. Evolution of soil salinity in a semi-arid Lebanese region between 1997 and 2000 [6.14, 6.22].

After several years of irrigation secondary salinization of clay loam soil and low productivity of salt-affected soils was evident. A comparison of EC means of selected soils with relatively similar histories of fertilizer and water application revealed the dependence of soil salinization on land use type and length of irrigation. Consequently, in similar areas where there are high evapotranspiration demands and water scarcity, the poor management of drip systems with a total absence of leaching fraction and drainage networks cannot be justified.

Farmers' response to yield reduction in the semi-arid conditions of North-east Bekaa, resulting from a build-up of salts and possible soil-borne diseases, was in most cases to abandon their land. Some farmers practised barley-based rotations, using mulch and one drip line irrigating two rows. The system serves year-round for five consecutive crops with the possibility to plough only in the furrow. After intensive input to watermelon and soil exhaustion, legumes are cultivated, followed by different vegetables (Table 6.5) and finally sprinkler irrigated barley is grown during the last year of the rotation. Observations indicated the soil EC returned to the initial value, either following this rotation or by simple land abandonment for several years, with normal values not exceeding 0.5 dS/m [6.14]. Low levels of skill and absence of effective extension services have been identified as the main causes of land degradation, which can be prevented by appropriate rotation, drainage infrastructure and good irrigation practices.

TABLE 6.5. TIME SCALE FOR ECE AND SALT ACCUMULATION DEPENDING ON CROPPING PATTERN IN NORTH-EAST LEBANON

Cropping system	Monoculture				Barley based rotation
Range of soil salinity ds/m	<1	1-2	4-6	>6	<1
Irrigation technique	Rain-fed flooding	Macro sprinklers	Drip	Drip	Drip followed by macro sprinkler
Age of exploitation (year)	1	3	5	7-10	8
Layer of salt accumulation (cm)	No salinity	40-80	0-40	0-40	No salinity problems

Due to high evaporation rates in Northern Bekaa, salts fluctuate in the soil profile depending on many factors including irrigation frequency and amount, climatic conditions and sampling procedures. The monitoring of salinity during the wet and dry periods showed an upward movement of salts where eventual soil salinity reached 9 dS/m at 20 cm depth. A study of fertilizer N recovery in traditional potato production in Central Bekaa showed relatively low values not exceeding 45% [6.24].

6.3. AVAILABILITY OF SALT-TOLERANT CROPS AND VARIETIES

Plants differ in their tolerance to soil salinity and salt abundance in water. Vegetables grown in Lebanon and specifically in the coastal region range from moderately tolerant to sensitive. Farmers do not possess adequate knowledge about the symptoms of salinity; they identify minor symptoms as nutrient deficiency or pests and diseases. There is no specific salt-tolerant crop variety currently being cultivated by farmers. Farmers tend to abandon the land once they know that it has become unproductive.

The crops cultivated in Lebanon are in general sensitive to moderately sensitive to salinity, except for barley. Salt-tolerant crops or varieties are not yet significantly targeted, as strategies consist of abandoning the open agricultural land subject to significant salinity rise for several years until it recovers by rainfall and natural drainage, and leaching of accumulated salts to deeper layers. Another practice consists of shifting irrigation techniques from localized to macro-sprinklers in order to leach salts. A new practice of salt removal from the soil through phytoremediation of salt-affected soils has been suggested, notably for greenhouse cultivation with an appropriate crop sequence and the cultivation of summer Jew's mallow (*Corchorus olitorius*), instead of applying leaching water to evacuate the accumulated soils [6.1].

6.4. MEASURES IMPLEMENTED TO ADDRESS SALINITY AT FARM LEVEL

Fertigation of protected tomatoes in open fields and in plastic greenhouses is usually achieved by drip irrigation. However, water and nutrients are applied intermittently. As a result, non-continuous fertigation can affect salt distribution within the soil profile, leading to a loss of some nutrients and slight accumulation of salts in the subsoil. Such fertigation practices have been shown to cause salt leaching that endangers groundwater quality [6.25]. Research and demonstration trials run by the International Atomic Energy Agency Regional West Asia (IAEA RAW) 5002 project "Water Balance and Fertigation for Crop Improvement" showed that continuous feeding of nutrients together with irrigation water (fertigation) resulted in more homogenous water application, soil moisture conditions and distribution of nutrients in the root zone [6.8, 6.14].

Farmers still rely on visual interpretation of soil moisture based on touching the soil underlying the surface layer and on the plants' appearance. The use of tensiometers to monitor the soil head potential and schedule irrigation is very rare. Irrigation is scheduled once a week in open fields or every three days in greenhouses, regardless of the climatic conditions and crop water demands. The crop coefficient is indirectly addressed by the farmers through the increase of irrigation hours. Therefore, the amount of water applied is estimated by the time of application (length of irrigation event) with no reliance on measured pressure within the system or on water meters to monitor the amount of water applied.

Two specialized energy balance Bowen Ratio weather stations were installed by the Lebanese National Center for Remote Sensing in Central Bekaa in 2015. The stations are equipped with pyranometers, net radiometers, temperature and relative humidity probes, soil moisture probes, soil heat flow plates, soil temperature probes, barometric pressure sensors, and wind direction and speed sensors. They use the energy balance Bowen Ratio technique to measure surface vertical fluxes of sensible heat, latent heat, net radiation, and soil surface heat flux. This allows for the measurement and monitoring of the actual evapotranspiration on a real-time basis. However, these two stations cannot provide information about the actual evapotranspiration in other regions in Lebanon – they are limited to the Bekaa region. Optimizing the network of observations of evapotranspiration will help Lebanon in assessing water demands in agriculture and in scheduling irrigation as well as use of water at critical stages of crops. Additional Bowen Ratio weather stations are needed to produce ET representative of the different regions in Lebanon in coastal areas and inland, and at different altitudes.

The role of stakeholders and Lebanese research institutes is crucial to combat salinity problems in Lebanon. Capacity building for stakeholders is needed and sometimes requested by the stakeholders to strengthen their abilities in the area of field monitoring and modelling. For instance, some stakeholders may have access to monitoring tools, but their workforce lacks the capacity to operate these tools. Also, hydrological models have been widely applied in Lebanon rather than crop models, with no application to, or acknowledgement of, saline conditions.

Research institutions are aware of the country's salinity problems, but the government still does not consider these problems very important. Research institutions are collaborating with international organizations to introduce new varieties tolerant to salinity and drought conditions. All related projects are still in the early stages. The recent cooperation between the IAEA and International Center for Biosaline Agriculture (ICBA) to support the Regional Arab States (RAS) 5072 project resulted in provision of several genotypes of salt-tolerant sorghum and millet to run adaptation trials in the Lebanese coastal area using saline water varying between 1 and 12 dS/m. The RAS team is using Nitrogen-15 to assess nitrogen recovery under salinity stress conditions. It is planned to use the neutron probe and soil moisture sensors to quantify water use efficiency under different salinity levels. Plant samples will be analysed for carbon isotope discrimination.

6.5. MAJOR GAPS TO FURTHER IMPROVEMENTS

Irrigation is a critical element of agricultural production in Lebanon. Irrigation management relies on the farmer's own skills and experience and still needs to be optimized in relation to prevailing soil and climatic conditions, crop variety and nutrient and water demands. Good management of soil and water resources requires the availability of skilled farm workers trained in the use of irrigation techniques, fertilization practices and crop and land management. A prerequisite to the sustainable use of saline soil and saline water in crop production is the availability of soil and water quality data and information, together with native and improved salt tolerant seeds, field and laboratory monitoring tools and a high level of knowledge.

6.5.1. Availability of data on soil quality

Soil information was updated with the production of the digital soil map of Lebanon at 1:200 000 scale [6.26] and creation of the new soil map of Lebanon at 1:50 000 scale [6.21] using the FAO- United Nations Educational, Scientific and Cultural Organization (UNESCO), World Reference Base for Soil Resources (WRB) legends and United States Department of Agriculture (USDA) soil taxonomy.

Other soil studies addressed rangeland degradation by overgrazing [6.27], observations on soil salinity on the southern coastal strip [6.10], the causes and impact of soil salinity on the Lebanese coast [6.8, 6.12] and inland North-east Bekaa [6.14, 6.22] and the evaluation of hydrodynamic features of alluvial soil from Bekaa [6.28]. Soil vulnerability to desertification based on soil chemical and physico-chemical properties was assessed for the national action programme (NAP) to combat desertification in Lebanon [6.24]. Pilot area studies on soil pollution assessed nitrate and heavy metal risk [6.3], heavy metal background values in the soils of North Lebanon [6.29], the risk of pollutant transfer to groundwater [6.30] and pesticide adsorption on soil particles [6.31]. More recently, soil resilience and the adaptation of the agricultural sector to climate change [6.32] and the impact of abandoned quarries on soil and water resources were assessed [6.33].

Human activities, industry, manufacturing and agriculture resulted in a slight accumulation of some heavy metals in the soil, resulting in possible contamination of the shallow water table with Ni, Cr and nitrates [6.34]. The cooperation project between National Council for Scientific Research (CNRS), Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and Federal Institute for Geosciences and Natural Resources (BGR) on soil-groundwater protection from pollution in a pilot area of the Central Bekaa plain proved that as well as the geogenic origin, excess fertilizer input, possibly carrying heavy metals as a by-product and the use of brackish irrigation water are the reasons for heavy metal input to the soil-groundwater system [6.3, 6.35]. Monitoring of soil radioactivity twelve years after the Chernobyl accident showed a relatively high ^{137}Cs activity of up to 6545 Bq/m^2 in the top soil layer (0-3 cm) of some Lebanese areas which decreased exponentially with depth [6.36].

6.5.2. Mismanagement of agricultural practices

In greenhouses in the coastal area, a steady increase in ECe from 0.4 dS/m to 15 dS/m was observed [6.10] and explained by poor soil levelling. However, soil salinity rose by up to tenfold inside the greenhouse compared to the outside soil (Figure 6.5). This was associated with excess input of fertilizers [6.8], use of saline water in irrigation, and chlorine accumulation in the soil [6.12].

Observations indicated that soil salinity inside the greenhouses reached 15–20 dS/m in the coastal area. The monthly peak which was observed in December corresponds to the maximum crop growth associated with upward water movement and high salt build-up in the soil. In coastal areas, it is necessary to consider the integrated management of irrigation water by avoiding excessive pumping from coastal groundwater, choosing appropriate high-analysis, soluble fertilizers instead of complex products with a high salinity index and taking into account the water demands and salt tolerance of the crops.

Although Lebanese soils are not naturally saline, increasing signs of salt build-up have been observed, notably in greenhouses along the coast and in North-east Bekaa. Salinity has increased to such levels in Jieh (on the southern coast) that it threatens the sustainability of agriculture in the coastal area. Coupled with the weakness of the extension service, poor farming practices are exerting additional pressure on vulnerable lands. The activation of extension services and dissemination of good agricultural practices is a national priority to protect soil and groundwater from salinity.

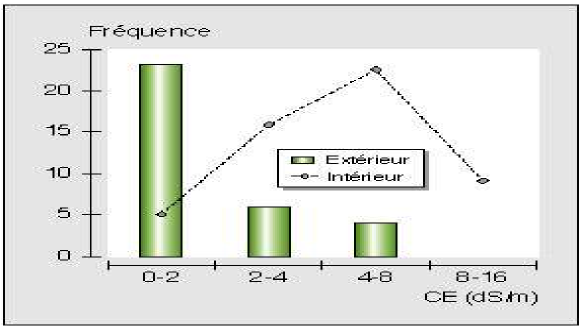

FIG. 6.5. Frequency of distribution of soil salinity inside compared to initial soil salinity outside the greenhouse in the coastal area; reproduced from [6.8].

6.5.3. Fragile soil–groundwater system

Modeling based on the German concept of degree of protection provided by the soil, preventing the transfer of soluble pollutants to the groundwater, showed moderate and low soil protection effectiveness. The residence time of NO_3 transfer with percolating water varied between several weeks and three years. Available data does not allow for judging the soil's complete reaction and resilience to accumulated salts. The fractured system (karst) of the surrounding mountain and soil permeability in the area points to the necessity of undertaking geophysical studies on the depth of groundwater, water table and nature of deposits overlying the aquifer in the Bekaa valley and the whole country in order to assess the vulnerability of soil and groundwater to rising salinity.

6.5.4. Pressure on groundwater

Following lower precipitation rates and a decline in water quality in Lebanon [6.37], the groundwater quality on the coastal area has been deteriorating; this is especially due to excessive pumping promoting seawater intrusion [6.13, 6.38].

With increasing pressure on surface water, farmers rely mainly on groundwater for irrigation, due to the absence of collective irrigation schemes. The coastal Choueifat area, south of Beirut, is considered among the major regions for producing strawberry, a crop which is sensitive to low levels of salinity [6.39]. EC values greater than 0.7 dS/m may lead to a gradual reduction in yield [6.40]. Observations between 1999 and 2002 showed that the wells of Choueifat displayed values largely exceeding 0.7dS/m. Therefore, the prevailing state of salinity in Choueifat threatens the production of strawberry, much as for pepper, lettuce and onions, which exhibit a similar response to salinity constraints. Tomatoes and cucumbers exhibit more tolerance to salinity up to 1.7 dS/m, at which point there is a gradual drop in production [6.40].

In the southern coastal area of Jiye, the situation is much more critical. The figures of groundwater salinity are higher than 2.3 dS/m. This state of salinization hampers production of many horticultural crops, especially tomatoes and cucumbers. A proper management of irrigation frequency and rationalization in the use of fertilizers would be necessary in order to minimize the effects of the salt on crops. Some wells in the neighbouring Rmeyle showed values of ECw that threatened the successful production of tomatoes and cucumbers. By Lebanese standards, the coastal area suffers from pronounced salinity hazards affecting crop production, especially during the germination stage. The poor affinity between rainfall and salinity development can be attributed to an overall recharge problem in the coastal area. Plant cover reduction caused by the high rate of urbanization leads to negative consequences on water balance in the area by increasing surface runoff at the expense of the natural recharge to groundwater.

A significant correlation exists between salinity and the intensity of pumping from the aquifers. Water abstracted from one well to irrigate 1 ha of protected tomato and the consequent groundwater salinity change was assessed (Figure 6.6). The correlation was found to be at the level of significance (r = 0.55).

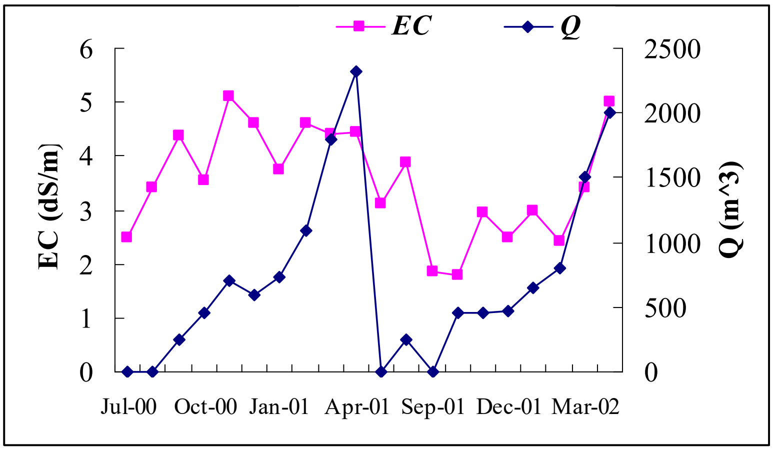

FIG. 6.6. Time variation of EC and water abstracted (Q) from well N J2 located in coastal Jieh.

Brackish water quality with sodium enrichment negatively affects crop production and soil quality, notably soil permeability.

The long-term accumulation of salts enriched partly with Na, coupled with mismanaged irrigation in the coastal areas of Lebanon, results in the formation of saline and saline-sodic soils. Monitoring and managing groundwater quality and use and improving the recharge of vulnerable groundwater are prerequisites for the sound management of limited water resources. This will improve soil protection to avoid the deterioration of the soil quality, which could result in further possible land degradation. In the Lebanese interior, the deterioration of groundwater quality is caused by the accumulation of nitrates and chlorides which is in turn caused by the increased use of complex fertilizer, a common source of nitrogen and chloride.

The dynamics of nitrate distribution are closely linked to the irrigation technique, with higher levels of nitrate leaching observed in sprinkler irrigation as compared to drip irrigation. Intensive application of fertilizer and irrigation techniques based on poor agricultural practices and land use policy, as well as deep ploughing, are the main factors contributing to the potential and actual risk of transfer of soluble pollutants to the shallow aquifer in Central Bekaa. Depending on hydrogeology and land use, the drilled boreholes varying in depth between 3 m and 7 m from the Central Bekaa area showed that the part of the aquifer near the boundary between the saturated and unsaturated zones is the most sensitive to pollution (Figure 6.7). In addition to infiltrated water, perched aquifers receive seepage from drainage canals with higher rates of mineralization.

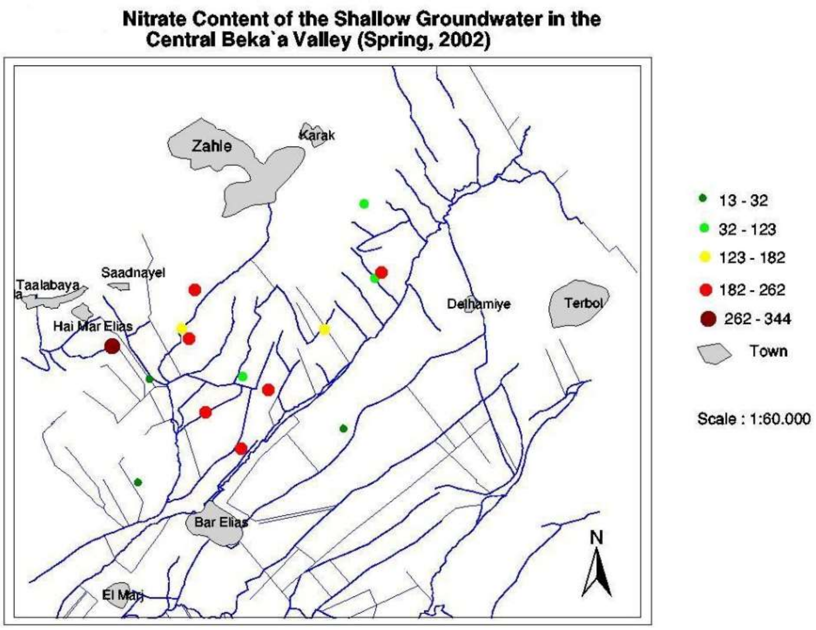

FIG. 6.7. Nitrate concentration in the shallow (perched) groundwater table of the Central Bekaa Valley in spring 2002; reproduced from [6.41].

The study undertaken within the framework of the Arab–German technical cooperation project [6.41], on the protection and sustainable use of soils and groundwater, proved that the concentration of nitrate in the relatively deep irrigation wells of Central Bekaa can reach values higher than 200 mg/l, and salinity can approach 2 dS/m (Table 6.6). This proves that the relatively deep groundwater in Central Bekaa is vulnerable to nitrate pollution. Dense sampling from a limited area (one well/4 km^2), with no natural salinity hazards demonstrated the dangerous impact of current land use on soil and ground water quality. This characterizes agriculture as a diffuse source of nitrate pollution.

TABLE 6.6. STATUS OF NITRATES AND SALTS IN THE DEEP WELLS OF CENTRAL BEKAA
Source: [6.41]

Nitrate		Salinity		
N° of wells	NO_3 content mg/l	N° of wells	Electrical conductivity dS/m	Total dissolved salts mg/l
10	>200	13	1.0-2.0	650-1300
6	100-200	4	0.6-1.0	400-650
8	40-100	13	<0.6	<400
	10-40			

6.6. SUGGESTIONS

Salinity and alkalinity conditions can increase the mobility of some terrestrial elements and pose health and environmental problems. Although dietary uptake of heavy metal and nitrate has been assessed [6.42, 6.43] cropping of vegetables on low quality lands is a general practice. For this purpose, the nationwide assessment of soil quality is suggested to ensure crop cultivation takes place on suitable land in order to prevent public health crises and negative impacts on the ecosystem.

Research findings need to be communicated to farmers through agricultural extension services. Research into salinity problems in Lebanon needs to be improved, because the problem of saline groundwater is becoming exacerbated in the coastal areas. Saline groundwater is intensively used for irrigation in these regions. Research findings will require dissemination tools and facilities in order to be accomplished through supported programmes.

Extension services will require capacity building and support to disseminate the findings of research to farmers. Communication days and technical workshops can be organized and attended by pioneer farmers. Coordination between farmers' associations, extension services and research institutions can be enhanced.

Based on the analyzed literature, the following is suggested:

(a) Develop skills in irrigation water management and the use of low quality and saline water in irrigation.

(b) Enhance the extension service to improve capacity building for farmers, especially in the management of water and fertilizers.

(c) Introduce salt-tolerant crop varieties and new cropping patterns based on legumes, cereals and pulses to support land productivity and food security.

6.7. THE USE OF NUCLEAR AND ISOTOPIC TECHNIQUES

To quantify nitrogen use efficiency under drought and saline conditions, the stable isotope ^{15}N has been in use by Lebanese researchers since the early 1980s. This precise and reliable technique was used in experiments for accurate data collection and estimation of nitrogen fertilizer recovery. Water consumption under moisture and salinity stress is another crucial criteria to assess agricultural management success, including irrigation. Soil water content is currently measured via the neutron probe technique to quantify water use efficiency by crop vegetation.

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CHAPTER 7. QATAR

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7.1. INTRODUCTION

The climate of Qatar is hot and extremely arid, with rainfall not exceeding 85mm per year and torrential in nature. Agriculture depends mainly on the limited groundwater of varying salinity. Irrigation is important for agriculture under such arid conditions, and generally leads to increased soil salinity [7.1]. Groundwater salinity in Qatar is increasing by an alarming 5% per year because of over-exploitation. The overuse of groundwater resources results in deterioration in water quality which in turn aggravates the salinity problem, particularly where the water quantity is insufficient for adequate leaching.

There is no surface water in Qatar and the main renewable water resource available for agriculture is groundwater. Treated sewage effluent (TSE) is used for irrigation of forage crops and public gardens.

7.2. SALT-AFFECTED LAND IN THE COUNTRY AND DIFFERENT REGIONS

Table 7.1 shows the levels of salinity and areas of the different soil mapping units and indicates that extremely saline soils, classified fully or partially as solids, (mapping units 11 and 17) cover approximately 7.2% of the land in Qatar. These are followed by shallow and deep sandy and/or sandy-rocky salt-affected soils (units 2, 10, 12, and 15) comprising approximately 50.2% of the land; most of the remaining soils also suffer from salinity to a lesser degree.

Halophytes are common along the coastal areas and inland salt flats and wetlands, where saline water is available in their natural habitats permanently or periodically. There are seven common halophytic communities found in Qatar, namely halophytes of the inland wetland, inland salt flat, coastal mangrove areas, coastal low marsh, coastal high marsh, coastal sandy shore and coastal sandy-rocky shore.

TABLE 7.1. SALINITY AND AREAS OF THE DIFFERENT SOIL UNITS AND THEIR PERCENTAGE OF COVERAGE FOR OUTDOOR FARMS IN THE STATE OF QATAR. Data from [7.2]

Soil mapping unit				Av. soil profile EC dS/m		
Symbol	Area		Taxonomic name (according to USDA 1990)	Soil depth in cm		
	Ha	%		0-10	10-40	>40
Unit 1	16 276.3	1.4	Lithic Torriorthents (1)	8.93	14.04	8.84
Unit 2	281 859.7	24.5	Haplogypsids & Petrogypsids (1)	19.66	20.39	17.29
Unit 3	242 150.6	21.1	Lithic Haplocalcids (1)	12.47	13.0	8.14
Unit 4	213 756.7	18.6	Haplocalcids; loamy (1)	17.64	17.33	11.75
Unit 5	9991.2	0.9	Typic Petrogypsids; sandy (1)	9.09	10.59	7.06
Unit 6	21 728.6	1.9	Typic Petrogypsids; sandy phase (2)	5.77	13.1	42.0
Unit 7	34 594.6	3.0	Haplocalcids; loamy and clayey (2)	7.05	9.33	9.23
Unit 8	9847.3	0.9	Haplocalcids & Petrocalcids; sandy and loamy (1)	22.5	17.99	6.85
Unit 9	1162.7	0.1	Lithic Calcigypsids; loamy and clayey (1)	81.1	46.0	-
Unit 10	26 353.4	2.3	Typic Torripsamments (1)	17.17	14.22	17.06
Unit 11	61 407.1	5.3	Typic Aquisalids (1)	15.18	34.53	30.6
Unit 12	14 431.7	1.3	Typic Torripsamments (2)	Sand dunes , not subjected to analysis		
Unit 13	32 427.4	2.8	Calcids & Torriorthents (2)	5.2	4.9	-
Unit 14	3053.7	0.3	Typic Psammaquents (1)	37.73	8.0	21.98
Unit 15	24 242.5	2.1	Typic Torripsamments (3)	2.42	27.07	29.83
Unit 16	7150.1	0.6	Haplocalcids & Torriorthents; sandy and loamy (3)	2.95	6.3	2.3
Unit 17	21 931.5	1.9	Typic Aquisalids & Typic Torripsamments (2)	1.87	46.51	6.45
Unit 18	22 401.9	1.9	Typic Petrogypsids & Typic Torripsamments (3)	12.39	12.08	-
Unit 19	17 178.2	1.5	Lithic Haplocalcids & Typic Torripsamments (3)	4.37	3.63	-
	46 519.4	4.0	Settlements			
	41 049.4	3.6	Farms			
Total	1149 513.9	100	All soil mapping units for the State of Qatar			

The total arable land in Qatar is estimated at 68 716 ha, of which 23 903 ha are inside the surveyed farms (Tables 7.1 and 7.2), and the rest outside. The corresponding estimates by the Directorate of Agricultural and Water Research [7.3] were 65 000 ha and 25 928 ha.

The physiography permits the development of young colluvial limestone deposits into the dominant arable farm soils which are composed of locally known rodha (depression) soils, where most of the farm arable land occurs [7.1]. These soils although limited in area (3.6% of land area) are considered to be the best arable and productive soils in the country. These depressions are usually surrounded and/or nested with other less suitable shallow rocky soils. The fact that existing farms are scattered in over 850 depressions of only a few hectares to 60 ha, places limitations on any wide scale farming approaches. Soil profile depths are also variable, ranging from 30 to 150 cm.

About 65% of farm land exhibits mild soil salinity, which means that together with the prevailing adverse climatic conditions, agriculture in the country is limited to winter vegetables, rodhas grass and alfalfa forage, and date palm cultivation.

TABLE 7.2. SALINITY AND AREAS OF DIFFERENT SOIL UNITS WITHIN FARMS IN THE STATE OF QATAR.
Data from [7.4]

Soil mapping unit (Subgroup symbol)				Average soil profile EC In dS/m
Symbol	Area		Taxonomic Name (USDA 1990)	
	in [ha]	in [%]		
01	912.2	2.3	Typic Haplogypsid (1)	5.6
02	2737.5	6.8	Lithic Haplogypsid (2)	25.5
03	245.3	0.6	Leptic Haplogypsid (3)	42.3
04	263.0	0.6	Typic Petrogypsid (4)	43.4
05	196.9	0.5	Calcic Petrogypsid (5)	Not Analyzed
06	268.2	0.7	Typic Calcigypsid (6)	4.3
07	5045.2	12.5	Typic Haplocalcid (7)	13.0
08	10 855.7	26.8	Lithic Haplocalcid (8)	5.6
09	128.3	0.3	Calcic Lithic Petrocalcid (9)	5.8
10	7572.3	18.7	Typic Haplocambid (10)	12.6
11	554.0	1.4	Lithic Haplocambid (11)	9.9
12	465.7	1.1	Typic Torriorthent (12)	6.9
13	9846.7	24.3	Lithic Torriorthent (13)	124.9
14	1167.9	2.9	Typic Torripsamment (14)	4.0
15	235.1	0.6	Lithic Torripsamment (15)	Not Analyzed
16	16.9	0.0	Typic Psammaquent (16)	Not Analyzed
17	Negligible Area		Typic Petrocalcid	Not Analyzed
Total	40 511.0	100.0	All farm soil mapping units	

7.3. MAJOR CAUSES OF SALINITY

Both primary and secondary soil salinity are present in Qatar. Primary salinity is due to shallow saline groundwater evaporation from the land surface, which usually results in extremely saline soil conditions. The present amount of well-water extraction is a clear example of excessive groundwater pumping. It is estimated to be more than three times the average natural recharge. This leads to lowering of the water table and consequent intrusion of saline water horizontally from the sea, as well as the intrusion of brackish water rising up from the underlying aquifer. Consequently secondary soil salinity occurs in existing farms, due to the utilization of the extracted well water to irrigate crops, which in conditions of high evaporation leads to salt accumulation in the soil profile.

7.4. THE EFFECT OF SALINITY ON MAJOR CROP PRODUCTIVITY

Soil surveys conducted in Qatar confirm that the soils of Qatar have significant limitations, and that substantial investments in land improvement will be needed in order to obtain reasonable yields. The dominant constraint for most crops is salinity, followed by gypsum and high $CaCO_3$ content. Some crops are also affected by high pH and shallow soil depth. Other (less prevalent) constraints are poor drainage and poor texture. All these constraints are characteristic of desert soils, which are invariably associated with lack of weathering, poor soil development, immature soil structure, poor water holding capacity, low organic matter, shallow depth, and chemical imbalances.

7.5. CROPS AND VARIETIES GROWN BY FARMERS IN SALT-AFFECTED AREAS

Selecting what crops to grow given Qatar's land and water constraints requires a focus on an integrated set of options:

(a) Optimization of land use.

(b) Increased productivity per unit of water.

(c) Use of modern technologies.

(d) Creation of an enabling institutional and policy environment.

(e) Strengthening of national capacity.

Different crops are grown in the two main cropping systems in the country as follows:

7.5.1. Open field agriculture

This is the core of Qatar's agriculture. The farm survey showed that farmers do not utilize their entire farm [7.5]: on average, only 41% of total farm area (and even less on large farms) was actually cultivated. According to the Department of Agricultural & Water Research (DAWR) statistics [7.3], the total cultivated area in 2006/07 was 8455 ha, of which fodder crops occupied 41%, vegetables 34%, fruit trees 9% and cereal crops only 1.2%. However, the farm survey in 2009 showed nearly equal shares for fodder crops, vegetables and fruit trees. This suggests that open field agriculture is dynamic and may vary in response to marketing difficulties, prices and other external pressures. The survey also revealed a degree of production specialization, with the percentage of area under vegetable crops being higher in large farms than in small and medium farms, while the reverse was true for forage crops. Water resources in agriculture were used as follows: 43% to irrigate fodder crops, 37% for fruit trees and 19% for vegetables.

7.5.2. Protected agriculture

Protected agriculture started in Qatar in 1976, but adoption of the technology has been extremely slow. In 2007, protected agriculture covered 92.2 ha, about 1% of the country's cultivated area [7.3]. However, only 12% of the farmers surveyed were using protected agriculture [7.5]. Greenhouses are the dominant technology, with numbers ranging from two to 98 units per farm. About 40% of the farms contained five greenhouses. The majority of greenhouses are non-refrigerated, and used only during autumn and winter. The most common greenhouse crops were cucumber, tomato, pepper, melon, beans and cut flowers; cucumber was grown in 73% of the greenhouses.

In addition to these cropping practices, Qatar is researching the possibilities offered by biosaline agriculture. This technology is one of the most effective options for useful biomass production on degraded salt-affected lands. At the Bio-saline Agriculture Experiment station in Dukhan Sabkha, studies are continuing on the development of useful biomass production systems for highly saline lands (EC >100 dS/m) underlain by super brine groundwater (EC >110 dS/m) at a depth of about 0.80 m. The soil is light-textured and completely depleted of essential macro/micro nutrients except sodium chloride and calcium.

At the station fodder biomass was sustainably produced from extremely saline lands by growing stress-tolerant plants irrigated with low-cost treated sewage water at Dukhan Sabkha, Qatar [7.6]. This was done by applying Good Agricultural Practices (GAP) and using a holistic approach (Table 7.3). Bio-saline agricultural practices were applied to exploit extremely saline lands (EC >100 dS/m) at Dukhan Sabkhan. The soil moisture retention properties of coarse textured soil were improved by the addition of a quantity of hydrophilic polymers to the active plant root zone soil to develop i) a high moisture storage zone for regulated supply of soil moisture to the plants and ii) a buffer zone to check the capillary rise of brackish water from shallow groundwater (EC=90 dS/m) at a depth of 80 cm. Extreme soil salinity in the plant root zone was diluted by the application of limited surface irrigation with low-electrolyte treated sewage water at the plant-soil contact point, using an advanced drip/bubbler irrigation system that also increased water use efficiency (WUE). Nutrient use efficiency was achieved by optimizing irrigation and fertilizer inputs to the selected stress-tolerant plants. During the peak hot and dry season (summer), the irrigation supply was increased to protect the plants against aridity and high temperature stresses. Plant growth has been sustained for the last seven years without any degradation in plant productivity; rather, it improved soil health by the addition of organic matter, decreased soil salinity and increased aeration and water retention status in the active plant root zone.

The fodder quality analysis showed all biochemical components to be fit for fodder use. No toxic metal accumulation was observed in the biomass over and above the safe range for use as ruminant feed.

TABLE 7.3. PROPOSED HOLISTIC APPROACH TO MAIN LIMITATIONS TO AGRICULTURAL ACTIVITY.
Data from [7.6]

Serial.No.	Limitations	Good Agricultural Practices (GAP) applied
1	Extremely saline land hostile for agriculture	Selection of highly salt-tolerant plants under biosaline agriculture practices
2	Coarse textured soil leading to little water storage in soil	Addition of hydrophilic soil conditioners to the active plant root zone to enhance soil water retention
3	Extremely brackish shallow groundwater used for irrigation	Dilution with low electrolyte-treated sewage water (TSW) through surface irrigation
4.	Extreme soil salinity in plant root zone	Dilution of salts in the plant root zone through drip/bubbler irrigation system to keep the salt level within tolerable limits for plant growth
5	Very limited availability of water for soil drainage	Drainage activity limited to very narrow root zone soil column through point source irrigation
6	Upward capillary rise of saline water from shallow water table	Checked by a high moisture buffer zone developed by hydrophilic soil conditioner material at active plant root zone and brackish shallow water table interface
7	Nutrient-free soil with no organic matter	Supply of essential nutrients and peat mass in the nursery sapling bags/root zone soil
8	Very high summer temperature and aridity	Selection of stress-tolerant plants and increased irrigation inputs during stress hours

During the adaptability stage, the salt-tolerant plants successfully adapted included kallar grass, *Kochia indica*, para grass, *Sesbania acculeata*, *Sorghum bicolor* hybrid, *Brassica* species, barley and wheat. Among the shrub plants *Acacia ampliceps*, *Atriplex lentiformus* and pomegranate successfully adapted. However, *Euclayptus camaldulensis* and *Prosopus juliflora* plants gradually died within one year of cultivation by 96 % and 90 %, respectively. Possibly, the plant roots extended downwards to the extremely brackish shallow water table (EC >90 dS/m) and decayed, leading to plant death. Some plants however managed to maintain their root proliferation horizontally above the brackish shallow water table and were still surviving. In particular, the surviving *Prosopus juliflora* plants attained maximum height on the farm. *Acacia ampliceps* plants attained vertical growth to a maximum height of 3 m (average), and lateral canopy expansion was also good. During the peak stress season, most of the plants shed their old leaf biomass, but emergence of new leaves helped in sustaining the plantation. These plants, too, were successfully used for direct grazing by ruminants.

7.6. FARMER KNOWLEDGE OF SALINITY AND ADAPTATION MEASURES

The relevant Government departments such as the Department of Agricultural Research and the Department of Agricultural Affairs are providing farmers with an excellent service. However, it is clear that much effort is needed to bridge the gap between farmers and extension agents. All agricultural technology, whether locally generated or brought from abroad for direct adaptation attempts, needs to find its way to farmers. Entrepreneurial farmers play an important role in this field and in some cases are ahead of scientists.

7.7. MAJOR GAPS TO FURTHER IMPROVEMENTS

The following information is available:

(a) Soil classification units map to the subgroup level of the United States Department of Agriculture (USDA) soil taxonomy classification system.

(b) Land evaluation map identifying land suitable for irrigation.

(c) Land use map (current).

(d) Land degradation map.

(e) Atlas of Soils for the State of Qatar.

(f) Several reports, research and studies on soil water and crops with different levels of relevance to salinity.

To use this information effectively to develop better cropping systems, the following is also required:

7.7.1. Availability of salt-tolerant crops and varieties

Most vegetable, fruit and forage species are adapted to some extent to the prevailing conditions of soil and water quality in Qatar and other Gulf Cooperation Council (GCC) countries with similar natural habitat conditions. The need for more adaptable varieties continues, and it is the job of research bodies, local colleges and universities to aim for adaptation of new varieties as well as breeding enhancements and improvements. The assistance of the International Center for Biosaline Agriculture (ICBA) in this regard is crucial to Qatar.

7.7.2. Availability of tools, knowledge and expertise

Taking into consideration the current prosperous socio-economic conditions of the country's population, the need for high-tech agricultural technology can be given high priority. Efforts to introduce and install fully automated production systems are welcomed by farmers. Increasing the number of International Atomic Energy Agency (IAEA) supported farmer days is essential to improve the project's appeal to farmers.

There is also a need for visits by experts, national staff capacity building at high-level world-class institutions, and improved field and laboratory equipment.

7.7.3. Capacity building

Capacity building focused on specific salinity management within the context of soil–plant–water relationships is a key priority for the State of Qatar.

7.8. THE USE OF NUCLEAR TECHNIQUES

The neutron probe technique is a reliable and accurate device when properly calibrated for measuring and monitoring changes in soil moisture and scheduling irrigation. The slowed neutrons are measured and correlated to water content. In Qatar, this technology has been found to be well suited despite the extreme saline conditions. When applied in these soils the neutron signal exhibits no influence by salts, maintains a large effective radius, and can take measurements at many depths. The large sphere of influence of this device is related to the moisture content of the soil but remains generally greater than other systems when applied in drier soils.

The accurate estimation of soil moisture is critical to effective soil salinity management. Soil moisture and salinity are two essential factors for effective crop irrigation and yield stability. Addition of nitrogen usually improves plant growth and yield regardless of whether the crop is salt-stressed or not. Nitrogen-15 can be used to evaluate the response of salinity adapted fodder crops to optimal and sub-optimal nitrogen fertilizer levels under extreme saline soil conditions.

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CHAPTER 8. SAUDI ARABIA

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8.1. INTRODUCTION

Saudi Arabia has an area of about 2240 000 km^2 that can be divided into four ecological regions: 1) the mountainous western highlands of Al Hijaz and Asir; 2) the rocky central plateau of Najd; 3) the more fertile, eastern low-lying coastal plain of Al Ahsa'; and 4) the sandy desert areas in the north, east and south. Saudi Arabia's Red Sea coastline stretches for about 1760 km while its Arabian Gulf coastline is roughly 560 km.

The desert in the south, known as Rub' al Khali (the Empty Quarter), is one of the largest deserts in the world, with an area of about 650 000 km^2. In addition, there are several hyper-saline environments (Sabkhas) that include coastal (marsh) Sabkhas distributed around the Red Sea in the west and the Arabian Gulf in the east, as well as the inland (continental) Sabkhas which are found in the north in Wadi (Village) Alsarhan, in the south at Rub' al Khali and at Najd in the central area [8.1].

Extreme heat and aridity are characteristic of most of Saudi Arabia and these, together with salinity, have a significant impact on agricultural productivity. Due to hostile environments and lack of permanent water resources, agricultural activities and all irrigation systems have been totally dependent on groundwater. This has led to salinization of substantial land areas in Saudi Arabia. Moreover, continued consumption of groundwater by farmers and agricultural companies and daily use as part of the municipal water network has resulted in depletion of groundwater, increasing the depth of the natural underground storage and wells and resulting in higher salinity in the groundwater. Furthermore, the salt-affected soils of the flat areas existing around the valleys (*Wadis*), have resulted from the massive accumulation of mud, clay, sludge, debris, etc. in the form of floods and torrents.

Saudi Arabia is considered to be a dry desert land with a population of 31 540,000 of whom only 3.88% are engaged in agriculture. The estimated area of winter cultivated crops in 2013 was 192 263 ha while for summer crops it was 267 595 ha.

8.2. DATA ON SALT-AFFECTED LAND IN THE COUNTRY AND DIFFERENT REGIONS

No accurate and up-to-date data are available on salt-affected land in Saudi Arabia. A rough estimate is that about 3641 Mha is affected by salinity, of which 50 000 ha is severely affected, 1.7 Mha moderately affected and 1977 Mha slightly affected [8.2]. Arable land in the Al-Ahsa Oasis was estimated at about 16 000 ha, but during the last 15 years, this area has decreased to about 8000 ha due to re-salinization of the soil caused by over-irrigation and/or inadequate drainage [8.3]. However, in practical terms, salt-affected land in Saudi Arabia can be divided into two major categories; the Sabkhas and the coastal plain. Sabkhas exist at many locations along the coastal plains of the Eastern Province and along the western shores at Jizan, Jeddah, Obhor and Al-Lith [8.1]. Sabkha soil is also reported to exist in Wadi Al-Sirhan in the north and in small areas in the Al-Qassim region and the Empty Quarter. The exact area of these Sabkhas is unknown, but are estimated to be about 2.0 Mha [8.4]. The eastern and western coasts extend to around 3600 km, where the actual areas of the coastal plains which can be used for agriculture are 110 ha of the Tihamah plain along the Red Sea coast, and around 610 km of the eastern plain, of which approximately half is fit for agriculture. The fertile land of Al-Hasa represents the southern part of this area.

8.3. MAJOR CAUSES OF SALINITY

About 54% of the cultivated area in Saudi Arabia suffers from moderate salinization [8.5]. Globally, a wide range of causes and factors contribute to salinity, but at the local level the major causes of salinity in Saudi Arabia can be summarised as follows:

(a) Groundwater is the main source for irrigation; it is more saline when drawn from deeper wells.

(b) Farms and plantations irrigated by groundwater start to exhibit salt-affected soil, especially those where groundwater is drawn directly from artesian wells.

(c) Increasing groundwater salinity combined with high rates of evapotranspiration results in saline soil.

(d) Excessive use of mineral fertilizers.

(e) Torrential rain, especially in winter.

(f) Deterioration of the natural drainage of the soil, which leads to a high water table by capillary action.

8.4. EFFECTS OF SALINITY ON MAJOR CROP PRODUCTIVITY

There is a lack of data and statistical surveys of the productivity of major crops affected by salinity. The estimated areas and production of all cereal crops (Table 8.1), wheat (Table 8.2), barley (Table 8.3), all fodder crops (Table 8.4) and alfalfa (Table 8.5). The estimated area of all crops is shown in Table 8.6 to demonstrate the trend during five successive years (2009–2013). The data reflects different trends (increasing and decreasing) which could result from several different factors and stresses (for example, the availability of subsidies, drought, heat, salinity, and rainfall).

8.5. CROPS AND VARIETIES GROWN BY FARMERS IN SALT-AFFECTED AREAS

In general, cultivation and production are carried out by licensed commercial companies which own thousands of hectares and greenhouses. However, these farms hire labourers on a daily basis to sow and harvest their own crops, with no requirement to keep records. Therefore, no inventory of crops and varieties grown by farmers in salt-affected areas is available because of the lack of implementation of best practices for agriculture. The estimated growing areas and levels of production for general crops grown in sensitive/moderated/strong saline conditions are presented in Tables 8.7–8.9, taking into account the irrigation techniques, which include surface irrigation, sprinkler irrigation and localized irrigation.

8.6. FARMERS KNOWLEDGE OF SALINITY AND ADAPTATION MEASURES

With reference to the lack of natural water resources in Saudi Arabia and the harsh climatic conditions (i.e. drought, heat, low rate of rainfall), agriculture is not seen as an attractive source of profit, and farmers have basic, if not poor, knowledge of salinity and adaptation measures. Farmers who own considerable cultivated areas for revenue hire agricultural engineers to supervise foreign workers who sow and harvest the farm according to the farmer's interests. However, the elite agricultural companies receive support and recommendations for the applications of agricultural products so that the best agricultural practice and knowledge on salinity and adaptation measures is available in commercial companies. Individual farmers tend to target their own immediate interests that bring most profit. As a result of the low level of farmers' knowledge of salinity and adaptation measures, and the mismanagement of irrigation and crop rotations, deterioration of the soil is accelerated and salinity increases.

TABLE 8.1. ESTIMATED PRODUCTION (tonne) AND AREA (ha) OF ALL CEREAL CROPS (Data from [8.6])

All seasons	2013		2012		2011		2010		2009	
Regions	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area
Riyadh	116 373	21 901	147 695	29 997	200 593	39 345	205 380	40 461	176 974	34 876
Mekkah	7411	2841	8040	3130	8277	3223	8947	3571	22 748	8938
Madenah	181	44	231	61	309	79	358	82	876	209
Qaseem	71 264	12 489	91 874	17 457	126 872	23 255	146 183	26 671	144 738	28 894
Eastern	84 459	16 062	108 948	22 518	150 564	30 019	156 374	31 320	128 541	31 427
Aseer	7284	2635	8117	3039	8843	3262	7492	2886	18 634	6784
Tabuk	89 052	12 848	115 090	18 042	159 039	24 066	154 005	25 665	116 950	18 187
Hail	193 700	27 363	224 357	33 204	277 753	39 908	274 630	40 701	273 254	40 895
Northern	6	1	7	2	8	2	9	2	46	13
Jazan	106 871	41 934	114 738	45 583	113 939	45 011	113 174	44 987	228 172	88 887
Najran	1336	332	1717	466	2353	616	1125	285	3056	799
Baha	650	188	753	226	905	262	594	207	2240	657
Jouf	206 425	27 367	266 782	38 431	368 705	51 264	502 673	70 094	476 176	68 159
Kingdom	885 012	166 005	1088 349	212 156	1418 160	260 312	1570 944	286 932	1592 405	328 725

TABLE 8.2. ESTIMATED PRODUCTION (tonne) AND AREA (ha) OF WHEAT (Data from [8.6])

All seasons	2013		2012		2011		2010		2009	
Regions	Prod	Area	Prod	Area	Prod	Area	Prod	Area	Prod	Area
Riyadh	105 095	19 638	135 997	27 591	188 564	36 901	194 508	38 205	157 258	30 896
Makkah	265	74	343	104	475	139	420	117	1268	371
Maudenah	147	33	190	47	264	63	303	66	815	194
Qaseem	69 860	12 214	90 402	17 160	125 346	22 951	144 761	26 426	117 038	22 792
Eastern	82 974	15 783	107 372	22 174	148 875	29 656	154 883	30 963	125 221	30 691
Aseer	1410	446	1825	627	2530	838	1785	625	9528	3155
Tabuk	87 275	12 639	112 938	17 758	156 592	23 751	151 900	25 396	114 725	17 889
Hail	109 133	14 473	141 223	20 334	195 810	27 196	203 680	28 048	164 673	23 558
Northern	0	0	0	0	0	0	0	0	0	0
Jazan	0	0	0	0	0	0	0	0	0	0
Najran	1246	312	1612	439	2235	587	1006	257	2907	763
Baha	276	73	357	102	495	136	257	90	1501	413
Jouf	202 464	26 928	261 997	37 833	363 268	50 600	495 886	69 312	457 513	65 162
Kingdom	660 145	102 613	854 256	144 169	1184 454	192 818	1349 389	219 505	1152 447	195 884

TABLE 8.3. ESTIMATED PRODUCTION (tonne) AND AREA (ha) OF BARLEY (Data from [8.6])

All Seasons	2013		2012		2011		2010		2009	
Regions	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area
Riyadh	2804	410	3396	557	3861	619	3748	612	4063	652
Makkah	111	47	135	64	153	71	141	60	658	306
Madenah	26	5	32	7	36	8	44	10	54	12
Qaseem	416	58	504	79	573	88	393	61	357	55
Eastern	409	60	495	82	563	91	700	107	1399	226
Aseer	234	77	284	105	323	117	256	101	1828	660
Tabuk	1777	209	2152	284	2447	315	2105	269	2156	278
Hail	1390	164	1684	223	1914	248	1980	310	2772	360
Northern	6	1	7	2	8	2	9	2	46	13
Jazan	15	4	18	5	21	5	15	4	75	16
Najran	72	16	87	22	99	24	114	26	137	33
Baha	107	22	130	30	148	33	145	34	272	60
Jouf	3900	429	4723	584	5370	649	6741	770	6626	801
Kingdom	11 267	1502	13 647	2044	15 516	2270	16 391	2366	20 443	3472

TABLE 8.4. ESTIMATED PRODUCTION (tonne) AND AREA (ha) OF ALL FODDER CROPS (EXCEPT ALFALFA) (Data from [8.6])

All seasons	2013		2012		2011		2010		2009	
Regions	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area
Riyadh	819 349	37 353	790 442	37 148	682 293	33 986	673 768	33 503	465 087	25 566
Makkah	39 071	3306	38 740	3346	33 185	3061	33 834	3142	70 766	5879
Madenah	5315	312	5163	311	4423	284	3974	254	9039	616
Qaseem	93 273	5391	91 788	5396	78 926	4937	64 030	4017	55 426	3677
Eatern	39 362	2791	39 221	2808	33 597	2569	30 152	2328	31 363	1887
Aseer	7102	554	7056	557	6044	509	6221	523	8589	514
Tabuk	18 777	868	18 847	878	14 144	804	2966	173	3335	185
Hail	92 272	5034	89 622	5030	76 771	4602	71 428	4266	85 024	4575
Northern	0	0	0	0	0	0	0	0	32	2
Jazan	181 548	12 049	181 022	12 277	155 063	11 232	172 275	12 448	212 944	13 257
Najran	11 623	842	11 857	860	9156	787	9299	797	10 690	795
Baha	1917	121	2008	127	1720	116	1741	116	2998	192
Jouf	8481	373	8888	387	5114	354	4939	332	19 372	1105
Kingdom	1318 090	68 994	1284 654	69 125	1100 436	63 241	1074 627	61 899	974 665	58 250

TABLE 8.5. ESTIMATED PRODUCTION (tonne) AND AREA (ha) OF ALFALFA (Data from [8.6])

All seasons	2013		2012		2011		2010		2009	
Regions	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area
Riyadh	1 318 391	64 338	1 306 074	63 866	1264 524	62 927	1264 579	62 879	966 738	50 090
Makkah	17 204	1026	17 043	1018	16 501	1003	13 860	841	11 572	638
Madenah	53 115	3037	52 619	3015	50 945	2971	46 657	2718	43 765	2485
Qassem	453 638	20 518	449 400	20 368	435 103	20 069	429 087	19 783	283 145	14 786
Eastern	52 734	2687	52 241	2667	50 579	2628	55 500	2820	48 105	2673
Aseer	20 025	1142	19 838	1134	19 207	1117	18 708	1090	25 886	1419
Tabuk	215 268	10 272	213 257	10 197	206 473	10 047	199 410	9724	188 715	9008
Hail	191 750	8700	189 959	8636	183 916	8509	182 530	8428	136 499	7127
Northern	26	2	26	2	25	2	22	2	87	6
Jazan	0	0	0	0	0	0	0	0	0	0
Najran	30 909	1872	30 620	1858	29 646	1831	28 125	1731	32 904	1914
Baha	504	29	499	29	483	29	389	23	906	52
Jouf	305 885	12 988	303 027	12 893	293 387	12 704	289 574	12 524	261 381	11 908
Kingdom	2 659 449	126 611	2 634 603	125 683	2 550 789	123 837	2528 441	122 563	1 999 703	102 106

TABLE 8.6. ESTIMATED AREA (ha) OF ALL CROPS IN DIFFERENT YEARS (Data from [8.6])

Regions	2013	2012	2011	2010	2009
Riyadh	230 234	240 623	246 594	245 140	211 796
Makkah	30 303	31 287	31 987	32 718	43 236
Madenah	26 662	26 877	27 506	29 918	29 140
Qaseem	93 187	98 956	104 215	107 011	102 903
Eastern	44 032	50 414	56 167	57 640	60 558
Aseer	14 018	14 407	14 486	13 658	20 101
Tabuk	38 919	44 440	48 868	48 716	41 086
Hail	73 082	79 391	84 228	84 529	86 911
Northern	191	195	115	117	136
Jazan	60 344	64 990	63 050	65 259	111 279
Najran	9720	9821	10 956	10 217	10 965
Baha	2988	2822	3420	3084	4577
Jouf	70 869	81 414	96 147	111 675	112 301
Kingdom	694 549	745 637	787 739	806 682	834 989

TABLE 8.7. ESTIMATED AREA AND PRODUCTION (2013) OF SELECTED VEGETABLES. CROPS GROWN IN GREENHOUSES ARE NOT INCLUDED
Data from [8.7]

Summer Season	Prod. (tonne)	Area (ha)	Winter Season	Prod. (tonne)	Area (ha)	Salt Tolerance
Tomato	76 204	4773	Tomato	148 045	8139	Mod. Tol.
Egg plant	33 533	2030	Egg plant	25 490	1781	Mod. Tol.
Squash	72 114	3475	Squash	32 450	2337	Mod. Tol.
Cucumber	9048	489	Cucumber	1851	110	Mod. Sen.
Okra	24 035	1523	Okra	20 419	1517	Mod. Tol.
Carrots	0	0	Carrots	56 121	3420	Sensitive
Potato	176 077	6941	Potato	21 4182	8271	Mod. Tol.
Dry Onion	0	0	Dry Onion	112 478	3890	Mod. Tol.
All Vegetables	1 236 837	59 989	All Vegetables	213 499	8794	

TABLE 8.8. ESTIMATED AREA AND PRODUCTION (2013) OF SELECTED FRUITS
Data from [8.5]

All Season	Prod. (tonne)	Area (ha)	Salt tolerance
Dates	1 095 158	156 901	Tolerant
Crapes	134 484	12 201	Sensitive
All Citrus	99 019	11 029	
All Fruits	1 688 661	226 763	

TABLE 8.9. ESTIMATED AREA AND PRODUCTION (2013) OF SELECTED CEREALS
Data from [8.5]

Summer Season	Prod. (tonne)	Area (ha)	Winter Season	Prod. (tonne)	Area (ha)	Salt Tolerance
Sorghum	47 115	19 124	Sorghum	63 184	22 977	Mod. Sen./Tol
Maize	95 356	15 626	Maize	42 258	6735	Mod. Tol.
Millet	1074	551	Millet	3412	2081	Tolerant

8.7. MAJOR GAPS

8.7.1. **Availability of data on soil and water quality**

(a) The Soil and Water Atlases of Saudi Arabia [8.7, 8.8] prepared and published by the Ministry of Environment, Water and Agriculture are now out of date.

(b) Isolated and independent studies are produced by academics and scholars at different institutes and universities as research papers/articles focusing on specific aquifers and soils.

(c) Although spatial data acquired by new technologies and approaches such as remote sensing and satellites are available, there is no public access to the information obtained due to issues of national security.

There are tens of thousands of individual farmers scattered all over Saudi Arabia, but no data are available on soil and water quality in their farms. Most farms are used for recreation/entertainment as well as crop production.

8.7.2. Availability of salt-tolerant crops and varieties

The only available data regarding salt-tolerant crops and varieties is from a major project in 2010 funded by King Abdulaziz City for Science and Technology on 'Water requirements of economic crops in Saudi Arabia'. Table 8.10 shows selected salt-tolerant crops and varieties for the various provinces around Saudi Arabia (3.0 dS/m) using different irrigation systems. In general, *Zygophyllum, Helopeplis, Saueda* and *Seidlitzia* are grown in the Sabkhas and *Hyphaene thebaica* (Doum palm) in areas near the Red Sea. Mangrove (*Avicenna*) is widespread around the closed basin along the eastern (Arabian Gulf) and western (Red Sea) coasts.

TABLE 8.10. SELECTED SALT-TOLERANT PLANTS AT (3.0 dS/m) WITH IRRIGATION SYSTEMS AND GROWTH AREAS
Data from [8.9]

Crop	Area	Growing days	Crop water use (m^3/ha/seas.) ET_c	Irrigation req. (m^3/ha/season)			Salt tolerance
				Surface	Sprinkler	Drip	
Wheat	Jouf	13	5071	9221	7377		Mod. Tol.
	Najran	130	4390	7981	6385		Mod. Tol.
	Eastern	130	5608	10 197	8157		Mod. Tol.
	Qaseem	130	5156	9375	7500		Mod. Tol.
	W.Aldwaser	130	6215	11 300	9040		Mod. Tol.
Barely	Riyadh	135	6516	11 547	9238		Mod. Tol.
	Najran	135	4128	7316	5853		Mod. Tol.
Alfalfa	Riyadh	365	26 329	48 101	38 481		Tolerant
	Jouf	365	26 377	48 189	38 551		Tolerant
	Makkah	365	21 315	38 941	31 153		Tolerant
	Najran	365	22 470	41 051	32 841		Tolerant
	Jazan	365	21 530	39 334	31 467		Tolerant
	Madenah	365	28 201	51 521	41 217		Tolerant
	Eastern	365	28 957	52 902	42 322		Tolerant
	Qaseem	365	25 356	46 323	37 059		Tolerant
	W.Aldwaser	365	30 170	55 118	44 095		Tolerant
Potato	Riyadh	108	3916	7831	6265	5221	Mod. Tol.
	Jouf	90	6908	13 816	11 053	9211	Mod. Tol.
	Eastern	105	4159	8318	6655	5546	Mod. Tol.
	Qaseem	105	4996	9991	7993	6661	Mod. Tol.
Tomato	Riyadh	120	4517	8678	6950	5792	Mod. Tol.
	Riyadh	90	59 810	11 799	9199	7666	Mod. Tol.
	Makkah	120	4963	9544	7636	6363	Mod. Tol.
	Madenah	120	5632	10 831	8665	7221	Mod. Tol.
	Eastern	120	4810	9 196	7357	6131	Mod. Tol.
	Qaseem	90	5806	11 166	8933	7444	Mod. Tol.
	W.Aldwaser	120	6491	12 483	9986	8322	Mod. Tol.
Millet	Jazan	105	2883	5766	4613		
	Jazan	90	4425	8850	7080		
Maize	Riyadh	90	5956	10 939	8751		Mod. Tol.
	Jouf	110	4366	8020	6416		Mod. Tol.
	Jouf	90	7050	12 949	10 359		Mod. Tol.
Sorghum	Makkah	105	3330	6366	5093		Mod. Sen.
	Jazan	90	3877	7413	5930		Mod. Sen.
	Jazan	90	4989	9537	7630		Mod. Sen.
	Jazan	105	3889	7434	5948		Mod. Sen.
Okra	Makkah	100	5971	11 557	9245	7705	Sensitive
	Madenah	100	8184	15 834	12 667	10 556	Sensitive
	Qaseem	100	7994	15 472	12 378	10 315	Sensitive
	W.Aldwaser	100	8196	15 863	12 691	10 575	Sensitive
Squash	Qaseem	90	4280	8559	6847	5706	
Onion	Madenah	120	5373	11 513	9210	7675	Sensitive

8.7.3. Availability of tools, knowledge and expertise

Saudi Arabia has excellent tools, knowledge and expertise for salinity and soil/water quality both at the research level and the public services level. There are more than 30 universities in Saudi Arabia and among these at least three (King Abdulaziz University, King Saud University and King Fasil University) have prestigious Agricultural Science departments carrying out studies into salinity and soil/water quality. King Abdulaziz City for Science and Technology has a long history of pure research investigating salinity and soil/water quality. In addition, the Ministry of Environment, Water and Agriculture has established and funded several major projects focusing on irrigation and drainage; these include the Irrigation and Drainage Authority Project in Al-Hasa and the Agricultural Development Project in Dumat Al-Jandal. King Abdulaziz City for Science and Technology has an excellent remote sensing and satellite programme, which provides advice concerning problems of salinity and soil/water quality.

8.7.4. Other soil and management factors affecting salinity

Unwise utilization of groundwater by both agriculture companies and individual farmers has resulted in depletion of the supply of groundwater, together with a decrease in water quality and an increase in salt-affected land. The failure of farm workers to follow best agricultural practice has contributed significantly to salt-affected soil and poor water quality. Some studies have indicated that desertification might be a factor in the increase of salinity, and with regard to this Saudi Arabia has programmed a range of activities including capacity building, controlling urbanization, sustainable agricultural development, and improvement of the water sector, legislation, rehabilitation of degraded rangelands, forest development and sand dune stabilization [8.10].

8.8. THE USE OF NUCLEAR AND ISOTOPIC TECHNIQUES

No nuclear or isotopic techniques have been used in Saudi Arabia in the past. However, ^{15}N has been purchased and will be utilized for the estimation of nitrogen use efficiency in salinity related experiments across the country.

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CHAPTER 9. SYRIAN ARAB REPUBLIC

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9.1. INTRODUCTION

Current trends point clearly to an unavoidable water crisis in the Middle East, which is affecting not only this region but also an increasingly large number of countries worldwide. In brief, the main constraint on agricultural development of arid and semi-arid land in the Middle East is availability of water and lack of available land for agricultural production due to soil salinity, since shortage of water and salinity usually occur at the same time. Most countries in the region with erratic rainfall patterns have already developed, or are developing, many of their economically usable available water sources – most importantly, saline groundwater and drainage, and brackish water. Without efficient control and proper water management, most of those countries will find that self-sufficiency in food and energy remains a mirage, while the land available for cultivation is decreasing dramatically due to soil salinization and degradation.

Although the physical availability of water in each country remains constant, the demand for it, especially fresh water, is set to increase steadily.

A system of efficient and environmentally sound management of the available water resources in each country is the only viable solution. The region needs feasible and realistic soil and water management strategies to address soil salinization and water shortages and to protect the soil from degradation and loss of productive capacity. At the present time, the policies and planning procedures in place to manage salinity and water shortages are inadequate.

One of the most important lessons learned over the past decade is that technical solutions alone cannot meet the needs of the ever-increasing population of the region for safe water supplies and proper environmental sanitation. The region needs to integrate the technical, institutional, managerial, social (including farmers), and economic aspects of water-resource management.

9.2. DATA ON SALT-AFFECTED LAND IN THE COUNTRY AND DIFFERENT REGIONS

According to the FAO/UNESCO soil map of the world, there are more than 3 320 000 km^2 of salt-affected soils, of which about 16.4% are located in the Near and Middle East. The Syrian Arab Republic, with a total area of 185 180 km^2, is bordered on the north by Turkey, on the east and southeast by Iraq, on the south by Jordan, on the southwest by Palestine and on the west by Lebanon and the Mediterranean Sea [9.1]. The country can be divided into four physiographic regions:

(a) Coastal region.

(b) Plains or interior.

(c) Badiah or semi-arid steppe.

(d) Desert area.

In 2005, total cultivable land was estimated at 5.91 million ha, or 32% of the total area of the country. In 2004 out of the 5.53 million ha of cultivated land, temporarily fallow land represented 0.80 million ha and cultivated land 4.73 million ha, of which over 30% was irrigated [9.2]. Although it is generally assumed that saline soils occur primarily in arid and semi-arid climates, they are found in almost every climatic zone. All soil types, whatever their morphological, physical, chemical and biological properties, can be affected by salinity [9.3]. Although different types of salts can occur in saline lands, sodium salts are predominant in many saline soils [9.4]**.**

Syrian Arab Republic is located in the arid and semi-arid zone except for a very narrow belt in the west coast, the mountains, the northeast corner, and a small area in the southwest. The climate is Mediterranean with a continental influence: cool rainy winters and warm dry summers, with relatively short spring and autumn seasons. Large parts of the Syrian Arab Republic are exposed to high variability in daily temperature. The maximum difference in daily temperature can be as high as 32°C in the interior and about 13°C in the coastal region [9.1].

The precipitation is very variable, and the country is divided into five agricultural zones or 'settlements' according to the average annual precipitation, as follows:

First settlement zone: Annual precipitation exceeds 350 mm. This is further divided into two subzones: 1) Annual precipitation exceeds 600 mm where rainfed crops may be successfully planted, 2) Annual precipitation between 350–600 mm and not less than 300 mm during two-thirds of the relevant years (i.e. 2 seasons out of 3 are rainfed).

This zone occupies 14.6% of Syrian Arab Republic's total land area, but it is mostly mountainous. The major crops are wheat and legumes; summer crops can usually be successfully planted as rainfed crops due to the relatively high precipitation).

Second settlement zone: Annual precipitation 250–350 mm with wheat, legumes and summer crops grown under irrigation. This zone occupies 13.3% of Syrian Arab Republic's total land area.

Third settlement zone: Annual precipitation not less than 250 mm during half of the years. Possible to plant crops during 1 to 2 seasons every 3 years, and sometimes it is possible to grow legumes. This zone occupies 7.1% of Syrian Arab Republic's total land area.

Fourth settlement zone: Marginal zone with annual precipitation between 200–250 mm, during half of the year. Permanent poor grazing crops. This zone occupies 9.0% of Syrian Arab Republic's total land area.

Fifth settlement zone: Desert and steppe. With annual precipitation less than 200 mm. Not suitable for rainfed agriculture. This zone occupies 55.1% of Syrian Arab Republic's total land area. The rain falls mainly during the winter and spring.

Only a relatively small area, known as the first settlement zone, can rely on rainfed agriculture with acceptable recharge of the groundwater [9.1]. The importance of this classification is that most of the salt-affected soils occur in the second, third, and fourth zones, and to a smaller extent in the fifth zone (e.g. Palmyra). Irrigation is essential in most years in these zones, and consequently the potential for soil salinization is high.

9.3. WATER RESOURCES AND SALINITY

There are four main sources of water in Syrian Arab Republic: rivers and springs (dams), precipitation, groundwater and all forms of wastewater. It is estimated that water resources generated from precipitation amount to about 7.1 km3/year. Internal renewable surface water resources are estimated at 4.3 km3/year and groundwater recharge at 4.8 km3/year, of which 2 km3/year discharge into rivers as spring water [9.5].

In Syrian Arab Republic, scarcity of fresh water, deteriorating water quality and soil salinity are major limiting factors for agricultural productivity and the sustainability of natural resources. Due to water scarcity, poor quality water is increasingly used for field crop production. Large areas of agricultural land in dry areas of the eastern part, central plain and other areas of Syrian Arab Republic are increasingly irrigated with saline groundwater or non-potable low quality water with a high salinity index, instead of with fresh water. This trend is quickly increasing and spreading to other areas, including near sewage water treatment stations; this will inevitably affect the choice of crops to be grown in the area, as well as the soil itself, and the design, irrigation methods and management practices.

Although up-to-date statistics are not available due to the current circumstances in Syrian Arab Republic, especially in the eastern part, according to the Ministry of Agricultural and Agrarian Reform's estimate in 1997, the total irrigated area in Syrian Arab Republic was about 1.2 million ha. About 600 000 ha consists of salt-affected soils, and this area is expanding very quickly at a rate of 5000 to 6000 ha/year. Therefore, demand for food, fibre and animal feed will continue to increase, and at the same time land and water resources required for crop production to meet the increasing demand will be very limited. For the time being rehabilitation of the salt-affected soils and reduction of the use of low quality water are the most urgent actions required. Also, water needs to be utilized more efficiently in terms of quantity and quality.

9.3.1. Land and water resources management

Appropriate management of land and water resources is vital to control salinity and prevent further salinization of soil and water. Additionally, a special management programme can be considered for rehabilitation of the already saline soils and the reuse of saline ground water.

As recently reported by the Economic and Social Commission for Western Asia (ESCWA), salinity problems have caused the loss of more than 900 000ha of agricultural land in Syrian Arab Republic [9.6]. Salinity affects not only the economic situation, but also family and social life, due to farmers abandoning the land and migrating to nearby cities.

Furthermore, it is also estimated that more than 100 000 hectares are currently irrigated with brackish groundwater. The International Centre for Agricultural Research in the Dry Areas (ICARDA) is conducting trials on the effect of using marginal quality water for wheat production. These trials aim to field-test several wheat varieties for salt tolerance, and the viability of using such low-quality water [9.7].

9.4. TYPES AND CAUSES OF SALINIZATION

In general, there are two types of salinization: primary and secondary. Primary salinization develops naturally due to dissolution and movement of water containing dissolved minerals to low-lying land through saline springs, saline seepage or groundwater upward fluxes driven by climatic dryness, or due to coastal influence in the surrounding land.

Secondary salinization is caused by human activities, such as: excessive or inadequate irrigation; irrigation with saline or low quality water; lack of drainage; improper management of soil and vegetation; and raising of the water table by installing new dams on higher ground, such as the Euphrates dam in Syrian Arab Republic which caused water seepage to the lower area near Rakka and Deir Ezzor provinces. Furthermore, the water quality of rivers and groundwater systems is also significantly affected [9.6].

Dissolved salt in the irrigation water tends to accumulate in the soil as the pure water passes back to the atmosphere through the evapotranspiration process. As plants absorb soil water and water evaporates from the soil surface, salt in irrigation water remains in the soil surface and tends to accumulate slowly after each irrigation. Therefore, the salinity of the soil is usually higher than the salinity of the irrigation water. When excess water is applied to the soil, or enters it by seepage from nearby dams, or leaching from delivery irrigation channels, waters percolates through the soil and the underlying strata, causing waterlogging in agricultural land at lower levels. As a consequence, saline soils are formed through the process of evaporation.

Where salinity is due to mismanagement of irrigation, reclamation usually takes the form of constructing a drainage system below the root zone and then flushing out the accumulated salt with fresh water. Although this is a practical solution to the problem, it requires a large amount of fresh water which is seldom available in the arid areas; it is also very costly, and does not cover even a fraction of the affected lands. Therefore, bio-reclamation using either salt-tolerant crops, shrubs and trees or integrated systems taking into consideration the climate, water, plants and soils are increasingly being explored.

9.5. MANAGING SALINITY

One of the most important measures ways of controlling salinity in irrigated land is by improving water-use efficiency and irrigation management. Such an approach is possible because salinity is a soil property that changes relatively quickly over time compared to other soil properties.

In 1997, a model regional project was conducted in Syrian Arab Republic in cooperation with the IAEA and involving the participation of many countries in the region. The results of this project were very promising in terms of the transformation of wastelands into productive agricultural land. These successes were based on growing salt-tolerant plants. Plant selection needs to be made by considering both the upper and lower parts of the selected salt-tolerant plants, and plants which are capable of adaptation to a harsh environment can be selected.

Some of the most important plants selected were: atriplex, sesbania, barley, kallar grass, alfalfa, sugar beet, and wheat varieties from Pakistan, together with other salt-tolerant shrubs and trees grown in salt-affected soils and irrigated with saline groundwater.

Forage crops were eventually used to feed animals and field trials showed no adverse effect on livestock. The results of this project included the introduction of new crops into the area. This included barley for grains, sesbania and kallar grass for forage, and a few salt-tolerant tree species such as acacia, eucalyptus, casuarina, olives, pomegranates and pistachios.

The project site in Syrian Arab Republic was completely covered with salt (Ec_s >30 dS/m) and the groundwater was of very poor quality (Ec_w >18 dS/m). Within a few years the area was converted into a sanctuary for birds and animals, and provided green cover and some fodder for the nearby farmers. This proves that serious and integrated work with saline areas could lessen the problem and convert the wasteland into relatively productive land, and has the potential to support poor farmers who actually own the land. The sustainability of a pilot study lies in using different scientific, technical and other approaches as specified above to overcome the many potential problems that may arise from the rehabilitation of saline land; one of the most important priorities is to establish what is the most suitable irrigation method of saline land, as well as the best crops to be grown.

In arid regions, one way of controlling soil and water salinization is by good management of evapotranspiration as well as by efficient and appropriately timed irrigation. For example, under drip irrigation the ratio of transpired to applied water is very high and water use efficiency can reach 90%; this represents water savings of 30 to 60% compared with other irrigation methods [9.8, 9.9].

Dissolved salts are left in the soil when the crops are irrigated, with the greatest deposition taking place near the edges of the wetted zone at the soil surface. As irrigation continues, excess amounts of salt will be deposited, especially when irrigating with saline groundwater. This deposited salt, if not properly managed, can cause severe damage to the crop when it moves down into the rhizosphere zone. Monitoring this salt movement is essential, especially during short, medium intensity rainstorms. In such situations the drip irrigation system needs to be kept working during the storm to prevent the accumulation of salts in the root zone, with consequent severe damage to the crop. As water moves and evaporates, the salt concentration increases and deposits commonly occur on beds, borders and around the edges of basins. For most crops the seedling is more sensitive to soluble salts in the soil than the established plant. Planting on the shoulder of the bed, or planting two rows on wide beds, prevents the salts from accumulating near the seedling and consequently reduces the damage by deposited salts. Under drip irrigation, proper management is required if the irrigation water source is saline water or the soil is high in total dissolved salts (TDS). The location of the drip line under these circumstances is critical to keep the accumulated salts away from the seeds or seedlings. Furthermore, the amount of applied irrigation water should not exceed the required amount, to prevent excess dissolved salts moving up from the lower soil profile. As the growing season advances, different management practices can be considered, because the salt concentration of the root zone increases as the soil moisture is depleted by evapotranspiration. Lower salt concentration in the root zone needs to be achieved for sustainable plant growth. This can be accomplished by maintaining the water content of the rhizosphere at higher levels. The best possible way to maintain high water levels in the rhizosphere is by frequent irrigation.

To increase the effectiveness of frequent irrigation, drip irrigation can be successfully used to apply irrigation water with relatively high salinity levels. The use of drip irrigation with proper management in conjunction with the selection of highly salt-tolerant crops may ensure the sustainability of crop production in saline soils.

9.6. CROPS AND VARIETIES GROWN BY FARMERS IN SALT-AFFECTED AREAS

In Syrian Arab Republic, self-sufficiency has been achieved for some crops, such as wheat, chickpeas, lentils, fava beans, cotton, potatoes, tomatoes, citrus and olive. There have even been cases of surplus production. However, domestic production of crops for sugar, vegetable oils (with the exception of olive oil), and of some kinds of red meat, and dairy products (cheese, butter and dried milk) is insufficient to meet domestic demand [9.10].

Crops and varieties grown by farmers in salt-affected areas in Syrian Arab Republic vary from location to location, depending on the degree of soil salinity and the levels of salinity in irrigation water, as well as on the diet of the local people. For example, at Deir Ezzor, most farmers grow barley, cotton, pomegranate, sugar beet, turnip, radish, squash, melon, tomato, corn, okra, cabbage, cauliflower, eggplant, pepper and potato. In other locations, such as the El Ghab area, most farmers grow cotton, sugar beet, okra, wheat and corn. The salt-affected soils of the north and north-east are mostly cultivated with sugar beet, cotton, barley, artichoke, asparagus, eggplant, tomato, pepper and potato. The variation in crop type is due to the degree of soil salinity and the availability of water of suitable quality for irrigation.

In a survey conducted by the General Commission for Agricultural Research in Syrian Arab Republic regarding the introduction of new salt-tolerant varieties, the following information was obtained [9.11]:

Cropping patterns: New forage crops introduced into some farmers' fields occupied 6% of the cultivated area of the total sampled area (Figure 9.1).

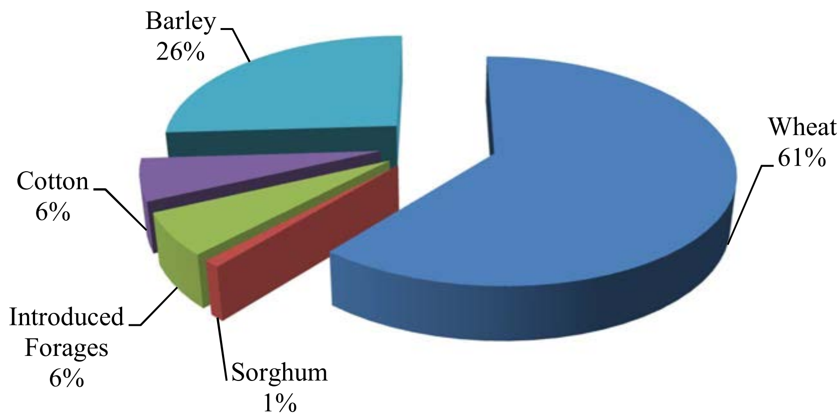

FIG. 9.1. Cropping patterns in the study area.

Knowledge about the project: It was found that 72% of the sample had heard about the project, 32% had participated in project activities, and 42% had participated in field days.

Crops trialed: Several crops were trialed by farmers, including new varieties of barley, sorghum, sesbania, pearl millet, and triticali. Farmers who participated in the project activities, and demonstrated leadership in their communities, accepted the challenge of experimenting with growing these crops, distributed as shown in Table 8.1.

TABLE 9.1. THE PERCENTAGE OF FARMERS GROWING 'NEW' CROPS OR CROP VARIETIES IN THE STUDY AREA

Crops	Farmers (% of total)
Sorghum	10
Pearl millet	4
Sesbania	12
Triticali	8
Barley	14

The farmers who experimented with the new crops constituted 28% of those sampled during the two seasons 2006 and 2007. The seeds of the new crops were provided by the agricultural research stations in Deir Ezzor, but grown under the management of the farmers. Those farmers noted that the new crops, characterized by some positive properties such as better production under saline and dry conditions, may help in changing the current situation if disseminated among farmers and popularized as alternatives to the traditional crops grown in saline conditions in this area.

Large amounts of of high-yielding varieties seeds of barley, triticali, millet, sorghum, and sesbania, in addition to salt-tolerant shrubs seeds such as *Atriplex* Sp., *Salsua vermicualta*, and *Artemisia herb alba* were produced at GCSAR research stations and at some farmers' sites and distributed to farmers who requested salt-tolerant high-yielding seeds [9.11].

Another outcome of the project conducted by the Syrian Atomic Energy Commission (SAEC) in collaboration with the International Atomic Energy Agency (IAEA), was that packages of different salt-tolerant plants, seeds and cuttings were distributed to the local farmers; these included sesbania, kallar grass cuttings, barley, wheat, *Brassica napus*, *Kochia indica* and other fodder crops. At that time, only 50 farmers agreed to accept the packages, but in the next year more than 300 farmers requested them, which indicated the acceptance of the introduced salt-tolerant varieties. Unfortunately, it was not possible to follow the fate of these crops because of the current situation in Syrian Arab Republic.

9.7. MAJOR GAPS TO FURTHER IMPROVEMENTS

Finally, it is important to notice that still there are still large gaps regarding the availability of non-traditional water supplies for irrigation, especially saline groundwater and brackish water. Also, no accurate figure is yet available for the areas of land affected by salinity, or the degree of salinity. There are some naturally occurring salt-tolerant plants in addition to the specially-bred varieties. Scientists in all institutes are working hard to tackle this problem, but sometimes equipment shortages, and long distances between the locations of the laboratory and the field, make it difficult to achieve the required outcomes.

9.8. THE USE OF NUCLEAR AND ISOTOPIC TECHNIQUES

One of the major causes of soil salinity is related to unsuitable irrigation management such as over irrigation with low water quality and inappropriate irrigation methods. To overcome such problems, irrigation scheduling can be employed that helps guide farmers to determine when and how much to irrigate for certain crops at certain levels of soil moisture. Therefore, one of the most accurate techniques for scheduling irrigation was used in this work, namely neutron scattering probe technique (NP) and irrigation water was applied accordingly. This technique proved to be an appropriate irrigation scheduling method, especially under saline conditions due to the fact that NP calibration should be done in the same field using the same water source. Through the use of this technique, the effect of water and soil salinity on the reliability of the NP is overcome.

Labelled nitrogen (stable isotope of ^{15}N) was also introduced to this work to assess nitrogen use efficiency and the suitability of nitrogen application methods since both tested crops (okra and barley) where grown under drip fertigation and all nitrogen fertilizer was injected through the drip irrigation system.

Carbon Isotope Discrimination (CID; $^{13}C/^{12}C$) was also used as a guide for salinity and drought tolerance for barley and wheat varieties at different irrigation levels.

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CHAPTER 10. UNITED ARAB EMIRATES

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10.1. INTRODUCTION

Agriculture in the United Arab Emirates (UAE) has developed rapidly since its initiation in the 1970s despite being severely constrained by climate, land and limited water resources. Although there have been a number of notable achievements, the limits of agricultural growth have become apparent in the last decade due to problems caused by salinity and increasing degradation of natural resources. Poor water quality has created soil management problems which have affected the suitability of the land for irrigation. Specific problems encountered include deterioration of soil structure, salt encrustation at the surface, and reduced ability of plants to take up water and nutrients.

On-farm management issues are also an important contributing factor to increases in soil salinity. With adequate leaching, soil water quality will not be significantly different from the underlying groundwater quality. Survey results on most of the 600 farms sampled have shown that the salinity of the soil in about 50 to 70% of farms was 10% higher than that of the irrigation water, indicating very poor irrigation management. This affected 70 % of all farms in other Emirates, except in Umm al Quwain where soil salinity was well managed on half of the farms.

10.2. DATA ON SALT-AFFECTED LAND IN THE COUNTRY AND DIFFERENT REGIONS

Soil surveys conducted between 2003 and 2012 identified an area of 41105.4 km^2 (i.e. about 63% of the total UAE land area of 83600 km^2) as non-saline (0-<2 dS/m), 2252 km^2 as very slightly saline (2-<4 dS/m) and 9864.7 km^2 as slightly saline (4-<8 dS/m). Excluding the unmapped area, about 11564.8 km^2 (13.8%) is classified as moderately to very strongly saline (8->40 dS/m) (Table 10.1).

TABLE 10.1. OVERALL SOIL SALINITY SITUATION IN THE UAE
Data from [10.1; 10.2]

Ratings	Area (km^2)
Non saline 0-<2 dS/m	41 105.4
Very slightly saline 2-<4 dS/m	2251.0
Slightly saline 4-<8 dS/m	9864.7
Moderately saline 8-<16 dS/m	2651.8
Strongly saline 16-<40 dS/m	2883.8
Very strongly saline >=40 dS/m	6030.1
Not mapped	5313.4

In 2013, a diagnostic analysis of the status and performance of the agricultural sector was undertaken by the International Center for Biosaline Agriculture (ICBA) to determine the main problems and issues. A total of 353 farms randomly selected from all the seven Emirates were surveyed for soil and water salinity. Based on the survey results, the estimated percentage distribution of the farms in different classes of soil salinity is shown in Table 10.2.

TABLE 10.2. PERCENTAGE OF FARMS IN DIFFERENT SALINITY CLASSES IN THE SEVEN EMIRATES
Data from [10.3]

Soil salinity classes	Abu Dhabi	Ajman	Dubai	Fujairah	Ras Al Khaima	Sharjah	Umm Al Quwian
Non-saline 0-2 dS/m	3.7	0.0	8.8	18.5	1.5	6.9	0.0
Very slightly saline 2-4 dS/m	12.8	0.0	26.5	23.1	13.4	24.1	6.3
Slightly saline 4-8 dS/m	19.7	71.4	29.4	12.3	11.9	20.7	37.5
Moderately saline 8-16 dS/m	28.2	14.3	29.4	16.9	13.4	13.8	37.5
Strongly saline >16 dS/m	35.6	14.3	5.9	29.2	59.7	34.5	18.8

Results from analysis of the water samples from the 353 farms for the whole of UAE are presented in Table 9.3. It is evident that close to 75% of the farms had water of very high to very strong salinity (2.5-45 dS/m).

TABLE 10.3. DISTRIBUTION OF WATER SALINITY CLASSES IN THE UAE
Data from [10.3]

Water salinity classes	No. of samples	%
Low salinity 0.1-0.25 dS/m	14	4.0
Medium salinity 0.25-0.75 dS/m	19	5.4
High salinity 0.75-2.25 dS/m	53	15.0
Very high salinity 2.25-10.0 dS/m	178	50.4
Strong salinity 10.0-25.0 dS/m	81	22.9
Very strong salinity 25.0-45.0 dS/m	8	2.3
Total	353	100.0

The percentage distribution of farms into different water salinity classes for the individual Emirates is presented in Table 9.4 and the groundwater quality and its suitability for crops [10.2]

TABLE 10.4. PERCENTAGE DISTRIBUTION OF FARMS INTO DIFFERENT WATER SALINITY CLASSES IN INDIVIDUAL EMIRATES

Water salinity classes	Abu Dhabi	Ajman	Dubai	Fujairah	Ras Al Khaima	Sharjah	Umm Al Quwian
Low salinity 0.1-0.25 dS/m	6.6	0.0	0.0	0.0	2.2	4.2	0.0
Medium salinity 0.25-0.75 dS/m	3.3	0.0	17.6	12.2	0.0	4.2	7.1
High salinity 0.75-2.25 dS/m	7.7	7.1	8.8	46.3	17.8	29.2	7.1
Very high salinity 2.25-10.0 dS/m	53.0	71.4	70.6	19.5	44.4	45.8	64.3
Strong salinity 10.0-25.0 dS/m	27.6	21.4	2.9	17.1	33.3	12.5	14.3
Very strong salinity 25.0-45.0 dS/m	1.7	0.0	0.0	4.9	2.2	4.2	7.1

Most of the samples from the surveyed farms fell in the water salinity classes C4-C7 (Figure 10.1). This means that the water is not suitable for use under ordinary conditions, but may be used occasionally under very special circumstances. The soils ought to be permeable, drainage need to be adequate, large volumes of irrigation water need to be applied to provide leaching, and highly salt-tolerant crops can be selected.

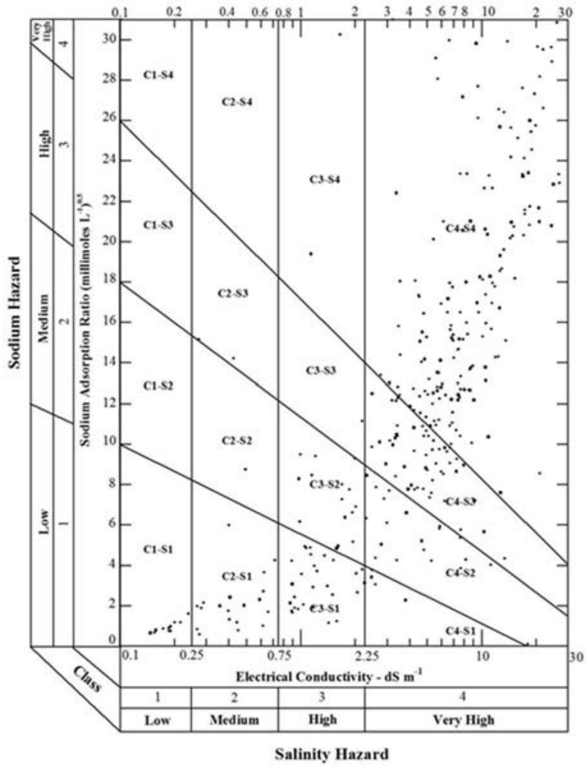

FIG. 10.1. The distribution of water salinity and sodicity at the sampled sites (reproduced from United States Department of Agriculture (USDA) classification with the addition of C5, C6 and C7 to accommodate water salinity levels from the surveyed farms).

10.3. MAJOR CAUSES OF SALINITY

In the UEA, there are four major causes of salinity:

(a) Naturally high groundwater salinity levels, which can reach more than three times the salinity of seawater along the coast.

(b) Seawater intrusion in many coastal areas in the Northern Emirates due to over-pumping in agricultural/farmed areas along the coast. Agriculture in the UAE depends on non-renewable groundwater with an estimated water use of 1.8 cubic km, which is almost two-thirds of all water use in the UAE. Expansion of agricultural areas and over-pumping of groundwater in the past two decades has resulted in intrusion of seawater and an increase in salt concentrations of the aquifers, to the extent that groundwater suitable for growing salt-sensitive crops is now very limited.

(c) Poor on-farm management.

(d) Migration of lower-quality water from underlying aquifers due to over-pumping. Most farm owners rely on unskilled foreign farm workers unfamiliar with the demands of an arid climate; this, together with the increasingly technical demands of irrigation systems, has led to poor soil management and salinity problems.

10.4. EFFECT OF SALINITY ON CROP PRODUCTION

There is insufficient information on yields of crops in relation to salinity. It is accepted that productivity of sensitive crops, such as most vegetables, is reduced by as much as 50% resulting from an increase in irrigation water salinity from fresh to slightly saline. Surveys conducted by ICBA reveal that sensitive crops are planted in areas in which 31% of the cropped area overlies moderately saline groundwater. As a result, average yields of sensitive crops are considerably lower. It is estimated that more than 71% of farms lost a quarter of their productivity, and almost a quarter saw their productivity halved, because of salinity.

10.5. INVENTORY OF CROPS GROWN BY FARMERS IN SALT-AFFECTED AREAS

A wide range of crops is cultivated in the UAE. The major crops and the areas under cultivation in 2011 are shown in Table 10.5 below. Date palm accounted for 58% of the area under cultivation, followed by Rhodes grass (26%). The major vegetables cultivated were tomato, squash, leafy greens, eggplant, cucumber, cabbage and black pepper.

10.6. MEASURES IMPLEMENTED TO ADDRESS SALINITY

Farmers' knowledge of salinity and the extent of adaptation measures implemented by them, are at very low levels. Most farmers are not commercially oriented and only about a third are interested in growing crops profitably. The majority of farm owners do not live on the farm, visit a few times a month and rely on low-skilled or unskilled foreign workers to run the farm on a day-to-day basis. This lack of skill and unfamiliarity with techniques to manage irrigation demand have led to deterioration in soil quality and reductions in crop yields.

TABLE 10.5. MAJOR CROPS AND AREA CULTIVATED IN 2011

Data from [10.3] Note that 1 donum = 0.1 ha

Crop	Area (donum)	Crop	Area (donum)	Crop	Area (donum)
Vegetables		Fruit crops		Perennial forage crops	
Tomato	13 514	Date palm	411 587	Rhodes	184 853
Squash	8198	Mango	6023	Alfalfa	19 172
Leafy green	4375	Jujube	5987	Napier grass	11 226
Eggplant	3289	Lime	2537	Others	6045
Cucumber	2774	Other citrus	1763	Total	221 296
Cauliflower	2735	Fig	1032		
Cabbage	2473	Chico	600	Other Field Crops	
Onion	2447	Pomegranate	593		
Pepper	1331	Gauva	526	Corn	3587
Bean	927	Indian Almond	461	Barley	250
Okra	881	Adalia lemon	338	Tobacco	224
Sweet melon	842	Grapefruit	197	Wheat	17
Water melon	723	Others	2335	Other	1171
Jews Mallow	355	Total	433 979	Total	5249
Others	5317				
Total	50 181		Grand total		710 705

10.7. MAJOR GAPS TO FURTHER IMPROVEMENTS

The following gaps have been identified:

10.7.1. Availability of data on soil and water quality

(a) Limited spatial data availability: existing monitoring stations do not fully cover the whole of the UAE. Accordingly, there are no data available for the areas which are not well covered. Using existing data and monitoring locations for interpolation showed only coarse and inaccurate interpolation results.

(b) Many locations in the Northern Emirates have data available for only one year.

(c) There is no clear information about the methods used for collecting the data, laboratory analysis, or analysing the data, which affects its reliability.

(d) Availability of data at farm level: the UAE has over 38 000 farms and all depend on groundwater for irrigating the crops. In spite of the severity of the problem of salinization of groundwater resources and the realization that irrigation is poorly managed, no data are available on soil and water quality in these farms. There is limited temporal historical data available on water quality/salinity: the length of historical records is short, with many gaps in many years. This is due to inadequate monitoring systems being in place.

10.7.2. Availability of salt-tolerant crops and varieties

Information on salinity tolerance or sensitivity of the crops grown in the UAE, along with the details of growing days and seasonal water requirements, has been compiled (Table

10.6). However, within each crop, the varieties being grown by the farmers and their level of salinity tolerance or sensitivity is not available.

TABLE 10.6. SALT TOLERANCE LEVELS, GROWING DAYS/SEASON AND IRRIGATION REQUIREMENTS FOR FIELD AND GREENHOUSE CROPS GROWN IN THE UAE
Data from [10.3]; where data are unavailable this is shown as NA

	Crop	Type	Growing days	Growing season	Crop water use (m3/ha/season)	Irrigation req. (m3/ha/season)	Salt tolerance
	Sweet/Musk melon	Field crop	123	Summer/ Winter	6225	8056	Tolerant
	Sweet/Musk melon	Greenhouse – Normal	123		4980	6445	Tolerant
	Sweet/Musk melon	Greenhouse – Modern	123		3735	4565	Tolerant
	Tomato	Field crop	164	Winter	5557	7845	Moderately sensitive
	Tomato	Greenhouse – Normal	130		4446	6276	Moderately sensitive
	Tomato	Greenhouse – Modern	130		3334	4707	Moderately sensitive
	Cucumber	Green house – Normal	105		3242	4577	Moderately sensitive
	Cucumber	Greenhouse – Modern	105		2594	3458	Moderately sensitive
	Hot pepper	Field crop	190	Winter/ Summer	6067	8565	Moderately sensitive
	Sweet pepper	Field crop	177	Winter/ Summer	5925	8365	Moderately sensitive
	Sweet pepper	Greenhouse – Normal	177		4740	6692	Moderately sensitive
	Sweet pepper	Greenhouse – Modern	177		3555	4740	Moderately sensitive
	Bean	Field crop	87	Winter	2000	2706	Moderately tolerant
	Bean	Greenhouse – Normal			1600	2259	Moderately sensitive
	Bean	Greenhouse – Modern			1200	1600	Moderately sensitive
	Marrow	Field crop	70	Winter	2300	3247	Moderately sensitive
	Eggplant	Field crop	85	Winter	2400	3388	Moderately sensitive
	Cauliflower	Field crop	69	Winter	2133	3011	Moderately sensitive
	Cabbage	Field crop	83	Winter	2300	3247	Moderately sensitive
	Watermelon	Field crop	123	Summer	5025	7094	Moderately sensitive
	Lettuce	Field crop	97	Winter	2000	2824	Moderately sensitive
	Spinach	Field crop	122	Winter	2967	4189	Moderately sensitive
	Okra	Field crop	145	Summer	8514	13 021	Sensitive
	Onion	Field crop	144	Winter/ Summer	5429	8303	Sensitive
	Parsley	Field crop	70	Winter	1900	2682	NA
	Mallow	Field crop	80	Summer	1796	2536	NA
	Palm tree			Perennial	14 800	21 707	Tolerant
	Jujube			Perennial	NA	NA	Moderately tolerant
	Pomegranate			Perennial	9500	14 567	Moderately tolerant
	Fig			Perennial	9500	14 567	Moderately tolerant
	Lime			Perennial	10 200	17 680	Sensitive
	Lemon			Perennial	14 800	25 653	Sensitive
	Grape			Perennial	9400	16 293	Sensitive
	Orange			Perennial	10 200	17 680	Sensitive
	Mango			Perennial	9500	16 467	Sensitive
	Banana			Perennial	17 200	29 813	Sensitive
	Almond			Perennial	16 000	27 733	Sensitive
	Guava			Perennial	9500	12 667	NA
	Grapefruit			Perennial	10 200	13 600	NA
	Rhodes grass	Field crop		Perennial	15 000	20 294	Moderately tolerant
	Alfalfa	Field crop		Perennial	15 700	22 165	Moderately sensitive
	Barley	Field crop	135	Winter	4500	5294	Moderately tolerant
	Wheat	Field crop	135	Winter	4500	5294	Moderately tolerant
	Corn	Field crop	90	Summer	5000	6176	Moderately sensitive
	Potato	Field crop	100	Winter	4400	6270	Moderately sensitive
	Cowpea	Field crop	70	Summer/ Winter	2400	3247	Moderately tolerant
	Tobacco	Field crop	-	Summer	6000	8118	Sensitive

10.7.3. Tools, knowledge and expertise

ICBA has extensive knowledge of groundwater and surface water modelling for both water flow and transport of contaminants, including:

(a) Groundwater flow and transport models
- i) MODFLOW
- ii) HYDRUS
- iii) AquaChem
- iv) Sigmaplot

(b) Surface water models: flow and transport
- i) Hec RAS
- ii) HYPE
- iii) CE-Qual

Human capital and technical advisory services are important in mitigating the impact of salinity. However, demand-driven high-quality research and technology supported by high-quality extension advice and technology dissemination are lacking, so that there is little prospect of a higher level of agricultural productivity in the UAE. As a result, UAE nationals have very limited information and knowledge about groundwater and surface water modelling. Due to limited data availability, minimal modelling has been done for the UAE.

It is generally known that modest to high soil salinity, naturally occurring or introduced through over-exploitation of groundwater resources and mismanagement of irrigation, depresses crop yields and hence crop production. Reclaiming salinized soils would be prohibitively expensive; so, the best approach would be to improve farmer and farm worker knowledge about practices that can control soil salinity.

10.7.4. Other soil and management factors affecting salinity

Results from farm surveys revealed that the current patterns of agricultural use of land do not correspond with the known soil quality and water quality, resulting in an inefficient production system. Where soils are suitable they overlie areas of poor quality water, while in other areas poor soils are served by good quality water. It is clear from the survey results that water management is deficient on many farms. Poor understanding of the need for regular leaching of soils to manage salinity build-up leads to soil salinization.

10.8. THE USE OF NUCLEAR AND ISOTOPIC TECHNIQUES

Soil salinity is widespread both in developing and developed countries and is expanding at a rapid rate. The reasons behind this can vary from inefficient irrigation/drainage systems, sea water intrusion, ground water contamination, and fossilized brackish water, but most importantly due to miss-management of irrigation systems, crops and cropping systems, climate change and other reasons. In order to tackle the problem of salinity and to formulate proper mitigation and adaptation strategies, it is imperative to have proper monitoring systems in place as an early warning tool. Different methodologies could be used to measure soil and water salinities on larger scale, and as rapidly as possible to act accordingly. Conventional methods (laboratory methods and some field methods) are sometime lengthy and time consuming and are often applicable on a small scale only. On the other hand technologies like Electromagnetic Conductivity Meter (EM38), sensor based system and neutron probe measurements can provide quick and accurate salinity measurements. However, none of the methodologies are 100% perfect and a combination is needed.

ICBA has been using many methods ranging from the conventional to new and improved technologies of increased accuracy and efficiency over large spatial scales. Lately ICBA has acquired a Soil Moisture Neutron Probe (SNP) through the IAEA as part of ARASIA project and the PA agreement between ICBA and IAEA. ICBA staff and other ARASIA project partners received training through IAEA-funded training course to assist the Member States for use as part of SNP to incorporate into a national work plan. Additionally, ICBA is planning to use mutation breeding tools in assistance with IAEA for improving new crops for fodder and biofuel production.

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CHAPTER 11. YEMEN

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11.1. INTRODUCTION

Yemen's extensive irrigation infrastructure has fallen into disrepair and soil salinity has spread across much of the irrigated areas of the central highlands, coastal plains and eastern plateau. According to some studies, more than 0.5 million hectares are irrigated and it is estimated that approximately 60% are slightly to moderately saline and another 40% have levels of salinity that prevent farming [11.1]. The issue of salt-induced land degradation is compounded by the increasing levels of salinity in the irrigation water from the groundwater resources due to mismanagement and recent events of climate change/variability.

Yemeni farmers depend on groundwater to irrigate their crops in the highland plains as well as in the coastal and desert areas. Some of these areas have low quality water due to high levels of minerals. Because of water shortages, many farmers endeavour to use the available water to grow crops to meet their need for food and safeguard their families from famine. They use resources of low quality water without recognizing the detrimental consequences for their land and the soil deterioration this causes. Often the soil reaches a point where it cannot grow any food crops due the high accumulation of salts in the root zone. Most chemical deterioration of soil is caused by using highly saline water. Soil salinity levels in some cases reach over 20 dS/m, which does not permit the growth of cereal crops. In the central highlands, mainly in Alulaib, Mabar and Dhamar (an important irrigated agricultural zone), some farmers have abandoned the cultivation of their land due to this situation. The quality of available irrigation water is quite low (electrical conductivity, EC, 5.85 dS/m), but inappropriate cropping practices and the absence of drainage systems have made the situation worse. The introduction of drainage systems may help to improve soil conditions when leaching requirements are fully implemented under such conditions.

11.2. DATA ON SALT-AFFECTED LAND IN THE COUNTRY AND DIFFERENT REGIONS

11.2.1. Land use systems in Yemen

Yemen is divided administratively into 21 governorates (provinces), with a total area of 455 000 km^2 (after the signing of a border treaty with Saudi Arabia in 2009), that consists largely of mountains and desert terrain. The total population is about 25 million with an annual growth rate of 3%, which is quite high by regional standards and compared with countries with similar levels of per capita income. Most of the population (about 84%) is concentrated in the northern governorates, while the rest occupy the southern two-thirds of the country.

Geographically, the country is divided into five main physiographical regions [11.2, 11.3]: 1) the coastal plains, 2) the Yemen mountain massif, 3) the eastern plateau, 4) the desert and 5) the island of Socotra.

Yemen's cultivated area is distributed among about 1.7 million landholders. Sixty-two percent of farms are less than 2 hectares; 4% of farms are more than 10 hectares. Roughly 60% of landholders have 2–5 plots; 8% of landholders have 10 or more plots. The trend is toward a reduction of the percentage owned by small landholders in favour of increasing amounts of land held by the largest and wealthiest landowners. Large landowners are often absent, increasing the extent to which power, wealth, and influence are situated in the cities, marginalizing the rural population and limiting their opportunities to gain access to networks of influence [11.4, 11.5, 11.6, and 11.7].

The extent of cultivated land in Yemen fluctuates from one year to another according to the amount of precipitation, which is unstable in nature. For example, it was about 1 142 000 ha in the year 2000 but rose to 1 200 000 ha in 2001, and shrank to 1078000 ha in 2003. However, this figure increased and reached 1 499 404 ha of which 50% (749 702 ha) was under rain-fed cultivation, while the rest was cultivated under different systems of irrigation. The extent of cultivation using underground water was 404839 ha [11.8].

Current land use in Yemen very closely reflects the environment, while management practices have evolved to mitigate the harshness of the environment and to maximize the returns from the land at the time of conserving resources. It should be noted that Yemen's land use map has not yet been produced [11.9]. The land use patterns figures shown in Table 11.1 are based on the calculation and analysis of the results of the Yemen- Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) study [11.10].

TABLE 11.1. LAND USE IN YEMEN

Category	Area (l000 km^2)	Area (%) of the total
Total area	45 545	100
Rock outcrops (Rocky areas)	31 252	68.6
Desert lands	4857	10.7
Active dune lands	5816	12.8
Forest land	272	0.6
Wetlands	48	0.1
Arable land	3300	7.2
Cultivated land	1700	3.7
Irrigated land	546	1.2
Rainfed land	1054	2.3

11.2.2. Climate

Yemen has a predominantly semi-arid to arid climate, with rainy seasons during spring and summer, and high temperatures prevailing throughout the year in low-altitude zones. Three large bodies of water affect the climate of Yemen: the Indian Ocean (including the Gulf of Aden and Arabian Sea), the Red Sea and the Mediterranean Sea. They are the sources of moisture for the passing air masses and have an impact on the general atmospheric circulation [11.2].

Yemen is characterized by diverse physical and topographical features, resulting in wide differences in climatic conditions and consequently, in different agro-climatic zones. Based on the variation in climate, the country has been divided into 14 agro-climatic zones [11.11]. The climate ranges from hot and tropical in the lowland region to temperate in the central mountain region. The maximum temperature in the summer may rise to 40ºC in the lowland areas and desert regions. In the winter, the temperature may decrease to below zero in the highland mountainous regions. The mean annual temperature ranges from 11ºC in the highlands to 300C in the lowlands [11.12].

11.2.3. Water resources

There are two main water resources in Yemen: surface water and underground water. Rainfall is considered the basic water resource. The mean annual precipitation on the mainland is estimated at 68–93.6 km^3, with the annual average estimated at 230 mm. Most of this rain falls on the western heights and the eastern plateau. The highland regions are characterized as runoff-producing zones with more or less permeable surfaces. Surface water is therefore, mainly the runoff from steep mountain slopes forming immediately after heavy rainstorms.

Numerous river systems and related catchment areas cover the territory of Yemen. As mentioned earlier, the country has been divided into five major drainage basins but in terms of water flow they are grouped into two main catchments. The surface flood water that flows through the main wadis in those catchments has been estimated at 2000 million m^3/year [11.13], but this quantity corresponds to the runoff from major rivers and does not include the runoff produced within the smaller catchments (Table 11.2).

TABLE 11.2. SURFACE RUNOFF WATER OF IN THE MAIN VALLEYS OF YEMEN

Western wadis	Water amount Mm^3	Eastern wadis	Water amount Mm^3
Mawr	162	Rub Al-Khali Basin	171
Sardud	69	Ramlat al-Sab'atayn Basin	315
Siham	89	Arabian Sea	235
Rima	90	Gulf of Aden Basin	535
Zabid	125		
Rasyan	45		
Harad	35		
Mawza	121		
Minor wadis	97		
Total	741		1259

Renewable groundwater resources are estimated to be about 1525 million m^3 per year, while the storage capacity of dams and reservoirs is estimated at 0.50 km^3. There are also about 50 dam structures that are not intended to store water, but to control and divert floods in the main valleys to the adjacent irrigation network (spate irrigation).

Groundwater is considered the main water resource for different water uses and the water level in most critical aquifers is declining due to over-extraction. In some cases, water is being extracted at three times the rate of water recharge. In 1990, total water withdrawal was estimated at 2932 million m^3/year, of which 92% was utilized for agricultural purposes; this grew to 3400 million m^3 in 2010. The decline in groundwater levels in all basins is quite alarming, especially in the highland regions, where the rate of decline ranges between 2 and 8 m/year. Spring-fed irrigation has reduced significantly as groundwater tables have dropped.

It is estimated that less than 10 % of extracted water is used for domestic and industrial purposes. Availability of fresh water per capita is decreasing with time; it has fallen from 1100 m^3 in 1990 to 500 m^3 in 1995 and more recently to around 137 m^3. Considering the present pattern of water utilization and the rate of population growth, it is expected that water availability per capita will fall to 70 m^3 in the coming 25–30 years. So, water availability is the most frequently mentioned constraint affecting the development of the agricultural sector in all parts of Yemen. Highland basins that rely on groundwater are experiencing rapid declines in the water table, and competition for this dwindling resource is fierce. Once this resource is depleted, there is no equivalent replacement source, and the continuation of farming, and even possibly habitation, and may be in doubt unless remedial measures are taken. Coastal areas are also utilizing ground water at an unsustainable rate, and salinity is becoming a serious problem there. For areas that are dependent on groundwater for agriculture, an urgent strategy that looks at water demands of various crops, competing uses, and estimates of water availability is needed to preserve the resource and to prevent or ameliorate the impact of groundwater depletion. Table 11.3 shows the total cultivated area and the different categories of irrigation patterns during 1991–2013.

In the urban areas, waste and sewage problems pose a threat to groundwater and lead to pollution. Water-borne diseases are a major cause of infant mortality in the country.

TABLE 11.3. THE TOTAL CULTIVATED AREA AND THE DIFFERENT CATEGORIES OF IRRIGATION DURING 1991–2013
Data from [11.8]

Year	Cultivated area ha	Irrigated area		Well irrigated		Spate irrigated		Spring irrigated	
		ha	%	ha	%	ha	%	ha	%
1995	1067667	488 276	45.7	368 295	75.4	99 709	20.4	20 272	4.2
2000	1143441	628 891	55.0	457 375	72.7	125 776	20.0	45 740	7.3
2005	1202113	564 553	47.0	393 089	69.6	137 163	24.3	34 301	6.1
2010	1452438	748 322	51.5	408 480	54.6	240 028	32.1	38 122	5.1
2013	1499404	685 228	45.7	404 839	59.1	239 905	35.0	40 484	5.9

11.2.4. Water quality

Brackish water is found in many locations in Yemen. In some locations, brackish water is naturally available, in others it is a result of over-pumping of groundwater and intensive use of irrigation water, which has led to increasing salinity.

The usable brackish water for agriculture in Yemen is about 300 million m^3/year, mostly in the coastal areas and particularly in the Tehama region. This water is used to irrigate about 38 500 ha. However, brackish water with high salinity is used for the water supply in Taiz city, by mixing with fresh water for domestic use without any desalination. Hence, Taiz city is the most critical city in terms of water resources in Yemen.

The rapid growth of population in Yemen is putting enormous pressure on water availability, and consequently on food security, which is directly dependent on water. Yemen is facing a grave water crisis which, if left unaddressed, will threaten the survival of both urban and rural areas. Urgent action needs to be taken to pull the country back from the brink of disaster. Conservation of water, use of non-conventional water sources, and improving agricultural productivity in relation to water use are the only means of salvation for Yemen. The results of the water quality studies conducted by the Water Resources Authority in 2011 pointed out that the salinity of groundwater increased vastly in many basins, particularly those in the coastal areas where seawater intrusion has placed the coastal areas in an extremely hazardous situation. There are no networks monitoring surface water quality in Yemen, as far as is known. However, various projects have measured surface water salinity, but only at a few sites; in most cases measurements of electrical conductivity have been obtained during current metering.

Groundwater quality has not been studied extensively for all regions of Yemen. The groundwater quality has been assessed with respect to its suitability for intended use for irrigation or drinking water. This means that the main determinant of water quality is the degree of mineralization. Hence, many measures of electrical conductivity have been taken all over the country, to produce a reasonable picture of the occurrence of fresh and brackish /saline water. Groundwater aquifers decline at a rate of 2–6 m annually with very rare recharge in most of the basins in Yemen, particularly in the Central Highlands and northern parts. This causes a deterioration of groundwater quality, including seawater intrusion in the coastal plain areas.

Groundwater quality in Yemen has a complex nature (Table 11.4). EC ranging from 2 to 5 dS/m is observed in some areas in the highland basins, as well as in the lowlands, particularly the wells located near the wadis. The groundwater salinity in the lowlands and coastal areas is low in the upstream and increases in the direction of the downstream, becoming very high near the coast. However, the salinity of the groundwater in the coastal areas increases from the water source towards the water divides between the wadis. EC values ranging between 8 to 14 dS/m are reported in some wells located near the coast and in the vicinity of water supply field wells. This is highly indicative of seawater intrusion as a result of excessive pumping.

TABLE 11.4. GROUNDWATER SALINITY IN SOME PILOT AREAS IN THE COASTAL, HIGHLANDS AND EASTERN AREAS
Data from [11.14, 11.15, 11.16, 11.17, 11.18]

Governorate	No of Samples	EC dS/m			SAR			Cl meq/l		
		0.1–2	2- 4	>4	1 -3	3 – 6	>6	0.1-4	4-10	>10
North Tihama[1]	20	5	11	4	10	9	1	1	2	17
Central Tihama[1]	31	24	5	2	21	7	3	7	17	7
South Tihama[1]	21	21	-	-	21	-	-	14	6	1
Abs & Algar Tihama[1]	26	23	3	-	23	-	-	1	16	9
Al-Baida +Radaa[2]	102	79	15	8	82	17	3	46	33	23
Lahj[3]	61	30	25	6	4	34	23	3	36	22
Al-Dhalea[3]	48	40	6	2	34	6	8	20	20	8
Mareb[4]	83	68	10	5	67	14	2	41	30	12
Al-Gawf[4]	12	3	3	6	3	6	3	1	2	9
Al-Mukala[5]	54	17	16	21	4	23	27	12	26	16

11.2.5. Soil Types of Yemen

Soils of Yemen [11.19] were classified according to the Soil Taxonomy of United States Department of Agriculture [11.20] and correlated with the World Soil Reference Base [11.21]. Based on the United States Department of Agriculture (USDA) classification system, the main properties used to differentiate soils were: texture and degree of stratification; depth; drainage; the presence of calcic horizon; salinity and/or alkalinity; and the presence of a surface organic horizon. Subsidiary properties were crack and slickenside development, and takyric features at the surface. The soil survey provided the foundation for geographic information systems used for land evaluation and land use planning and good land management. It describes the characteristics, limitations and best potential uses for the different soil types found across the country. The soil map is supported by a database containing data from about 1123 soil profiles. Analytical data were available for 21 variables. The remote sensing satellite data (geocoded false color composites) of 2001 generated from bands 4, 3 and 2 were visually interpreted. Simultaneously, the topographic sheets on 1:500 000 scale were also considered. The soil was classified according to subgroup. Soil mapping units and legends were revised and finalized and a soil classification map was generated at a 1:500000 scale by using Arc Geographical Information System (GIS). The soil map indicates that five international soil orders of the Soil Taxonomy [11.20] were recognized in Yemen (Entisols, Inceptisols, Aridisols, Mollisols and Rock outcrops).

It should be noted that the remaining mapping units are represented by the rock outcrops, which occupy 55% of the total land area. The calculation of the surface area for each mapping unit was done using ArcGIS software. Table 11.5 details the soil mapping units classified according to soil order and their surface area [11.19].

TABLE 11.5. SOIL MAPPING UNITS COMBINED UNDER SOIL ORDER

Soil order	Mapping unit symbol	Area (ha)	% of the total land area
Aridisols	Act, Agr, Asf, Ast	3 457 662	7.6
Entisols	Etc, Etu, Ett, Etf, Ehu, Eur, Est, Ess, Eut, Euu, Eup, Euo, Eto, Eft, Eub, Eoc, Ehc	15 802 348	35
Inceptisols	Luc, Luu, Lcu,	746 428	1.6
Mollisols	Mtc,Mhr, Muh	134 407	0.3
Rock outcrops	Rcc, Rtt, Rtc, Ruo	25 405 676	55
Total area		45 546 521	100

11.2.6. Land degradation and soil salinity

Land degradation in Yemen has expanded and intensified, especially in the coastal regions due to seawater intrusion caused mainly by extensive pumping of groundwater. Soil salinity is caused mainly by using low quality water and engaging in intensive agriculture and mismanaged irrigation practices, such as applying water in excess of irrigation requirements. Desertification covers a great part of the land, accounting for over 50 percent of the total land area. The potential for greater desertification is considerable. The main driving forces for desertification are water erosion, overgrazing and depletion of tree cover, abandonment of terraces, and changes in socioeconomic factors and farming practices that lead to unsustainable practices for land cultivation [11.1].

It should be noted that Global Assessment of Soil Degradation (GLASOD)_ methodology was used to prepare the land degradation map of Yemen after making the necessary modifications so as to make it compatible with the local conditions of the Republic of Yemen. Table 11.6 describes the pattern of land degradation and the types of land in Yemen (extracted from [11.10]).

TABLE 10.6. TYPES OF LAND DEGRADATION IN THE YEMEN

Type of land degradation	Area (km^2)
Desert land	48 568.97
Chemical degradation of land (saline agricultural land)	370.90
Sand dunes	58 159.37
Land degraded by erosion by heavy winds	4752.46
Land degraded by erosion by light winds	1029.43
Physically degraded lands (i.e. compaction)	127.17
Rocky land	281 968.04
Mountainous terraces	6615.04
Naturally stable land with forests and trees	2721.54
Land affected by light erosion by water	6439.60
Land affected by medium erosion by water	18 468.13
Land degraded by heavy erosion by water	25 798.35
Wetlands (Sabkhas)	483.46

Soil salinity is concentrated mainly in the coastal areas of western part of the country (Tihama Plain) and in the southern-eastern coastal area that include parts of the Lahj, Abyan, Shabwa, Hadramout and Al-Mahara governorates. Salinity is more established in the areas closer to the shore. It also occurs in small pockets in some areas of the highlands, due to the use of low quality water. Continuous application of large amounts of flood water for irrigation in some valleys and farms has resulted in the raising of salinity levels in these areas. The high evaporation rate of these areas is another factor in raising salinity. Table 10.7 shows the chemical characteristics of some soil samples from different parts of the coastal areas. It is clear that salinity has reached high levels in some locations such as Upper Hajr, ranging from 1.4 dS/m to 16.8 dS/m in the surface layer and from 4.1 dS/m to 43.5 dS/m in the subsurface layer. The sodicity or exchangeable sodium percentage (ESP), ESP, ranges between 10 and 25%, but in some cases it exceeds that and may reach 100%, as in the subsurface sample from Om Al-Shatr in Upper Hajr. The soils of the al-Kod Research Farm reflect less salinity, although they have been cultivated for a long time due to their coarse and medium structure. Abandoned land exhibits high levels of salinity, but as soon as it is cropped for few seasons it loses the effects of salinity; this is shown in samples from pits 1 and 2 in Shabwa governorate.

TABLE 11.7. CHEMICAL CHARACTERISTICS OF SOME SOIL SAMPLES FROM DIFFERENT AREAS OF THE COASTAL AREAS Data from [11.22, 11.23, 11.24].

Location	Depth cm	pH	EC dS/m	$CaCO_3$ g/kg	Org. C. g/kg	Avail. P ppm	Exchangeable ions meq/100g	
							Na	K
Al-Sadarah, Upper Hajr[1]	0 - 15	8.3	6.1	440	13	4.0	2.1	0.6
Al-Sadarah, Upper Hajr[1]	15 - 50	8.4	4.4	560	6	2.0	1.3	0.2
Om Al-Shatr, Upper Hajr[1]	0 - 55	7.8	14.4	495	18	2.0	7.2	3.4
Om Al-Shatr, Upper Hajr[1]	55 - 85	6.6	43.5	610	17	2.0	33.5	2.3
Al-Hergah, Upper Hajr[1]	0 - 8	8.3	1.6	520	16	3.0	3.0	0.3
Al-Hergah, Upper Hajr[1]	8 - 30	7.0	18.5	600	9	1.0	1.0	0.2
Manzel Al-Ghamera, Upper Hajr[1]	0 - 15	8.2	4.9	420	17	4.0	4.8	1.0
Manzel Al-Ghamera, Upper Hajr[1]	15 - 45	8.2	4.1	560	7	2.0	3.8	0.4
Al-Ghoal, Upper Hajr[1]	0 - 20	7.8	16.8	580	6	4	4.2	0.3
Al-Ghoal, Upper Hajr[1]	20 - 35	8.2	24.6	520	13	4	12.5	1.9
Al-Hotah, Upper Hajr[1]	0 - 7	7.1	6.2	850	16	2.0	2.9	0.40
Al-Hotah, Upper Hajr[1]	7 - 30	7.2	4.6	783	13	1.0	1.3	0.17
Jizwell, Upper Hajr[1]	0 - 55	7.1	2.9	740	16	4.0	2.6	0.45
Jizwell, Upper Hajr[1]	55 - 80	7.0	10.0	690	17	2.0	4.6	0.47
Block 3 plot 1, El-Kod Research Farm[2]	0 - 31	8.3	4.4	111.8	2.8	4.0	-	-
Block 3 plot 1, El-Kod Research Farm[2]	31 - 42	8.3	3.3	93.8	1.3	2.0	-	-
Block 2 plot 2, El-Kod Research Farm[2]	0 - 25	8.4	2.2	129.3	4.6	11.0	-	-
Block 2 plot 2, El-Kod Research Farm[2]	25 - 30	8.4	1.6	142.5	4.8	5.0	-	-
Block 3 plot 2, El-Kod Research Farm[2]	0 - 32	8.3	1.8	113.6	4.4	8.0	-	-
Block 3 plot 2, El-Kod Research Farm[2]	32 - 45	8.3	3.1	108.8	-	3.0	-	-….
Pit 1 (Site A, Stallion), Shabwa[3]	0 - 25	8.1	8.32	273	-	1.9	5.6	0.90
Pit 1 (Site A, Stallion), Shabwa[3]	26 - 50	7.6	10.80	270	-	3.8	6.4	1.40
Pit 2 (Clinic Site), Shabwa[3]	0 - 25	8.5	1.90	23.5	-	4.1	0.77	0.31
Pit 2 (Clinic Site), Shabwa[3]	26 - 50	8.5	1.40	29.8	-	2.5	0.77	0.36

11.3. MAJOR CAUSES OF SALINITY

The major factors leading to salinity in the Yemen are:

(a) Practicing crop farming without good knowledge of the available soil and water qualities.

(b) Continuous intensive farming including applying amounts of water in excess of crop requirements.

(c) Using water of low quality for irrigation.

(d) High groundwater abstraction in the last three decades, causing seawater intrusion in some parts of the coastal areas.

(e) Cultivating crops with high water requirements in unsuitable areas.

(f) Mismanagement of flood water in the lowlands due to over-use of water for irrigation in this type of cropping pattern.

(g) Over-use of some fertilizers as chicken manure for growing vegetables in the Highlands or chemical fertilizers for qat (khat) crops in all areas.

11.4. CROPS AND VARIETIES GROWN BY FARMERS IN SALT-AFFECTED AREAS

A wide range of crops is cultivated in the Yemen. The major crops and the area under cultivation in 2013 are shown in Table 11.8. Sorghum accounted for 36.5% of the area under cultivation, followed by sorghum fodder (16.7%) and millet (13.8). The major vegetables cultivated were sesame, kidney bean, tomato, okra, onion and groundnuts.

TABLE 11.8. MAJOR CROPS AND AREA CULTIVATED IN 2014
Data from [11.25]

Crop	Area (ha)	Crop	Area (ha)	Crop	Area (ha)
Vegetables		Fruit crops		Perennial forage crops	
Tomato	3667	Date palm	12 716	Sorghum fodder	80 700
Potato	532	Mango	11 799	Alfalfa	7082
Radish	607	Papaya	1301	Grasses	2790
Eggplant	399	Mandarin	373	Total	90 572
Cucumber	535	Apple	121	Other Field Crops	
Garlic	180	Fig	25	Sorghum	176 335
Cabbage	50	Banana	7340	Barley	860
Carrot	187	Orange	1031	Maize	5140
Onion	2804	Pomegranate	19	Millet	66 381
Pepper	81	Guava	378	Wheat	9974
Green bean	260	Sweet melon	6787	Coffee	1526
Leek	102	Water melon	6787	Cotton	14 275
Okra	3125	Grapes	15	Tobacco	10 110
Jews Mallow	747	Peach	10	Other	10 634
Fenugreek	23	Lemon	1618	Total	295 235
Haricot bean	48	Total	50 320		
Kidney bean	14 722				
Sesame	15 756				
Groundnuts	2153				
Others	459				
Total	46 437				
				Total	482 564

11.5. EFFECTS OF SALINITY ON MAJOR CROP PRODUCTIVITY

There is little information available on crop yields in relation to salinity except that which is found in the scientific references. It is known that productivity of sensitive crops, such as most vegetables, is reduced by as much as 50% when irrigated with highly saline water, and may be reduced by 100%. Surveys conducted by the Agricultural Research and Extension Authority (AREA) reveal that sensitive crops are planted in some coastal areas irrigated by moderately saline groundwater, which has resulted in reduced yields.

11.6. MEASURES IMPLEMENTED TO ADDRESS SALINITY AT FARM LEVEL

Farmers' knowledge of salinity and adaptation measures implemented are at low levels. Many farmers are commercially oriented and more than half are interested in growing crops for profit. The majority of farmers cultivate their lands themselves and have accumulated experience in dealing with the harsh and difficult climate. They mostly depend on family workers as well as animals for labour. Economic factors reduce their ability to change to mechanized techniques. In some flood irrigation cropping patterns, they apply large amounts of water to irrigate their crops and to wash down any salt accumulation in the soil profile.

11.7. MAJOR GAPS TO IMPROVEMENTS

11.7.1. Availability of data on soil and water quality

(a) Shortage of data in many areas, since only old and limited soil and water surveys have been carried out in some parts of the country and these have focused on the zones that are most promising for agricultural production.

(b) Few and insignificant research activities carried out in the field of salinity diagnosis and suitability of crops for saline conditions.

(c) Shortage of skills and knowledge among researchers and extension workers about salinity measures and how to cope with soil salinity.

(d) Shortage of skilled laboratories to carry out proper diagnostic analysis in the surrounding area with acceptable costs for all farmers.

(e) Lack of varietal crops tolerant to soil salinity as well as limited knowledge of the behavior of the existing ones.

(f) Lack of awareness at the decision makers' level for the responsibility for the problem and the need to deal with it.

(g) Farmers' lack of adequate knowledge on how to deal with the problem as well as whom to target.

11.7.2. Availability of salt-tolerant crops and varieties

Plants differ in their tolerance to soil salinity and salt abundance in water. Vegetables grown in Yemen and specifically in the coastal areas are sensitive to moderately tolerant to salinity. Most farmers do not know the symptoms of salinity disorders; they ascribe symptoms of deficiency to nutrient deficiencies or pests and disease disorders. At present, there is no specific crop variety that is fully tolerant to cultivation in saline conditions. Farmers usually tend to abandon the land once they know that it has become unproductive. Some of them remove and destroy the topsoil.

The problem of salinity is mainly found in the coastal areas of Yemen, in specific spots adjacent to the sea. Crops that grow in these areas are fodder sorghum, bananas, date palm, papaya, tomato, cotton and okra. The problem of salinity will be exacerbated in the near future because of the continuous use of low quality water, together with climate change and the over-exploitation of resources. The crops cultivated in Yemen are in general sensitive to moderately sensitive except for barley and alfalfa. The salt-tolerant crops or varieties have not yet been evaluated for different levels of salinity.

11.7.3. Availability of tools, knowledge and expertise

Fertigation of some vegetable crops (potatoes, tomatoes and peppers) in the open field is carried out by drip irrigation in the central and northern highlands research stations. This technique has also been applied to farmers' fields; however, it has not been widely adopted due to high costs.

Farmers still rely on visual and experiential interpretation of soil moisture based on touching the soil subsurface layer and on the plant's appearance. Tensiometers are used only in the fields at AREA's research stations, and monitoring of the soil head potential and scheduling of irrigation very rarely takes place. Irrigation is scheduled at ten-day intervals in the open field or every three to four days in greenhouses, regardless of the climatic conditions and crop water demands. The crop coefficient is indirectly considered by the farmers through the increase of irrigation hours at different crop stages. Therefore, the amount of water applied is measured by the time of application (length of irrigation event) with no reliance on measuring pressure within the system or on using water meters.

AREA has several meteorological stations located in different ecological zones. All of them are manually operated by a team of technicians. These stations are used to measure surface temperature, relative humidity, sunshine, wind speed and precipitation. There are problems in using these stations because they are old and manually operated, so it is envisaged that they will be replaced with a modern meteorological network in the near future.

The role of stakeholders and research institutes is crucial to combating salinity problems in Yemen. For instance, some stakeholders (in the private sector) may have access to monitoring tools, but their workforce lacks the capacity to operate these tools. We still lack the use of hydrological models in Yemen which are needed in addition to crop models.

Although research institutions are aware of salinity problems, the government still does not give any priority to this issue. Research institutions are collaborating with regional and international organizations to introduce new varieties tolerant to salinity and drought conditions. This work is still in the early stages. The recent cooperation between the IAEA and ICBA to support the RAS project will see an attempt to provide genotypes of salt-tolerant traits to run adaptation trials in the coastal areas using saline water varying between 1 and 20 dS/m. The RAS team will try to use Nitrogen-15 in their future programmes to assess nitrogen recovery under salinity stress conditions. It is planned to use soil moisture sensors to quantify water use efficiency under different salinity levels.

Increased research into the salinity problem in Yemen is vital because the problem of saline groundwater is becoming worse in the coastal areas as well as in some of the northern, southern and central highlands, where farmers depend on groundwater for irrigation. Saline groundwater is intensively used for irrigation in the coastal areas. The follow-up to research findings will require dissemination tools and facilities so that progress can be achieved through supported programmes.

Extension services will require capacity building and support to disseminate the research findings to farmers. Communication days and technical workshops can be organized and attended by pioneer farmers.

11.7.4. Suggestions

(a) Technical and instrumental support is required for the research teams who work on salinity issues, especially those in the coastal regions.

(b) Specific studies and surveys are required to diagnose the spread of salinity and what types exist in the affected areas.

(c) Governmental and institutional support can be provided so that research activities can be carried out to help farmers and improve cropping systems.

(d) Cooperation can be strengthened with regional and international institutions that work in the field of salinity to improve experience and knowledge.

(e) Capacity building is required for the researchers and extension agents who work in these areas.

(f) Farmers' knowledge of measures to combat salinity can be improved.

(g) It is envisaged that the AREA's meteorological stations located in different ecological zones can be replaced with a modern meteorological network in the near future.

(h) Capacity-building for stakeholders regarding combating soil salinity problems are greatly needed and sometimes requested by the stakeholders to strengthen their capacities in the skills of field monitoring and modelling.

(i) Increased research into the salinity problem in Yemen is suggested. However, it is necessary to communicate research findings to farmers through agricultural extension services.

(j) Coordination between farmers' associations, extension services and research institutions can be improved.

11.8. THE USE OF NUCLEAR AND ISOTOPIC TECHNIQUES

Nuclear and isotopic techniques have been in use in agriculture in Yemen since 1998. Studies have been conducted in different research stations to identify the optimal rate of nitrogen fertilizer and water applications for potato and onion crops. This work was done via the ^{15}N and neutron probe device.

These studies were carried out under a TC project supported by the IAEA. The results of this work helped to identify the amount of nitrogen and water needed for optimal yields of the aforementioned crops. To add to this work, on farm trials were conducted to confirm obtained results using drip fertigation methods in different locations across Yemen. Significant results have been obtained resulting in great success in which nitrogen fertilizer and irrigation water application rates were reduced by half.

These results have been published in peer reviewed journals and within the IAEA newsletters. Success with potatoes have encouraged researchers in Yemen to investigate the use of water and nitrogen in other crops such as garlic, tomato, and papaya. In addition to these studies, there have been good results of using carbon isotope discrimination ($^{12}C/^{13}C$ ratio) as a tool to screen wheat cultivars under two water management systems to help identify drought and salinity tolerance.

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18-03531

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ISBN 978–92–0–101918–9
ISSN 1011–4289