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Research Report 11

Prospects for Productive Use of Saline Water in West Asia and North Africa

John Stenhouse and Jacob W. Kijne

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Comprehensive Assessment of Water Management in Agriculture

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Contents

Abstract

This study of the potential to use saline water for irrigation in Egypt, Jordan, Syria and Tunisia concludes that it is technically feasible but its economic viability remains to be established. Expert opinion suggests that saline irrigated agriculture is most likely to succeed in the West Asia/North Africa region as a complement to small-scale mixed livestock and cropping farming systems. Precise quantification of the available saline water resources is not possible because of the lack of hard data. As a result, precise quantification of the likely impact of introducing saline irrigated agriculture on poverty alleviation and food security is also impossible, although anecdotal evidence suggests that this would be positive. The report argues that the environmental effects of saline irrigated agriculture – both positive and negative – need to be integrated into policies and decisions on the use of saline water. Uses other than agricultural (for example, amenity uses, industrial, landscaping, carbon sequestration or biomass production for energy) also need to be considered, and may be more socially and economically beneficial.

Summary

The use of saline water and land for agricultural production has long been proposed as an option to augment limited freshwater resources, particularly for the water-scarce regions of West Asia and North Africa (WANA). But the scope for this and its possible contributions to social and economic development have been poorly defined. This report attempts to quantify the potential for agricultural use of saline water to alleviate poverty and generate other social and economic benefits in WANA. The first part of the report describes the nature of the salinity problem, reviews the economic incentives that may need to be in place to encourage the local reuse of saline drainage water, and discusses the competing options for the productive use of saline water. The second part reports the findings from case studies of the available saline water resources in Egypt, Jordan, Syria and Tunisia. The report aims to quantify the saline water resources, its prevailing possible uses in the different farming systems and the potential impact of such uses on poverty and livelihoods of the poor in each of the countries. The report concludes that it is technically feasible to integrate the use of saline water and land for irrigated agricultural production into the mixed farming systems of the WANA region, but the economic viability of production needs to be confirmed. It was not possible to quantify the direct impacts of agricultural use on poverty alleviation; it is likely that these will be positive but limited. In many situations, fish farming or other non-agricultural uses of saline water may be more appropriate than its use for crop agriculture; for example, in landscaping, industry, environmental greening and amenities in the oil-rich countries of the Arabian Peninsula or in low-cost inland desalination to provide drinking water. New developments in the demand for renewable energy may present major opportunities for biomass production and carbon sequestration using saline land and water resources but the environmental, economic and social impacts remain to be quantified.

Prospects for Productive Use of Saline Water in West Asia and North Africa

John Stenhouse and Jacob W. Kijne

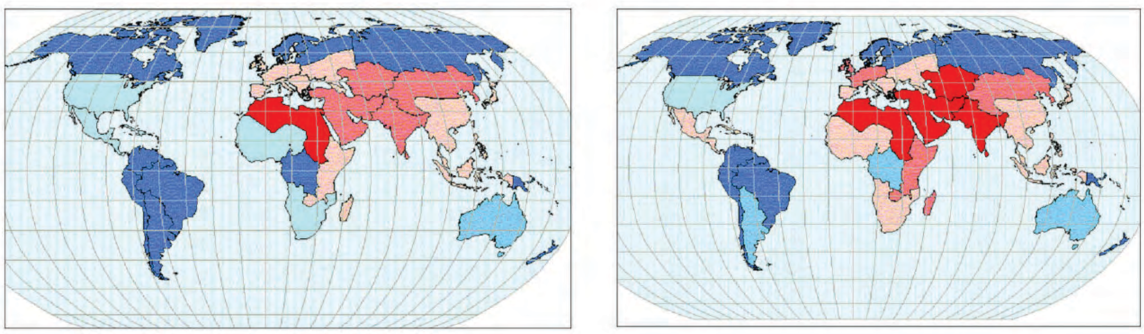
Introduction

In a world that faces increasing challenges of water scarcity, the optimum use of all available resources becomes critical. This is particularly true for the hyper-arid, arid and semi-arid regions where per capita water availability is already less than the “critically low” level of 1000 m^3 per annum. The most of North Africa falls into this category and much of the West, Central and South Asia have per capita water availabilities of less than 2000m^3 per annum and are predicted to drop below 1000m^3 per annum by 2025(figure 1).

Many of these same arid and hyper-arid areas that already face or will soon face extreme water scarcity also have known reserves of saline water that remain largely unused. These include seawater, saline groundwater, agricultural drainage water and process water from industry. The same areas also possess significant areas of saline land; either natural in origin or that has become saline as a result of human interventions, particularly mismanaged irrigation.

To what extent can these resources of saline water and saline land be exploited and made to contribute to social and economic development? This report reviews the potential uses of saline water to alleviate poverty through agricultural production and other social and economic gain. It reports the results of studies in four water-scarce countries of West Asia and North Africa – Egypt, Jordan, Syria and Tunisia – to assess the saline water resources, particularly saline groundwater, and also attempts to define the scope for their productive use in the different social and economic circumstances that prevail in the four countries, against a background of other potential uses for the resources.

FIGURE 1.
Global water availability 1995-2025 (in ‘000 m^3).



Source: Shiklomanov, 1999.

The Salinity Problem

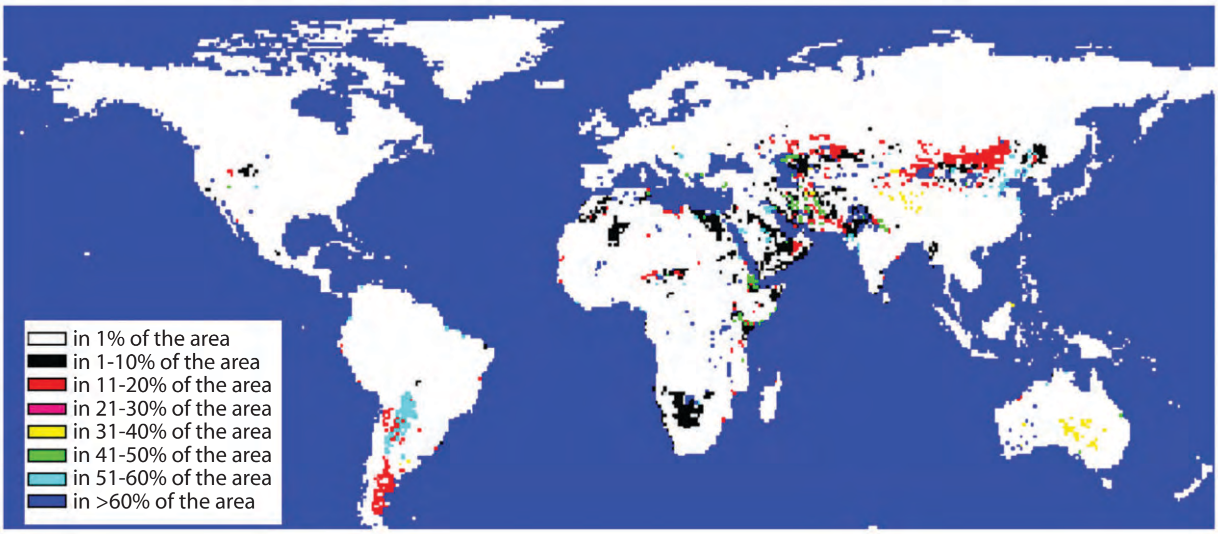
Saline Soils

Saline soils fall into two main categories: saline and sodic. These are defined in terms of soluble salt content as measured by electrical conductivity, sodium content and pH as shown in table 1. Saline soils have excess soluble salts, mainly comprising chlorides, sulphates and bicarbonates of sodium, calcium and magnesium that have direct deleterious effects on plant growth. Alkaline or sodic soils, on the other hand, have excess sodium on the exchange complex of the soil. This adversely affects the soil structure and properties, leading to the blockage of soil pores and impeded movement of water and air, creating conditions that are unfavorable for plant growth, development and nutrient uptake.

The global distributions of saline and sodic soils are illustrated in figures 2 and 3. Figure 2 shows that saline soils are widely distributed across the continents. Major areas in Central and South Asia, West Asia and North Africa, Latin America, Africa and Australia are affected. Sodic soils (figure 3) are also found on all the main continents but are particularly concentrated in Australia, Europe and Latin America.

Salinisation results from the mobilization of salts dissolved in rainwater and their concentration in water and soil, often far from their origins. This can occur due to natural processes or as a result of human activity. Primary salinity, arising from natural processes, results from the gradual accumulation of weathering products or from historical submergence under the sea.

FIGURE 2.
Global distribution of saline soils.



Source: FAO/UNESCO Soil Map of the World.

TABLE 1.
Characteristics of saline and sodic soils.

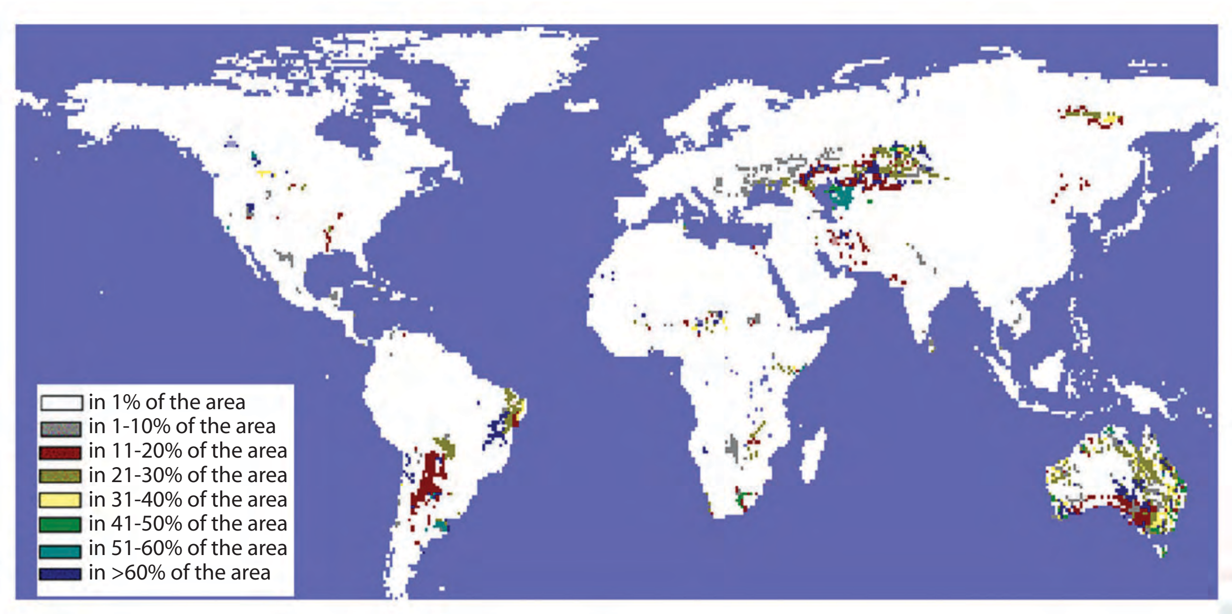
Type of soil	Electrical conductivity (dS/m)	Exchangeable sodium percentage	Sodium adsorption ration	pH
Saline	>4	<15	<13	<8.5
Sodic	<4	>15	>13	>8.5

Source: US Salinity Laboratory Staff (1954).

Soils affected by primary salinity are found throughout the world, particularly in arid and semi-arid regions. Their condition varies in severity from slight salinity with little effect on plant growth to severe salinity where agricultural production is almost impossible.

Secondary salinity arises when salt stored in the soil profile or groundwater gets mobilized and enters the root zone. This generally happens when extra water enters the system due to irrigation or other human interventions, such as land clearing. Extra water raises water tables or increases pressures in confined or semi-confined aquifers causing the upward movement of water to the soil surface. Saline water from deep aquifers or salt deposits from deep soil horizons can move upwards with the rising water. When the watertable comes near or reaches the soil surface, appreciable upward movement of water occurs due to evaporation from the soil surface and salts accumulate in the root zone (Abrol 1989). Beyond the threshold level of the watertable, the rate of evaporation and associated salinisation increase rapidly. Different soil types have different threshold levels, but these are

FIGURE 3.
Global distribution of sodic soils.



Source: FAO/UNESCO Soil Map of the World.

commonly reached in irrigated situations. Secondary salinisation can also occur due to the use of inadequate quantities of irrigation water to leach salts that accumulate in the root zone due to evaporation (Umali 1993).

The total area of saline soils in the world, resulting from both primary and secondary salinisation, has been estimated at about 955 million ha (Szabolcs 1989). FAO (1996) has estimated 397 million ha of saline soils and 434 million ha of sodic soils globally. According to Oldeman et al. (1991), more than 76 million ha of agricultural land is salt affected due to human interventions; the majority of it in Asia and Africa (table 2). Dregne et al. (1991) estimated that about 43 million ha of irrigated land was affected by degradation, including waterlogging, salinisation and alkalization, and that a further 1.5 million ha were being lost annually. Other authors have derived different figures by different methods (e.g. Postel 1990; Kovda 1983), but the estimate by Ghassemi et al. (1995) that approximately 76 million ha of agricultural land is affected by salinity, of which approximately 45 million ha are in irrigated areas and 30 million ha are in dryland farming areas with a further 1-1.5 million ha being added to the total every year (Le Houérou 1998) is generally accepted.

These figures indicate that approximately 20 percent of irrigated land and about 3 percent of dryland agricultural areas are affected by salinity. The estimates could be conservative since most of the data used to reach these estimates originated in the 1980s and hence do not reflect salinisation that has occurred in the intervening years – for example, more recent estimates of the extent of salinisation in Australasia suggest about 2.5 million ha (SCARM 2000)—far more than the 0.9 million ha quoted in table 2[2]. The validity of these data could be questioned not only because of the lack of recent field surveys on the extent of salinity in many of the affected countries, but also because the area recovered each year from saline-sodic conditions by reclamation is unknown and not accounted for. It seems reasonable to expect that reclamation efforts would try to keep up with the rate of degradation and that in countries where money and technical means are available the rate of soil degradation due to salinity and sodicity would decline over time. The general lack of reliable data on degradation and reclamation rates is regrettable.

TABLE 2.
Global extent of human-induced salinisation (million ha).

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

Source: Oldeman et al. (1991).

[1]The categories of human-induced salinity in table 2, ranging from light to extreme, appear subjective. For details on the distinctions between these categories the reader is referred to Oldeman's paper (1991).

Saline Water Resources

Primary and secondary salinisation of surface and groundwater resources occurs in the same manner as soil salinisation. Water in rock formations that occurred in marine conditions is often saline. Weathering of salts from rock strata with naturally high salt content also leads to salts moving into aquifers where they can accumulate. Because of the higher density of saline water than that of fresh water, salinity levels generally increase with depth. However, locally reversed salinity gradients have been observed in areas where groundwater is pumped up for irrigation (Kijne and Vander Velde 1992).

Rising water tables not only induce secondary salinisation of land due to the upward migration of salts from saline aquifers and saline soil horizons but also lead to the increased movement of water and salts into rivers and streams, causing salinisation in downstream areas or later in the aquifer flow system. Discharge of irrigation return flows and accelerated groundwater seepage to surface systems are the main causes of water salinisation. In some countries, discharges of domestic and industrial wastewater also contribute to surface water salinisation and may pose significant pollution risks because of other contaminants.

Salinisation of groundwater resources also results from the intrusion of seawater into coastal aquifers. This usually occurs when the over-extraction of the freshwater that normally overlies saline water in hydraulic connection with the sea in coastal areas leads to changes in the balance of fresh and saline water in the aquifer and induces the movement of seawater inland. Similarly, in multilayered aquifers that have good quality water in some layers and low quality water in others, the extraction of good quality water at rates higher than the replenishment rate leads to net increase in the salinity level. Generally speaking, the over-extraction of groundwater leads to the double jeopardy of decreased water availability due to the dropping of water tables and depletion of aquifers, and the increased salinity of the water that remains.

The extent of the salinisation of water resources, whether by natural processes or induced by human activities, is not well defined in most countries. The volumes of water affected and the degree of salinisation are usually poorly quantified. Lack of effective regulation of groundwater use in general and saline groundwater use in particular also contribute to the paucity of hard data[3]. The dynamic nature of both the quantity and quality of water across seasons and years contributes to the difficulty. For surface water resources, relatively more data are available: river flows and water quality are monitored on most of the world's major river systems and salinisation patterns along their courses are well established. But for groundwater, the available data are sporadic in space and time, making it difficult to evaluate the real potential for the use of the resources.

Traditionally, four levels of saline irrigation water have been distinguished: low salinity defined by electrical conductivity of less than 0.25 mmhos/cm (in current terminology equal to 0.25 dS/m); medium salinity (0.25 to 0.75 dS/m); high salinity (0.75 to 2.25 dS/m), and very high salinity with an electrical conductivity exceeding 2.25 dS/m (US Salinity Laboratory Staff, 1954). Later, it was realized that the reaction of crops to saline irrigation water was affected not only by the salinity level but also by soil characteristics, irrigation practices such as the type of system and timing and the amount of irrigation applications. Moreover, different crop varieties react differently. Whether to use irrigation water of marginal quality would also depend on the level of yield reduction one is prepared to accept (Rhoades and Loveday 1990). For conventional surface irrigation, and a leaching fraction of 0.1 (i.e. 10% more water than is needed to satisfy the crop evaporative demand), water salinity should not exceed 1dS/m for sensitive crops. For

[2]A notable exception is the work done in Jordan (Chebaane et al. 2004).

moderately sensitive, the threshold is 1.8 dS/m; for moderately tolerant, 3.3 dS/m; and for tolerant crops, 5.8 dS/m. In each of these categories, water of higher salinity would lead to yield decline. Higher leaching fractions move the threshold value up, but by how much, depends on the circumstances (Rhoades and Loveday 1990).

For the analyses in this paper, we have relatively more information on saline drainage water and naturally, saline groundwater, than on other potential sources of saline water, such as domestic and industrial wastewater. Although the latter sources of water are increasingly used in irrigation, especially in peri-urban agriculture around many cities in developing countries, this paper does not discuss their present and potential use in agriculture[4].

Effects of Salinity

The effects of salinisation on agricultural productivity can be severe. The most extreme example is presented by the disastrous effects of irrigation-induced soil salinisation in the basins of the two rivers that feed the Aral sea. Thousands of square kilometers of irrigated land were degraded and the fisheries industry of the Aral Sea was destroyed. Fortunately, elsewhere the effects are rarely so catastrophic. However, waterlogging and salt accumulations in agricultural land affect plant growth adversely and reduce crop production. In the advanced stages, plants can be killed and the land, rendered unusable. The sheer scale of salinisation of agricultural land causes massive economic loss at the global level. Ghassemi et al. (1995) estimated the annual global income losses due to salinisation of agricultural land at US$11.4 billion in irrigated land and US$1.2 billion in non-irrigated areas. Hayes (1997) estimated losses due to salinity in the Murray-Darling basin alone at AUD130 million (US$ 91 million) per annum and they have been predicted to reach AUD 500 million (US$ 350 million) per annum by 2025 (NSW Legislative Assembly 2004). For the Colorado River Basin, estimates of damage due to salinity run to US$ 300 million per annum (Barnett 2005).

In addition to the losses of agricultural production, salinity causes other economic loss through its direct effects on infrastructure and drinking water. Salt is highly active chemically, and can cause the break up of roads and buildings (Abdel-Dayem 2005). High water tables cause subsidence of roads and other structures. Salinisation of drinking water sources can lead to social disruption as people are forced to move to find other water sources or take measures to protect their water supply.

And finally, salinity causes direct and indirect effects on the environment in general by inducing changes in vegetation cover and physical and chemical soil properties. It can cause loss of biodiversity, impacts on wildlife (Barnum 2005) and disruption of ecosystems leading to loss of ecosystem function (Barrett-Lennard et al. 2005) that affect local climate and water cycles. All these effects of salinity impact communities inside and outside irrigated areas and the social and economic costs have to be paid by society at large (Abdel-Dayem 2005). The economic consequences of the negative impacts of the use of saline water are discussed in the next section.

[3]Reference is made to the paper by Huibers and Van Lier's (2005) on the use of wastewater in agriculture, and to other papers on wastewater addressing health and environmental impacts of wastewater use, in the special issue of Irrigation and Drainage volume 54, supplement 1, July 2005.

Externalities of the Use of Saline Water

Negative impacts (externalities) of irrigation include soil erosion by surface runoff, deep percolation of excess irrigation water often causing waterlogging and groundwater degradation, and damage caused by inadequate disposal of saline drainage water. Sustainable irrigation demands efficient irrigation, drainage management and salt disposal. In addressing these issues, farmers and policy makers should agree on farm level and regional efforts to intercept, isolate and dispose of or reuse saline drainage water in a sustainable manner (Oster and Wichelns 2003). The critical issue we are concerned with here is the environmentally safe use and disposal of saline drainage water. Disposal in evaporation ponds located in low-lying lands and underground strata is suitable only for the final disposal of drainage water once its quality is such that it has no further possible use. Reuse of drainage water within or near the area where it originates should be the preferred option, particularly in those regions of the world where freshwater resources are already severely limited.

As stated by Oster and Wichelns (2003), the use of low-lying lands for cyclic and sequential reuse of saline drainage water should be encouraged. Both types of reuse could play a role in reducing the volume of saline drainage water that has to be disposed of eventually. Cyclic reuse of saline drainage water requires the availability of good quality irrigation water that can be used to establish the crop and also during the most salt-sensitive growth stages of the crop. And, saline drainage water would be used during the more salt-tolerant growth stages. Cyclic reuse is obviously conditional on the timely availability of good quality water. Sequential reuse, in contrast, entails applying good quality water to a crop with low salt tolerance and then using the drainage water from that field to irrigate more salt tolerant crops. This process could be repeated several times in what has been called a water chain approach (Huibers and van Lier 2005). Policies that encourage cyclic and sequential reuse encourage salt disposal within the region where the saline drainage water originates. This helps farmers, and also the regional government, to see the link between irrigation practices and the saline drainage flows. On a regional scale, the primary beneficiaries of good drainage management and salt disposal are downstream and groundwater uses.

However, farmers, even in areas with insufficient good quality irrigation water, are often reluctant to implement the reuse of saline drainage water because they expect it to be labor intensive and not worth the effort (Kijne and Vander Velde 1992). Implementation is indeed easier where the irrigated fields are drained by a sub-surface (tile) drainage system and the drainage water can be collected without difficulty, than in fields with only a rudimentary surface drainage system. Economic incentives may be required to motivate the farmers to reuse drainage water and economic decision making should be integrated with the environmental sustainability.

There are various types of economic incentives that could be deployed. Oster and Wichelns (2003) list four types of incentives that modify the on-farm price or the opportunity cost of irrigation and drainage water: (i) water allotments or water rights; (ii) water marketing among farmers, basins and economic sections; (iii) higher prices for irrigation water; and (iv) subsidies and fees. Allotments are particularly helpful where the available water is insufficient to meet crop water demands or where the present water distribution is not equitable. Water allotments do not necessarily require volumetric measurements of water supplies as allotments can be made on the basis of each farmer's share of the total irrigable area. However, water marketing and water pricing are contingent on quantitative and qualitative measurements of water volumes, which are rarely available in irrigation systems in developing countries.

Public subsidies of irrigation and drainage development are common. Many countries also have support prices for basic commodities in order to keep food prices in cities low. For example, many governments set support prices for staples and these are independent of the amount of water used. However, the use of support price policies to reduce drainage flows or stimulate the reuse of drainage water is problematic. For example, sprinkler and micro-irrigation systems apply water more precisely, thereby reducing drainage volumes. But changing price support policies and the cost of irrigation and drainage services to encourage farmers to shift from surface irrigation systems to sprinkler or micro-irrigation systems also requires volumetric measurement of irrigation and drainage flows. Likewise, a salt surcharge on excessive irrigation deliveries requires an accurate measurement of the salt concentration of farm-level soil and water resources (Oster and Wichelns 2003). The cost of such measurements will probably continue to be too high for many developing countries to bear.

Many countries have seen calls to subsidize irrigation water and reused drainage or wastewater to produce food and other value-added products, but governments are often reluctant to do so because of the many competing demands for funds. A number of developed countries have been moving for full-cost pricing in irrigation. The reasons for full-cost pricing include the need to reduce dependence on tax revenue, to shift cost back to water users, and to make water users responsible for the environmental impacts of water management (OECD 2002). To achieve these objectives, a recent paper from Australia proposes a two-tier price system consisting of a cost recovery component and a volumetric charge (Hatton MacDonald et al. 2005). The cost recovery component is a fixed charge to recover the fixed cost of past investments in infrastructure. This charge is already in place in Australia. The volumetric charge includes all the cost of providing the water management services (for example pumping, infrastructure upgrading, and monitoring) and the costs of the externalities. The externality charge would be higher for the first time use of good quality water that is not reused (owing to a disposal charge) than for reused water (which does not carry this disposal charge) (Hatton MacDonald et al. 2005). This example illustrates the complexity of developing pricing systems aimed at cost recovery, economic efficiency and a specific set of externalities. As this two-tier pricing system is once more contingent on volumetric measure of water flows, it would at present not be practical for most developing countries. Nevertheless, good governance requires considering financial incentives for mitigating the negative externalities associated with saline irrigated agriculture, however complex this issue may be.

Principles for the use of saline water have been set out on various occasions (e.g. Rhoades et al. 1992). Following those principles remains important even if completely satisfactory pricing mechanisms may not now be feasible in many developing countries. One of the principles is the need to closely monitor environmental impacts of the use of saline water for crop production in order to take timely action when the impacts exceed expectations.

Various Uses of Saline Water in Agriculture

Because of the pivotal role of irrigation, and particularly, over-irrigation combined with poor drainage in the creation of the salinity problems that now face the world, agriculture is and will probably remain the largest single user of saline water for years to come. Agricultural drainage water in particular is widely reused, deliberately or inadvertently, to irrigate field crops. Much of this water is of higher salinity than could normally be considered suitable for irrigation; accumulated experience from many countries and cropping situations, however, demonstrates that it can be used successfully for the production of selected crops under the right conditions and has also helped develop management practices that facilitate such use (Rhoades et al. 1992). Specific management practices depend on the possibility to blend saline water with good quality irrigation water or to use the saline water intermittently (especially during those growth stages that the crop is most tolerant to salinity). In most instances where farmers are forced to use saline water sources because fresh water is no longer available, there is no choice but to use such sources.

A huge body of information has been amassed in the literature on the salinity responses of different field and forage crops, fruits and vegetables, and ornamental and landscaping plants, notably by Maas and coworkers (Maas 1986). Considerable research effort has been made over many years to establish productive potential under different levels of salinity and demonstrate the potential uses of both conventional and non-conventional crop species in saline environments. The following section describes the current status of the use of saline water in agriculture under several headings; these headings are not mutually exclusive, however, and the fact that a particular plant species or class of species has been mentioned under one heading does not necessarily mean that it cannot fit under another.

Irrigation of Conventional Crops

Examples of the successful use of saline water for irrigation have been reviewed in the past (Rhoades 1990; Rhoades et al. 1992). Saline water has been used for irrigation for several decades in arid parts of the southwestern USA. The main crops grown are cotton, sugar beet, alfalfa and small grains. Experience has shown that a good production of these crops can be obtained with saline water up to 11 dS/m electrical conductivity, provided care is taken to avoid damage to seedlings—the most susceptible growth stage. Some of the cultural practices that have been instrumental in minimizing damage to seedlings and promoting good crop stands include alternate furrow irrigation to “push” salts towards the un-irrigated furrow, avoiding accumulation on the ridges where seedlings are sown, and double-row planting on the edges of flat beds, where salt accumulation is minimal.

In the Nile valley and delta of Egypt, population pressure and water shortage lead to the extensive use of drainage water in irrigation, sometimes directly and sometimes blended with fresh water. Currently, approximately five billion cubic meters of drainage water is being used annually. Direct use of saline drainage water is particularly common in the northern Nile delta where there are either no or very limited alternative water supplies. The major crops grown include Berseem clover, rice, wheat, barley, sugar beet and cotton. Waterlogging and salinity cause yield reductions of about 25-30 percent but farmers continue to crop in these conditions. Such agricultural production has continued successfully for several decades but has led to gradual deterioration in water quality and the expansion of the salinity affected areas in spite of the attempts to mitigate damage by a range of agronomic and water management techniques.

In central Asia, approximately half of the irrigated area of about 10 million ha is affected by salinity (FAO 1999). The affected areas continue to be used predominantly for cotton and wheat cultivation, although efforts are being made to diversify into other crops that require less irrigation water in an attempt to break the cycle of over-irrigation, waterlogging and salinisation that has caused major damage to agricultural production (and reduced water inflows to the Aral Sea causing the environmental catastrophe that has ensued).

Salinity management is required in most irrigated areas in the semi-arid regions of the world in order to sustain agricultural production. In Egypt, a large proportion of the irrigated land is supplied with sub-surface drainage systems which make it possible to maintain a relatively salt-free rootzone. Drainage networks also facilitate the reuse of saline drainage water. By contrast, large parts of the irrigated lands of the Indo-Gangetic Plains are without adequate drainage systems. But even there, many farmers practice some form of drainage management, for example by over-irrigating fields that show signs of harmful soil salinity levels or through crop rotation where rice serves as the leaching crop (Kijne and Kuper 1995). Optimizing the leaching fraction is especially relevant in areas with saline and rising groundwater. The aim of optimizing the leaching fraction is to maintain an acceptable low salinity level in the rootzone while, at the same time, having it as small as possible to prevent further rise of the watertable. For example, it has been reported that in the wheat/cotton rotation as practiced in the Sirsa District of India with critical salt tolerance levels of 6 dS/m for wheat and 7.7 dS/m for cotton, the leaching fraction can be as low as 5 percent in case of fresh groundwater (EC < 1.5 dS/m) and should be 15 percent in case of moderately saline groundwater (EC = 5.0 dS/m) (Leffelaar et al. 2003). Whether a 15 percent leaching fraction would lead to a rising watertable depends on the site-specific hydrological conditions.

Due to similar attempts to manage salinity of soil and water resources, the production of conventional crops that form the basis of the farming system continues in West Asia and North Africa. Crop cultural practices to mitigate the effects of salinity have been devised (Pasternak 1987) and are widely applied. In spite of the best efforts to lessen the impact of salinity, major yield penalties are often incurred due to salinity. Nevertheless farmers generally stay faithful to known crops with established uses and markets. The extent to which this can be done depends on the inherent salinity tolerance of the important crops but at least as much on the ability to successfully use and manage waters of various salinity levels for irrigation (Hamdy et al. 1996). When the need arises farmers tend to move from salinity sensitive to salinity tolerant crops within and even outside their acceptable spectrum. Advice from extensive services is known to help in the adoption of new crops such as date palms. If salinity management fails, however, salinity and/or waterlogging levels would render conventional cropping uneconomic and it would have to be abandoned.

Irrigation of Non-conventional Crops

Many plant species that tolerate high levels of salinity have been identified over the last 50 years and proposed as alternative crops for cultivation in saline conditions (Aronson 1989; NAS 1990; Yensen 1999). Ahmad and Malik (2002) discuss some practical approaches (e.g. biotechnology) for saline agriculture and afforestation, and describe examples of cultivating salt tolerant/halophytic plants (viz. wheat, rice, millet, halophytes and mangroves) for commercial interest on salt-affected land or with highly salinized water in Australia, Central Asia, Egypt, Pakistan and Russia. Suitable crops include a wide range of types of plants – food, forage and browse, timber, ornamental and landscaping species – with salinity tolerances up to and beyond the equivalent of seawater (Glenn et al. 1998).

Seawater agriculture is defined as growing salt-tolerant crops on land using water pumped from the ocean for irrigation. The system appears to work well in the sandy soils of desert areas, but requires larger water applications than irrigation with low salinity water (Glenn et al. 1998). Research into identifying suitable crop species has focused either on breeding salt tolerance into conventional crops or the domestication of halophytes. The more productive species are *Salicornia, Suaeda* and *Atriplex* (family: *Chenopodiaceae).* Other high producers were *Distichlis* (salt grass -*Poaceae*), and Batis (*Batidaceae*). Goats and sheep fed on a diet where hay was replaced with *Salicornia*, *Suaeda* and *Atriplex*, gained as much weight as when hay was used. The animals' meat was unaffected by the halophyte rich diet, but the feed conversion ratio was 10 percent lower than that of animals eating a traditional diet (Glenn et al. 1998).

In practice, however, farmers have adopted few of these species for commercial cultivation. This probably reflects the failure of these non-conventional crops to compete economically with alternative crops or some other limitation to their commercialization such as lack of familiarity of farmers with the plant species, absence of well established production packages and lack of established markets and post-harvest processing mechanisms. The exception appears to be *Salicornia bigelovii* which provides an example of successful commercialization of a non-conventional crop, grown using saline irrigation water. *Salicornia* is an estuarine plant found in many parts of the world. It is traditionally harvested from the wild and the fresh shoot tips eaten as a salad vegetable during the summer months in the Mediterranean areas of Europe. With suitable irrigation and crop cultural practices for commercial production, *salicornia* produces yields of 15-20 t/ha of shoot tips. Market research suggests a potential market of over 1000 tons per annum if the crop could be made available throughout the year (Glenn et al. 1995; Grattan et al. 1999; Troyo et al. 1994 and references therein).

The *salicornia* example illustrates several features that are likely to have facilitated successful commercialization. It builds on an existing niche market and is better than having to promote a completely unknown product, but still requires significant market development. It involves the complete value-addition chain, from production through to market, allowing coordination of efforts and rapid response to client demands. It also contrasts with efforts to promote the use of *salicornia* as an oilseed in Pakistan and Saudi Arabia, which have failed to come to fruition in spite of successful research results on oil productivity and quality and major efforts to promote cultivation.

Forage and Browse Production

The production of salt-tolerant forage, fodder and browse for animals on saline soil and water resources is another area where impact on farmers' fields has been achieved. Forage species have demonstrated very high levels of salt tolerance in tests (Grattan et al. 2004). In both irrigated and rainfed situations, salinity-tolerant plant species capable of producing valuable animal feed have been identified and adopted by farmers, which not only increase forage supplies but can also play a role in drainage water management (Qadir and Oster 2004). The fact that animal feed does not constitute a new commodity but contributes to the production of already recognized and marketed products – meat, milk, wool – may be a strong part of the reason that fodder and browse have proven attractive to farmers. For irrigated forage production, Rhodes grass (*Chloris gayana*) and alfalfa (*Medicago sativa*) are widely grown by farmers in India, Pakistan, and West and Central Asia using water of high salinity levels (up to 10 dS/m), suitable only for salt-tolerant crops. Varietal differences in salt tolerance have been noted for both crops (Anand et al. 2000, El Nahrawy 1996). For rainfed conditions, a number of species suitable for establishing pastures in highly saline soils have been identified: for example *puccinellia* (*Puccinellia ciliata*), tall wheat grass, tall fescue (*Festuca arundinacea*) and *phalaris* (*Phalaris aquatica*) are being marketed for saline and waterlogged areas in Australia. Farmers in India and Pakistan have adopted Kallar grass (*Leptochloa fusca*) particularly for highly saline, waterlogged conditions. A number of other halophytic grasses capable of growing in very high salinity levels – up to and beyond 30 dS/m – without accumulating high salinity contents in their plants have been identified and evaluated in research trials in different countries. For example, *Distichlis* and *Sporobolus* species of saltgrasses have been tested under irrigation at up to 30 dS/m in the Arabian Peninsula and shown to produce annual dry matter yields of 40 t/ha (ICBA 2003). *Distichlis* has also been tested in Australia and USA and is being marketed in both countries for forage production and rehabilitation of saline land. A number of forage legumes are also under test in research stations and farmers' fields, and a number – particularly *Melilotus* and *Trifolium* species – have shown good productivity under saline conditions, both rainfed and irrigated, although the legumes are generally less tolerant than grasses (ICBA 2003; Pasternak et al. 1993).

Also, shrub and tree species that provide browse for animals and can tolerate high salinity levels in soil and water have been identified (Le Houérou, 2002) and are being used by farmers. Saltbushes, *Atriplex* species, in particular have been widely adopted throughout the Middle East and in Australia, for cultivation in rainfed saline soil areas. They provide a valuable feed resource, particularly for drought periods when other feed is not available. Establishment and management regimes have been devised, often by pioneering farmers, as well as feed management systems that allow *Atriplex* browse to be utilized in combination with other feed sources and avoid the problems associated with high salt content. Trees, such as *Acacia*, *Leucaena*, and *Eucalyptus* species, also provide sources of browse for animals and are being promoted as such in several countries, e.g. Pakistan and Tunisia, as well as for their ability to remove water and contribute to lowering water tables. However, a study on the performance of various tree species grown under saline conditions in Pakistan revealed poor survival rates of *Eucalyptus camaldulensis* (Marcar et al. 2003).

Saline Forestry

Saline forestry is currently relatively undeveloped. Some research trials have been conducted in several countries, notably Pakistan and Australia, and it has been established that a number of tree species have the potential to produce wood of acceptable quality for conventional forestry products – timber, plywood, chipboard, paper, firewood, charcoal – when grown in saline conditions. *Acacia*, *Eucalyptus*, *Casuarina*, and *Melaleuca* species have been researched in Australia (Feikema et al. 2005; George et al. 2005; Marcar et al. 1995) and other species elsewhere. Limited areas of plantations have been established in Pakistan, India and Australia, but it is not immediately obvious whether these were established as forestry projects or for broader agricultural and environmental goals.

Agroforestry can play a role in the management and disposal of saline water and in lowering the watertable in waterlogged lands. Irrigating salt-tolerant trees and other crops with saline drainage water concentrates the salts and reduces the volume of drainage water which must ultimately be treated or disposed of. At an agroforestry demonstration site near Mendota, California, drainage water with an electrical conductivity averaging 10 dS/m was applied to *Eucalyptus camaldulensis* and other salt tolerant trees. Drainage water from the Eucalyptus plantation was recaptured by a tile drain system and applied to *Atriplex canescens* and other halophytes to further reduce the drain water volume. Drainage water from the *Atriplex* plantation was discharged into evaporation ponds. In this way, drainage water from farms was concentrated and disposed of locally. The economic contribution of agroforestry to the farm depends on the value of the biomass produced for the local marketplace, and on the avoided costs of even larger evaporation ponds and treatment facilities that would otherwise be necessary (Jorgensen et al. 1992).

Saline Aquaculture

Inland saline aquaculture is a relatively recent phenomenon that has arisen partly as a response to waterlogging and salinisation. Saline aquaculture makes use of an unutilized water resource on land that has been abandoned for field agriculture. It also presents an opportunity to diversify on-farm income. It has been adopted on a small scale in several developing countries, most notably in the eastern part of the Nile delta in Egypt. As with other technologies for the use of saline water that have found favor with farmers, it involves a commodity for which there is already and established market and ready demand.

Overview of Agricultural Uses

A wide range of conventional crop species and halophyte species with potential to be transformed into crops for saline areas has been identified around the world, including many that have not been mentioned here. A number of the halophyte species have become commercially successful on a limited scale. Generally these already have established markets or direct, on-farm uses.

The fact that few farmers have adopted halophyte species suggests strongly that their economic benefits are insufficient to overcome the risks and uncertainties of dealing with a new crop. This is borne out by most of the limited number of economic analyses that have been carried out, most of which show marginal profitability at best (Pannell 2005). However, the cropping options that make use of saline land and saline water also have environmental and social benefits that are hard to value: for example, lowering water tables to the benefit of other locations, providing ground cover that helps prevent erosion, etc. Bringing these advantages into the equation would possibly change the balance, but this would require appropriate policies and incentives to be in place before farmers would likely change their practices.

A considerable effort has been expended over many years to select improved varieties of crop plants through screening and breeding for salinity tolerance. These efforts have met with limited success. Effective use of the water of marginal quality by salt-sensitive crops is conditional on the development of greater salt tolerance. In most crops, the reproductive stage is salt-sensitive. New biotechnological tools could possibly complement conventional plant breeding efforts to radically alter the salt tolerance of conventional crops. One needs to know the traits, and the genes that control these traits, for yield under drought and salinity conditions. For salinity tolerance, a relatively easy- to- determine trait is the maintenance of K/Na-selectivity in the plant, particularly in growing regions of roots and leaves (Lauchli and Luttge 2002). Sets of so-called Quantitative Trait Loci for salt tolerance have been detected in some crops, but unfortunately most studies on salt tolerance focus on survival during salt stress in the vegetative period rather than on productivity after a season of realistic salt stress, including the reproductive stage (Bennett 2003). Yet, enhanced salt tolerance of staple crops could well be many years away. But if the efforts bear fruit, and the world comes to terms with using genetically modified crops, there may be less need to identify halophytes with potential for economic production and greater urgency to improve salinity tolerance of known species of food, forage, fiber and fuel crops.

Amenity and Environmental Uses

In addition to their use for crops, saline land and water can be used to grow plants for amenity and environmental purposes. For example, saline drainage water is already used extensively to irrigate gardens, parks and sports fields (Harivandi 2005; Marcum 2004) in many urban situations in desert climates. The development of more salt-tolerant turfgrasses has facilitated this (Duncan and Carrow 2000). Shelterbelts alongside roads for protection against strong winds and moving sands are also often irrigated by saline groundwater. Coastal golf courses irrigated with seawater or diluted seawater are now found in several countries, including the Middle East. Private sector companies that specialize in greening and landscaping leisure, residential, commercial and industrial developments have appeared and sell their services to establish and manage such facilities.

Reforestation of coastal zones with mangroves has become a priority in many areas for coastal protection and stabilization as well as for beneficial effects on fish populations. Particularly, following the December 2004 tsunami, the role of mangroves in coastal protection has been more appreciated. The potential of mangroves to contribute to the sustainable livelihoods of local communities has been demonstrated in several countries, including the Gulf States (de Soyza et al. 2002).

In Australia, native tree species and introduced species are being planted (Joint Venture Agroforestry Program 2000) and deep-rooted perennial pasture crops cultivated (Hofmann et al. 2005) to help remove water from soil profiles to limit the spread of salinity. Many of the species are salt tolerant and are being planted in discharge areas that have already become saline as well as in other areas to intercept groundwater movement. The benefits that these plantations generate often accrue far from the plantation sites and to other farmers. Other environmental examples were mentioned above in the section on agroforestry.

In a world that is increasingly conscious of the threats of environmental pollution, disposal of all types of wastewater is an issue of concern. Oil production, for example, is often accompanied by the generation of huge quantities of contaminated saline water. Usually, this is disposed of by injection into deep aquifers. Injecting this polluted water underground is costly, energy intensive, and has implications for the environment because of hydrocarbon and heavy metal pollutants. Oil companies are interested in less expensive methods of disposal and ways of using the water itself as a resource. A promising technology involves the filtering of oily wastewater through reed beds to remove oil and heavy metals, and using the cleaned water to irrigate salt-tolerant plants. A pilot system has recently been set up by ICBA.

Other industries have similar effluent disposal problems that involve the removal of different types of pollutants – tanning, mining, wine making, aquaculture, for example – and finding a way of making use of the remaining saline water. The actual technologies deployed to separate pollutants from the water concern us less than the possible reuse of the cleaned but saline water source.

Overview of Amenity and Environmental Uses

A number of strict amenity and environmental uses of saline water and soils for the improvement of the aesthetics of our living environment present themselves. Significant investments are generally required to provide communities with green areas, parks and leisure facilities that do not in themselves generate economic returns but only contribute to the general wellbeing of the population. Landscaping of resorts, hotels, municipalities fall into this category, enhancing the salability of the larger project and depending on it for their justification. This kind of uses of saline water resources is appropriate for affluent communities, such as those in Western countries and the oil-rich states of the Middle East, which can afford to invest resources for somewhat intangible returns. The market for services in this sector is already established and being addressed by a small but growing number of private companies. This kind of water use mainly benefits the urban population but provides little or no benefits to rural communities.

Some uses of saline water including agricultural uses contribute directly and indirectly to environmental benefits that are difficult to evaluate. These might include the restoration of eroded and degraded soils, protection of soils from further degradation through providing vegetation cover, increasing soil organic matter, enlarging water holding capacity of the soil, and increasing evapotranspiration to decrease the infiltration of water to the groundwater. Other benefits of such uses of saline water include reduction of saline water contamination of streams and watercourses, reduced waterlogging, increased biodiversity, and beneficial use of brine after dilution. The extent to which these benefits influence the adoption of technologies will depend on the extent to which environmental and social policies support such adoption. Again, support for environmental benefits is most likely to be forthcoming in the short term in the more affluent nations of the world. There is considerable scope in developing countries, however, for environmental support to be used to alleviate poverty as it is often the activities of the poorest sections of society that impact most directly on the environment (FAO 2002, 2003).

Carbon Sequestration and Energy Capture

The need to develop clean, renewable energy sources to replace hydrocarbons is driving the exploration of many options, including biomass production. Because of the scale of likely future needs, however, biomass production for carbon sequestration and energy production is likely to be practical only if it can be carried out using resources that do not compete with food production and show net carbon sequestration (sequestered in biomass minus produced during the process of manufacturing the necessary equipment, decay of organic matter, fuel burned in the process and so on). The large unutilized desert areas of the world could fit that requirement, but of course lack water. The possibility of using seawater or other unutilized sources of saline or polluted water to irrigate desert areas for sustainable biomass production is therefore receiving serious consideration in many quarters (Ahmed and Abdullah 1979; Glenn et al. 1996).

As mentioned, many tree species capable of growth and production in highly saline conditions are available and can be harnessed for saline forestry. Saline forestry also meets the objective of carbon sequestration by tying up large quantities of carbon dioxide in the plant biomass. This use of desert areas and saline water for renewable energy production, however, is highly speculative as long as the necessary conditions for large-scale positive carbon sequestration balance have not been ascertained.

Other Products

The most obvious product from saline land and water resources, and one that has been traditionally produced in many areas of the world, is salt itself. Evaporation of saline water, particularly seawater, usually in open-air evaporation ponds, leads to the precipitation of salt that can be harvested for sale and use. Salt is used in industrial processes, food processing, road de-icing, and for a variety of minor activities.

Desalination of seawater is a major industry in many parts of the world, particularly in the Arabian Peninsula, where approximately one half of global desalination capacity is located. A variety of different desalination technologies are available but the most common involves heating salty water, usually under reduced pressure, to produce water vapor that is then condensed into fresh water. The process produces brine as a by-product that has to be disposed of and also results in a significant heat pollution of cooling water used for condensation. Disposal of saline byproducts is a key issue with respect to sustainability of these processes and the controlled impacts on the environment. Typically, costs of disposal are not included in the costs of desalination, which is currently quoted as approximately US$0.50 per cubic meter[5] and probably even less in the future. Desalinating brackish water is cheaper. These costs remain high compared with the costs of freshwater from other sources where these are available. In some situations such as small islands, desalination of brackish groundwater or seawater is the only available source of drinking water.

[4]See for example World Water and Environmental Engineering vol. 24, issue 46 (November/December 2001), page 20.

There are a number of other highly specialized uses of seawater and brackish water. Generally speaking these are very limited in scope and economic importance. Production of various algae – both macroalgae or seaweed and microalgae for various food products for humans and fish, vitamins, pigments, minerals and other products for use in the food and aquaculture industries – serve niche markets with limited total demand.

Case Studies on the Use of Saline Water for Irrigated Agriculture

Introduction

During 2004, case studies of the current status and availability of saline water resources were carried out for four countries of West Asia and North Africa – Egypt, Jordan, Syria and Tunisia. National experts from each of the countries collated and interpreted information on the quantity and quality of the saline groundwater, poverty distribution and farming systems and set out to review the prospects for saline irrigated agriculture. Areas were identified in each country where the availability of saline groundwater, poverty and suitable farming systems coincided and where the potential contribution of saline irrigated agriculture for poverty alleviation could be evaluated. Draft reports produced by the national experts were discussed during a two-day workshop conducted at ICBA, Dubai in June 2004. Country reports were subsequently finalized on the basis of the discussion during the workshop and a synthesis report was prepared, based on the discussions and the country reports.

An important outcome of the workshop and one that has direct bearing on this report is the conclusion that up-to-date databases at country-scale and within-country regional-scale on the availability and current use of saline water resources are not available. In addition, it was posited that local and regional socio-economic information, e.g. on poverty distribution, is scarce.

This section summarizes the evaluation of the potential for saline irrigated agriculture, or biosaline agriculture, in the four countries and also explores the possible wider applicability of the findings to other semi-arid or arid countries. Readers should recognize, however, that because of the site-specificity of the conditions for success, extrapolation from the four case studies should be made with caution.

Saline Water Resources

Data on the overall water resources for the four countries are readily available; however they are inconsistent. The differences between data from diverse sources are illustrated in table 3 by the water diversions as a percentage of the total amount of renewable water in the four countries. Calculations of the natural renewable amounts, which include the portion of flow that enters a country from a neighboring country, were perhaps done differently in the different databases. Moreover, data on renewable water resources do not specify its quality. The data in table 3, however, clearly illustrate that water scarcity is more pressing in Egypt and Jordan than in Syria and Tunisia. Even the latter two countries, with over half of the total renewable amount of water committed (according to the recent assessment of the World Resources Institute) have a need to conserve water and to make good use of all the sources of low-quality water.

Groundwater and drainage water from irrigated agriculture are the two most abundant sources of saline water that could be used in agriculture. This study focuses on the availability of drainage water including pumped groundwater. Although extensively recycled for irrigation, especially in Egypt, agricultural drainage water often contains

TABLE 3.
Water resources in the four countries of the study.

	Water resources			Water withdrawals		Water withdrawals as % of natural renewable	
	Internal renewable (km^3)	Natural renewable (km^3)	m^3/ person	km^3	m^3/ person	WRI 2002-2004	World Bank 2003
Egypt	1.8	58	830	66	1055	127	96
Jordan	0.7	1	169	1	255	143	143
Syria	7.0	26	1541	12	844	55	27
Tunisia	4.2	5	576	2.8	312	54	61

Note: Total internal renewable is the sum of surface and groundwater resources minus the volume that is common to both, such as when aquifers contribute to surface flow and the recharge of groundwater by surface flow. Natural renewable resources include natural flows to and from other countries, or the quantity of flows reserved for neighboring countries through formal and informal agreements and treaties (World Resources Institute, 2003).

not only salts but also residues of agrochemicals and could therefore be a less attractive source of water. Other sources of wastewater, such as sewage water and industrial wastewater, present their own health hazards and would also need to be treated before their use in agriculture. And finally, there are other sources of saline water, such as saline springs and natural saline depressions and lakes, but these are rather limited in scope.

To use any of these sources of saline or contaminated water, the rights to their use and the associated cost need to be established. Appropriate infrastructure and a management organization need to be in place if saline water is to be pumped, distributed within a sizable area and allocated to the recipient farmers[6]. There also needs to be an environmentally sound way of disposing of the residue and brine. The salt load in the drainage water may be such that treatment is necessary before any reuse if feasible. Treatment of drainage water then becomes a necessary component of irrigation sustainability. Additional conditions for the successful introduction of saline irrigated agriculture include the presence of suitable land, appropriate farm sizes (perhaps to be achieved through land consolidation), people who are willing to try this type of agricultural production system, and markets for the products. The tentative conclusion therefore is that, to test the assertion that saline irrigated agriculture holds promise for poor people, the preferred water source is either saline groundwater that can be pumped at low cost (i.e. from a shallow aquifer) containing no or low levels of other pollutants, or saline drainage water that requires little or no treatment before use. Much depends on the local conditions; for example, the presence of a suitable distribution system for saline drainage water could lead to a different strategy.

The following sections discuss the occurrence of saline groundwater as part of total water resources for each of the four countries of study.

Water Resources in Egypt

In Egypt, the main source of water is the Nile River, all of which is consumed in the Nile valley and delta. The second source of water is groundwater from the Nubian aquifer, underlying nearly 80 percent of the country area. This groundwater resource is almost totally non-renewable. Groundwater in the Nile valley and delta is not a resource in itself as its recharge depends almost entirely on the percolation of Nile

[5]There are places where the existing infrastructure developed for the distribution of fresh water can be used for the distribution of saline water. This is the case in the Jordan valley where saline irrigation replaces irrigation with fresh water.

river water. Rainwater and flash floods, if properly harvested and conserved, could amount to an additional 1.5 km^3 (1500 MCM) of fresh water in Egypt.

Pressure on the water resources will increase as demands for water rise while the possibilities to augment supply are limited. This may change if desalination of brackish groundwater and seawater continues to become cheaper and more energy-efficient. However, some of the water resources may become unfit for certain uses because of increased contamination. The upshot of an increasing population coupled with the decrease of water resources means that the food self-sufficiency in Egypt is expected to dwindle.

Water rights in the Nile valley and delta depend on land ownership, cultivated area, type of crop, and availability of water—a situation that leads to conflicts especially between head and tail-enders in water distribution systems. In areas that depend on groundwater, a licensing system ensures the rights to water, but with an increase in production wells in areas with low-quality groundwater (mainly for desalination), additional licensing has been introduced for the disposal of brine.

The salinity of the Nubian aquifer of Egypt is generally low (total dissolved salts, TDS, is less than 1000 ppm), whereas water from the coastal aquifers usually contains far more salts. If a safe yield from the Nubian aquifer is taken as two-thirds of the total exploitable volume divided by 100 years, 3330 MCM (3.3 km^3) could be extracted per year. The present rate of extraction from this aquifer is only 110 MCM. The implication of extracting water at the rate of 'a safe yield' is that in 100 years time one-third of the present volume would still be left in the aquifer. Support for this approach is often derived from the expected future low cost of desalinized seawater and brackish groundwater that would permit timely substitution of pumped groundwater by desalinized seawater and brackish groundwater to make irrigated agriculture sustainable over time. This, of course, is speculative as nothing is known about future costs of desalinization and of transporting desalinized water from the coastal plant to the recharge location.

Agricultural drainage water is extensively reused for irrigation in the Nile valley and delta (presently estimated at 5000 MCM per year), and the practice is approved by the government because of the low water use efficiency at field level in the irrigated areas of the Nile valley. However, with the implementation of integrated water management and irrigation improvement projects in the old land, the available drainage water is expected to decrease and its quality, to decline. Agricultural drainage water is also used in fish farms in the delta, but because of its poor quality, farmers tend to shift to saline groundwater.

Water Resources in Jordan

As was indicated in table 3, Jordan's renewable water resources are of the order of 1000 MCM (1 km^3). But according to the National Water Master Plan of the Ministry of Water and Irrigation (digital version, published in July 2004), water demand for 2005 already exceeds that amount by about 50 percent. By 2020, the water demand is expected to grow to 1616 MCM. The difference between renewable supplies and the demand is made up by groundwater, which leads to the severe depletion of aquifers. Groundwater supplies nearly half of the water resource (47%), and surface water, 39 percent. The remainder comes from treated wastewater. How much of the groundwater is renewable is a contentious issue, but estimates put it at about 260-270 MCM per year, which is approximately equal to 3 percent of the annual rainfall volume.[7]

The strategy of the Ministry of Water and Irrigation is to reduce water use to a level that is sustainable. The difficulties in implementing this strategy are illustrated by the present discrepancy between planning figures and actual irrigation practices as found in the Disi area. This area

[6]For a more detailed discussion, reference is made to Comprehensive Assessment Paper 9 (Courcier et al. 2005).

covers 5500 ha for which an irrigation supply of 43 MCM is planned based on an annual irrigation requirement of 780 mm per year. Farmers in the region, however, apply at least 1200 mm per year not knowing what the real crop water requirements are. Several projects are now being carried out by the National Center for Agricultural Research and Technology Transfer to address the issue of over-irrigation in areas where water quality is relatively good, as in the Disi area. Water resource management in Jordan is made even more difficult by increasing degradation of surface and groundwater in various parts of the country, where farmers are already using various gradations of saline water.

It is estimated that nearly 250 MCM of saline and brackish water is available in Jordan that could be used for saline irrigated agriculture (table 4). The classification and estimates of the availability of brackish water in table 4 are based on the extent to which an aquifer is renewable and on its flow conditions. The values in the last column of table 4 are conservative: 1 MCM is deemed to be available in the Wadi Arba alluvium, 20 MCM, in the Zerqa group of aquifers of the Jordan valley, and 225 MCM per year, in the sandstone aquifers of the Jafer, Sirhan, Azraq and Harman basins. The best estimate of the current usage of brackish/saline groundwater is 46 MCM per year.

Water Resources in Syria

In Syria, about 15.9 km^3 of water is diverted for the irrigation of about 1.25 million ha, which implies an average water application of about 1250 mm per year. In addition, annual domestic water use is about 1 km^3, industry needs approximately 0.3 km^3 and some 2 km^3 are lost through evaporation. Hence, the total use is in excess of 19 km^3 per year. Annual amounts of surface and renewable groundwater are estimated 4.3 km^3 and 5.6 km^3 for a total of less than 10 km^3 per year. In addition, Syria is allowed to use 6.6 km^3 per year of water from the Euphrates, i.e. 42 percent of the average annual flow of 500 m^3 per second (about 15.7 km^3 per year). A comparison of available resources and demands for water indicates a deficit of approximately 3 km^3 per year. In other words, the water balance for the country is negative. It should be noted that some of the data from Syrian sources used in this paragraph are at variance with the data in table 3. In contrast with the data in the public domain, the data used here clearly indicate that the natural, renewable resources are inadequate to satisfy current water demands.

The right to use surface or groundwater is licensed by the Ministry of Irrigation. The license specifies the number of wells, their discharge and the maximum depth of 150 m, and can be withdrawn if the user does not comply with the conditions or uses the water for some other purpose than intended. However, installing a pump on public surface water without a license can be done for a nominal fee. A new comprehensive and unified water law, which takes into account irrigation development, groundwater depletion, water quality concerns and land reclamation issues is currently under consideration.

TABLE 4.
Brackish groundwater resources in Jordan.

Source	Salinity range(ppm)	Safe yield (MCM/year)	Availability (MCM/year)
Renewable brackish groundwater	800-7000	80-85	1
Non-renewable, flowing brackish groundwater	600-8000	115-125	20
Non-renewable, stagnant brackish groundwater	>5000	225	225
Total		420-435	246

Source: ICBA unpublished data.

An overview of the amounts and salinity of groundwater is given in table 5. The amounts of exploitable groundwater as given in table 5 exceed the recharge, which is estimated at 700 – 1000 MCM per year (ICBA 2003). At present most of the groundwater is not used for agriculture.

Water Resources in Tunisia

Table 6 presents Tunisia's water resources as specified for the three main regions of the country.

Renewable groundwater is estimated at 1200 MCM per year, which includes all water from the shallow (phreatic) aquifers (at depths less than 50 m) and less than 500 MCM from the deep aquifers (at depths between 400 and 500 m). The remainder of the deep groundwater is considered non-renewable. Groundwater exploitation, also in Tunisia, exceeds the renewable amounts. Best estimates are that in 2000 nearly 780 MCM was pumped from the phreatic aquifers, representing some 106 percent of the renewable resource, while in 2001 nearly 1120 MCM was pumped from the deep aquifers. Excess pumping took place especially in the central part of the country.

About one-fifth of the water pumped from the shallow (phreatic) aquifers has a salinity of less than 1500 ppm (EC < 2.4 dS/m), 32 percent has salinity between 1500 and 3000 ppm. Because of the rainfall distribution in the country and hence the groundwater recharge, relatively more of the saline groundwater occurs in the south. Of the pumped deep groundwater (1120 MCM in 2001), nearly 900 MCM has salinity of less than 3000 ppm (EC < 4.7 dS/m), and another 180 MCM had salinity between 3000 and 5000 ppm. Most of this water (850 MCM) was used for irrigation, 175 MCM for drinking and some 40 MCM for industry. Some of the remaining water of higher salinity was desalinized for use as drinking water and some was used untreated for industry.

TABLE 5.
Specification of Syria's saline groundwater resources.

Basin	Location/area (100 km^2)	Estimated exploitable groundwater (MCM/year)	Water quality (dS/m)
Al Yarmouk	Eastern Syria/67	267	Good (< 3)
Barada and Awaj	Western mountains/86	838	West to east: 0.5 – 4
Coastal	West, along Mediterranean/51	778	< 1
Orontes	South of border with Syria/216	1,607	Not known
Al-Badieh	Central Syria/708	183	South to north: 1—12
Euphrates and Aleppo	East, from border with Turkey to Iraq/211	371	7-14
Tigris and Al-Khabour	North-east/211	1,600	1-8
Total		5,644	

TABLE 6.
Surface water and groundwater in Tunisia.

Region	Surface water	Ground water resources	
	(MCM/year)	Phreatic aquifers (MCM/year)	Deep aquifers (MCM/year)
North of Tunisia	2,190	396	216
Center of Tunisia	273	221	272
South of Tunisia	237	102	722
Total	2,700	719	1,210

Enhancing Sustainable Livelihoods of the Rural Poor in West Asia and North Africa by Saline Agriculture

Introduction

The Introduction of this report posed the question as to what extent the resources of saline water and saline land can be exploited and could contribute to social and economic development in the countries of West Asia and North Africa (WANA). This section attempts to answer that question. It first discusses present farming systems and then considers the link between agricultural production and poverty.

Present Farming Systems

A list of farming systems (FS) in WANA is presented in table 7 together with the prevalence of poverty in each system. Not surprisingly, the incidence of poverty in irrigated agriculture is moderate, even with the generally small farm sizes in the irrigated areas of WANA (Dixon et al. 2001). The highland mixed FS is the most important in the region in terms of population; about one-fifth is irrigated. Poverty within this system is especially extensive in the sub-system based primarily on raising livestock (mostly sheep) on communally managed lands. In some cases, both the livestock and the people who herd them are transhumant, migrating seasonally between lowland steppe in the more humid winter and upland areas in the dry season. The rainfed mixed FS has high population densities as it contains almost 18 percent of the agricultural population in WANA but occupies only two percent of the land (Dixon et al. 2001). The farming systems of the lower rainfall areas, such as the dryland mixed and the pastoral FS, have the highest incidence of poverty and the least potential for growth. Livestock plays a major role in these farming systems. In the dryland mixed FS livestock interacts strongly with the cropping and fodder production. In good rainfall years, barley is grown for grain, but when the rains fail it is fed as fodder to livestock.

Table 7 shows the various farming systems in the WANA region together with their relative importance in terms of the percentages of the population involved in each of the FSs, and it also gives some indication of how prevalent poverty is in each of them. Table 8 shows the potential for growth and poverty reduction for the six most relevant farming systems, also

TABLE 7.
Farming systems in WANA and the prevalence of poverty.

Farming system	Area (%)	Agricultural population (%)	Livelihood*	Prevalence of poverty
Irrigated	2	17	Fruits, vegetables	Moderate
Highland mixed	7	30	Cereals, sheep	Extensive
Rainfed mixed	2	18	Tree crops, cereals	Moderate (small farmers)
Dryland mixed	4	14	Cereals, sheep	Extensive (small farmers)
Pastoral	23	9	Sheep, goats, barley	Extensive (small farmers)
Sparse	62	5	Camels, sheep	Limited
Coastal (fishing)	1	1	Fishing	Moderate
Urban	<1	6	Horticulture, poultry	Limited

* Includes off-farm income.

Source: Dixon et al. 2001.

according to Dixon et al. (2001). Where the potential for poverty reduction is low to moderate, and rather independent of the potential for growth, the best household strategies for poverty reduction are departure from agriculture and increased off-farm income. In areas where poverty coincides with a source of saline water, sustainable saline irrigated agriculture probably has the greatest potential within existing FSs. In the WANA region as a whole, the largest numbers of poor people are found in the mixed irrigated (24%), and mixed rainfed (23%) FSs. It appears then that the introduction of saline irrigated agriculture in WANA should focus on the mixed irrigated and mixed rainfed FSs, mainly in the arid and semi-arid regions where access to water especially for the small farmers is a serious constraint. However, crop and forage production should not be seen as the only solution for poor farmers. In some cases alternatives such as fish farming, as practiced already in the Nile valley delta, may be the preferred solution for poor farmers with a poor quality water resource.

Poverty Alleviation through Agriculture

Demographics

The most significant demographic trend in WANA over the past decades has been rapid urbanization and a consequent reduction in the importance of agriculture in the region's GDP. By 2001, the overall contribution of agriculture to GDP in the WANA region had fallen to 14 percent (World Bank 2003).

According to Dixon et al. (2001), in WANA, two groups of people have been excluded from most development initiatives: poorer farmers living in dryland areas, and the pastoralists who occupy a unique role in the rural economy and in the long-term maintenance of a stable environment in dry areas. For the region as a whole, though, FAO considers the prospects for reducing agricultural poverty to be fairly good.

A recent report (IFAD 2003) indicates that in the WANA area about 43 percent of the rural population lives in abject poverty with incomes of $1 or less. Rural poverty occurs especially in Egypt and Jordan and it is aggravated by unemployment which, for example, in Jordan is officially at 14 percent (2001), but unofficially more likely around 23 percent.

Different countries have different definitions of poverty so that a consistent comparison between countries based on the same definition is often not possible. This problem is made worse by regional differences in poverty within countries and also by uncertainty about the accuracy of reported data. All of this makes international comparisons of poverty notoriously difficult. Nevertheless, the available data indicate that the rural population and those active in agriculture constitute a significant part of the population (much larger for the relatively low contribution from agriculture to the GDP which makes one think). It also indicates that many of the rural

TABLE 8.
Farming systems and strategies for poverty reduction.

Farming system	Potential for: Growth	Potential for: Poverty reduction	Two best strategies for poverty reduction
Irrigated	High	High	Diversification, intensification
Highland mixed	High	Moderate	Exit from agriculture, increase of off-farm income
Rainfed	High	High	Intensification, increase of off-farm income
Dryland mixed	Moderate	Moderate	Exit from agriculture, increase of off-farm income
Pastoral	Low	Moderate	Exit from agriculture, increase of off-farm income
Sparse (arid)	Low	Low	Exit from agriculture, increase of off-farm income

Source: Dixon et al. 2001.

poor are farmers on poor land with poor water resources.

Prospects for Saline Irrigated Agriculture in WANA

The introduction of the productive use of saline resources in agriculture is expected to include possibly the small landowners and tenant farmers in the rainfed areas of Jordan, Syria and Tunisia, small farmers in irrigated areas of Egypt and Tunisia and also rangeland pastoralists in Syria. In several of these countries, the demand for forage has outpaced domestic supply, dramatically increasing the amount of imported fodder in recent years. Other beneficiaries could be landless farmers who entirely depend on seasonal employment in agriculture and agriculture-linked informal rural industries. These people would benefit from increased and diversified agricultural productivity while the entire rural population will be helped if, by substituting saline water for fresh water where appropriate, the pressure on the scarce supply of good quality water is eased.

In many of the selected sites, women and children play a particularly important role in the care and management of livestock. Their activities include watering, feeding, care of new-born animals, gathering manure, and milking. In some cases, women also participate in shearing sheep and milk processing. If the introduction of the productive use of saline water eases the pressure on women and children, for example by having an ample supply of fodder at hand rather than having to go out and search for it away from the farm, they would also be better off.

After discussions at the ICBA Workshop, country representatives defined an array of generic criteria for the selection of suitable sites for the introduction of the productive use of saline resources in agriculture. They are listed in table 9. Using these criteria, areas in each of the countries studied, with the best prospects for saline irrigated agriculture were identified by the country representatives, based on their expert knowledge of their countries.

Government Policies and Introducing Productive Uses of Saline Resources

According to Dixon et al. (2001), development policies and investments in public goods in the WANA region have had a strong urban bias for many decades. Development policies have tended to favor cheap food for urban populations, and infrastructural investments have also been made mainly in major urban centers. These

TABLE 9.
Generic criteria for the selection of sites for biosaline agriculture.

Criterion	Description
Source of water[7]	Saline groundwater; saline water in a depression; or saline surface water
Characteristic of resource	Absence of an alternative water source; sustainable in terms of quantity and quality; acceptable quality; acceptable cost
Where to use it	On location or transport to another location
Community	Poor people either in situ or prepared to move into the area; acceptance by farmers
National policies	Government support for well development through policies and regulations
Farming systems	Small-scale livestock farming and mixed farming
Synergies	Presence of other development projects in the area
Infrastructure	Existing wells and markets for produce

[7]The source of water is taken to be various levels of saline water. The discussion implied that the same criteria would also apply to the reuse of industrial or domestic wastewater.

investments were primarily in the provision of water, basic services and communication links. The development of road systems has generally served national security or urban objectives, rather than rural development needs. Inevitably, urban expansion was often at the expense of good quality agricultural land near the cities.

Further land reform remains necessary, even in countries that have officially undertaken land reform in the past, because many farmers hold onto fragmented holdings which hinder efficient farming practices. Migration of young people to the cities however indicates that the desire to change the current system of land ownership and inheritance is weak at best. Apparently, change has only occurred where larger operators have been able to buy out small farmers. Nevertheless, according to FAO a more thorough reorganization of land holdings is a prerequisite for the introduction of technologies that will conserve soil and water resources in the long run (Dixon et al. 2001).

National policies that encouraged the import of cheap feed grains without regulating livestock numbers, have led to overstocking and overgrazing of rangeland. The heavy stress on natural rangeland resources resulted from modern methods of moving livestock around combined with the transport of water for the animals[9]. Moreover, the lack of regulation has weakened the system of communal range management which was designed to manage the resources sustainably (Dixon et al., 2001). As Mellor (2002) has argued, agriculture in developing countries produces many goods that cannot be traded, such as food crops of lower quality and animal fodder and feed. These goods that are not traded internationally give agriculture a prominent role in poverty reduction and buffer the national economy from shocks to the international market in agricultural commodities. Because the production of these non-tradable goods generally requires few skills, the poor and unskilled people are likely to find employment in such production. One could therefore conclude that it is to the advantage of national governments to support agricultural production systems on marginal lands, such as saline irrigated agriculture, because of these multiple benefits, i.e. land conservation, rural employment and protection from international markets.

Based on the irrigated area and efficiency, it is calculated that nearly 60 percent of the available water in the WANA region is now being used in irrigation (Dixon et al. 2001). As shown in table 2, several countries, including Egypt and Jordan, are already withdrawing volumes that exceed their annual resource recharge. FAO (2002) expects that by 2030 the total irrigated area in the region will have grown by another 20 percent, which will bring the total irrigated area to about 77 percent of all land with irrigation potential. Taking into account expected improvements of water management in irrigation, some expect that by 2030, water use for irrigation will account for 67 percent of the total renewable water resources in the region. Others, however, expect that by 2030 less than 20 percent of the renewable water resource will be used in agriculture, which will be reserved for high-value crops, mostly fresh vegetables (Faruqui 2003). According to this author, all cereal crops grown in improved rainfed systems or irrigated with low-quality waters, such as treated wastewater will have to be imported. In fact, all domestic wastewater will by then be treated and reused in and around cities, in urban and peri-urban agriculture. Regardless of which prediction is closer to the mark, irrigated agriculture in the semi-arid and arid regions of WANA is bound to undergo major changes before 2030.

Thus, investments in the development of the necessary infrastructure for supplemental irrigation to facilitate the inclusion of saline water and saline land in farming systems may not only reduce the stress on water resources (even if only temporarily), but also achieve additional goals such as enhancing economic growth and

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[8]It could be argued that the use of saline water for forage production leads to the expansion and intensification of livestock production. However, this should not necessarily lead to further degradation of grazing land if animals are fed within an enclosure, with fodder grown on saline-irrigated land nearby.

poverty alleviation in rural areas[10]. This is supported by several studies on the effects on rural poverty in India resulting from massive investments in agriculture and rural infrastructure (Fan et al. 1999). These studies also appear to indicate that the marginal returns to several infrastructural investments in India may now be higher in many rainfed areas than in irrigated areas, and also have a greater effect on reducing rural poverty (Bhalla et al. 1999). The relation between agriculture and poverty, according to Timmer (2003) is now, as a result of globalization, less direct than during the green revolution. During the period of the green revolution, poverty reduction followed rather directly from enhanced food production after heavy investments were made in HYV crops, irrigation and fertilizers. Timmer argues that stimulating agricultural productivity to mitigate the effects of rural poverty would now require a far more subtle role by the government. Attention should be more on the rural economy in general than on food production per se, since staple crops could also be purchased on the global market.

The conclusion of this section then has to be that governments and donor agencies should increase their investments in technologies for sustainable agriculture in rural areas, including the introduction of drought and salt-tolerant varieties, the utilization of sources of saline water for supplementary irrigation, the introduction of water-saving technologies, and improved rangeland management techniques. All of which are expected to help alleviating rural poverty.

Assessment of Possible Impact on Livelihoods

As elsewhere in developing countries, the population increase, rapid urbanization and an increase in spendable income have led to a sharp increase in the demand for meat products in the WANA region. Some of these effects are illustrated by the trend data in table 10.

The data in table 10 show the trends in production and cereal import growth rates over a period of forty years, but not the large variations from year to year. The latter, mainly resulting from periodic droughts in the region, are illustrated in table 11 by the net production growth rates for the WANA region for 1992-2001 (FAO 2002).

Drought is a recurrent phenomenon in WANA and some analysts believe that the frequency and severity of drought have increased in the last decades. These periodic droughts obviously cause wide fluctuations in agricultural production as is evidenced by the data in table 11. Cereal production and livestock populations and their productivity are especially affected. Livestock accounts for between 30 and 50 percent of total agricultural GDP in WANA and is of great importance in sustaining the livelihood of the rural population (FAO 2002). Large losses in livestock

TABLE 10
Increase in meat production, numbers of goats and sheep, cereal production and cereal import, expressed as percentage increase per year for the period 1961-2001.

	Increase (% per year 1961-2000)			
	Meat production	Number of sheep and goats	Cereal production	Cereal imports
Egypt	4.3	3.4	2.7	5.0
Jordan	6.6	2.9	2.0	4.1
Syria	4.8	2.7	4.0	3.3
Tunisia	3.8	1.1	2.2	5.1

[9]The investments required for the successful development of saline agriculture may be hard to justify on the basis of the expected agricultural products alone. However, their justification may be found in the additional benefits of poverty alleviation and economic growth in rural areas.

numbers, therefore, adversely affect household food security, especially of those people who are living in remote areas and are most vulnerable to drought. The cumulative effect of consecutive droughts is not only high animal mortality, but also much reduced productivity of the surviving weak and often diseased animals. The devastating effect of drought on range vegetation forces the resource-poor farmers to purchase feed at the expense of household consumption. In the areas most severely affected by drought, the problems are of course exacerbated by water scarcity for farming households and their livestock.

The data in table 10 indicate that cereal production in the four countries of this study has not kept pace with demand. This is a long-term trend, and as such, not directly related to the incidence of droughts. Over the last forty years, the average annual increase in cereal import was as high as 5 percent. (An annual increase of 5 percent means a doubling of imported cereals about every 14 years). This phenomenon is not limited to WANA. According to the International Food Policy Research Institute (Pinstrup-Andersen et al. 1999), although food production up to 2020 will increase much faster in developing countries than in developed countries, it will nevertheless not keep pace with demand, and food imports will need to increase. To fill the gap between demand and production, developing countries imported 231 million tons of grain, equivalent to 72 percent of the worldwide imports. These statistics illustrate that developing countries play a major role in the international agricultural trade and are highly susceptible - in terms of food security - to changes in the world agricultural market. For the poorest countries, an increase in domestic agricultural production is the key to improving food security.

In WANA and elsewhere, the increased demand for cereals results from the population increase, but equally importantly (and indirectly) from the demand for more meat in the diet, as more animals eat more feed. It is here that the introduction of saline water for the production of animal fodder and feed will have its main impact. Moreover, better quality water can then be used for household needs and for growing produce with greater added value such as fruits and vegetables.

Current governmental drought management and mitigation interventions in the region consist mostly of short-term relief operations, which are often quite expensive (FAO 2002). However, experience elsewhere (e.g. Australia) shows that countries with long-term drought management policies are generally better prepared to deal with droughts while spreading the ensuing costs more evenly over a longer period than those that only manage the effects of the latest crisis. Hence, the optimal use of saline water should be part of the governments' long-term drought management policies. If successful, many people in rural areas could potentially benefit from its results and it could also contribute to slowing down migration to urban areas which at present is more attractive to the younger generation than an uncertain and risky future in farming.

TABLE 11
Net production growth rates (%) in WANA during 1992-2001.

Year	Agriculture	Cereals	Crops	Food	Livestock
1992-96	3.3	3.3	3.7	3.4	2.9
1997	-2.7	-12.1	-6.4	-3.3	6.0
1998	9.0	16.8	11.0	9.8	3.3
1999	-4.2	-17.7	-6.4	-4.3	1.7
2000	0.0	-6.1	-0.2	-0.1	0.0
2001	-1.9	2.8	-2.6	-1.9	-0.4

Source: FAO 2002.

Discussion and Conclusions

The most important conclusion from the study is that it is possible and feasible in the four countries studied to introduce viable farming systems in which saline groundwater is used for the production of salt-tolerant species of traditional crops, including fodder crops. In addition, as discussed before in this report, ICBA (ICBA 2004) and others are developing special grain and fodder crops such as pearl millet, barley, fodder beet and buffel grass (*Cenchus cilaris)* as well as other grasses (*Spirobolus, Distichlis* and *Paspalum),* shrubs (*Atriplex*) and trees (*Acacica ampliceps)* for amenity uses, that can grow well even when watered with saline water with an electrical conductivity in excess of 15 dS/m. The feasibility is indicated not only because suitable plant material is available, but also because there are sites with sufficient saline groundwater (as identified by the participants in this project), where communities of poor farmers would directly benefit from greater availability of fodder, especially as winter feed. The latter is important as in several of these countries the demand for winter forage, i.e. from perennials that continue to produce at low temperatures, is far greater than the domestic supply. As mentioned, this is the result of a fast growing demand for meat in WANA. In this region, where livestock accounts for between one-third and one-half of the agricultural component of GDP, its contribution to sustaining the livelihoods of the rural population is essential.

Discussions of the participants in the project helped formulate a set of conditions for the successful introduction of the use of saline water (and land) in agriculture. They are listed in table 12. These criteria could be used to evaluate the prospects in other locations in WANA than the target sites mentioned earlier and described in Appendix 1, and also in other arid and semi-arid areas outside the WANA region. The list of table 12 is not necessarily complete but it makes a first attempt to specify the desired characteristics of water resources, farming systems, farmer communities and government policies.

It seems unlikely that all conditions will be satisfied for the introduction of agricultural systems anywhere. However, this list presents conditions that those involved in implementation in selected target areas need to aim for. Nor are all conditions equally important. In the introduction in different places, some aspects will turn out to be of less importance than was expected, while others need to be added to the list. Nevertheless, this list should be useful as a checklist in the selection of additional sites within and outside the WANA region that seem suitable.

It was found that the four countries of this study have much in common in terms of the arid and semi-arid climatic conditions, inadequate water resources which limit agricultural development, and over-exploitation of the resources. The data and information about the water resources, although readily available at country level, were not complete and data from different sources rarely agreed. Moreover, data at regional level within the countries were often lacking as was information about how much of the saline water resources is currently used for agriculture or for other uses. Saline water resources consist of saline groundwater and saline drainage water from irrigated areas. Water from saline springs has not been considered in this study as not much is known about its availability or degree of salinity.

The publicly available data indicate that water scarcity is more pressing in Egypt and Jordan than in Syria and Tunisia. Yet, country data appear to indicate that demand for water exceeds the sustainable supply. In other words, in each of the countries, there is a strong need to conserve water and to make good use of the available sources of saline water. Food policy specialists expect that due to the combination of population growth and decreasing amounts of good quality water for agriculture, food self-sufficiency in the region will decline.

The study found that quantifying poverty, for example in the selected areas for the use of saline resources, was problematic. Various

TABLE 12
Conditions for successful introduction of biosaline agriculture.

	Aspects	Specific demands
Water resources	Pumped groundwater	Infrastructure for distribution, allocation and management
	Drainage water	Water management to control salt balance in root zone
	Treated wastewater	Environmentally safe disposal of waste and brine; assessment of possible health hazards
Biosaline farming system	Mixed irrigated	Appropriate salt-tolerant crops; agronomic practices; soil-nutrient management, suitable land
	Mixed rainfed	Appropriate salt-tolerant crops; agronomic practices; soil-nutrient management; suitable land; supplementary irrigation
Farmers	Land and water	Participation in planning new farming systems; assured property rights; agronomic advice (extension services)
	Markets	Infrastructure for access to markets; fair prices for produce
	Profits	Assured return on risk and investments; credits
	Labor	Low opportunity cost of labor
Government policies	Rural infrastructure	Support for rural roads, markets and produce of biosaline farming system; availability of credit
	Tariffs	Land and water rights, land reform and consolidation; reasonable prices for water and services
	Rangeland	Protection and rehabilitation of rangeland
	Migration	Stimulate employment in rural areas for younger people

poverty indicators are in use and the available data are often conflicting. In addition, regional differences in poverty levels usually go unrecorded. The data of this study indicate that the rural population and those active in agriculture constitute a significant part of the population and that many of the rural farmers are probably poor. Poor people in rural areas often live in the most fragile ecosystems of arid and semi-arid regions. The study concluded that starting production systems using saline resources in these areas could help to mitigate poverty among the households living in these places.

Farming systems using saline resources have to include more than the distribution of salt-tolerant crops. To contribute to the easing of rural poverty, the distribution of seeds has to be combined with soil-nutrient management and field-level water management. These are all, to some extent, site-specific and need to be developed for the chosen target areas. The study confirmed that the use of saline water for supplemental irrigation in forage production systems is quite promising in many parts of the WANA region. But, some aspects of this farming system, such as soil-nutrient management, agronomic practices, including plant protection measures still need to be worked out. It was concluded that the development of these other aspects of the farming systems and the evaluation of the potential benefits and costs should be done next on the road towards the successful introduction of the use of saline resources in agriculture in the target areas. The economics can only be tested through monitoring farm incomes before and after in a number of target areas. The timescale of this project did not allow the actual incorporation of the integrated use of saline resources into existing farming systems and the monitoring of its impact on farmers' incomes. Yet, this should now be the next priority.

According to many observers of development projects, government policies and investments in public goods in the WANA region have for a long time been biased towards urban areas by favoring cheap food for urban populations. Overgrazing of rangelands by too many animals has repeatedly been the result of national policies that encouraged the import of cheap feed grains without at the same time regulating livestock numbers. To reverse this trend, national governments should realize the advantages of supporting agricultural production systems, such as those using saline resources for agricultural production, on marginal lands, because they help not only in land conservation, but they also stimulate rural employment and reduce the need for imports. Supplementary irrigation, including irrigation with saline water, is especially beneficial during periodic droughts that have decimated herds and drastically reduced household incomes in the past. The most vulnerable and seriously affected were dryland farmers, including cereal producers, olive and fruit growers and sheepherders. Many farmers had to buy more animal feed at the expense of household consumption. The study therefore concludes that the productive use of saline resources in agriculture should be part of the governments' long-term drought management policy, which could at least in part replace the need for short-term drought relief measures.

Overall Conclusions

1. It is technically feasible to integrate saline irrigated production of salt-tolerant, conventional and non-conventional crops including forage crops, into mixed farming systems in WANA. The economic viability of such farming systems is not fully established and requires verification through pilot projects.

2. Available saline groundwater and drainage water resources are poorly documented, making precise quantification of the potential for their productive use impossible. However, expert opinion is well able to identify specific areas within countries where the water resources and social and economic circumstances favor small-scale saline irrigated agriculture to complement existing mixed livestock and cropping farming systems.

3. Precise quantification of the likely impact of saline irrigated agriculture on poverty and food security of the poor in WANA was not possible. The specific natural resources, social and economic requirements for successful use of saline resources in agriculture suggest that the economic impacts would be limited. However, there is ample anecdotal evidence to conclude that options to complement and diversify livelihood streams of the rural poor would lead to improved household incomes and food security.

4. The benefits of saline irrigated agriculture systems extend beyond the economic value of their production. They include environmental benefits such as mitigating the degradation of the natural resource base and social benefits such as providing additional livelihood options that slow down the drift of population to the cities. These benefits need to be factored into policies and decisions on the use of saline water.

5. A range of potential uses compete for saline water resources. The most appropriate use for any particular situation will depend on the cultural, social and economic circumstances as well as the available saline land and water.

6. Non-crop uses of saline water will probably outweigh crop production uses in the more affluent countries of the Arabian Peninsula, where landscaping, greening and other amenity utilization already dominate.

7. Irrigation of coastal deserts with seawater to produce biomass for carbon sequestration and renewable energy may represent a major future use of saline water resources. The likely environmental, economic and social impacts, however, remain to be quantified.

Appendix 1

Potential Sites for Saline Irrigated Agriculture and Their Characteristics

Egypt

The country is characterized geographically by its four main regions: (i) the Nile valley and delta, where most people live and most agricultural production takes place, (ii) the Western desert including the Mediterranean littoral zone and its oases, (iii) the Eastern desert, including the Red Sea littoral zone, and (iv) the Sinai Peninsula with shore lines along the Mediterranean Sea, the Gulf of Suez and the Gulf of Aqaba. The average rainfall over the whole of the country is only 10 mm per year with large regional differences. The highest average rainfall is some 140 mm per year along the Mediterranean coastal zone where the most of the rain falls during the winter months.

Agriculture accounts for about 17 percent of GDP, and employs some 32 percent of the working population. Food self-sufficiency, defined as the ratio of production over the sum of production and net import of staple crops, is expected to decrease from 73 percent in 1997 to 40 percent in 2017. The objective of Egypt's socio-economic development is to enlarge the habitable part of the country from about 5 percent at present to 25 percent in 2017. Main constraints in reaching this objective are limitations in natural resources, especially water, and in the necessary appropriate infrastructure and services (e.g. roads, housing, and health services).

Sites in Egypt

Three areas were identified in Egypt by focusing on the availability of low-quality groundwater, including water of different salinities from more than one aquifer. These areas, each with a majority of poor people, have been earmarked by the government for resettlement or are locations where the livelihoods of the poor have been affected by mismanagement of low-quality water resources. Areas in the Middle and NE Sinai (Al Arish, Sheikh Zouid, Rafa) have the greatest potential for biosaline agriculture. Here the groundwater is fed by seawater intrusion and rainwater. The present population consists of very poor Bedouins. In the center of the Middle Sinai, the introduction of biosaline agriculture could benefit from the presence of a project financed by the Islamic Development Bank for the settlement of Bedouins. This project evaluates and designs water use and water harvesting systems. In the NE Sinai, over-pumping has led to seawater intrusion affecting the farming of dates, olives and livestock. Here potential synergies exist with a USAID project for the settlement of communities in the Wadi Al Arish, which was selected because livelihoods of the poor farmers had been adversely affected by the decline of the Palestinian market for their produce.

Other potential areas include an area in the SE desert, bordering the Red Sea in the east and the Nile valley in the west. In an area 100 km north of Hurgada, landless poor people have been relocated from the eastern desert to Wadi Dara, where they grow jojoba in a project supported by a private investor. The third potential area in Egypt, be it with lower priority, is on the NW coast, where a World Bank-funded project is developing techniques for rainwater harvesting and storage of flash floods to supplement low-quality groundwater. The relevant information is summarized in appendix table 1.1.

As mentioned, the economics of biosaline agriculture in these areas still need to be evaluated. In the North and Middle Sinai, tomato is one of the most important crops. If one assumes that producing tomatoes with low-quality water of salinity in the range of 2-5 dS/m would yield about 15 percent less than the average production in Egypt with fresh water, the net return from 0.4 ha (1 acre) would still be LE 4,000 (US$ 640) per season. Likewise, growing wheat

APPENDIX TABLE 1.1
Specifications of potential sites for saline irrigated agriculture in Egypt.

Target Areas	Middle and North Sinai	South-East Desert	North-West Coast
Water salinity range (dS/m)	1.5-35	2-20	2-25
Depth to groundwater (m)	0-800	0-70	0.5-55
Exploitable volume (MCM/year)	18	25	8
Current abstraction rate	3	5	2
Potential additional abstraction in range 2-25 dS/m	7	15	4
Current use of pumped water	Small-scale farming and drinking	Small-scale farming and drinking	Small-scale farming and drinking
Present crops	Berseem, dates, vegetables	Berseem, vegetables	Wheat, barley, berseem, figs, grapes
Estimated area for irrigated saline agriculture	1,650	1,850	750

with water in the salinity range of 5-15 dS/m, yielding about 45 percent less than the national average, would give a net return of LE 1500 ($ 240) from 0.4 ha during the winter season. These figures are no more than preliminary estimates that need to be ascertained in real field situations. Monitoring production systems in the field would also allow the assessment of benefits that could accrue from greater integration between livestock and crop production, which is considered possible especially in the North Sinai.

Jordan

Jordan has borders with Syria to the north, Iraq to the east, Saudi Arabia to the south, and across the river Jordan or Yarmouk with Israel and Palestine to the west. In the south-west of the country, Jordan has access to the Red Sea through the Gulf of Aqaba. Some 8 percent of the land area is used for agriculture, and only 750 km^3 of farmland is irrigated, much of it in the Jordan valley. This area is below sea level and enjoys a warm and temperate climate throughout the year.

The average annual rainfall in Jordan is about 160 mm, with large regional variations ranging from 600 mm in the northern highlands to nearly none in the south-eastern corner of the country. It is estimated that 92 percent of what rainfall reaches the country is lost to evaporation. Agriculture contributes about 2 percent of the GDP, mainly from fruits and vegetables grown in the Jordan valley, but it uses approximately 70 percent of the country's water resources. In 2000, employment in agriculture as share of the total employment in Jordan was estimated at just over 6 percent. Jordan is heavily dependent on imports to meet its food demands.

Sites in Jordan

In Jordan, several potential sites were identified, but for most of these, detailed information is not yet available. The specifics of two areas, Al Khaldieh and Azraq, are given in appendix table 1.2. Al Khaldieh is in Mafraq Governorate, which contains 170,000 ha of agricultural land, representing 19 percent of the total agricultural area of Jordan. Some 22,600 ha (or 11 % of the national total) are currently cultivated. Of this, about 5,500 ha are rainfed and almost wholly devoted to olives. The remaining 17,000 ha are irrigated for the production of summer vegetables, fruit trees, and field crops. The Mafraq Governorate is the third poorest in the country.

The Azraq basin is an area with widely fluctuating salinity levels in the shallow groundwater due to localized interactions between two aquifers, one with fresh and the other with saline water. Due to over-pumping, in part for irrigation, water quality in the area has

APPENDIX TABLE 1.2
Potential sites for saline irrigated agriculture in Jordan.

Target areas	Al Khaldieh	Azraq
Location	North-east of Amman	East of Amman
Availability of saline water	Ample	Ample
Salinity of groundwater (dS/m)	<4.5	<7
Soils	Medium textured	Medium textured, high percentage of gypsum
Soil salinity	Variable, up to 25 dS/m	Variable, up to 25 dS/m
Forage crops	Alfalfa, Sudan grass, barley, maize, pearl millet	Alfalfa, Sudan grass, barley, maize, pearl millet
Livestock	Sheep (38% of country total), goats (17%) and cows (24%)	Important, especially small ruminants and some camels
Farm size	> 2 ha	> 2 ha

deteriorated rapidly in recent years. The annual rainfall is less than 100 mm. The potential agricultural land in the Azraq area is 29,000 ha of which 7,000 ha are currently irrigated. In both areas, livestock production is important. Alfalfa production is concentrated in the summer months when conditions are favorable for growth, as are most of the other forages. There is however an acute need of winter forages, particularly perennials that can grow under cold temperatures and produce during the winter months. Now farmers are importing feed from neighboring areas and abroad. For areas with high soil salinity, *Atriplex* species have shown promise, particularly those species that are native to the area, such as *A. halimus* and *A. leucoclada*.

There are 417 artesian wells in the Azraq area of which only 113 are licensed. Most wells are about 150 m deep. Animals are raised in about 450 private holdings or grazed on communal lands. Incomes in the Azraq area are well below the national average and about 70-80 percent of the population lives in poverty, receiving government assistance.

Al Khaldieh lies within the target area of the Income Diversification Project 1994-2001 which aimed to increase and stabilize the household incomes of disadvantaged, resource-poor women and men by improving the productive potential of their livestock, land, water resources and labor. Loans were provided for women to purchase small ruminants to help improve their family incomes, but difficulties in finding feed for the animals are curtailing this program.

Synergy is also expected with an IAEA regional project on the use of saline water in wastelands that has operated at Azraq since 1999. It has demonstrated a number of forage trees and shrubs to farmers. Any future project on application of saline agriculture will build on this experience.

Syria

Syria borders on Turkey, Iraq, Jordan and Lebanon, and on the Mediterranean Sea north of Lebanon. The climate is mostly semi-arid and is dominated by the moderating influence of the Mediterranean. Annual precipitation ranges from 1400 mm in the western coastal heights to about 100 mm in the far eastern parts of the country, with a country-wide average of about 250 mm. Actual rainfall may be twice as high in wet years than in dry years. On the average, it is estimated that nearly 80 percent of the precipitation is lost through evaporation leaving some 10.3 km^3 available for various uses. Recharge to groundwater is estimated to be between 0.7 and 1 km^3 per year.

The cultivated area in Syria is about 5.5 million ha, i.e. 30 percent of the land area, of which some 20 percent is irrigated. Agriculture contributes 29 percent to the country's GDP, and employs nearly 25 percent of the workforce, with another 50 percent of employment in manufacturing also dependent on agriculture. Self-sufficiency in wheat, i.e. production divided by the sum of production and net import of wheat, improved from about 0.5 in 1989 to 1.41 in 1997. Similar improvements were noted for barley and cotton, while the aggregate self-sufficiency in cereal production (excluding rice) rose from 0.83 to 0.92 during the same eight-year period. However, these increases could only come about through unsustainable water use practices.

Sites in Syria

In Syria, the best opportunity for the introduction of biosaline agriculture lies in expanding the margins of the irrigated areas of the Euphrates Basin. One potential area is located in the Basin between the Deir Al Zoor city and the Iraqi border. This area is about 180 km long and 12 km wide and has over 200 drainage wells. More details of this area are presented in appendix table 1.3. Other similar areas in the Euphrates Basin are in Deir Al-Zoor province between Khaboor and the Euphrates, as well as in Raqqa province in the Euphrates and Aleppo Basin. These two areas have the same characteristics as listed in appendix table 1.3, except that the soils are lighter-textured and the farm sizes, larger than in the Euphrates Basin. The potential for biosaline agriculture in these two areas depends on the availability of water and on the soil salinity, which is governed by the salinity of irrigation water and the presence or absence of a drainage system.

There are other suitable areas in Syria for which detailed information is not yet available, such as the Al Jezira area in the north-west corner of the country and the Rasaffa area between Lake Assad and the northern Palmyrian mountains. In the north of Jezira, an extensive aquifer is an important source of water although its yield and quality vary much from one area to another. Groundwater salinity is high over a large part of it and biosaline agriculture offers a possibility for agricultural development. The introduction of biosaline agriculture in the Rafassa area would assist in the desired settlement of Bedouins. This area has been mismanaged for years. First, rainfed barley and wheat were introduced in this prime steppe grazing area and subsequently, irrigated cotton. The use of saline groundwater on heavy soils led to salinization and ultimately to the abandonment of cotton production.

APPENDIX TABLE 1.3
Prospects for saline irrigated agriculture in the lower Euphrates basin of Syria.

Target Area	Euphrates Basin
Location	Along the Euphrates river, south-east of Deir A
Saline water availability	Discharge of the wells is about 150 m^3/day
Salinity of groundwater	2-5 dS/m – 18%5-15 dS/m – 44%15-25 dS/m – 38%
Soils	Medium textured alluvial soils with good internal drainage
Soil salinity	Large variability with > 100 dS/m in some locations
Field crops	Wheat, cotton, sugar beet
Forage crops	Vetch, barley, medic and trifolium
Livestock	A small number of sheep; a few farmers have one or two cows
Average farm size	3.1 ha
Estimated area	15,000 ha

Tunisia

Tunisia borders on the Mediterranean between Algeria in the west and Libya in the east. Tunisia has much in common with the other countries studied, with respect to the arid and semi-arid climate, inadequate water resources which limit agricultural development, and over-exploitation of the resources. The country is characterized by three agro-ecological zones: the northern part of the country benefits from the proximity of the Mediterranean Sea in that the temperatures are less extreme and average rainfall is between 400 and 600 mm per year. It is suitable for the production of annual crops in the north-east and has mountain pastures in the north-west. The rainfall in the central part of Tunisia is between 200 and 400 mm per year, and it represents an agro-pastoral ecological zone. The southern part has a irregular rainfall of 100 to 200 mm, and the soils are vulnerable to erosion. Its agriculture is pastoral with vegetable production in oases where water is available. The annual average rainfall for the whole of the country is just over 200 mm, or 36,000 MCM. But the variation from one year to the next is such that the total annual rainfall ranges from as little as 11,000 to as high as 90,000 MCM.

In the arid south, no sustainable agriculture is possible without irrigation. During the past decades, the increasing water demand for agriculture, industry and domestic uses has led to the over-exploitation of groundwater. As a result, aquifers are gradually depleted and seawater intrusion occurs in coastal regions. Saline groundwater is relatively abundant in south Tunisia, and in some areas such as the Jefara Plain strip, farmers have become increasingly dependent on saline or slightly saline water for irrigation.

Sites in Tunisia

In Tunisia, the introduction of biosaline agriculture in the saline areas of the south could contribute to large-scale changes in regional coastal land use. Salt-tolerant plants are already established in a demonstration site at El Hicha, Gabes, in southern Tunisia. Since 1997, a total of five demonstration sites, including in Medenine and Kairouan, have been established where the growth of various plant species is being monitored. Specifics of two possible target sites are presented in appendix table 1.4.

APPENDIX TABLE 1.4

Possible sites for saline irrigated agriculture in Tunisia.

Target sites	El Hicha, Gabes	El Khessim, Medenine
Saline water available (MCM/year)	150	3.5 MCM/year from the phreatic aquifer underlying the island of Djerba
Salinity (ppm)		1,000-15,000
Soil type	Sandy soils of varying thickness overlying a hard gypsum layer	Poorly developed soils overlying a gypsum layer
Soil salinity	5-20 dS/m, varying with the season	SAR = 15 to 20%
Forage crops	Many salt-tolerant crops have been identified	Many salt-tolerant crops have been identified

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