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SALINE IRRIGATION MANAGEMENT FOR A SUSTAINABLE USE

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INTRODUCTION

The goal of sustainable development should be to make sure that the unlimited natural resources are available for future generation. Sustainable development of water resources requires that we respect the hydrologic cycle by using renewable water resources that are not diminished over the long term by their use. In many countries of the Middle East and the Mediterranean region, specially those in the arid climate zone with high rates of population growth, urbanization and industrialization, water is becoming a scarce resource. The increasing competition for water shall greatly affect the water supply for irrigated agriculture in these countries. Generally, available quantities will be reduced and costs will be increased. There is now growing realization that an increasing number countries in those regions are approaching full utilization of their surface water resources and that the quantity of good water quality supplies available to agriculture is diminishing. What is left is water of marginal quality and agriculture have to cope with this situation.

In the Mediterranean, the ambitious development activities tend to siphon off more and more water. Thus, water demand often exceeds reliable and exploitable water resources. Such existing imbalance between the limited water supply and the steadily increasing demand leads to serious conflicts over water and to the degradation of water quality in all users' sub-sectors within major countries of the region. We have to reach an appropriate balance between the limited supply and the increasingly demand which, at the moment, is heavily unbalanced. This is the dilemma challenging most developing countries of the region: *what are the options available and what are the alternatives that could provide a sustainable solution to avoid water conflicts and to meet the increasingly water demand in all the water user sectors and particularly the agricultural one?*

In the agricultural sector, the use of non-conventional water resources as an additional source for irrigation is one of the practical solutions to be recommended. Its use is nowadays a must in the arid and semiarid countries in the region to satisfy the increasingly water demand in irrigation; expanding the irrigated areas and thereby reducing the existing sever gap in food and fiber production.

In most countries of the region, particularly the arid ones, the importance role of the use of non-conventional water resources including the saline water and the treated wastewaters is well recognized. Considerable amounts of such water are available in various countries of the region, but, there are still marginally practiced in irrigation, although they could be successfully used to grow crops without long-term hazardous consequences to crops or soils by applying appropriate management practices.

There is ample evidence to illustrate the wide spread availability of saline waters and a wide range of experience exists around the world with respect to using them for irrigation under different conditions. This evidence and experience demonstrates that water of much higher salinities than those of customarily classified as "unsuitable for irrigation" can in fact, be used effectively for the production of selected crops under the right conditions. However, the reuse of non-conventional water resources, including the use of drainage and shallow saline groundwater for crop production, through an apparently simple and appropriate technology is indeed a complex one. It has a multidisciplinary inter-linkage with different sectors such as environment, health, industry, agriculture and water resources.

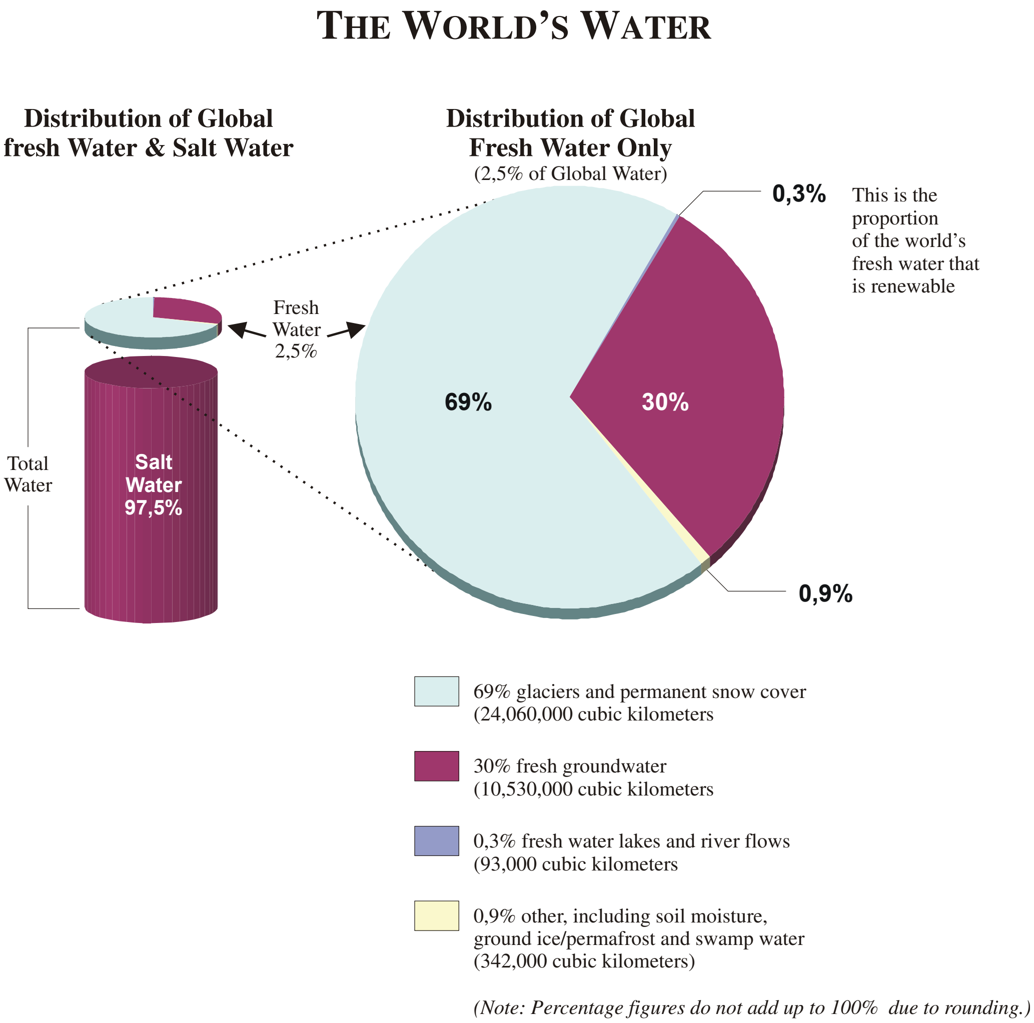
Aware of these complex inter-linkages, great efforts are now being directed to the development and use of non-conventional water sources notably artesian, drainage and brackish water for irrigation. This certainly will result in greater amounts of water for irrigation but to the detriment of its quality. In the long run, this could seriously affect crop production and deteriorate the soil productivity.

Thus, if low quality water is proposal to be used on a large scale for irrigation, the complex interaction of water, soil and crop in relation to water quality must be well understood before hand. Equally, the technology and concepts of using and managing saline water in irrigation must be available and well developed for sustained production on a permanent economic basis. The success of saline water use in irrigation requires the development of new scientific practices, new guidelines for use that cope with the prevailing local conditions and new strategies that facilitate its use on a relatively large scale.

This paper discusses the options and main guidelines which are necessary towards sustainable utilization and management of low quality water, particularly the saline one.

LIMITS ON FRESHWATER

Contrary to popular impression, water is a finite resource. There is a fixed amount on the planet - nearly 1.4 billion km^3 - which can be neither increased nor decreased. Most of it - 97.5% - is salt water and is of little direct use of people. A further 1.76% is locked away in permafrost, ice cups and glacials. Nearly all of the remainder is stored underground, leaving only 1.4 billion km^3- less than 0.4% of the world's fresh water- in rivers, lakes, reservoirs, the soil, swaps, the atmosphere and in living organisms (Fig.1).



Source: Igor Shiklomanov, "World Fresh Water Resources" in Peter H. Gleick, ed. *Water in Crisis: A Giude to the World's Fresh Water Resources*, 1993

Figure 1. The World's water

WATER SCARCITY IN THE MEDITERRANEAN

Although water remains abundant in some countries, in others like those of the Southern and Western parts of the Mediterranean, the continual subdivision of renewable water resources among more people is leading to unsustainable uses of water or sustainable declines in water availability and quality. In the year 2025, it is expected that water availability per capita in the Southern countries of the Mediterranean will drastically drop (50 to 70%) with respect to the year 1987, with an average around 60%, but availability will be reasonably stable in the Northern countries with very little differences not exceeding 10% (Hamdy and Lacirignola, 1993).

In the arid and semiarid countries of the Mediterranean, the efforts to encourage water conservation face special challenges not in counter with other natural resources. In much of those countries, water is not controlled by market mechanisms because it is either free for the taking or unmetered. Nor is water a global resource that can be treated like petroleum or given in aid like food or medicine. In addition, today, most easily accessible renewable fresh water resources already have been developed (Egypt, Syria, Jordan, Israel, and Libya). The cost of developing less accessible ones will be high and the process is time consuming. The environmental and human costs of projects can also be enormous. This, evidently, confirm that more and more marginal water quality should be used to meet the future increasingly fresh water demand, particularly in the irrigation sector.

More efforts should be directed towards the establishment of new management and practices strategies under irrigation with saline water that provide on the long term, on one hand, a favorable crop production and, on the other one, keeping the soil at good productivity level without further deterioration in its physical and chemical characteristics.

SALINE WATER ORIGIN AND SOURCE

The study of the origin of salinity is important for long term management of salinity problem and to foresee the durability of costly reclamation projects which depend upon a proper understanding of the regional climate, hydrology, geohydrology, geochemistry, salts input through mineral weathering process, rainfall, and redistribution and sink mechanism processes. (Doneen, 1958; Shalhevet and Kamburov, 1976; Rhoades, 1977; Singh, 1998).

A common source of saline water is ground water. Arid and semiarid areas of many countries are mostly underlain by saline ground water. In many regions, rivers or canals flow from humid and subhumid areas to semiarid and arid areas, where fresh and saline water exist in a close proximity. In sea coastal areas, fresh and saline waters also occur in proximity. The pumping of fresh ground water invites encroachment or upcoming of salts in inland areas while sea water intrusion occurs in coastal irrigation (Kovda, 1973; Tanwar and Kruseman, 1985; UNESCO/UNDP, 1970).

Ground waters render low in quality by the natural process of mineralization, contamination and pollution owing to human activities. Besides variation in quality, groundwater also varies in quantity as per the aquifer framework characteristics and intensity of recharge sources. It is imperative to carry out scientific investigation, exploration and assessment for the use of saline water in various situations.

The process of groundwater mineralization with aquifer salinization is more active in the arid and semiarid areas, which continuously increase the salinity in water under the process of evaporation and deposition of salts (Crag, 1980; Dhir, 1998). The salinity of ground water in inland closed basins is reported upto 55 dS/m (Tanwar, 1981; UNDP/FAO, 1985; CSSRI, 1998).

The world over important source of saline water are: (1) seawater intrusion in coastal regions, (2) tidal influence of sea on coastal surface water, (3) ground water mineralization in rock formations, (4) process of evaporation/evapotranspiration more so in arid and semiarid regions and enrichment of salts in surface and ground water, (5) waterlogging and secondary salinization of soils, (6) drainage effluent, and (7) sewage effluent. Numerous investigations have shown that water within sedimentary rocks becomes increasingly saline. The subsurface regime with increase in depth, reflects sulphate rich water near the surface, saline barcarbonate water at an intermediate level, and more concentrated chloride water at greater depth (Crag, 1980; FAO, 1992).

THE SALINE WATER IRRIGATION PROBLEM

The harmful effects of saline water irrigation are mainly associated with accumulation of salts in the soil profile and are manifested through reduced availability of water to plants, poor to delayed germination and slow growth rate (Feizi, 1998; Shalhevet, 1994; Letey *et al*., 1990; Mass, 1990; CSSRI, 1998). Osmosis is a normal process with the fresh water irrigation. But, if the irrigate water is saline, the plant has to work harder to absorb water from the soil.

When irrigation is practiced with highly saline water, the process of osmosis can become reserved. Where the solution outside the plant roots is higher in salt concentration than that of the root cells, water will move from the roots into the surrounding solution. The plant loses moisture and thus suffers stress. The symptoms of high salt damage are similar to those from high moisture stress damage. If saline water is sprayed directly on leaves, it can cause salt scorch and uaf damage even at lower salinities.

Some of the visual symptoms of saline water irrigation are that the plants look stunted and leaves are smaller but thicker and have often-dark green colour as compared to plants growing in a salt free soil irrigated with good quality (Bernstein, 1964; Van Hoorn, 1971; Minhas, 1998).

The salt concentration takes place more than two times in fine textured clay and clay loam soils. Saline water of a high salt concentration having ECw of 12 dS/m may be used for growing tolerant and semitolerant crops in coarse textured loamy sand and sandy soils under normal rainfall of more than 400 mm. But, in fine textured soils of clay and clay loam nature, waters with ECw more than 2dS/m would often create salinity problem (Tyagi, 1998; Abrol, 1982; Kandiah, 1990). The saline water of ECw more than 4 dS/m will cause salt toxicity in most of the crops in areas with annual rainfall less than 250 mm.

The chemical constituents of the irrigation water including the concentration of both cations and anions impose specific negative effects on the growing media as well as the crop production. As an example, the alkali or sodic water constitutes a significant proportion of groundwater in arid and semiarid areas. The sodium bicarbonate is the predominant salt in this water; calcium and magnesium salts are with relative proportion much smaller as compared to sodium salt which constitutes 70 percent of the total cations. In certain cases, the calcium salts may be nearly absent (Eaton, 1950; Hem, 1970; Abrol, 1972).

The harmful effects of alkali/sodic water irrigation are mainly associated with increased exchangeable sodium percentage (ESP) and reduced infiltration (Oster and Schroer, 1979; Bajwa, 1998). Long term use of water leads to breakdown of soil structure due to swelling and dispersion of clay particles (Richard, 1954; CSSRI, 1994; Bingham *et al*., 1979). Fine texture soils remain disposed and puddle when wet and then hard when dry. It does not attain proper soil moisture condition for activation.

A thin crust formed at the surface of soil acts as a barrier to penetrating irrigation water to the soil and to the emergence of seedling (Minhas, 1998; CSSRI, 1988). The increase in soil pH reduces availability of a number of plant nutrients like nitrogen, zinc, iron etc. Calcium and magnesium find decrease, and toxicity of sodium increases and consequent toxicity also increases of elements like boron, molybdenum, fluorine, lithium and selenium (Bottcher *et al*., 1981; FAO, 1992).

EXTENT OF AGRICULTURAL SALT PROBLEM

On irrigated lands, improper water use and systems management not only prevent attainment of potentials, but also cause productive land to be lost to cultivation through waterlogging and increasing salinity or sodicity. The net result is physical, chemical and biological degradation of land on a very large scale. Salinity is reported to affect one billion hectares mostly located in arid and semiarid regions (Table 1).

Szabolcs (1989) has made quite a different estimate of the world wide salt-affected surface areas (including also non-irrigated land): about 340 million ha (23%) of cultivated lands are saline and another 560 million ha (37%) are sodic. These figures indicate that, approximately, one-third of the developed agricultural lands in arid and semiarid regions reflect some degree of salinity accumulation. In some agricultural systems as much as 50% of the presently irrigated land is salinized (Table 2).

Table 1. Extent for salt-affected soils by continents and sub-continents

Region	Milions of hectares
Africa	80,5
Australia	357,3
Europe	50,8
Mexico and Central America	2,0
North America	15,7
North and Central Asia	211,7
South America	129,2
South Asia	87,6
South East Asia	20,0
Total	954,8

*Source: data Table 19.3 of World resources 1987, a report by the International Institute of Environment Development and the World Resources Institute, published by Basic Books, Inc., New York.

Table 2. Estimates of percentage of irrigated land affected by salinization for selected countries

Country	% affected	Country	% affected
Algeria	10- 15	India	27
Egypt	30 - 40	Iran	< 30
Senegal	10 - 15	Iraq	50
Sudan	< 20	Israel	13
United States	20 -25	Jordan	16
Colombia	20	Pakistan	< 40
Peru	12	Sri Lanka	13
China	15	Syrian Arab Republic	30 - 35

*Source: data Table 19.3 of World resources 1987, a report by the International Istitute of Environment Depelopment and the World Resources Istitute, published by Basic Books, Inc.,New York.

The salt affected soils in the Mediterranean countries amount to some 16 million ha, with Egypt (7.4 m), Algeria (3.2 m) and Turkey (2.5 m) being the most affected.

For irrigation land, Szaboles (1989) estimates that some ten million ha are abandoned yearly as a consequence of salinization, sodification and waterlogging. It is a consensus of specialists that without proper soil and water (irrigation and drainage management), on site effects of salinization will continue to increase (Table 3).

Table 3. On-site and off-site effects of salinity in irrigated agriculture

1- On-site effects:

- 30% of irrigated land in arid and semi-arid areas is salt-affected.
- Mediterranean countries: 16 million ha of salt affected soils.
- 10 million ha of irrigated land are abandoned yearly.
- Without proper soil, irrigation and drainage management on site
- Effects of salinization will continue to increase.

2- Off-site effects:

- Irrigation return flows high in salts, nutrients, sediments,
- Pesticides and trace elements

According to the estimates of UN and affiliated Organizations, more than half of all irrigated territories of the world are more or less salinized, alkalized or water-logged due to the improper methods of water for irrigation and use of saline water also contribute to the process of so-called secondary salinization which is expanding in our days at an accelerated rate. The total territory of secondarily salinized lands increases by more than 10 million hectares yearly and in several countries this result in serious economic problems by devastating the irrigation systems.

DESERTIFICATION AND SALINIZATIONS INTERRELATIONS

Among the adverse processes that leading to the deterioration of land and the impoverishment of many nations, desertification and salinization are quite common. The two processes are different, however, closely interrelated, that progressive salinization induces the development of desertification and vice-versa, the desertification commonly is associated with increasing salinity.

Consequently, when studying or combating either salinization or desertification the other process, too, should be taken into account because increasing salinization in arid areas always furthers desertification and, on the other hand, in desert areas salinization can, as a rule, hardly be neglected.

An increasing awareness of continuing soil salinization and sodication lead the United Nations Conference on Desertification (UNCOD), held in Nairobi in 1978, to adopt the following recommendations:

- it is recommended that urgent measures be taken to combat desertification by preventing and controlling water-logging, salinization and sodication by modifying farming technique to increase productivity in a regular sustained way, by developing new irrigation and drainage schemes where appropriate, always using an integrated approach and, through improvement of the soil, social and economic conditions of people dependent on agriculture.

The actions against, either salinization or desertification should be conduced jointly and reciprocally because salinization had at least the following correlation with desertification:

- salinization promoting desertification
- salinization developing concurrently with desertification
- salinization induced by desertification
- salinization strengthened by desertification.

Table 4. Interrelations between attributes and consequences of desertification and salinization

Salinization	Desertification
	Reduction of water availability
Increase of salt accumulation	Hindering of nutrient uptake
Decrease of leaching	Reduction of biota diversity
Increase of salt concentration in ground and surface waters as well as in soil layers	Limitation of plant cover on the soil surface diminishing of humus content Worsening of thermal and water-physical soil properties
Secondary increase of water soluble compounds	Adverse consequences of irrigation, overgrazing and deforestation

Source: I. Szabolcs, 1991

ASSESSING THE SUITABILITY OF SALINE WATER FOR IRRIGATION

The sustainability of irrigated agriculture with saline water is a real challenge. The concept of improvement and maintenance of the crop productivity at economic level is the core idea of sustainability. In saline environment, the major issues involved are: (1) the effect of saline water irrigation on crop productivity, (2) the economics of the saline water use, and (3) the environmental protection to safe guard the soil crop and human health.

Many problems associated with irrigated agriculture arise from the chemical composition of water applied. The use of various quality for irrigation, as well as the advantage of predicting problems that might develop when different quality of irrigation water is being used, created the need for a system of water quality classification that is completely different from the system in use for geochemical, industrial, aquatic life and sanitation purposes (Frenkel, 1984).

The evaluation and classification of irrigated water depends on its ultimate use. When water is to be used for crop irrigation purposes, five factors should be considered in evaluating water quality:

(1) the total salt content and chemical composition of the water; (2) the climate of the regions; (3) the prevalent soils and drainage conditions; (4) the principal crops to be irrigated; and (5) crop cultural practices, mainly irrigation method. The interaction of these five factors in effect constitutes a water classification. A source of water may be classified as suitable or unsuitable for irrigation after it has been examined in the light of these five factors. Such a classification scheme is essentially a summary of our knowledge concerning the interaction of these five factors. As such, it is always subject to revision and improvement as our knowledge advances.

Obviously the evaluation of a source of saline water is complex and has to be done individually for each region, depending on local conditions. Nevertheless, for simplification some general schemes of water classification have been proposed and used. Most schemes have three basic criteria: total salt content (salinity); sodium, carbonate and bicarbonate ion concentration in relation to calcium and magnesium ion concentration (sodicity); and toxicity of specific ions, e.g. Cl^- and B^-. They have ranged from general schemes designed for average conditions (U.S. Salinity Laboratory Staff, 1954; Doneen, 1967; Rhoades and Bernestein, 1971; Rhoades, 1972; Rhoades and Merille, 1976; Ayers and Westcottt, 1976) to specific water quality rating based on a given crop in a specific region (Thron and Thron, 1954; Doneen, 1959).

Although the several proposed methods of classifying irrigation waters differ somewhat, they agree reasonably well with respect to criteria and limits. However, in all these criteria proposed, much emphasis has been placed on an attempt to answer the question: "How good is the water?" rather than "what can be done with these waters?" (Tables 5, 6, 7 and 8).

Table 5. Laboratory determinations needed to evaluate common irrigation water quality

Water parameter	Symbol	Unit[1]	Usual range in irrigation water
Salinity			
Salt Content			
Electrical Conductivity (or)	Ecw	dS/m	0 – 3 dS/m
Total Dissolved Solids	TDS	mg/l	0 – 2000 mg/l
Cations and Anions			
Calcium	Ca^{++}	me/l	0-20 me/l
Magnesium	Mg^{++}	me/l	0-5 me/l
Sodium	Na^+	me/l	0-40 me/l
Carbonate	CO_3^{--}	me/l	0-1 me/l
Bicarbonate	HCO_3^-	me/l	0-10 me/l
Chloride	Cl^-	me/l	0-30 me/l
Sulphate	SO_4^{--}	me/l	0-20 me/l
Nutrients[2]			
Nitrate-Nitrogen	NO_3-N	mg/l	0-10 mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0-5 mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0-2 mg/l
Potassium	K^+	mg/l	0-2 mg/l
Miscellaneous			
Boron	B	mg/l	0-2 mg/l
Acid/Basicity	PH	1-14	6.0-8.5
Sodium Adsorption Ratio[3]	SAR	$(me/l)^{1,2}$	0-15

Source : FAO, 1985

1. dS/m = deciSiemen/metre in S.I. units (equivalent to 1 mmho/cm = 1 millimmho/cer metre)
mg/l = milligram per litre ~ parts per million (ppm).
me/l = milliequivalent per litre (mg/l ÷ equivalent weight = me/l); in SI units, I = 1 millimol/litre adjusted for electron charge.
2. NO_3 – N means the laboratory will analyse for NO_3 but will report the NO_3 in terms chemically equivalent nitrogen. Similarly, for NH_4-N, the laboratory will analyse nitrogen available to the plant will be the sum of the equivalent elemental nitro. The same reporting method is used for phosphorus.
3. SAR is calculated from the Na, Ca and Mg reported in me/l.

Table 6. Modified US salinity laboratory water classification

Class	Salinity m mhos/em	Salinity mg/l	Evaluations
C_1	< 250	< 200	Low – good for most crops.
C_2	250-750	200-500	Medium – some leaching required with sensitive crops.
C_3	750-2250	500-1500	High – tolerant crops and leaching
C_4	2250-4000	1500-2500	High – only with permeable soils and tolerant crops.
	4000-6000	2500-3500	Very High – only with very permeable soils and very-very tolerant crops.
	> 6000	> 3500	Excessive – not usable

Source: Thorne DW and Peterson HB, 1954; irrigated Soils, The Pakistan Co. Inc, New York

The classification of saline water has been proposed by FAO (1992) given in Table 7.

Table 7. Classification of saline water based on salinity hazard

Water class	ECw (dS/m)	Salt concentration (mg/l)	Type of water
Non-saline	< 0.7	< 500	Drinking and irrigation water
Slightly saline	0.7-2	500-1500	Irrigation water
Moderately saline	2-10	1500-7000	Primary drainage water and ground water
Highly saline	10-25	7000-15000	Secondary drainage water and ground water
Very high saline	25-45	15000-35000	Very high saline water
Brine	> 45	> 35000	Sea water

Source: FAO irrigation and Drainage Paper 48, 1992

Table 8. Guidelines for interpretation of water quality for irrigation

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity				
EC_W[1]	dS/m	<0.7	0.7-3.0	> 3.0
or				
TDS	mg/l	< 450	450-2000	> 2000
Infiltration				
SAR[2]+ 0-3 and EC_w		> 0.7	0.7-.02	< 0.2
3-6		> 1.2	1.2-0.3	< 0.3
6-12		> 1.9	1.9-0.5	< 0.5
12-20		> 2.9	2.9-1.3	< 1.3
20-40		> 5.0	5.0-2.9	< 2.9
Specific ion toxicity				
Sodium (Na)				
Surface irrigation	SAR	< 3	3 – 9	> 9
Sprinkler irrigation	me/l	< 3	> 3	
Chloride (C1)				
Surface irrigation	me/l	< 4	4 – 10	> 10
Sprinkler irrigation	m^3/l	< 3	> 3	
Boron (B)	mg/l	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous effects				
Nitrogen (NO_3-N)[3]	mg/l	< 5	5 – 30	> 30
Bicarbonate (HCO3)	me/l	< 1.5	1.5 – 8.5	> 8.5
pH		Normal range 6.5 – 8.4		

Source : FAO (1985)

1. EXw means electrical conductivity in deciSiemens per metre at 25ºC
2. SAR means sodium adsorption ratio
3. NO_3-N means nitrate nitrogen reported in terms of elemental nitrogen

The disadvantage of such simplified schemes is in their neglect of the other factors influencing water suitability. Consequently a source of water may be rejected where it is usable or accepted where it should not be used because of unfavourable local conditions. Nevertheless, when scheems, based on water chemical composition alone, are used as general guides only in conjunction with other considerations, the classification may become very useful. This illustrates the limitation of generalized water-classification schemes and the need for a more quantitative means of assessing water suitability; one that takes into account the specific conditions of use. The rigid definition of salinity classes as being suitable or not is an oversimplification. The quantitative description of the limitation of use added to each class is generally insufficient.

These guidelines appear to be very conservative in respect of EC_w and SAR of irrigation waters. The limits of HCO_3 apply only for overhead sprinklers and not for flood irrigation. The basic assumptions in the guidelines comprised crop yield potential, soil conditions, methods of timing of irrigation, water uptake pattern of crops and three divisions of the restriction on use. These guidelines do not consider rainfall, better quality water for conjunctive use, and possible use for supplemental irrigation.

A major point that emerges from discussion so far is that it is presently impossible to set precise general standards of wide applicability for judging irrigation water quality as the actual suitability of a given water for irrigation depends very much on the specific conditions of use and on the relative economic benefit that can be derived from irrigation with that water compared to others. In addition, it is difficult to define absolute standards of irrigation water quality as the relationship of the composition and concentration of the soil solution to those of the irrigation water both complex and dynamic, being dependent upon a large number of factors that may be difficult to quantify. Soils and plant responses are not necessarily related to the properties of the soil solution.

In this regard, much work has to be done with much emphasis on how to manage such water and how to manage soils and crops irrigated with such water rather than on how to judge the water quality.

To avoid problems when using these poor quality water, there must be a sound planning to ensure that the quality of water available is put to be the best use.

Therefore, in assessing the suitability of saline water for irrigation it is important to take into considerations:

- cropping system: crop tolerance to salinity must be known on a quantitative basis for all specific ecological conditions of concern;
- prevention of salt accumulation in the soil; the dynamic of salts in the soil must be quantitatively known for all specific soils, climatic and hydrological conditions of concern. Furthermore, the interrelationship of leaching to crop response must also be understood;
- use of advanced irrigation and drainage technology: irrigation methods must be adjusted to the use of brackish water and must be very efficient, technically as well as economically; a drainage system must be provided when necessary.

"Ultimate" method for assessing the suitability of such water for irrigation consists of:

- predicting the composition and matric potential of the soil water, both in time and space resulting from irrigation and cropping;
- interpreting such information in terms of how soil conditions are affected and how any crop would respond to such conditions under any set of climatic variables (Rhoades, 1972).

A computer model for assessing water suitability for irrigated which uses these criteria has been developed (Rhoades and Merill, 1976). A simplified version of it, called "watsuit", has also been developed and used to assess drainage waters for irrigation -a description of "watsuit" and example outputs are given in (Rhoades, 1984a).

Prognoses of suitability are made after the soil water compositions are predicted. A soil salinity problem is deemed likely if the predicted root zone salinity exceeds the tolerance level of the crop to be grown. Use of the water will result in a yield reduction unless there is a change in crop and/or leaching fraction (LF). If yield reduction can be tolerated, then the appropriately higher salinity tolerance level can be used in place of the no yield loss threshold values.

The sustainable use of saline water for irrigation requires that our research programmes should be modified from the individual to the integrated ones where crop rotation, water management and soil amendements are all combined. Thus, many very poor quality water can be sustainability and successfully used.

THE POTENTIAL OF USING SALINE WATER IN IRRIGATION

Although the number of documented reports on successfully using brackish water for irrigation are relatively limited, enough exist to support the premise that water, more saline than conventional water classification schemes allow, can be used for irrigation (Box 1).

Recent research development on plant breeding and selection, soil crop and water management, irrigation and drainage technologies enhance and facilitate the use of saline water for irrigated crop production with minimum adverse impacts on the soil productivity and the environment. Extensive reviews of the world literature conducted on this topic, include those by Bressler (1979), Gupta (1979) and Gupta and Pahwa (1981).

Box 1. The potential of using saline water in irrigation

- In the USA, extensive areas (about 81,000 ha) of alfalfa, grain sorghum, sugarbeet and wheat are irrigated (by gravity flood and furrow methods) in the Arkansas Valley of Colorado, with water salinity not less than 1,500 mgl^{-1} and up to 5,000 mgl^{-1}(Miles, 1977). In the Pecos Valley of Texas, groundwater averaging about 2,500 mgl^{-1} of total dissolved salts, but ranging far higher, has been successfully used to irrigate cotton, small grains, grain sorghum and alfalfa, for three decades (Moor and Hefiner, 1976).
- Cotton is successfully grown commercially in the Nahal Oz area of Israel with saline groundwater (EC of 5 dS/m^{-1} and SAR of 26). The soil is treated annually with gypsum and National Carrier water (non-saline) is used (usually during the winter) to bring the soil to field capacity to a depth of 150 to 180 cm prior to planting (Harden, 1976; Bresster, 1979).
- In Egypt, 3 to 5 thousand million m^3 of saline drainage water are used for irrigating about 405,000ha of land. About 75 percent of the drainage water discharged into the sea has a salinity of less than 3,000 mgl^{-1}. The policy of the Government of Egypt is to use drainage water directly for irrigation if its salinity is less than 700 mgL-1; to mix it 1:1 with Nile water (180 to 250 mgl^{-1}) if the concentration is 700 to 1500 mgl^{-1}; or 1:2 or 1:3 with Nile water if its concentration is 1,500 to 3,000 mgl^{-1}; and to avoid reuse if the salinity of the drainage water exceeds 3,000 mgl^{-1}(Abu-Zeid, 1991).
- The saline Medjerda river water of Tunisia (annual average EC of 3.0 dS/m^{-1}) has been used to irrigate date palm, sorghum, barley, alfalfa, rye grass and artichoke. The soils are calcarious (up to 35% $CaCO_3$) heavy clays which crack when dry (Van't Level and Haddat, 1968; Van Hoorn, 1971).
- Salt tolerant cereal crops, vegetables, alfalfa and date palms are being successfully irrigated with water of 2000 mgl^{-1} TDS in Bahrain, 2400 to 6000 mgl^{-1} in Kuwait and 15000 mgl^{-1} in the Tagoru area of the Libyan coastal plain. Forest plantations have been established in the United Arab Emirates using groundwater with up to 10000 mgl^{-1} TDS (Arar, 1975).
- Extensive use of saline groundwater from shallow aquifers (106,000 hectare-meters per year) is being undertaken in nine districts of Haryana State in India. In four of the districts, the brackish water is used directly for irrigation, while in the remaining five it is used after blending with fresh canal water, or by alternating between the two supplies (FAO, 1990).

The assessment of saline water suitability for irrigation, combined with these latter cited worldwide references, give the evidences for the relatively high potentiality for using saline water for irrigation.

MANAGEMENT PRACTICES UNDER SALINE IRRIGATION WATER

With the use of saline waters for irrigation, there is need to undertake appropriate practices to prevent the development of excessive soil salination for crop production. Management need not necessarily attempt to control salinity at the lowest possible level, but rather to keep it within limits commensurate with sustained productivity. Crop, soil and irrigation practices can be modified to help achieve these limits. To maintain the efficacy of the control practices, some system of sensing the status of soil salinity is advisable.

Management practices for the control of salinity include: selection of crops or crop varieties that will produce satisfactory yields under the resulting conditions of salinity, use of land-preparation and planting methods that aid in the control of salinity, irrigation procedures that maintain a relatively high soil-moisture regime and that periodically leach accumulated salts from the soil, and maintenance of water conveyance and drainage systems. The crop type, the water quality and the soil properties determine, to a large degree, the management practices required to optimize production.

There is usually no single way to control salinity, particularly in irrigated land several practices can be combined into an integrated system that functions satisfactorily. Summaries of the hydraulic, physical, chemical and biological practices and human aspects to improve productivity are described in Box 2 and Fig. 2.

Box 2. Management practices using saline water for irrigation

- Hydraulic management:
    - Leaching (requirement, frequency)
    - Irrigation (system, frequency)
    - Drainage (system, depth, spacing)
    - Multiple water resources (alternating, blending)
- Physical management
    - Land levelling
    - Tillage, land preparation, deep ploughing
    - Seedbed shaping (planting resources)
    - Sanding
    - Salt scarping
- Chemical management
    - Amendments
    - Soil conditioning
    - Fertility, mineral fertilization
- Biological management
    - Organic and green manures
    - Crops (rotation, pattern)
    - Mulching
- Human management
    - Farmer
    - Socio-economic aspects
    - Environmental aspects
    - Policy

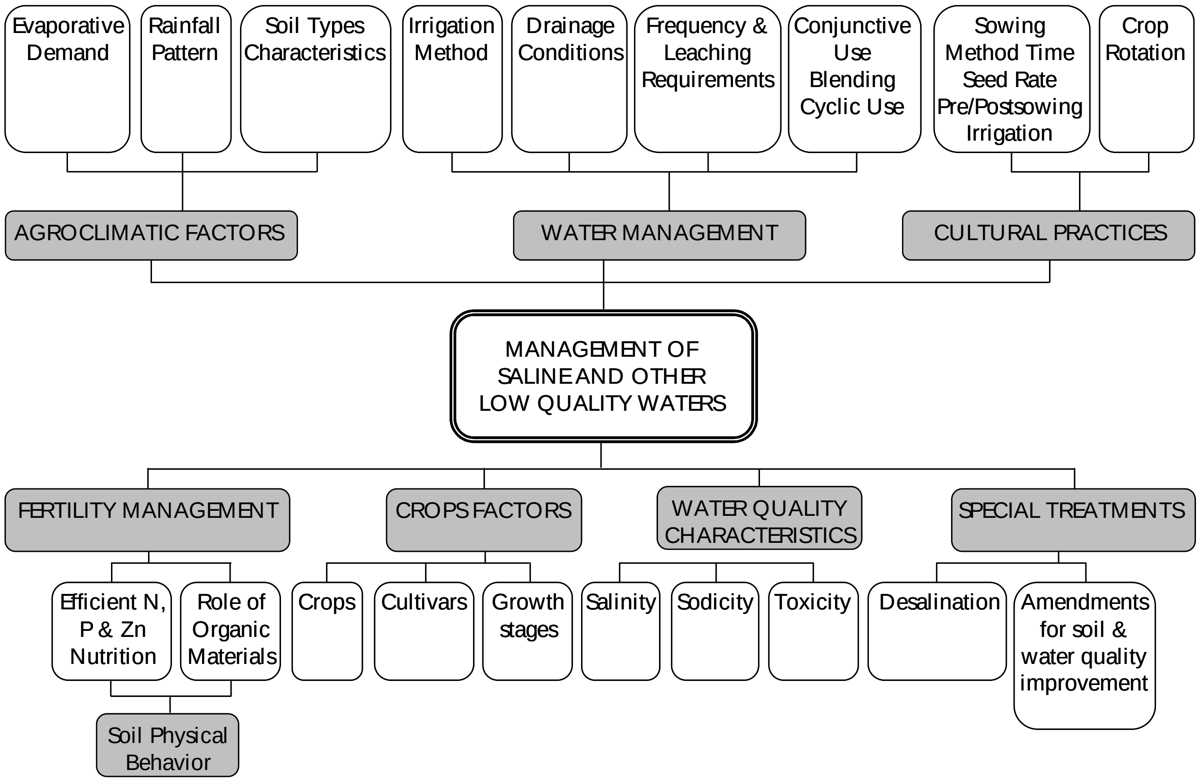


Figure 2. Management of saline water

The sustainability of a viable, permanent irrigated agriculture, especially with the use of saline irrigation waters requires the implementation of appropriate management practices to control soil and water salinity, not only with irrigated soils, but also within entire irrigation projects and even whole geo-hydrologic systems.

Three general management strategies seems practical: (a) control salinity within permissible levels, (b) change conditions to improve crop response, (c) change management to maintain yield at the field level when salinity causes damage at the plant level. All three can be used together, but the first one is the most commonly used.

Irrigation Practices and Management

Irrigation practices which are important in the management of saline water are: irrigation scheduling (amounts and interval); leaching scheduling (amount and timing); irrigation method and management of multi-source irrigation water of different qualities (Shalhevet, 1984).

Irrigation Scheduling

The irrigation scheduling should allow both good crop yields and adequate leaching of the soil when saline irrigation is practiced. Irrigation scheduling is complicated under saline water application mainly due to: i) information of consumptive use of many crops under saline water irrigation is not available and ii) under saline water practices the leaching requirements (LR) of the crops related to the salinity level of water must be calculated and included in the crop water requirements.

Successful saline irrigation requires a new production functions that relates crop yield to water consumption with acceptable irrigation intervals for the various crops.

In general, two approaches to estimate crop-water production functions are apparent in the literature. One approach synthesizes production functions from theoretical and empirical models of individual components of the crop-water process. Parameter values are obtained, in principle, by direct measurement. The second approach estimates production functions by statistical inference from observations on alternate levels of crop yield, water applications, soil salinity and other variables.

Most production functions are estimated based on the assumptions that water applications are uniform and soil conditions are relatively homogeneous. However, in most fields, depths of applied water and conditions of the soil vary in space considerably. Thus, field-level production functions may differ from those estimated from small agronomic plots of theoretical models that assume homogeneous conditions.

Different formulas and equations were proposed describing the production of several crops under saline water (Stewart *et al*., 1974; Shalhevet *et al*., 1983; Hanks *et al*., 1978; Frenkel *et al*., 1982; Para and Romero, 1980; Hoffman and Jobes, 1978; Meiri *et al*., 1980). The field and greenhouse results obtained by those authors offer convincing evidence of the unified relationship between yield and evapotranspiration, independent of changes in the two variables caused by salinity or water stress. These results are empirical and correlative. They do not shed light on the causes and mechanisms involved when osmotic or matric stresses are imposed on growing crops.

Several models to simulate crop-water production functions were developed recently (Feinerman *et al*., 1984; Letey *et al*., 1985; Bressler, 1987). The results of Bressler's model (1987) suggest full compensation between irrigation water amount and salinity for a relatively wide range irrigation water salinities. However, the results of the model of Letey *et al*. (1985) suggest that increasing the amount of irrigation water compensates only partially for the irrigation water salinities.

The dynamic models of Bressler (1987), Van Genuchten (1987), Hanks *et al*. (1977) can be used to stimulate seasonal crop water production functions for various irrigation schedules, if appropriate input data for the given model is available. Solomon (1985) and Letey *et al*. (1985) presented seasonal water-salinity-production functions based on our current understanding of the response of crops to water, the salt tolerance of crops and the leaching process.

Both the dynamic models and the seasonal models of Solomon and Letey *et al*. assume a unique relationship between yield and ET for a given crop and climate that is independent, regardless of whether the water stress leading to the reduced ET is caused by deficit water supply, excess salinity, or both. Beginning with this premise, Solomon (1985) stated the following:

- for any given amount and salinity of irrigation water, there will be some point at which values for field ET, leaching and soil salinity all are consistent with one another. The yield at this point is the yield to be associated with a given irrigation water quantity and salinity.

Letey *et al*. (1985) combined the relationships of yield versus ET, yield versus average root zone salinity and average root zone salinity versus leaching fraction to develop an equation that related yield to the amount of seasonal applied water of a given salinity. The combination of these relationships led to the point that, as Solomon stated, "The value for yield, ET, leaching and soil salinity are all consistent with one another".

The statistical/econometric approach to production function estimation differs from the approachs taken in both dynamic and seasonal production function models. The latter models tend to be formulated on conceptual and theoretical grounds. The statistical models often use *ad hoc* functional forms, although Dinar *et al*. (1986) indicates that this need not always be the case. A more significant difference is the method used to estimate unknown parameter values. The dynamic models presumably rely on actual measurements of the relevant parameters. In the statistical approach, parameter values are inferred from observations on alternate levels of yields and inputs. Statistical models can predict the conditions under which they are estimated reasonably well but will likely be less transferable to other areas as compared with dynamic production function models and the seasonal ones.

There is no doubt that substantial progress has been made in developing empirical models that can be used to relate crop yields and irrigation management under saline conditions. However, further work is needed before these empirical models to be reliably applied under a wide variety of field conditions. Further work also is required on the relation of ET to soil and environmental conditions. In many instances, potential ET or transpiration is determined externally to the model. However, potential ET depends in part on the size of the plant, which depends on irrigation management during the previous part of the irrigation season. Hence, relative and maximum or potential ET should be endogenous variables.

Non-uniform applications of water and spatial variations in soil parameters significantly affect seasonal water production functions. To date, little or no work has been done to estimate transient production functions under non-uniform conditions. Procedures for estimating uniformity distributions on a scale relevant to the plant also are needed. Variations in the environment affect the growth of the plant, so random effects related to the weather need to be included in models of the growth of plants under saline conditions.

Irrigation Intervals

Plant growth is a function of the osmotic and matric potential of soil water; osmotic potential can be controlled by leaching, whereas matric potential is controlled by adequate and timely water application.

The question arises of whether it is necessary to narrow the watering intervals to keep the soil solution concentration low (to diminish harmful effects of the salt) or whether it is possible to lengthen the interval and to apply large amounts of water?

Analysing the process that occurs when evapotranspiration reduces soil water content between waterings shows that as the soil dries, the matric potentials -as well as the soil solute potential- decreases (increases of soil solution concentration). Because of the decreased soil solute potential, beneficial effects from decreasing the irrigation intervals as soil salinity increases could be reasonably expected (Allison, 1964; Ayers and Westcott, 1967). This process is counteracted by the effect of irrigation intervals on the shape of salt distribution in the soil profile and on the overall level of salinity. Under steady state conditions, increased irrigation results in an upward shift of the peak of the salt distribution profile, thereby increasing the mean salt concentration in the upper main root zone. Furthermore, ET increases as irrigation becomes more frequent, leading to additional water applications and an increase in the salt load (Van Schilfgaarde *et al*., 1974).

The effect of irrigation intervals on the final crop yield was studied by several workers (Bernstein and François, 1975; Hoffman *et al*., 1983; Hamdy, 1990a). The data obtained indicated that increasing irrigation frequency did not significantly benefit crop production and may increase, rather than decrease, the effect of salinity.

Irrigation scheduling is a major parameter for assessing an appropriate saline irrigation management. However, this subject did not receive the attention of researchers in this field. A frequent constraint to improving on-farm water use is the lack of information of when an irrigation is needed and what capacity of replenishment is available within the root zone.

Irrigation scheduling requires some method of assessing the water availability to the crop with sufficient lead time to provide for a water application before significant stress occurs. In addition the amounts of water needed for replenishment of the depleted soil moisture from the rootzone and for leaching must be determined. Prevalent methods used to determine the onset of stress include both direct and indirect measurement. Leaf water potential can be measured with a pressure bomb and used to determine stress; however, the method does not give information with which to predict when the stress will occur in advance of its occurrence nor does it provide a measure of the *amount* of water to apply. Infrared thermometry can be used to indirectly measure plant water stress which results in the partial closure of stomata and in reduced transpiration, causing leaf canopy temperature to rise above ambient air temperature. This temperature difference can be interpreted in terms of a crop water stress index with which irrigation need can be assessed (Pinter & Reginato, 1981). It suffers the same limitations as the leaf water potential method. Other scheduling methods can be used which are based on irrigating when depletion of soil water per se or soil water potential, or some associated soil or water property, reaches some predetermined level (set-point). The attainment of this level can be ascertained either by direct measurement of some appropriate soil property or estimated from meteorological data. With the latter method, daily reference evapotranspiration of a full ground-cover crop (usually a well-watered healthy grass) is calculated from measurements of air temperature, humidity, solar radiation and wind. The actual evapotranspiration (ET) of the crop is then estimated from empirically determined crop coefficients (Wright, 1981). The summation of these daily

ET values is a measure of accumulative soil water depletion. A plot of depletion versus time gives a way to project the need for irrigation when the degree of allowable depletion is known. The same approach can be used based on direct measurements of soil water content, or a related parameter, using neutron meters, resistance blocks, time-domain reflectometric (TDR) sensors, four-electrode sensors, or various soil matric potential sensors.

Most of the methods suffer the limitation of needing an empirical determination of the set-point value for irrigation which varies with crop rooting characteristics, stage of plant growth, soil properties and climatic stress. Furthermore, measurements of soil water content or matric potential cannot be used (at least not conveniently) to assess or control the leaching fraction as is required to prevent an excessive build-up of soil salinity. For saline water, irrigations should be scheduled before the total soil water potential (matric plus osmotic) drops below the level which permits the crop to extract sufficient water to sustain its physiologic processes without loss in yield.

According to Rhoades & Merrill (1976), the frequency of irrigations would ideally be determined by the total soil water potential in the upper root zone where the rate of water depletion is greatest. On the other hand, the amount of water to apply depends on stage of plant development and the salt tolerance of the crop and, consequently, should be based on the status of the soil water at deeper depths.

In conclusion, to avoid problems and for a sustainable water saline use in agriculture, further work has to be done and directed to fulfill this gap. The subject is not easy but it is a further complex one, this complexity is due to the fact that under saline water irrigation, the irrigation scheduling is not only governed by the prevailing climatic and pedological conditions but also with the salt content of irrigation water as well as the crop under cropping.

Irrigation Methods

Proper choice of the irrigation method greatly facilitates reduction in drainage volume, uniform leaching and use of poor quality water. Poor selection of irrigation method not only aggravates salinization but may also create drainage problems. Utilization of saline water resources in the long term, calls for scientific knowledge of soil-water-plant relationships and its modifying influence on irrigation techniques.

The method used for saline water irrigation may be guided by:

- the distribution of salt and water under different irrigation methods;
- crop sensitivity to foliar wetting and the extent damage to yield, and
- the ease with which solubility and matric potential can be maintained in the soil.

In the case of border or basin irrigation, salinity will increase in the top layer during the irrigation interval and decrease during watering more or less homogeneously if the land is well graded.

Under saline irrigation, the period of germination and emergence of the seedlings is the most critical stage of crop growth. A failure at this stage leads to a poor stand and a considerable yield decrease. Failures recorded where saline water was used can often be attributed to failures during germination and emergence and not to excessive soil salinity at a later stage (Hamdy, 1990b; Hamdy *et al*., 1993). Salt accumulation can be especially damaging to germination and seedling establishment when raised beds or ridges are used and "wet-up" by furrow irrigation. Seed bed shape and seed location should be managed to minimize high salt effects. For soils irrigated with saline water, slopping beds (Fig.3) are the best where the seedling can be safely established on the slope below the zone of salt accumulation (Bernstein *et al*., 1955; Bernstein and Fireman, 1957).

Under flood or sprinkler irrigation where water and salt transport is downward and away from the seedling, limited pre-planting leaching of the upper soil strata may take care of the germination and establishment inhibition. Under furrow and drip irrigation there is downward component of water and salt transport, but another component is lateral and upward in the spaces between furrows or laterals. With these methods the adjustment of the soil surface contour and seedling or planting position according to the expected salt distribution can limit significantly this damage.

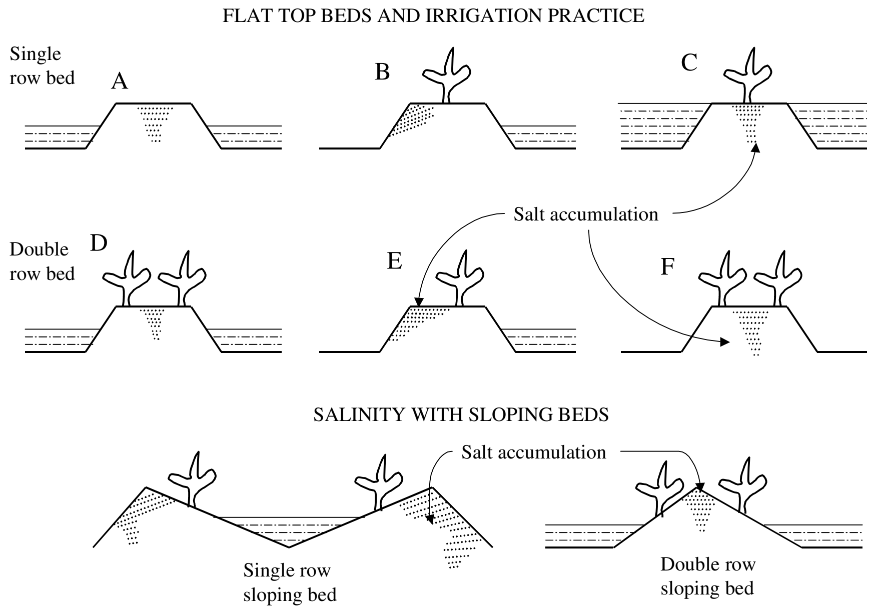


Figure 3. Typical salt accumulation pattern in ridge and bed cross section in soils irrigated by furrows (Bernstein et. al., 1955; Bernstein and Fireman, 1957)

Irrigation by sprinkling allows close control of the amount and distribution and is often used on land where the slope is too great for other methods. In addition, both in soils with a high infiltration rate and those with soil structure problems sprinkling may provide alternative. The principal problem encountered with sprinkler irrigation using saline water is wetting of foliage with consequent tip and marginal burning of the leaves and ultimate defoliation. Provided foliar burn is avoided, sprinkler irrigation has the advantageous that salt-removal efficiency with sprinkler irrigation tends to be substantially higher than with flood or trickle irrigation.

Evaluating the ability of the irrigation method under saline water practice, the prevailing moisture conditions under the drip methods provides the best possible conditions of total soil water potential for a given quality of irrigation, besides avoiding leaf injured. The roots of the growing plants tend to cluster in the leached zone of high moisture near the trickles, avoiding salt that accumulates at the wetting front. Moreover drip irrigation offers the advantage of supplying water on a nearly daily base, in that way keeping the water content of the soil and the salinity of soil solution at a stable level (Ragab, 1998).

Furthermore, under drip irrigation, crop yields are higher with better quality water, reduced weed growth, uniformity of irrigation, water saving as well as better fertilizer application and low operating cost.

The main limitations of drip irrigation lie in the higher initial cost, low root soil aeration, dense root mass, constant power and water supply needs, and higher level of know-how. The development of a salt interface at irrigated and non-irrigated zone may damage the next crop without proper leaching of salts before planting of the next crop. The water distribution uniformity is greatly influenced even when 1 to 5 percent emitters are completely closed with 2 to 8 emitters per plant. The value of uniformity coefficient more than 90 percent is considered excellent and less than 60 percent unacceptable. The discharge rate of emitters having laminar and unstable flow regimes increases with the increase in temperature but the effect is minimum for the turbulent emitter. The ageing or deterioration due to drying, wetting, chemicals in water, exposure to rodent and insect etc. may increase the coefficient of variation.

When high salinity water is used with drip irrigation in arid regions, the salts tend to accumulate at the soil surface and towards the periphery of wetted soil. The space between the parallel drip lines remains dry and escapes salinity processes. The salts that accumulate below the emitters can be flushed down continuously by daily or alternate day irrigation. If the leaching requirement ratio is more than 0.1, the daily irrigation should include enough extra water to maintain a continuous downward movement of water to control salts. The higher the salt content of irrigation water, the higher the leaching requirement. The crops more sensitive to salinity requires more leaching than salt tolerant crops. (Dainel, 1997; ICID, 1998; CSSRI 1998).

Subsurface systems provide no means of leaching the soil above the source. Continuous upward water movement and evaporation cause salt to accumulate near the soil surface. Unless the soil is leached by rainfall or surface irrigation, salt levels will certainly become toxic. Generally, this system, is not suitable over the long-term, especially when salts are high in water supply.

Salt distribution within the root zone is influenced by the water extraction pattern of the crop and the method of water application. Salt distribution under different irrigation systems is illustrated by Fig.4 (Oster *et al.*, 1984).

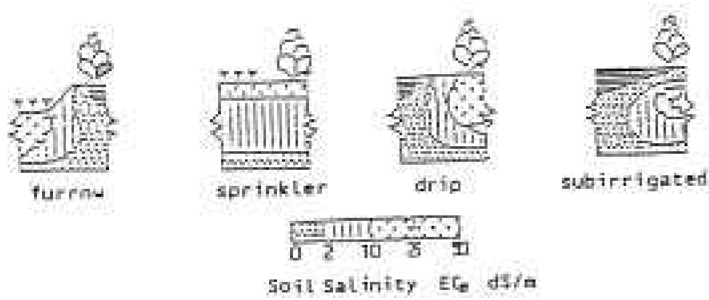


Figure 4. Salt distribution with the root zone (Oster *et al.*, 1984)

The irrigation regime greatly influences the moisture and salinity profile and refers to the variables of water supply to the soil: dripper discharge, water quantity applied during one irrigation and the irrigation interval. Increasing the discharge generally enlarges the diameter of the wetted area and increases the water content of the upper soil layer close to the dripper. The lower the hydraulic conductivity of the soil and the longer the duration of the irrigation, the more pronounced will be this effect (Bressler *et al.*, 1971). Reducing the irrigation interval without changing the total amount of water will mean smaller amounts of water being applied each time. Wetting will be shallower, but a higher average water content will be produced in the main region of water flow, due to the shorter period available for drainage. There will also be a change in the salt concentration sites (Goldberg *et al.*, 1971).

Leaching Management for Salinity Control

Leaching is the key factor by which soil salinity can be maintained at acceptable levels without undue damage to crops. Thus appropriate natural or installed drainage and disposal systems are essential.

Soil salinity control becomes more difficult as water quality decreases. Greater care must be taken to leach salts out of the root-zone before they reach levels that might affect yields. Alternatively, steps must be taken to plant crops tolerant to the expected root-zone salinity. The frequence and amount of leaching depend on water quality, climate, soil and crop sensitivity to salinity.

The frequency and amount of leaching depend on water quality, climate, soil and crop sensitivity to salinity, the crop seasonal period as well as the accumulated salts in soils.

For efficient leaching management, it is questionably desirable to use extra water to every watering to leach the soil, at the same time increasing the peak requirements of an irrigated area or, on the contrary, to apply less water and to apply less leaching complements when more water is available. This will greatly depend on the salt distribution, which is related to the growing season. Leaching during a period of peak, consumptive use means that not only are greater amounts of water applied but also that greater amounts of salts are brought into the soil. Moreover with permanent leaching there is greater risk of water stagnation and suffocation of the crops. On the other hand, seasonal leaching during a period of low consumptive use can also draw advantage from rainfall, at least in the Mediterranean area and the Middle East where rainfall occurs during the winter.

The findings of Bernstein and François (1973), François (1981) and Hamdy (1990c) support the idea that applying the required leaching when salt accumulation becomes excessive -periodically rather than at every irrigation- is a better strategy for short-season crops.

The adoption of LR as excess water at every irrigation, its indirect benefit is a maintenance of a higher soil water content, in comparison with water application without leaching, for a significant time after each irrigation. The effect is most significant under frequent irrigations. Under such conditions the positive crop response to leaching can be due to both higher soil moisture and reduced soil salinity (Bressler and Hoffman, 1986; Meiri and Plaut, 1985).

The adoption of LR as excess water at every irrigation is most undesirable when saline water is added to a field having a lower salinity level than the acceptable maximum for the crop and salinity build-up occurs. The additional saline water may aggravate the salinity stress as it enhances the salinization for a short season crop it may also result in a higher EC values of extracted soil solution.

Leaching at every irrigation may be accompanied with large unintended errors. Since LR is usually a small fraction of irrigation dose, a small error in the estimate of ET may introduce a considerable error or in the intended L.R and as a result an over leaching practices.

Irrigation tests in Tunisia (Van Hoorn, 1991) have shown that leaching during the period of peak demand can quite well be reduced or postponed. This also follows from salt balance calculations. Leaching during a period of peak consumptive use means that not only are greater amounts of water applied but also that greater amounts of salt are brought into the soil. So, this surplus amount of salt counterbalances to a certain extent the advantage of more leaching water. The author also revealed that, as permanent leaching means greater water applications, there is greater risk of water stagnation and suffocation of the crops. On the other hand, seasonal leaching during a period of low consumptive use can also draw advantage from rainfall, at least in the Mediterranean area and the Middle East where rainfall occurs during the winter.

However, the point still needs to be settled: if leaching should be practiced periodically, at which growing stage should leaching be administrated and what is the appropriate leaching fraction?

Hamdy and Nassar (1991) concluded that for maximum utility and better saving of fresh water, leaching should be carried in accordance with the salinity tolerance of the growing stage and in proper quantities (L.F.). In this regard, the extent to which leaching can be minimized is limited by the salt tolerance of the crops being grown, salt composition of irrigation water and soil characteristics. Increase efficiency or reducing leaching under the proper circumnstances can result in more effective water use in the first instance, a reduction in the salt load needing disposal and a substantial reduction in the volume of drainage water.

A part of the research programme carried out by Bari Institute was developed to leaching practices and management with salty water. In this regard, Hamdy (1989) recommended the followings:

- Two main principles should be carefully considered when leaching with low quality waters; firstly, the EC value of leaching water must be lower than that of the soil EC and, secondly, frequent tests should be performed on soils under leaching bearing in mind that the target to aim at is a soil salinity equivalent to that of the water to avoid the potential danger of reintroducing salts by excessive leaching.
- Under saline irrigation practices, leaching even with saline water played an important role in reducing salt accumulation in soils and improving all the parameters under study (physiological, plant growing and crop field). Such improvements varied according to the variation in the salt content of the leaching water. The lower the salt content in leaching water the greater the improvements. Leaching with waters of EC value around 3 dS/m, particularly, when ECi are relatively high, showed to be advantageous than leaching was practiced with more saline water of 6 and 9 dS/m.
- If leaching is practiced with saline water of the proper leaching fraction, we can bring our soil to an EC value around that of the leaching water. Consequently, the choice in plant selection will be limited and the crop rotations should be rearranged so as to include crops that can tolerate the

prevailing salt conditions. Leaching with the good quality water could completely eliminate such disadvantages and offer a free hand possibilities in the choice of crops. Therefore, under saline irrigation practices, it is always recommended that leaching should be practiced with waters of an EC value lower than the irrigation water.

- Indeed, irrigation with saline water and leaching together with saline water is a complex one. This subject should be regarded more carefully due to its importance, particularly in the arid regions. Further studies are urgently needed under controlled conditions as well as in the fields to have more information to fulfil the knowledge gab in this subject.

Finally, to increase the efficiency of leaching and reduce the amount of water needed, the following practices are suggested (Box 3):

Box 3. Efficient leaching practices

- Leach during the cool season (rather than during the warm season) when ET losses are lower;
- Use sprinklers at lower application rate than the soil infiltration rate to favour unsaturated flow, which is appreciably more efficient for leaching than saturated flow;
- Use more salt-tolerant crops, which require a lower LR and thus a lower water demand;
- Use tillage to slow overland water flow and reduce the number of surface cracks which bypass flow through large pores and decrease leaching efficiency; and
- Where possible, schedule leachings for periods of low crop water use, or postpone leaching until after the cropping season.

CONJUNCTIVE USE OF SALINE AND FRESH WATER

The conjunctive use can be defined as the development and management of multiple water resources in a coordinated manner such that the total yield of the system over a period of years exceeds the sum of the yields of the individual components of the system resulting from an uncoordinated operation. The objective of conjunctive use implies not only the combined use of water resources of more than one type but also their exploitation through efficient management in techno-economic terms by taking advantage of the interaction between them and the impact of one on the others.

It refers to the integrated management of surface water and ground water and it requires: (1) quantification of annual recharge and its spatial distribution to assess potential of conjunctive use, (2) simulation of the ground water basin parameters to analyse the impacts of irrigation and development of the ground water on the changes in water levels in the aquifer, and (3) identification of conjunctive use strategy that is most suitable for the given hydrologic, hydrogeologic, agroeconomic and hydrochemical conditions. The conjunctive use planning methods include: (1) engineering considerations for feasible ground water operations based on simulation of ground water basin, and (2) resource allocations based on both simulation and mathematical programming approach.

In the conjunctive water use process, water balance is estimated considering rainfall, surface runoff, seepage from canals, drains and natural streams and irrigation water recycling. The water table fluctuations and its rise are determined. The optimum water yields that can be drawn from the wells or tubewells with different operation schedules are determined. The available quantity of surface water from canals, lakes or ponds is estimated. The water quality of surface water and ground water is evaluated. A matching cropping plan with the irrigation requirement is developed and the salt tolerances of crops are determined.

The conjunctive use planning must include principles involved in the two water systems considered independently, but must also include principles to guide the optimal development of the complementarity of the two systems. Conjunctive use is planned and practised with the following objectives:

I. mitigating the effect of the shortage in canal water supplies often subject to steep variation in river flow during different periods in the year;
II. increasing the dependability of existing water supplies;
III. alleviating the problems of high water table and salinity resulting from introduction of canal irrigation;

IV. facilitating the use of poor quality water which cannot otherwise be used without appropriate dilution;
V. storing water in ground water basins closer to the users, to ensure water supply to the users in case of interruption of surface water supply;
VI. minimizes drainage water disposal problem.

MANAGEMENT OF THE MULTI-QUALITY WATER RESOURCES

Operation strategies that permit an optimal increase in cropped area and maximize the use of all available water of different qualities can be outlined under the following two major operational techniques:

Blending water (network dilution): different quality waters are mixed in the water supply permitting the predetermination of water quality for every field according to the tolerance of each crop to salinity, thereby either reducing the total salt concentration or changing the composition of the water reducing SAR. This procedure may increase the total quantity of water available for irrigation but at the same time will lower the quality of good water available.

Blending water either to increase the quality of water resource or to improve the relatively poor quality is a common practice. This has shown a good performance under many projects (Australia, Egypt, Israel, Pakistan and India). So far, results of studies show that this practice is not costly, more economic and easier to implement on large farms than other alternatives uses of water. In addition, blending may be more practical and appropriate, providing the drainage or shallow groundwater is not too saline per se for the crop to be grown. Nevertheless, for an extensive reuse of saline water, agronomic trials seems indispensable in order to select salt tolerant cultivars. In addition, specific site allocation of the saline water and the tolerant crops may limit the use of such water. In many cases, there is only a limited choice of tolerant crops with relatively low profit. Furthermore, even the yield of tolerant crops may be influenced by sensitive growth stages.

The suitable blending or mixing ratios of surface and ground water are worked out to plan conjunctive use of surface water and saline ground water. Considerable research efforts dealing with technical aspects of dilution process (mixing different kinds of water into a single distribution system) within the water distribution network have been pursued (Jury *et al.*, 1980; Tyagi and Tanwar, 1986). However, such blending is counter productive (Rhoades, 1983 and 1988).

The following logic is applied. A plant must expend bio-energy (that would otherwise be used in biomass production) to extract water from a saline (low osmotic potential) soil solution. When a water of excessive salinity for crop production is mixed with a low-salinity water and used for irrigation, the plant removes the "good water" fraction from the mix until the fraction of the mix made up of the excessively saline portion is left. This saline fraction is still as unusable (from the the plant energy expenditure point of view) as it was before mixing. But salt-sensitive crops can not concentrate the solution to this point without excessive yield loss. Thus, a fraction of the low-salinity (fully usable) water used to make the blend was made unavailable for transpiration as a consequence of blending. Thus diluting excessively saline water with less saline water does not stretch the water supply for crops of the same or lower salt tolerance. This "saline water" component is only usable by crops that are more salt-tolerant than those grown which produced the drainage.

Conjunctive use of good and poor quality water (recycling-alternation):
i) Soil water dilution through alternate (series/cyclic) use of good and poor quality waters according to water availability and crops needs.
ii) sequential application: the water source is changed during the season according to the specific salt tolerance of the crops at each growth stage.

This technique is centering on the possibility of applying alternatively fresh and brackish water according to the varying tolerance of crops during growth stages. This reuse strategy that avoid blending has been demonstrated in field projects to be viable and advantageous in well-managed irrigation projects (Rhoades, 1984; 1988 and Rhoades *et al.*, 1988).

The experimental studies carried out by Bari Institute to evaluate the fore-mentioned two water application strategies favored more the alternate water application than the blending one (Box 4) (Hamdy, 1991 and 1993):

Box 4. Alternating use of good and poor quality water (advantages)

- Avoiding the deterioration of the good water quality. This water could be used at the time it should be most needed, for instance at the germination and seedling stages which are very sensitive to the salinity level of irrigation water as well as to satisfy the leaching requirements which requires water of relatively good quality;
- With the plants which are sensitive to the salinity level in irrigation waters, satisfactory production could only be achieved with water of good quality through alternative application modes. The disadvantages appearing under mixing could be completely eliminated and offer a free-hand possibility in using the different water resources according to the prevailing conditions;
- The cyclic use of water of low and high salinity prevents the soil from becomings too saline while permitting, over a long period, the substitution of brackish water for a substantial fraction of the irrigation needs.
- Cyclic strategy provides a vast choice of the crops to be included in the crop rotation as compared with the blending technique where crop selection is limited to the tolerant ones.

Although cyclic strategy has more potential flexibility than the blending one, there may be difficulty in adopting the cyclic strategy on small farms. In addition, application implies a double distribution system of water -both saline and fresh- to farms.

However, the matter is not simply the alternation of water resources. A suitable cropping pattern is also required that allows the substitution of saline water by normal water to irrigate certain crops in a suitable tolerant growth stage. Indeed, the timing and amount of possible substitution will of course, vary with the quality of the two waters, the cropping pattern, the climate, certain soil properties and the irrigation system.

To overcome the shortage in available fresh water resource in arid and semiarid countries, particularly those of the Mediterranean and for a better reuse of low quality water and for a more fresh water saving through conjunctive water use nationally, it is needed a critical review of the prevailing situation vis-a-vis available water resources and their use in the cropping pattern now being followed. Such an exercise should ideally be focussed on the following requisites:

i) definition and delineation of appropriate agro-climatic irrigation zones for current assessment and future planning of water resources with respect to the use of irrigation;
ii) assessment of the quantum of water available for irrigation in different zones;
iii) estimation of the irrigation requirements on the basis of cropping pattern and recommended irrigation practices;
iv) assessment of the current utilization of irrigation water and ascertaining the magnitude of its over and under use in different zones as in (i) above;
v) determination of alternative pattern of cropping, irrigation practices and supply of irrigation water together with related policy measures such that available water is optimally used to maintain ground water level within safe limits and to keep the short and long-run economic effects in proper balance.

INTEGRATED STRATEGY TO FACILITATE THE USE OF SALINE WATER FOR IRRIGATION AND TO MAXIMIZE THE BENEFICIAL USE OF MULTIPLE WATER SOURCES

In this section, a crop/water management strategy that should increase the practicality of using saline waters for irrigation, is described. Aspects of this strategy have been recently discussed elsewhere (Rhoades, 1983, 1984, 1985; Rhoades *et al.,* 1988a, b). The impetus for the strategy-has its origin in the assumption that typical farmers will not use brackish water for irrigation if access to enough water of lower salinity is available, unless the brackish water can be used without significant losses in yield, cropping flexibility or significant changes of farming practices.

The proposed management strategy, which meets these requirements, is to substitute the saline water (such as drainage or shallow groundwater) for the "good" water when irrigating certain crops in the rotation when they are in a suitably salt-tolerant growth stage; the "good" water is used at the other times. The maximum soil salinity in the rootzone that can result from continuous use of brackish water will not occur when such water is used for only a fraction of the time. The timing and amount of substitution will vary with the quality of the two waters, the cropping pattern, the climate, and the irrigation system. Whatever salt build-up occurs in the soil from irrigating with the brackish water is alleviated in the subsequent cropping period when a more sensitive crop is grown using the low-salinity water for irrigation. (It should be noted that a soil will not generally become unduly saline from use of a saline water for a part of a single irrigation season and often not for several seasons)

Furthermore, the yield of the sensitive crop should not be reduced if proper preplant irrigations and careful management are used during germination and seedling establishment to leach salts out of the seed area and shallow soil depths. Subsequent "in season" irrigations will leach these salts farther down in the profile ahead of the advancing root system and "reclaim" the soil in preparation for the brackish water which will be used again to grow a suitably tolerant crop. This cyclic use of “low” and “high” salinity waters prevents the soil from becoming excessively saline while permitting, over the long period, substitution of the brackish water for a low-salinity water for a large fraction (50%) of the irrigation water need.

In this regard we shall briefly describe two field experiments as examples illustrating a new crop/water management strategy to facilitate the use of saline waters for irrigation (Rhoades, 1988).

- The first concerns a 16 ha experiment in the Imperial Valley of California. Two sources of surface water were available: "good" irrigation water from the Colorado River containing approximately 900 mg/l TDS and water from the Alamo River, which is in essence a drain to dispose of agricultural drainage into the Salton Sea, with 3000 mg/l TDS. The objective was to grow a mixture of salt tolerant and salt sensitive crops in rotation, using that water source for any one irrigation that was suited to the crop and its stage of growth. The results verified that excellent crop yields could be maintained on a field scale with conventional surface irrigation, even if salt sensitive crops followed salt tolerant crops in the rotation, with a substitution of Alamo River water for Colorado River water over 50% of the time. Thus, this experiment demonstrated that the reuse of drainage water could reduce the need for fresh water without impact on crop yield.
- The second experiment, in the lower San Joaquin Valley of California, made use of well water at 8 ds m-1 (and 5.5 mg l-1 boron), California's Aqueduct water (0.6 dS m-1) and a 50-50 mix. In this case, the objective was to grow cotton with a minimum of fresh water. Again, results verified that highly respectable cotton yields could be obtained with saline water, especially if fresh water was used for seedling establishment and plant density was increased from conventional practice. As in the previous experiment, the call on fresh water could be reduced substantially.

The findings of the above-mentioned experiments indicate that the dual-rotation cyclic strategy for management of the multi-quality water resources not only resulted in relatively high freshwater saving, but also facilitated the use of saline water for irrigation. This can be clearly demonstrated by considering the following:

- In both experiments all over the cropping period including the different crop rotations, irrigation with freshwater including the leaching requirements amounted to nearly 50% of the total irrigation volume without any significant yield losses.

The maximum possible soil salinity in the rootzone resulting from continuous use of saline water does not occur when this water is used only for a fraction of the time.

Alleviation of salt build-up resulting from irrigation of salt-tolerant crops with the saline water occurs later when a salt-sensitive crops (s) is irrigated with the low-salinity water supply, or during off season periods of high rainfall.

Proper preplant irrigation and careful irrigation management undertaken during germination and seedling establishment are made using the low-salinity water supply to leach salts accumulated from saline irrigations out of the seed-area and from shallow soil depths.

The 50% saving in freshwater on one hand, keeping the soil at its productivity level maintaining soil salinity and alkalinity level within acceptable limits for seedling establishment and the subsequent growth of the individual crops growth in rotation along with the high crop yields on the other hand, support the credibility of the recommended cyclic, dual-duration (crop and water strategy) to facilitate the use of saline water for irrigation.

However, in order to plan and implement a successful practice involving the use of the cyclic, dual-rotation strategy for irrigating with saline waters, various other considerations must be addressed. The intention here is not to provide a step-by-step process that must be followed nor a rigid set of criteria to address these considerations, since most management decisions are subjective and case specific, but to discuss some of the factors that should be considered and to provide some rough guidelines for selecting appropriate management practices.

Perhaps the most important management decision to make before implementing a reuse practice is crop selection. In most cases, it is recommended that crops of high tolerance to salinity be selected when saline drainage water is to be used for irrigation. However, crops of intermediate tolerance (e.g. alfalfa, melons, tomatoes and wheat) may also be used in some cases, especially if the crop quality is sufficiently benefitted. For example, drainage water (EC 4-8 dS/m) significantly increased the protein content of wheat and alfalfa (Rhoades *et al.,* 1989a), soluble solids in melons and tomatoes (Grattan *et al.,* 1987), total digestible nutrients in alfalfa (Rhoades *et al.,* 1989a), and improved colour and netting of cantaloupe (Rhoades *et al.,* 1989a), and improved peelability in processing tomato (Grattan and Rhoades, 1990). While improved plant quality should not be the major factor in adopting a reuse practice it may be an important factor in crop selection. Use of saline water to irrigate crops of intermediate tolerance to salinity is feasible, of course, only after seedlings have been established by good quality water.

FACILITATING THE USE OF SALINE WATER FOR IRRIGATION: ESSENTIAL PARAMETERS OF PRIORITY CONSIDERATION

Operation Delivery Systems Efficiency

Water delivery and distribution systems must be operated efficiently to facilitate the timely supply of water in the right quantities and to avoid waterlogging and salinity build-up in irrigated lands, especially when saline waters are involved. The amount of water applied should be sufficient to supply the crop and satisfy the leaching requirement but not enough to overload the drainage system. Over-irrigation contributes to the high water table, increases the drainage requirement and is a major cause of salinity build-up in many irrigation projects. Therefore, a proper relation between irrigation, leaching, and drainage must be maintained in order to prevent irrigated lands from becoming excessively waterlogged and salt-affected.

In this regard, it is all important when using saline water for irrigation having reliable data or appropriate methods to predict project water requirements. FAO (1984) has developed methods to determine project water requirements based on actual crop water needs, leaching requirements and irrigation efficiencies, a computer programme (CROPWAT, 1992) and a complementary computerized database programme (CLIMWAT, 1991).

Excessive loss of irrigation water from canals constructed in permeable soil is a major cause of high water tables and secondary salination in many irrigation projects. Such seepage losses should be reduced by lining the canals with impermeable materials or by compacting the soil to achieve a very low permeability.

Furthermore, provision for effective flow measurement should be made. It is generally computed that many delivery systems encourage over-irrigation because water is supplied for fixed periods or fixed amounts, irrespective of seasonal variation in on-farm needs and thereby salinity and water table problems are often the result. In addition, and to achieve high efficiency and to facilitate salinity control, it is of paramount importance that the distribution system to be designed and operated as to provide water on demand and in metered amounts as needed.

Irrigation Efficiency

Improvements in salinity control generally come hand-in-hand with improvements in irrigation efficiency. The key to the effective use of saline irrigation waters and salinity control is to provide the proper amount of water to the plant at the proper time. The ideal irrigation scheme should provide water as nearly continuously as possible, though not in excess, as needed to keep the soil water content in the rootzone within optimum safe limits. However, carefully programmed periods of stress may be needed to obtain maximum economic yield with some crops; cultural practices also may demand occasional periods of dry soil. Thus, the timing and amount of water applied to the rootzone should be carefully controlled to obtain good water use efficiency and good crop yield, especially when irrigating with saline water. As mentioned above, this requires water delivery to the field on demand which, in turn, requires the establishment of close coordination between the farmer and the entity that distributes the water; it calls for the use of feedback devices to measure the water and salt contents and potentials in the soil and devices to measure water flow (rates and volumes) in the conveyance systems.

A frequent constraint in improving on-farm water use of saline water is the lack of knowledge of just when an irrigation is needed and of how much capacity for storage is available in the rootzone. Ways to detect the onset of plant stress and to determine the amount of depleted soil water are prerequisites to supplying water on demand and in the amount needed. Prevalent methods of scheduling irrigation usually do not, but should, incorporate salinity effects on soil-water availability (Rhoades *et al.,* 1981). When irrigating with saline waters, the osmotic component of the soil water potential of the rootzone must be considered in scheduling decisions.

Saline Water Irrigation Planning and Management Models

A couple of models are developed to predict long term behaviour of ground water, rootzone salinity index, desalinization of a tile drained soil profile, quality of ground water and drainage, efficient solute transport, crop water requirement and crop response models to simulate crop production. Some computer models are indicated as follows:

- **SIWATRE Computer Model:** It was developed in ILRI, the Netherlands for simulation of water management system in arid regions (unsaturated flow model) which has the components as sub-model design for water allocation to the intakes of the major irrigation canal, sub-models WDUTY for estimation of water requirement at farm level, sub-mode REUSE for the water losses to the atmosphere, and WATDIS sub-model for water distribution within the command.
- **SGMP Computer Model:** It was developed in ILRI, the Netherlands as a numerical ground water simulation model to quantify the amount of recharge from the top system to the aquifer and its spatial variation and to assess its effects on water table depths.
- **SALTMOD Computer Model:** It was developed in ILRI, the Netherlands to predict long term effects of ground water conditions, water management options, average water table depth, salt concentration in the soil, ground water use, drain and well water yields, dividing the soil-aquifer system into four resources surface reservoir, soil reservoir (root zone), an intermediate soil reservoir (vadose zone), and a deep reservoir (aquifer).
- **UNSATCHEM Computer Model:** It was developed in US Salinity Laboratory in USA and is one dimensional solute transport model, which simulates variably saturated water flow, heat transport, carbon dioxide production and transport, solute transport and multi-component solute transport with major ion equilibrium and kinetic chemistry. UNSATCHEM package may be used to analyse water and solute movement in the unsaturated, partially saturated, or fully saturated porous media. Flow and transport can occur in the vertical, horizontal, or in an inclined direction. This package is a good tool to understand the chemistry of unsaturated zone in case of saline water use and development of analytical model to predict the changes in ground water and soil quality.
- **SWASALT/SWAP Computer Model**: It was a package on an extended version of SWATRE model. The depth and time of irrigation applied, quality of irrigation water used, soil type and initial soil quality can be modified and the effects on crop performance, soil salinization and desalinization process, soil water storage (excess/defecit) can be obtained from the model output.
- **WATSUIT Computer Model:** It was developed in US Salinity Laboratory USA is a transient state model and is used for assessing water suitability for irrigation which can incorporate the specific

influences of the many variables that can influence crop response to salinity, including, climatic, soil properties, water chemistry, irrigation and other management practices.

- **CROPWAT Computer Model:** It was developed to calculate crop water requirement and irrigation water requirement including irrigation schedules for different management conditions and calculation of water supply scheme for different cropping patterns (FAO, 1992). CLIMWAT program is available to obtain the required climatic data for CROPWAT (FAO, 1991).
- **SALTMED Model:** The model runs on a PC under Windows 95/98 operation System. The model's input consists of: Climate data, Soils data, crop data, irrigation data (system, amount, salinity), soil parameters, crop parameters, and other model parameters. The model has default values and includes database for soils and crops. In the model, the Richards Equation and the Convection-Dispersion Equation describe the water and solute movements respectively. The daily potential and actual evapotranspiration were calculated using Penman-Monteith equation according to FAO Irrigation & Drainage paper No. 56. The model runs for a variety of irrigation systems, crops, soils, and water salinity levels. The daily model output (graphs and data files) includes, yield, potential and actual water uptake, salinity, soil matric potential and soil moisture profiles, crop water requirements, leaching requirements, plant growth parameters, Potential and actual evapotranspiration, bare soil evaporation and plant transpiration. The model is friendly and easy to use benefiting from the windows environment (Ragab, 2002) Wallingford, Uk.

CROP MANAGEMENT

The crop management is an important aspect in addition to water management and soil management to obtain optimum crop production by irrigation with saline water. Sustainable use of saline water for irrigation cannot be achieved unless we have an integrated management approach including the three primary production elements: water, soil and plant.

Excess salinity within the plant rootzone has a general deleterious effect on plant growth which is manifested as nearly equivalent reductions in the transpiration and growth rates (including cell enlargement and the synthesis of metabolites and structural compounds). This effect is primarily related to total electrolyte concentration and is largely independent of specific solute composition. The hypothesis that best seems to fit observations is that excessive salinity reduces plant growth primarily because it increases the energy that must be expended to acquire water from the soil of the rootzone and to make the biochemical adjustments necessary to survive under stress. This energy is diverted from the processes which lead to growth and yield.

The plants can extract and use more water from the salt free soil than from the salty soil. Salts have an affinity for water. If water contains salts, more energy per unit of water uptake must be expended by the plants to absorb relatively pure water from a salty soil water regime. The added energy required by plants to absorb water from the salty soil (soil osmotic potential) is additive to the energy required to absorb water from a salt free soil (soil water potential).

Not all growth depression of plants can be ascribed to the effect of osmotic pressure of the soil solution and decrease of moisture availability. Salinity may also affect the plants by the toxicity of specific salt, either through its effect surface membrane to plant roots or in the plant tissues or through its effect on intake or metabolism of essential nutrients.

The soil salinity may be a main limiting factor, but other factors may also limit crop production or modify crop salt tolerance. These factors may include: (1) climate, (2) production potential of soil with level of soil fertility, soil structure, aeration capacity, and intensity of soil moisture regime, (3) crop plant variety and growth stages, (4) crop cultural practices, and (5) application of irrigation methods.

Crop Tolerance to Salinity

Crop plants greatly vary in their ability of germinate, develop and produce yield under saline environment. It is the crop’s sensitivity or tolerance to salinity, which defines the salinity of soil or soil water.

Salt tolerance in plants is a polygenetic trait controlled by the genes that synthesize enzymes responsible for a variety of biochemical and physiological processes. Genetic variation in salt tolerance does exist within and among the plant species. This differential capacity of plants to endure the effects of salinity has been the basis in screening and breeding studies for commercially marketable salt tolerant varieties of crops (Mass, 1977; FAO, 1979; Doorenbos and Kassam, 1979; Gilani and Ghaibah, 1998; Singh, 1998; CSSRI, 1998).

The worldwide efforts have been made towards understanding the mechanism of plant salt tolerance with the eventual goal of improving the performance of crop plants in saline soils, more dealing with the effects of excess NaCl in the media. Plants use different strategies at the cell, tissue and organ level. A widely used approach to unravel plant salt tolerance mechanism has been to identify cellular processes and genes whose activity or expression is regulated by salt stress (Zhu *et al*., 1997).

Plants under saline conditions have to deal with four major overlapping problems in order to become a salt tolerant one: (1) ability to either exclude or take up and compartmentalize Na and Cl using ion channels, porters and AT Passes, (2) ability to maintain internal water status through the increased activities of enzymes, (3) ability to prevent direct or indirect damage by Na and Cl to sensitive cellular structures, and (4) ability to prevent any nutrional deficiency to occur (CSSRI – Salinity Management in Agriculture, 1998).

Growth suppression is typically initiated at some threshold value of salinity, which varies with crop tolerance and external environmental factors which influence the need of the plant for water, especially the evaporative demand of the atmosphere (temperature, relative humidity, windspeed, etc.) and the water-supplying potential of the rootzone, and increases as salinity increases until the plant dies. The salt tolerances of various crops are conventionally expressed (after Maas and Hoffman, 1977), in terms of relative yield (Y_r), threshold salinity value (a), and percentage decrement value per unit increase of salinity in excess of the threshold (b); where soil salinity is expressed in terms of EC_e, in dS/m), as follows:

$$Y_r = 100 - b\left(EC_e - a\right)$$

where Y_r is the percentage of the yield of the crop grown under saline conditions relative to that obtained under non-saline, but otherwise comparable, conditions. This use of EC_e to express the effect of salinity on yield implies that crops respond primarily to the osmotic potential of the soil solution. Tolerances to specific ions or elements are considered separately, where appropriate.

Mass (1984, 1986 and 1990) presented the information in standard tabular forms on salt tolerance of selected crops and their yield potential as influenced by irrigation water salinity (EC_{iw}) or soil salinity (EC_e) giving the salinity at which crop yield begins to decline (threshold values) and the rate of crop yield decline with increased salinity.

Ayers and Westcot (1989) suggested salinity potential of different crops in relation ECe (Table 9). Rhoades *et al*. (1992) Salt tolerance threshold of different field crops, vegetables and fruit trees (Table 10).

Table 9. Salinity tolerance and yield potential of different crops in relation to EC_e (dS/m)

	Crops	Yield potential (%)			
		100	90	75	50
Field Crops					
1.	Barley	8.0	10.0	13.0	18.0
	(a) Mustard	8.0	9.0	12.0	-
2.	Cotton				
3.	S.beet	7.0	8.7	11.0	15.0
4.	Sorghum	6.8	7.4	8.4	9.9
5.	Wheat	6.0	7.4	9.5	13.0
	Wheat (Durum)	5.7	7.6	10.0	15.0
6.	Soybean	5.0	5.5	6.3	5.7
7.	Cowpea	4.9	5.7	7.0	9.1
8.	Groundnut	3.2	3.5	4.1	4.9
9.	Rice	3.0	3.8	5.1	7.2
10.	Sugarcane	1.7	3.4	5.9	10.0
11.	Maize	1.7	2.5	3.8	5.9
12.	Broad veab	1.5	2.6	4.2	6.8
13.	Bean	1.0	1.5	2.3	3.6

Source: Ayers and Westcot, 1989

Table 10. Salt tolerance threshold of field crops, vegetable and fruit trees

Crop	Electric conductivity of saturated soil extract Threshold dS/m	Tolerance level
Barley	8	T*
Bean	1	S
Broadbean	1.6	MS
Cotton	7.7	T
Maize	1.7	MS
Sorghum	6.8	MT
Soybean	5	MT
Sugarbeet	7	T
Wheat	6	MT
Alfalfa	2	MS
Clover	1.5	MS
Asparagus	4.1	T
Carrot	1	S
Beet, red	4	MT
Broccoli	2.8	MS
Brussels sprouts	1.8	MS
Okra	1.2	S
Onion	1	S
Pea	1.5	S
Spinach	3.2	MS
Strawberry	1.5	S
Tomato	0.9	MS
Almond	1.5	S
Date Plam	4	T
Grape	1.5	MS
Orange	1.7	S
Peach	1.7	S
Guayule	15	T

Source: Rhoades *et al*., 1992; FAO, 1935

*T: tolerant; S: sensitive; MS: moderately sensitive; MT: moderately tolerant.

Guidelines on Salt Tolerance Limit in some Mediterranean Countries (Syria, Tunisia, Libya)

The Arab Center for Studies of Arid zones and Dry Lands (ACSAD) in League of Arab States, Damascus, Syrian Arab Republic have studied the crop responses and yields to different salinity levels of low quality irrigation water obtained through blending of irrigation water with drainage water and through use of saline ground water at field conditions in Syria, Tunisia and Libya. The EC_{iw} ranged from 1.5 to 11.4 dS/m for Syria; 0.3 to 5.46 dS/m for Tunisia; and 3.9 to 16.7 dS/m for Libya (Addelgawad and Abdelrahman, 1998). Table 11 provides threshold (ECe) values for different crops in Syria. Table 12 includes data of Tunisia. Table 13 provides data for Libya. The data on salt tolerance in these three tables can be considered as guidelines for the use of saline water in irrigation.

Table 11. Relative salt tolerance of crops (Syria) (EC_{iw} range = 1.5, 4.4, 6.4, 8.4, 9.4, 11.4 dS/m)

Crops	Threshold	Slope	Leaching fraction	EC_{iw} of Zero yield
Cotton	4.75	11.0	0.0	13.8
	4.81	9.8	0.15	15.0
	4.72	9.1	0.30	15.7
	4.78	10.2	All	14.7
Maize	3.99	17.5	0.0	9.7
	4.02	16.1	0.15	10.3
	3.87	15.5	0.30	10.3
	3.88	15.9	All	10.2
Vetch	2.90	5.52	0	21.5
	2.99	6.60	15	19.4
	2.98	6.60	30	18.0
	2.95	6.14	All	19.8
Wheat Grain	3.61	10.2	0	13.4
	5.43	8.3	0.15	17.5
	4.36	9.6	0.30	14.8
	4.36	9.51	All	14.9
Wheat Hay	4.6	8.62	0	16.1
	7.89	9.91	0.15	18.0
	6.96	11.6	0.30	15.6
	7.2	10.4	All	16.7
Barley Grain	7.14	7.5	0	20.5
	8.02	6.6	0.15	23.1
	5.72	6.7	0.30	20.5
	6.95	7.0	All	21.4
	6.4	9.9	0.0	16.5
	7.33	9.5	0.15	17.9
Barley Hay	6.4	9.4	0.30	17.0
	7.05	9.3	All	17.8
Alfalfa Dry	6.1	11.7	0.0	14.6
	6.1	11.7	0.15	14.6
Production	4.4	10.2	0.30	14.0
	6.4	12.4	All	14.5

Source: Abdelgawal and Abdelrahman, 1998

Table 12. Relative salt tolerance of crops (Tunisia)

Crops	Threshold	Slope	Leaching fraction	EC_{iw} of zero yield
Tomato	3.27	14.7	0.15	10.1
Melon	1.83	9.1	0.15	12.8
Maize	1.2	8.6	0.15	12.9
Pepper	2.12	8.9	0.15	13.3
Water melon	1.43	8.3	0.15	13.5
Clover	0.33	7.58	0.15	13.5
	1.2	6.9	0.15	15.6
Potato	0.58	5.5	0.15	18.8
Broccoli	2.87	4.5	0.15	25.2

Source: Abdelgawal and Abdelrahman, 1998

Table 13. Relative salt tolerance of crops (Libya) (EC_{iw} : 3.9, 8.0, 11.6, 16.7 dS/m)

Crops	D. Threshold	Slope	Leaching fraction
Barley	6.97	1.72	0.2
Barley hary	6.89	2.49	0.2

The fact that there is ample information on crop tolerance to salinity, but, it is important to recognize that such salt tolerance data cannot provide accurate quantitative crop yield losses from salinity for every situation, since actual response to salinity varies with other conditions of growth including climatic and soil conditions, agronomic and irrigation management, crop variety, stage of growth, etc. While the values are not exact, since they incorporate interactions between salinity and the other factors, they can be used to predict how one crop might fare relative to another under saline conditions.

Climate Variation

Plant tolerance may be strongly affected by climate variables. Climatic factors: temperature, humidity and rainfall may interact with salinity so that tolerance levels reported from one location may not be applicable under other conditions, although these is general agreement as to the relative tolerance of many crops (Framji, 1976).

Most crops can tolerate greater salt stress if the weather is cool and humid than if it is hot and dry. Yield is reduced more by salinity when atmospheric humidity is low. Ozone decreases the yield of crops more under non-saline than saline conditions, thus the effects of ozone and humidity increase the apparent salt tolerance of certain crops. Rainfall, though does not have a direct effect on crop tolerance, may indirectly affect by leaching the response of plants to irrigation with saline water.

Crop Growth Stages (Germination, Emergence and Early Seedling Growth)

These stages are the most critical periods for a crop to obtain a good stand. Losses in plant density during this period cannot be compensated for later and will cause an equivalent loss in production. In case of irrigation under saline conditions, either with saline water or in saline soil, the crop generally encounters more problems during germination, emergence and early seedling growth than during later growth stages and may even fail to establish.

The losses in plant density encountered during the first growth stages are not so much due to a lower salt tolerance during this period. The essential difficulty is the high salinity in the top layer of the soil, exposing the germinating seed and the seedlings to a much higher salt concentration than at later growth stages (Hanks *et al.*, 1978).

Field studies and laboratory on salt distribution in furrow irrigation and laboratory studies (Rhoades and Merrill, 1976) indicated a very pronounced local salt concentration. To avoid seed germination damage in furrow irrigation various alternatives of bed shaping, placement of seeds and irrigation conditions may be used (Greenway and Munns, 1980).

The delay in germination and emergence of seedlings caused by salinity may be increased or germination prevented under unfavourable soil and weather conditions. High temperature may speed up germination but will at the same time increase evaporation and capillary rise of salts. Low temperature may delay germination so much that the seedlings are caught in the crust formed in the meantime. So it is dangerous to transfer results obtained with saline water irrigation from the laboratory to the field or from one region to another without carefully considering the condition of the soil and weather during germination.

Soil texture has its great impact on seed germination as well as seedling development under saline irrigation practices. In the heavy textured (clay) soil, although salts accumulated relatively more than in the sandy clay, seedlings were better developed than in the sandy clay soil. Moreover, in the sandy soil where salt accumulation was the lowest with respect to the other investigated soils, the seed germination percentage as well as the seedling development were the worst. The selection of the salt concentration level in irrigation leading to good germination percentage as well as to well developed seedlings must be decided not only in view of the salt tolerance degree of the crop but also to other factors such as soil properties and climatic conditions (Hamdy, 1999).

Under irrigation with saline water or in saline soils, good emergence of the seedlings with the shortest delay is of primary importance for the development of the crop. This could be achieved by the use of fresh water during germination, if this water is available, followed by saline water once the seedlings are already established (Hamdy, 2002).

To ensure proper crop management at these sensitive growth stages, the following precautions should be adopted (Van Schilfgaard and Rhoades, 1979; Puntamkar *et al*:, 1972; Hamdy and Ragab, 1999):

- germinating seeds should receive good quality water especially if plants are sensitive and, in the case of lack of fresh water, only for tolerant and semi-tolerant plants, fair seed germination can be obtained by using water of EC values not exceeding 4 dS/m;
- under saline irrigation practices, fresh water at germination efficiently improves the growing parameters of the developed seedlings, especially at the relatively high salt concentration levels in irrigation water;
- fresh water at germination not only improves the seedling growth but also reduces, on an average of 35%, the accumulated salts in the soil with respect to the irrigation treatment with permanent saline water.

In this respect, it is wise to recall the benefit which could be achieved in improving crop production through the alternation of low and good quality water rather than blending (Hamdy, 1993; Oster *et al*., 1984 and Hamdy, 1990b).

Vegetative Growth and Yield

Plant growth is directly affected by the salinity level of the soil rather than the salinity of irrigation water, except where direct contact between foliage and irrigation water results in leaf burn. Decrease of growth due to salinity at the vegetation stage is not necessarily followed by a decline in yield (Rhoades, 1972; Shalhevet and Kamburov, 1976; Allison, 1964 and Agarwal *et al*., 1978).

Many data are available with regard to salt tolerance of crops, but most of this information refers to the total period from the late seedling stage to maturity. For many crops the germinating and early seedling stage is the most sensitive. Much less is known about the sensitivity during later growth stages, e.g. flowering, seed formation. If crops appear to be sensitive during specific periods, it could be beneficial to lower soil salinity in the upper part of root zone with the highest root density by applying fresh water during sensitive periods, if such water is available to the farmer.

Efficient crop management under saline irrigation practices requires that the critical growing stage for the majority of crops be identified. A suitable irrigation method can be selected, based principally on how and when it should be applied to prevent stressing the plant during the sensitive stages of its growing cycle (Hamdy and Ragab, 2002).

Varietal Differences

Varietal difference among crops may cause strong differences regarding salt tolerance among varieties and root stocks of fruit trees and vine crops. Tolerant plants require multiple adaptations to enable them to grow in saline environments. The problem faced by plant scientist wishing to enhance tolerance in crop plants is how to manipulate complex multigenic traits. The research work needs to be aimed at basic information about the genetic of physiological traits and attempts to discover genes regulating salt tolerance following the imposition of salinity stress and understating signaling cascades.

Modern molecular techniques can be used to analyze the genetics of quantitative traits determined by quantitative traits loci (QTLS) developing practical makers and map their positions for positional cloning to discover genes. The use of DNA-based technology is capable of dealing with large number of samples, markers may be a valuable means of assisting in the development of salt tolerance in plants. The molecular biological approaches may be helpful to enhancing salt tolerance (CSSRI, 1993).

Crop Selection

Crop selection is an important management decision. The most desirable characteristics in selecting crop for irrigation with saline water are: (1) high marketability (2) high economics value, (3) ease of management (4) tolerance to salts and specific ions, (5) ability to maintain quality under saline conditions, (6) low potentional to accumulate trace elements, and (7) compatibility in crop rotation (Grattan and Rhoades, 1990; Tanji, 1994).

CULTURAL PRACTICES

Many factors that facilitate the use of saline water are related to management practices for short and long term salinity control. Adequate drainage and leaching to control salinity within the tolerances of the crops are the ones most appropriate management practices for long term salinity control.

Seed treatment, land smoothening and grading, plant population and placement, fertilization, irrigation doses and frequency and methods of irrigation are important short term cultural practices, highly related to crop management. Such cultural practices can have profound effect upon germination, early seedling growth and ultimately on yield and crop.

MANAGING SOIL UNDER SALINE IRRIGATION

Several physical, chemical and biological soil management measures help facilitate the safe use of saline water in crop production. Some important ones in this regard are: tillage, deep ploughing, sanding, use of chemical amendments and soil conditioners, organic and green manuring and mulching.

Tillage

Tillage is a mechanical operation that is usually carried out for seedbed preparation, soil permeability improvement, to break up surface crusts and to improve water infiltration. If tillage is improperly executed, it might form a plough layer or bring a salty layer closer to the surface. Sodic soils are especially subject to pudding and crusting; they should be tilled carefully and wet soil conditions avoided.

Deep Ploughing

It is most beneficial on stratified soils having impermeable layers lying between permeable layers. In sodic soils, deep ploughing should be carried out after removing and reclaiming the sodicity, otherwise it will cause complete disturbances and collapse of the soil structure. Deep ploughing to 60 cm loosens the aggregates, improves the physical condition of these layers, increases soil-water storage capacity and helps control salt accumulation when using saline water for irrigation. Crop yields can be markedly improved by ploughing to this depth every three or four years.

The selection of the right plough types (shape and spacings between shanks), sequence, ploughing depth and moisture content at the time of ploughing should provide good soil tilth and improve soil structure (Mashali, 1989).

Sanding

It is a process aiming to have a fine textured surface soil more permeable. It results in improved root penetration and a better aeration and water permeability which facilitates leaching of salts when surface infiltration limits water penetration.

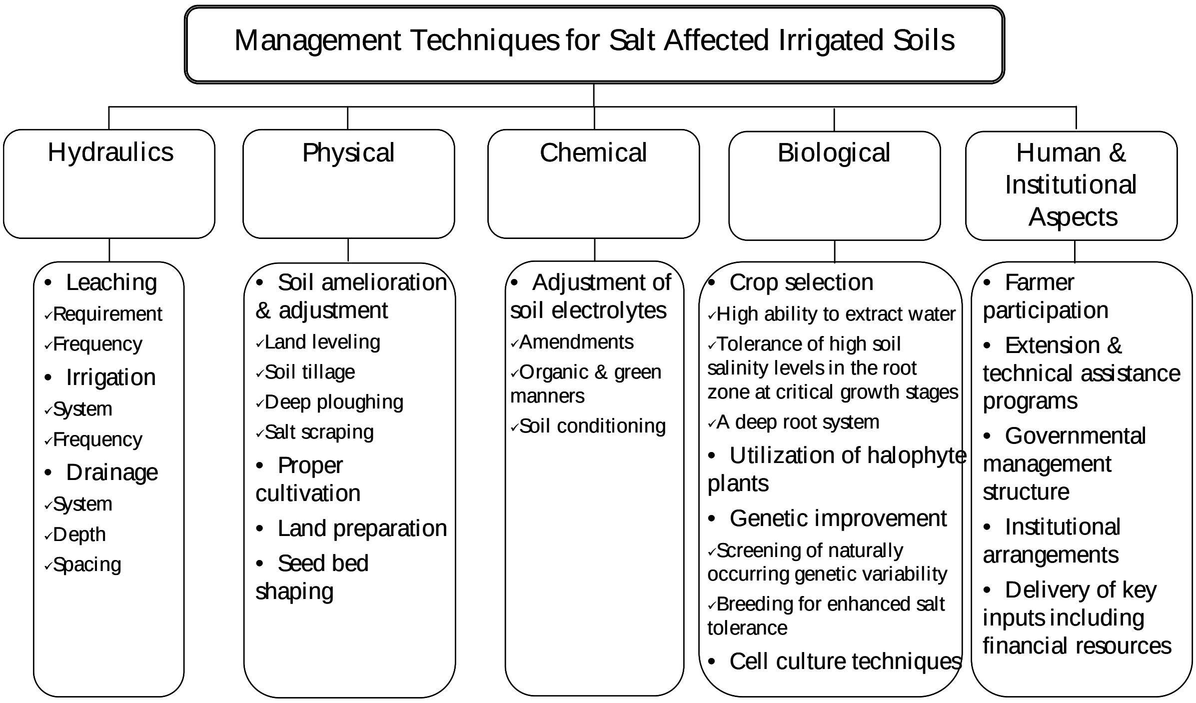


Figure 5. Management techniques for salt affected irrigated soils

Chemical Soil Amendments and Their Quantities

These amendments are used to neutralize soil reaction, to react with calcium carbonate and to replace exchangeable sodium by calcium. This decreases the ESP and should be followed by leaching for removal of salts derived from the reaction of the amendments with sodic soils. They also decrease the SAR of irrigation water if added in the irrigation system.

Unlike saline soil water, alkali soil/water responds to chemical amendments materials that directly supply the soluble calcium for replacement of exchangeable sodium. The choice of amendment and the quantity required for reclamation depends on the physico-chemical properties of the soil, the amount of exchangeable sodium to be replaced, the desired rate of improvement, the quality and quantity of water available for leaching and the cost of the amendment. The common amendments are given in (Box 5). Gypsum by far is the most common amendment for sodic soil reclamation when using saline water with a high SAR value for irrigation.

Box 5. Gypsum equivalent of different amendments

Amendments	Amount equivalent to gypsum
Gypsum ($CaSO_4$. $2H_2O$)	1.00
Sulphur (S)	0.19
Sulphuric Acid (H_2SO_4)	0.57
Lime Sulphur (24%S)	0.77
Calcium Carbonate ($CaCO_3$)	0.58
Calcium Bicarbonate Dehydrate ($CaCl_2.2H_2O$)	0.85
Ferrous Sulphate ($FeSO_4.7H_2O$)	1.61
Aluminium Sulphate ($Al_2(SO_4)_3;18H_20$)	1.29
Iron Pyrite (FeS_2.30%S)	0.63

Prather *et al.* (1979) have reported the advantages gained by using the different amendments in combination. The quantity of amendment needed to reclaim an alkali soil is determined as a product of gypsum requirement (the equivalent amount of exchangeable sodium to be replaced in the soil) which is multiplied by a factor (1.2-1.3) to compensate for the inefficiencies. Based on pH value of soil in 1.2 soil water suspension, Abrol *et al.* (1973) have developed a graphical relationship to determine the gypsum requirements of light, medium and heavy alkali soils (Fig. 6). The quantities of gypsum computed by this method are, however, approximate.

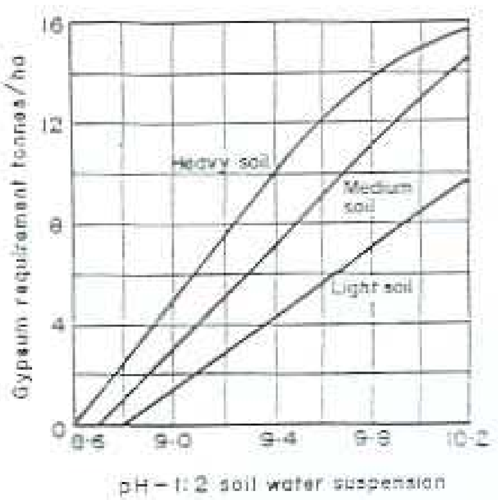


Figure 6. Nomogram for calculating gypsum requirement in alkali soil

The addition of gypsum (either to the soil or water) can often help appreciably in avoiding or alleviating problems of reduced infiltration rate and hydraulic conductivity. For more specific information on the effects of exchangeable sodium, electrolyte concentration and pH, as well as of exchangeable Mg and K, and use of amendments on the permeability and infiltration rate of soils reference should be made to the reviews of Keren and Shainberg (1984); Shainberg (1984); Emerson (1984); Shainberg and Letey (1984); Shainberg and Singer (1990).

ORGANIC AND GREEN MANURES AND MULCHING

Incorporating organic matter into the soil has two principal beneficial effects of soils irrigated with saline water high SAR and on saline sodic soils: improvement of soil permeability and release of carbon dioxide and certain organic acids during decomposition. This will help in lowering soil pH, releasing calcium by solubization of CaCO3, and other minerals, thereby increasing ECe and replacement of exchangeable Na by Ca and Mg which lowers the ESP.

Mulching is effective in reducing evaporation losses lowering the upward flux of soluble salts and thereby decreasing the opportunity for soil salinization.

When using saline water where the concentration of soluble salts in the soil is expected to be high in the surface, mulching can considerably help leach salts, reduce ESP and thus facilitate the production of tolerant crops. Mulching to reduce evaporation losses will also decrease the opportunity for soil salinization.

MINERAL FERTILIZERS

Salt accumulation affects nutrient content and availability for plants in one or more of the following ways: by changing the form in which the nutrients are present in the soil; by enhancing loss of nutrients from the soil through heavy leaching or, as in nitrogen, through denitrification, or by precipitation in soil; through the effects of non-nutrient (complementary) ions on nutrient uptake; and by adverse interactions between the salt present in saline water and fertilizers, decreasing fertilizer use efficiency.

Crop response to fertilizer under saline or sodic conditions is complex since it is influenced by many soil, crop and environmental factors. The benefits expected from using soil management measures to facilitate the safe use of saline water for irrigation will not be realized unless adequate, but not excessive, plant nutrients are applied as fertilizers. The level of salinity may itself be altered by excess fertilizer application as mineral fertilizers are for the most part soluble salts. The type of fertilizer applied, when using saline water for irrigation, should preferably be acid and contain Ca rather than Na taking into consideration the complementary anions present. Timing and placement of mineral fertilizers are important and unless properly applied they may contribute to or cause a salinity problem.

CONCLUDING REMARKS AND RECOMMENDATIONS

Saline water is a potential source of irrigation and freshwater saving in irrigated agriculture. Recent research developments on salt tolerance of various crops, water, soil and crop management, irrigation and drainage methods and the reuse of drainage effluents, will enhance and increase its potential use for irrigation. There is ample evidence to illustrate the widespread availability of saline waters and a wide range of experience exists around the world with respect to using them for irrigation under different conditions. This evidence and experience demonstrates that waters of much higher salinities than those customarily classified as “unsuitable for irrigation” can, in fact, be used effectively for the production of selected crops under the right conditions.

Salinity is not the property of irrigated agriculture but occurs in response to the kind of management imposed on the system. Management of salinity is a multidimensional problem requiring the understanding of the genesis, and the development of appropriate technology which is socially acceptable and economically viable. Irrigation technology developed so far has considerably enhanced our capacity to manage land and water salinity problems. But as the concern for protecting the natural environment grows, the need to refine the technology and shift emphasis on drainage volume reduction and reuse will also increase.

In considering the use of a saline water for irrigation and in selecting appropriate management to protect water quality, it is important to recognize that the total volume of a saline water supply cannot be beneficially consumed for irrigation and crop production; and the greater its salinity, the less it can be consumed before the salt concentration becomes limiting. In the Mediterranean countries, particularly the arid and semiarid ones, focus should be directed towards the setup of new crop/water management strategies that facilitate the use of saline water for irrigation and minimizing the negative drawbacks of its use on soil productivity, yield production and the environment.

Regarding the strategies of saline water use, it is recommended that the practice of blending or diluting excessively saline waters with good quality water supplies should only be undertaken after consideration is given to how this affects the volumes of consumable water in the combined and separate supplies. Blending or diluting saline low quality waters with good quality waters in order to increase water supplies or to meet discharge standards may be inappropriate under certain situations. More crop production can usually be achieved from the total water supply by keeping the water components separated. Serious consideration should be given to keeping saline waters separate from the "good quality" water supplies, especially when the latter waters are to be used for irrigation of salt-sensitive crops. The saline drainage waters can be used more effectively by substituting them for "good quality" water to irrigate certain crops grown in the rotation after seedling establishment.

Sustainable and safe use of saline water for irrigation and to maximize freshwater saving in the agricultural sectors, to achieve these goals, it is needed:

- ✓ An integrated, holistic approach is needed to conserve water and prevent soil salinization and waterlogging while protecting the environment and ecology. Firstly, source control through the implementation of more efficient irrigation systems and practices should be undertaken to minimize water application and reduce deep percolation to promote.
- ✓ To promote conjunctive use of saline groundwater and surface water to aid in lowering water table elevations, hence to reduce the need for drainage and its disposal and to conserve water.
- ✓ New technologies and management practices must be developed and implemented. Efficiency of irrigation must be increased by the adoption of appropriate management strategies, systems and practices and through education and training. Such measures must be chosen with recognition of the natural processes operative in irrigated, geohydrologic systems, not just those on-farm, and with an understanding of how they affect the quality of soil and water resources, not just crop production.
- ✓ To introduce the participatory approach in saline irrigation practices and management. There is a wide gap of knowledge level between the technical staff and the farmers. The use of saline water and its management is a complex process and needs adequate knowledge at farmer's level. Farmers' participation and involvement in planning and management is the key point leading to success and/or failure in saline irrigation projects. Many of the irrigation and drainage projects failed because of the non-cooperation and non-involvement of the local users in their planning, design, construction, operation and maintenance.

There is usually no single way to achieve salinity control in irrigated and associated waters. Some practices can be used to control salinity with the crop root zone, others for larger units of management such as irrigation projects and river basins beside those to protect offsite environment and ecological systems including the associated surface and groundwater resources. Indeed, the approaches are numerous, but, the difficulties exit in selecting the appropriate approach to be followed as it depends upon economic, climatic, social as well as edaphic and hydrogeological situations. Thus, there is no procedure to be given for selecting the appropriate set of control practices that could be adopted in the different countries of the Mediterranean. Every country has to search and decide on the most appropriate control practices in view of the prevailing local conditions and to integrate and combine them into satisfactory control systems.

The future research in land/water salinity management will have to give more attention in the following areas:

- ✓ integrated management of water of different qualities at the level of farm, irrigation system and drainage basins with the explicite goals of increasing agriculture productivity, achieving optimal efficiency of water use, preventing on-site and off-site degradation and pollution, and sustaining long-term production potential of land and water resources;
- ✓ further research is needed in developing and use of mathematical and computer simulation models to relate crop yield and irrigation management under saline conditions so far that those empirical models can be reliably applied under a wide variety of field conditions;
- ✓ at present, there is no clearly defined policies and strategies on the use of saline water and/or the reuse of drainage water for irrigation. To arrive at these policies and strategies, monitoring programs are required on both water quantities and qualities, as well as on soils;
- ✓ low volume and localized water application methods like sprinklers, drip and earthern pitchers can considerably reduce the drainage volumes. Pilot projects need to be established in saline groundwater areas having rising watertable trend to evaluate efficacy of such methods;
- ✓ in the past leaching and drainage were considered the ultimate solution for resolving salinity problems. The growing environmental concerns have put question mark on the sustainability of drainage system itself. There is a need to study the trade-off between provision of full drainage and drainage volume reduction;
- ✓ the groundwater flow models should incorporate salinity component to predict the development of not only waterlogging but also of soil water salinity. Regional agro-hydro-salinity models should be of immense value in planning appropriate water management strategies;
- ✓ the emphasis so far has been on development of technology hardware. The role of policies and institutions in creating demand for technology has not been fully appreciated. There is

need to give adequate attention to this very important aspect if sustainability of irrigated agriculture in saline environment has to be ensured;

- ✓ much important and useful research on potentials and hazards of the use of saline water in irrigation were undertaken in relative isolation and no mechanism existed for coordinating the research work and to utilize effectively the research fingings. In this regard it is needed:
  - ❖ To establish working relationships on national, regional and international institutions dealing with this subject through the formulation of networks; as successful examples in the Mediterranean region, the CIHEAM/MAI-Bari Non-conventional Water Resources practices and Management (NWRM) and WASAMED Networking projects.
  - ❖ To conduct and foster a comprehensive multi-disciplinary basic and applied research programme in coordinating fashion on the sustainable use of saline water in irrigation and related problems and obstacles.
  - ❖ Provide facilities for research workers and to train associated personal in techniques and methods for dealing with saline water practices and related salinity problems.

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