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Hamdy A.

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Atef Hamdy [1]

Introduction

In many countries of the Mediterranean, 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 increase.

Moreover, in the arid and semiarid regions of the Mediterranean, water requirements of the competing sectors will always remain relatively small percentage of the naturally available supplies.

In the Mediterranean area, irrigation represents 72% of the total water withdrawals. In the Southern Mediterranean countries, nearly 90% of the available water resources are allocated for irrigation. The limiting water resources in these countries, on one hand, and the relatively high rate (3.5%) of population growth, on the other hand, will be the major constraint for further agricultural and socio-economic development. There is now growing realization that an increasing number countries in the region 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 has to cope with this situation.

Marginal quality water, in a broad sense, would include saline water, water containing toxic elements and sediments as well as treated or untreated waste water effluents. The overriding guidelines, quality problems of municipal wastewater concern biological oxygen demand

[1] *Mediterranean Agronomic Institute of Bari, Via Ceglie 9, 70010 Valenzano (BA), Italy*

and public health, in contrast to the salinity or toxicity problems of most of the marginal quality water potentially available for irrigation. In the developing countries of the Mediterranean, the major challange facing water planners and managers in the 1990's is that while physical availability of water is fixed, its demand will continue to increase steadily in the foreseable future. Accordingly, the problem is how to balance demand and supply of water under those difficult conditions.

The practical solution to satisfy the increasing demand of irrigation and to overcome the shortage in food demand and to reach satisfactory level of food production can only be met by using water of low quality.

In the situation of a limited supply of good quality water, agriculture is likely to be forced to use more and more marginal quality water, either brackish water or treated sewage effluent.

In this regard, the question which yet remains to be answered is: can agriculture make use of marginal water in a way that is technically sound, economically viable and environmentally non-degrading. In other words, is it a viable proposition to use marginal quality water for agriculture production?

Great efforts are now being directed to the development and use of unconventional 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 and economics strategies.

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

1. LIMITS ON FRESH WATER

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).

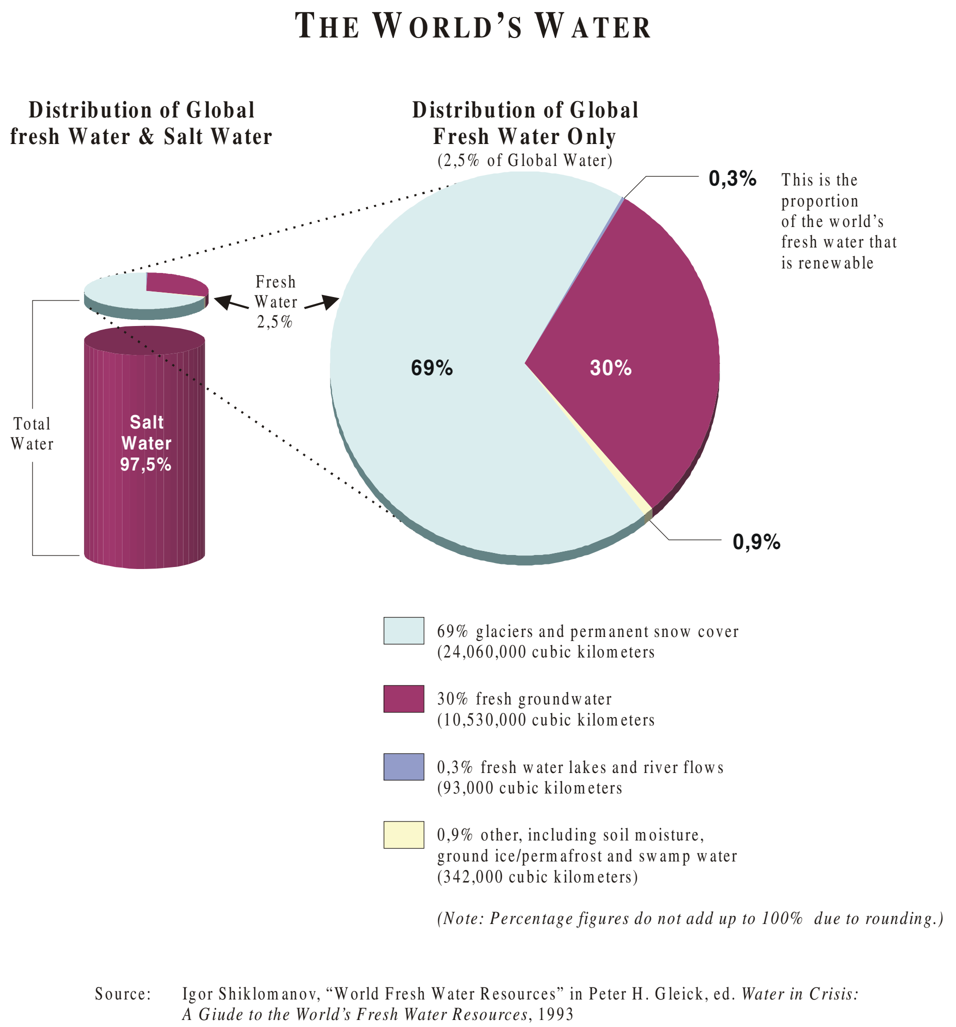

Fig. 1. The World's Water

Between 1940 and 1990, world population has more than doubled, from 2.3 billion to 5.3 billion of human beings. Simultaneously, the amount of fresh water has roughly quadrupled from about 1.000 cubic meters to about little more than 4.000 cubic kilometers (Fig.2).

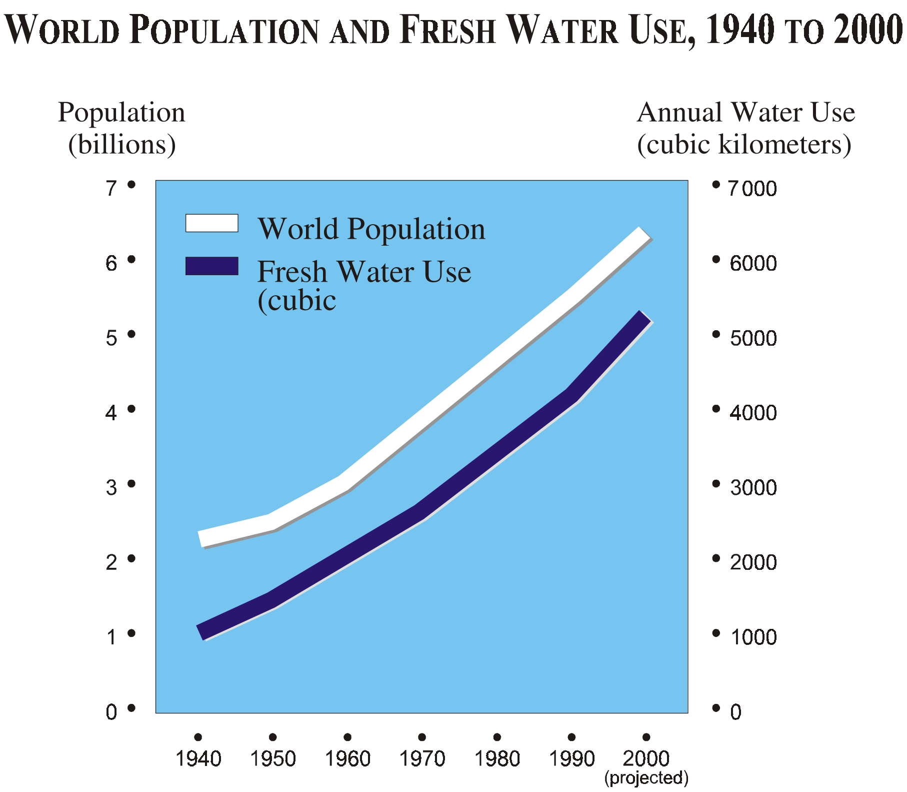

Fig. 2. World Population and Fresh Water Use (source: Peter H. Gleick, Pacific Institute for Studies in Development, Environment and Security)

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 challanges 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 medecine. In addition, today, most easily accessible renewable fresh water resources already have been developed (Egypt, Syria, Jordan, Israel, 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 favourable crop production and, on the other one, keeping the soil at good productivity level without further deterioration in its physical and chemical characteristics.

2. 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 reflects 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 (10).

Region	Milions of hectares
Africa	80,5
Australia	357,3
Europe	50,8
Mexico and Central Amenca	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 Istitute of Environment Depelopment and the World Resources Istitute, 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.

3. 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 (I. Szabolcs, 1991).

Salinization	Desertification
Increase of salt accumulation Decrease of leaching Increase of salt concentration in ground and surface waters as well as in soil layers	Reduction of water availability Hindering of nutrient uptake Reduction of biota diversity 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

4. ASSESSING THE SUITABILITY OF SALINE WATER FOR IRRIGATION

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?'

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.

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 necessarly 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:

1) predicting the composition and matric potential of the soil water, both in time and space resulting from irrigation and cropping;
2) 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 thershold 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 ans successfully used.

In addition, more emphasis should be given to development of appropriate models, criteria and standards under non steady state conditions.

5 - THE POTENTIAL OF USING SALINE WATER IN IRRIGATION

Although the number of documented reports on successfully using brackish water for irrigation is relatively limited, enough exist to support the premise that water, more saline than conventional water classification schemes allow, can be used for irrigation. 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. Several extensive reviews of the world literature had been conducted on this topic, including those of Bressler (1979), Gupta (1979) and Gupta and Pahawa (1981).

At Bari Institute, several studies were conducted for more than 15 years; enough evidence is available to show the potentiality of using water with saline up to 6 dS/m for major cereal crops.

Rhoades (1977) concluded that the bulk of drainage waters in the US (presumably in the world as well) have potential value for irrigation. Use of such water would not only permits the expansion of irrigated agricultural, but could also reduce drainage disposal and pollution problems as well.

In the United States, extensive areas (about 200.000 acres) of alfalfa, grain sorghum, sugarbeets and wheat are irrigated (by gravity and furrow methods) in the Arkansas Valley of Colorado with water containing less than 1500 mg/l of Total Dissolved Solids (TDS) and up to 5000 mg/l (Miles, 1977).

In the pecos Valley of West Texas (United States), groundwater averaging about 2500 mg/l, but ranging far higher, has been successfully used for irrigation of about 200.000 acres of land for three decades (Moore and Hefner, 1976).

Jurey et al. (1978) grew wheat in lysimeters with water up to 7.1 dS/m without deleterious effects on yield. Paliwal (1972) carried out several experiments in India, continuously irrigating with relatively high-salinity water. Shalhevet and Kamburov (1976) suggested that water with up to 6000 mg salt/l were often classed as acceptable and indeed used. Frenkel and Shainberg (1975) and Keren and Shainberg (1978) reported that cotton could be grown commercially in Israel with water having an electrical conductivity of 4.6 dS/m. Several workers, after testing water of salt concentration level between 4 dS/m and 15 dS/m concluded that such water could be used for certain crops without drastic yield reduction (Harden, 1976; Bressler, 1979).

Other evidence of the potential to use saline water for irrigation successfully under hot dry (arid) climate was demonstrated by Ayers and Westcott (1985) and Rhoades (1988a). The experience of Israel of sixteen years of research carried out in the fields of Ranat Negev experimental station (Pasternak et al., 1984), evidently support the potentiality of using relatively high saline water for irrigation under arid conditions even under the harch desert conditions of Israel for variable crops that could be grown commercially such as: wheat, sorghum, sweet corn, sugarbeets, cotton, tomato, asparagus, broccoli, beets, celery, melons and lettuce.

O'Leary (1984) has shown that several halophytes have potential use as crop plants and can be grown under field irrigation with very saline water. Yields have been achieved under high salinity conditions which exceed the average yield of crops, like alfalfa, irrigated with fresh water. The most productive halophytes yielded the equivalent of 8 to 17 times of dry matter per hectare. These yields amounted to 0.6 to 2.6 times of protein per hectare, which also compared to that of alfalfa with fresh water irrigation. These crops yield even more when grown with water of lower salinity. For example, about double the above yields are obtained using water of 10 000 mg/l for irrigation. The use of drainage waters for the growth of such crops would facilitate the disposal of drainage waters as proposed by Van Schilfgaarde and Rhoades (1984).

Several examples can be found on the successful use of saline water in Middle East and Northern Africa. The saline Medjerda river water of Tunisia (annual average EC of 3.0 dS/m) has been used to irrigate date palm, sorghum, barley, alfalfa, rye grass and artichoke. With properly timed irrigation and the selection of appropriate crops, this saline water is being used successfully to irrigate even relatively impervious soils (Van't Level and Haddad, 1968, Van Hoorn, 1971). According to Arar (1975), salt tolerant cereal crops, vegetables, alfalfa and date palms are being successfully irrigated with water of 2000 mg/L TDS in Bahrain, 2400 to 6000 mg/l in Kuwait and 15000 mg/l 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 mg/l TDS. In Egypt the total amount of drainage water discharged annually varies between 14 billion m3 in 1984 to 12 billion m3 in 1989. The EC value of the drainage water around the year is of an average 3000 mg/l. The amounts of drainage water presently used in irrigation is 4.7 billion m3 annually, which is expected to be increased gradually and reach 7.0 billion m^3 by the year 2000 (Abu-Zeid, 1991).

The use of water with higher salt levels including that of sea water for irrigation of various food, fuel and fodder crops has been reported by many researchers including Aronson (1985; 1989), Boyko (1967), Epstein (1983; 1985), Gallagher (1985), Glenn and O'Leary (1985), Iyengar (1982), Pasternak and Y. De Malach (1987) and others. These scientists have produced grains and oilseeds; grass, tree and shrub fodder; tree and shrub fuelwood, and a variety of fibre, pharmaceutical and other products using highly saline water.

The water suitability assessment procedure described in the preceeding section, combined with these latter cited worldwide references, indicate that waters of much higher salinities than those customarily classified as suitable can be used effectively for irrigation selected crops.

6 - 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 Fig.3.

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.

7 - 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).

7.1 - Irrigation Scheduling

One of the most important problems in irrigation under saline conditions involves determining of the irrigation scheduling which allows obtaining, on the one hand, good crop yields and, on the other hand, adequate leaching of the soil.

Under saline water application the set up of such an irrigation scheduling is much more complicated than when fresh water is applied. This is mainly due to the fact that:

information on consumptive use of many crops under saline water irrigation is not available and,

under saline water practices the leaching requirements (LR) of the crops as related to the salinity level of water must be calculated and included in the crop water requirements.

As a matter of fact, information on consumptive use of many crops is available for irrigation with non-saline water. The question arises whether this information is also applicable for saline water irrigation, and if not, what adjustments need to be made. The answer to this question is of great importance. If the information is not applicable, then a whole new body of data needs to be developed, as was done for good water irrigation.

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.

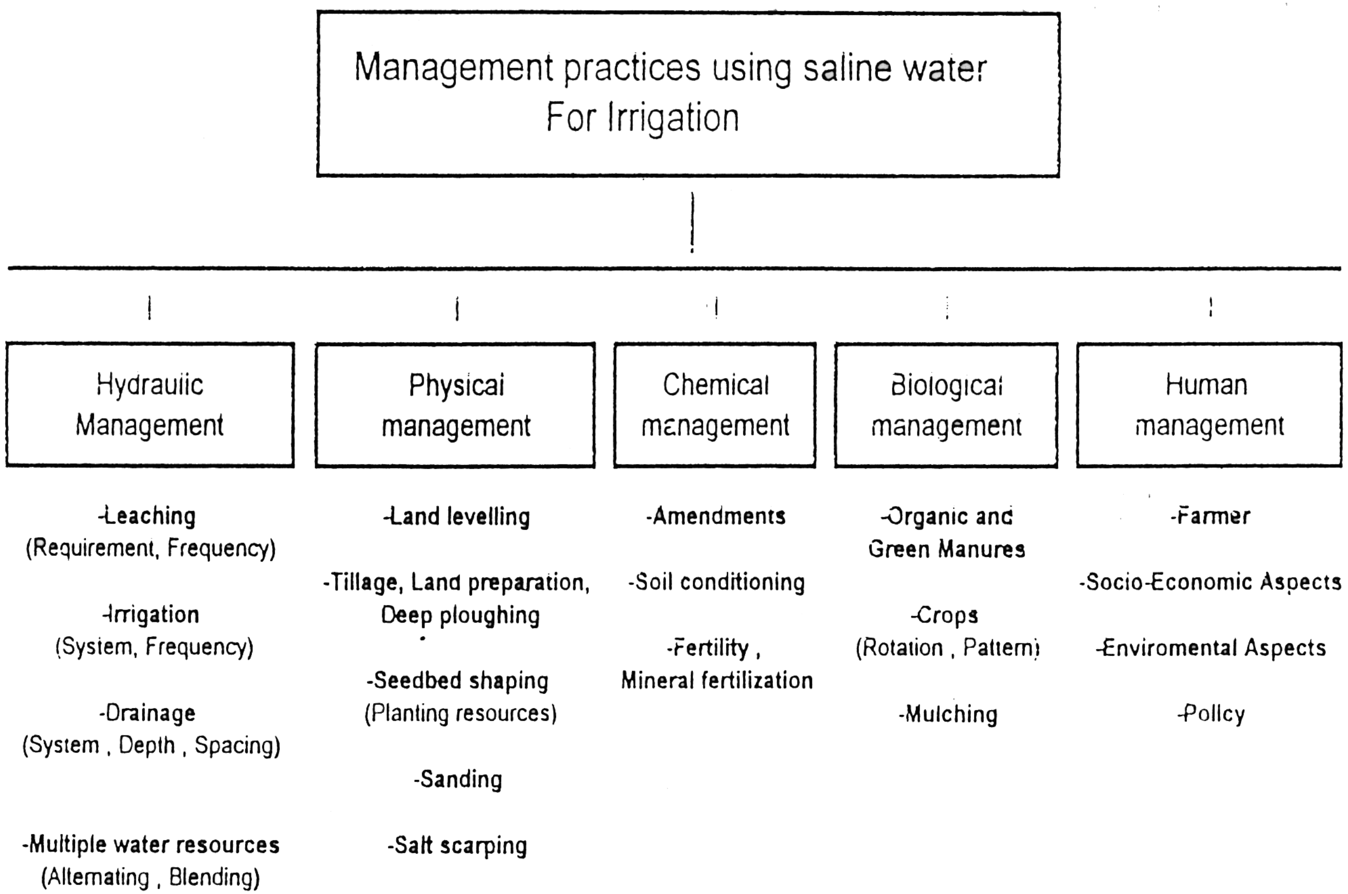

Fig. 3. Management practices using saline water For Irrigation

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 can 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.

Nonuniform 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 nonuniform 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.

7.2 - Irrigation Interval

Plant growth is a function of the salinity and matric potential of soil water; salinity could 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 diminuish 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); Bernstein and François, 1973a).

Simgah and Singh (1976) showed that the soil solution concentration adjacent to roots growing in a saline soil was 1.5 - 2.5 fold higher than in the bulk soil. The larger the difference, the wetter the soil and the higher the transpiration rate. Thus, keeping the soil wet by increasing irrigation frequence may change, rather than decrease, the effect of salinity.

The net results of starter irrigation intervals on the final crop yield was studied by several workers (Bernstein and Francois, 1975; Heller et al., 1973; Hoffman et al., 1983). The data obtained indicated that increasing irrigation frequency did not significantly benefit crop production, despite the much larger fluctuations in soil matric potential in the long-interval compared of the short-interval treatment. Detrimental effect of increased frequency on crop response were found by Bernstein and François (1975) with bell peppers and by Ayoub (1977) with senna. They attributed reduced yields to flushing salts accumulated near the surface into the root zone, causing osmotic shock and the foliar damage occuring with more frequent irrigation.

Recently, Hamdy (1990a) studied the influence of varying irrigation frequencies under saline water application on both corn yield and salt accumulation and distribution under variable soil textures. He concluded that:

- Frequent irrigation led to much greater salt accumulation at the soil surface; such accumulation accounts for the less-than-proportional yield increase.
- Greater irrigation frequency to increase yield is not a good choice in saline water management and would lead to:
- a low crop yield that would not compensate for the expense of growing it;
- deteriorated soils where salts are intensely accumulated,especiallyin the surface layer.

The bulk of evidence does not support shortening irrigation intervals when saline water is used; this may even determined under some circumstances.

A frequent constraint to improving on-farm water use is the lack of information of when an irrigation is needed and what capacity for replenishment is available within the rootzone. Under saline conditions, this requires some "extra" water for leaching -a minimum commensurate with salt tolerance of the crop being grown. 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 rootzone 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.

Irrigation scheduling is a major parameter to be considered for assessing an appropriate saline irrigation management.

However, this subject did not receive the attention of the researchers in this field. Therefore, to avoid problems and for a sustainable water saline use in agriculture, further work has to be done and directed to fullfil 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.

7.3 - Irrigation Method

Proper choice of the irrigation method greatly facilitates reduction in drainage volume, uniform leaching and use of poor quality water. Excess water through different methods of irrigation may be applied because of improper design of the system, improper choice of the method of water application, lack of control on water application depths during the process of irrigation and non-uniform application resulting from non-uniformity in soil infiltration rate or irrigation system or both.

Improper selection of irrigation method, not only aggravates salinization, but may also create drainage problems. The distribution within and the degree to which a soil profile becomes salinized are functions of the degree and manner of water application utilization of saline water resources on long term calls for scientific knowledge of soil-water-plant relationship and its modifying influence on irrigation technique.

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 the soil.

Border strips, furrows and level basin are the commonly used surface methods of water application. Continuous flooding can be used for paddy fields as well as for soil desalinization when water is moderately saline. In contrast, discontinuous wild flooding from head ditches on poorly leveled land with fairly large streams of water results in large irregular patches of salinized soils (this method is now mostly disregarded). Basin, check and border systems are also not advisable when using saline water, particularly on low permeability soils. When the basin floor is corrugated, however, this method ensures a satisfactory salt leaching. Where irrigation is by flood or furrow methods, careful land grading, such as that obtained using laser-controlled earth moving equipments, is desirable to achieve more uniform water application and consequently better salinity control (Dedrick et al., 1978).

When using brackish or saline water, 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 and 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, even when the average salt levels in the soil and irrigation water are moderately low. This problem is appreciably magnified when saline waters are used for irrigation. Seedbed shape and seed location should be managed to minimize high salt effects.

Since salts move with the water, the salt accumulates progressively towards the surface and center of the raised bed or ridge and is most damaging when a single row of seeds is planted in the central position (Fig.4). With double-row beds, under moderately saline conditions, most of the salt is also carried into the center of the bed, leaving the shoulders relatively free of salt for seedling establishment. Sloping beds are best for soils irrigated with saline water bacause the seedling can be safely established on the slope below the zone of salt accumulation (Bernstein et al., 1955; Bernstein and Fireman, 1957). The salt is moved away from around the seedling instead of accumulating near it. Planting in furrows or basins is satisfactory from the stand-point of salinity control but is often unfavourable for the emergence of many row crops because of crusting or poor aeration.

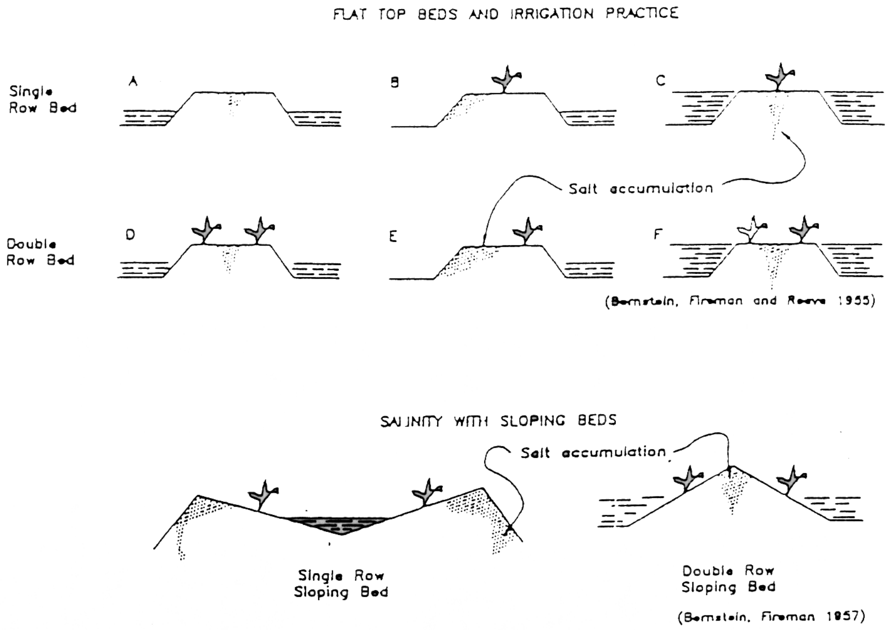

Fig. 4. Typical Salt Accumulation Patterns in Ridge and Bed Cross Section Under Furrow (Bernstein et al. 1955; Bernstein and fireman 1957)

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 (Rhoades, 1989). 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. Thus, planting near the water supplying furrow, using double row beds, irrigating alternate furrows and planting on sloping beds, will all push away the salt from the seed or seedling.

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. In Tunisia, sprinkling was used for these purposes during germination and early seedling growth, even with irrigation water of 5 dS/m. The results were favourable for both cases; water saving on a light sandy soil, where water applications were reduced from 140 to 40 mm, and improving germination and emergence on clay soil, where a good soil structure obtained by tillage did not deteriorate under the small amounts applied by sprinkling (Van Hoorn, 1991).

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. Thus the salinity of water applied by sprinkler irrigation could be higher than that applied by flood or furrow irrigation with a comparable degree of cropping success.

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. 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 (Yaron et al., 1973; Shalhevet et al., 1983; Hamdy, 1991a). The only problem with this method is the need to remove salts that accumulate at the wetting front. Sub-irrigation, in which the water table is maintained high enough so that the "capillary fringe" at the rootzone coincide, is generally not suitable over the long-term when salts are high in the water supply. If sub-irrigation is to be used, the water table should be lowered periodically to allow leaching of accumulated salts by rainfall or surface water applications.

Subsurface systems provide no means of leaching, the soil above the source of water. 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.

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.5 (Oster et al., 1984).

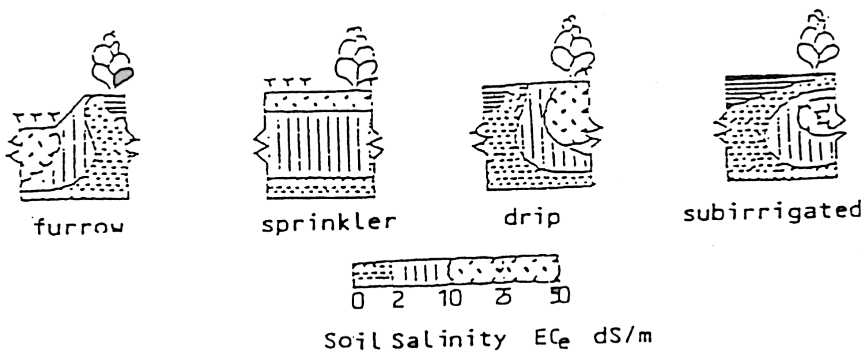

Fig. 5. Salt distribution wuith the root zone.Oster et al 1984

Lateral salt distribution is relatively uniform under sprinkler irrigation, but soil salinity increases with depth under furrow or drip. Salinity levels are low immediately beneath the water source and they increase with depth. Midway between the furrow or drip sources, soil salinity is high; levels may be highest at the soil surface, particularly if the wetting patterns do not overlap and the soil remains dry. The distribution resulting from point sources -a drip system with widely spaced emitters increases the directions from the emitter- as the rate of water application increases the salinity distribution changes from elliptical (with the major axis in the vertical direction) to circular. 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, Rinot and Karue, 1971).

7.4 - 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.

With 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 efficiency can be defined as the amount of salt removed from the root-zone by drainage water at a given fraction of the irrigation water. This efficiency depends on salt content and distribution in soil, on solute composition, and on irrigation method and management.

Increase efficiency or reducing leaching under the proper circumstances, it can lead to 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. This will greatly help in solving the drainage water disposal problems as well as creating a more favourable environmental conditions.

To effect high efficiencies requires a high level of management skills coupled with the use of modern technology. In the typical surface irrigation system, there tends to be an unavoidably large difference in water stored in the soil across a field because of a difference in opportunity time, length of time the water stands on the surface and a difference in infiltration rate. These inefficiencies can often be reduced, but not eliminated by modern laser-assisting grading techniques, so-called "dead-level" basin, or surge irrigation. Solid set or movable sprinkler lines have similar problems. Linear move or pivot sprinklers are better adapted for achieving high level of efficiency, while poorly designed and managed drip system can indeed come close to perfect uniformity.

The settlement of an efficient and a proper leaching management, the frequency and amount of water for leaching should be evaluated in view of the irrigation water quality, climate, soil and crop sensitivity to salinity, the crop season and period as well as the accumulated salts in soils.

The point which still under discussion is the leaching scheduling (amounts and intervals) allowing to have an efficient and effective leaching management. In this regard, numerous field leaching trials have been conducted (Shalhavet, 1984; Bernstein and Francois, 1973b; Francois, 1981; Meiri and Shalhavet, 1973; Meiri et al., 1977; Hamdy, 1990c and Hamdy and Nassar, 1991).

The findings by those authors were contradictory; a part of the results fully support the idea that leaching should be done at every irrigation, whereas the others were in favour of periodical leaching when salt accumulation in soils becomes excessive.

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.

The findings of Bernstein and Francois (1973b), Francois (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.

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

In this regard, an investigation was carried by Hamdy (1990d) which consisted of four periodical leaching treatments: T1 = Leaching at each irrigation, T2 = Leaching after one month of irrigation with saline water; T3 = Leaching after two months of irrigation with saline water;
T4 = Leaching after harvest in combination with 4 salinity levels of irrigation (0.9, 3, 6, 9 dS/m) using durum wheat as indicator plant.

The result obtained showed that the different investigated parameters, the plant (Table 5), the soil (Table 6) and the leaching drainage water table (Table 7) are all in favour of periodical leaching rather than the frequent leaching each irrigation. The T3 treatment was highest in efficiency in reducing the accumulated salts in soils, it also led to the best yield marks.

The author recommended that for having an efficient leaching management, leaching should be carried out in accordance with the critical stage where stress should be prevented. In fact, such stage will vary according to plant grown, its growing stage tolerance as well as the salt level in irrigation water.

Table 5 Straw, Grain yield weight and Grain/Straw Ratio under different leaching tratments.

Leaching Treatments												
Eci*	Straw weight(g/m^2)				Grain yield(g/m2)				Grain/Straw ratio			
(dS/m)	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
0.9	785	830	824	784	578	586	579	549	0.67	0.71	0.70	0.70
3.0	836	845	828	822	587	581	586	551	0.70	0.69	0.74	0.70
6.0	733	736	757	755	505	506	519	573	0.70	0.65	0.69	0.63
9.0	652	604	575	689	385	389	372	341	0.57	0.65	0.65	0.55

* Electrical Conductivity of Irrigation water

Table 6 Average Ecs values (dS/m) and chloride concentration (meq/l) in soils under different leaching treatments.

Leaching Treatments								
ECi *	T1		T2		T3		T4	
(dS/m)	ECs	Cl-	ECs	Cl-	ECs	Cl-	ECs	Cl-
	dS/m	meq/l	dS/m	meq/1	dS/m	meq/l	dS/m	meq/l
0.9	1.4	12.9	1.7	16.5	1.3	11.8	1.6	16.0
3.0	8.0	83.7	8.3	86.8	5.2	55.6	6.8	67.8
6.0	12.3	109.4	12.8	121.5	10.8	118.0	13.6	137.7
9.0	15.5	153.7	15.1	156.8	12.2	122.4	17.2	170.5

* Electrical Conductivity of Irrigation water

Table 7 Chloride output (mg) in the lechates.

Chloride Output (mg)				
Leachinc Treatments				
ECi * (dS/m)	T1	T2	T3	T4
0.9	1.65	0.34	3.39	1.74
3.0	8.28	2.57	14.59	10.46
6.0	9.38	6.11	32.43	13.36
9.0	15.52	8.17	28.18	19.44

* Electrical Conductivity of irrigation water

Hamdy and Nassar (1991), in their experimental trials concluded that under saline irrigation practices, for maximum utility and better saving of fresh water, xon one hand, and the achievement of satisfactory crop production on the other one, leaching should be carried at the proper time corresponding to the degree of salinity tolerance of the growing stages and in the proper quantities (L.F) according to the salt concentration level in irrigation water as well as the degree of salt accumulation in the soils. In this regard, it is important to consider carefully the aspect of minimizing the leaching requirement applications to achieve efficient leaching and avoiding the overload of the drainage system or the increase in the salt load of the groundwater. The extent to which leaching can be minimized is limited by the salt tolerance of the crops being grown, salt content and composition of water producing leaching and soil characteristics including exchangeable cation composition (sodicity) texture, clay minerals, soil mineral weathering, salt dissolution and precipitation and structural stability.

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:

- 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.

7.5 - 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:

A) 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.

B) 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.

   Recently, 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).

C) Conjunctive use of good and poor quality water (recycling-alternation):

   i) soil dilution: crops are irrigated by alternating between water resources so that the dilution occurs in the root-zone;

ii) sequential application: the water source is changed during the season according to the specific salt tolerance of the crops at each growth stage.

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.

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.

In areas where mixing is not advisable nor technically feasible, special practices may be applied, 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, 1984a; 1984b; 1987; Rhoades et al., 1988a; 1989b and 1988c).

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.
- A third set of experiments, under the auspices of researchers at U.C. Davis, applied a somewhat less stringent restraint; in it, one water quality or another is used for a full season (Grattan and Shannon, 1990 personal communication). The general principle, however, is the same.

Although cyclic strategy has more potential flexibility than the blending one, there may be difficulty in adopting the cyclic strategy on small farms where the drainage water produced is too little or does not coincide with the peak crop water demand. To overcome this constraint, a surface storage reservoir has to be constructed to return the low water quality until its use is required. In addition, application implies a double distribution system of water -both saline and fresh- to farms.

An intensive research programme was carried out in Bari Institute and lasted for more than 5 years to evaluate practically the forementioned two water application strategies. The data and results obtained (Hamdy, 1993) favoured more the alternate water application than the blending one.

Hamdy (1991b) summarized the advantage of the recycling strategy with respect to the blending one in the followings:
- 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 sensetive 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 sensetive to the salinity level in irrigation waters, satsfactory 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;
  - blending will not reduce the total salt load, but may allow more cropping area to be planted because of the increase in water volume caused by dilution.

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.

8 - CONCLUDING REMARKS

- World wide experience in the use of saline water for irrigation indicates the high potentiality of using such water.
- 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 facilitate the use of relatively saline water for irrigation.
- The use of low water quality for irrigation is a complex practice and its sustainable use requires great care, in considering agronomic as well as water management and economic factors without neglecting the long term effects of this practice on the physical and chemical soil properties, on crop yields and on the environment.

- Much work on potentials and hazards of the use of saline water, mostly done under controlled conditions in greenhouse, in small plots, is already available but hardly used in practice. Therefore, results are needed to be tested and demonstrated under the real world conditions where farmers and the operational organizations (irrigation department, sand water users associations).
- At present there are no clearly defined policies and strategies on the reuse of drainage water and on the mitigation of its adverse environmental impacts. To arrive at these policies and strategies, monitoring programs are required on both quantities and qualities.
- Much important and useful research work has been carried out by a number of research institutes and organizations on problem related to saline water management and waterlogging and salinity. However, those activities were undertaken in relative isolation and no mechanism existed for coordinating the research work or for ensuring that the readily available research findings could be effectively utilized. 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. This will allow to bring together the latest research experience for review and dissemination as well as identifying areas of needed research.

∗ 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.

∗ Develop practical solutions to problems associated with the saline management aspects.

∗ Provide facilities for research workers and to train associated personal in techniques and methods for dealing with saline water practices and related salinity problems.

- There are relatively few places where farmers are using successfully saline documented.
- Farmers participation and involvement in planning and management is the key point to overcome the gap between researchers and users.

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