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ADVANCED AND INTEGRATED APPROACHES FOR CROP TOLERANCE TO POOR QUALITY IRRIGATION WATER IN EGYPT

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Introduction

"Egypt is the gift of the Nile" as expressed by Herodorus for several centuries ago. The main source of water in Egypt comes from the Nile River. Egypt's share from the Nile water is 55.5 billion m^3a^{-1}. The other sources such as ground water and drainage water constitute about 3.1 billion m^3 and 4.7 billion m^3 respectively. Rainfall is scarce and its amount in the Northern coastal area range from 100-200 $mm^{-1}a^{-1}$ in which few winter crops could be grown (El-Mowlhi and Abd El-Hafez, 1999).

In arid and semi-arid region, the insufficiency of fresh water resources is the main factor limiting the expansion of the cultivated area in order to meet the necessary food demands for the progressively increasing population. Therefore, to overcome the shortage in food demands and to reach satisfactory level of food production, the utilisation of other water resources beside the fresh ones is now a must.

In fact, in the recent years more attention was given to the utilisation of alternative water resources. This certainly results 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 physico-chemical soil characteristics. To avoid such situation 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.

In irrigated agriculture, the hazard of saline water is a constant threat. Poor-quality irrigation water is generally more concerning as the climate changes from humid to arid conditions. Salinity is not normally a threat where precipitation is the major source of salt-free water for crop production, since the percolating water flushes (leaches) soluble salts. Less rainfall however, means smaller amounts of precipitation available to leach salts.

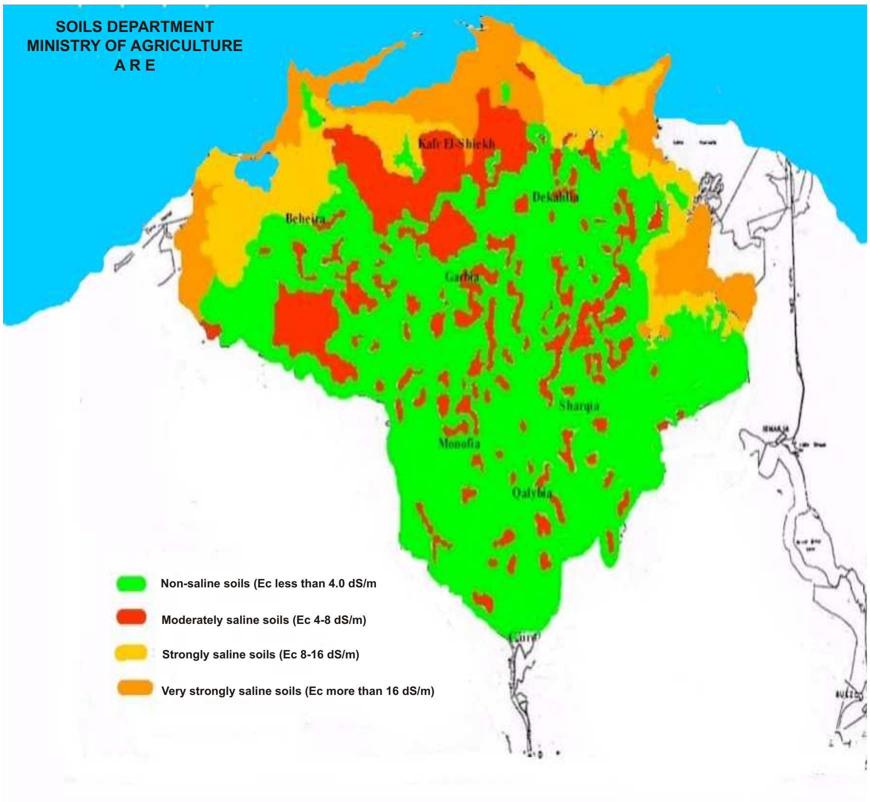
Most of our crop species are glycophytes and are not adapted to high salinity concentrations and there are large differences among these species in their growth and yield response to salinity (Mass and Hoffman, 1977). A few salt-tolerant crops (e.g. barley, date palm, and sugar beet) are standard crops for the saline areas.

Plants are classified as halophytes or glycophytes in relation to their response to salinity. Halophytes are salt tolerant plants whereas glycophytes, to which most of the vegetable crops belong, vary in response to salinity from very salt sensitive to moderately salt resistant, (Mangal, 1999).

Seawater agriculture must fulfil two requirements to be cost-effective. First, it must produce useful crops at yields high enough to justify the expense of pumping irrigation water from the sea. Second, researchers must develop agronomic techniques for growing seawater-irrigated crops in a sustainable manner-one that does not damage the environment. Clearing these hurdles has proved a daunting task, but we have had some success.

Soil Survey: Salinity Status

Map 1 shows the general status of soil salinity in the Nile Delta. The soils of the southern part of the Delta are generally non-saline, as the electric conductivity of their saturation extracts is below 4 dSm^{-1}. The salinity problem becomes more severe when approaching the Mediterranean coast and around the north lakes where soils are extremely saline. The total soluble salts in general increase with depth, due to the effect of the ground water, (Abdel-Aal, 1971). Soluble magnesium exceeds soluble calcium at this site due to contamination from the seawater. Sulphates are relatively higher near Manzala Lake due to secondary gypsum formation usually found in Sirw area, (Abdel-Aal 1971).

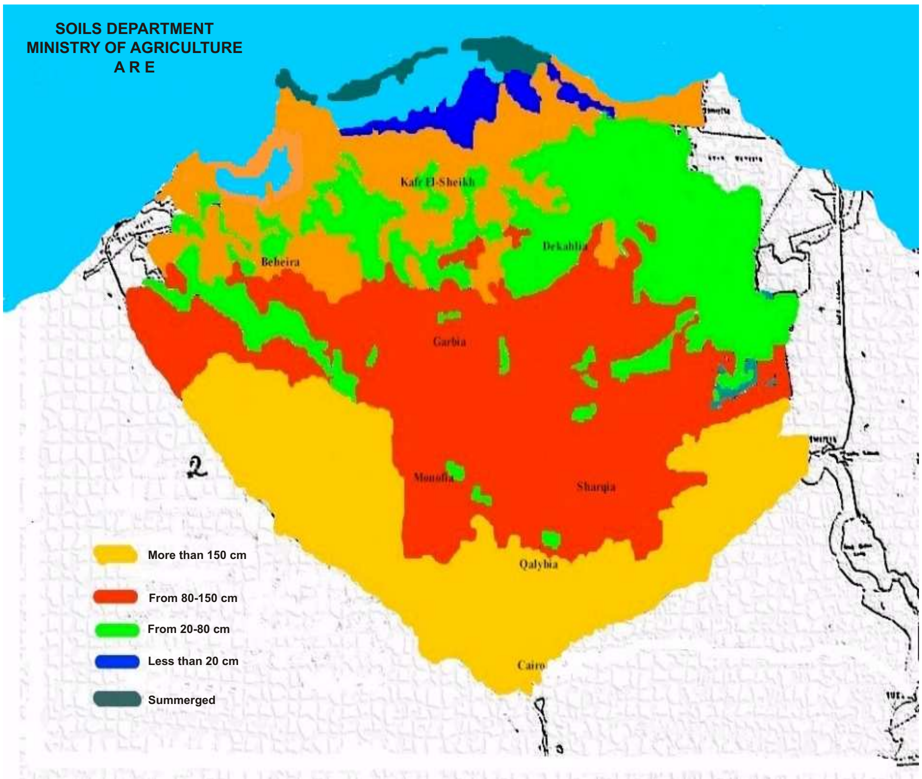


Map 1. Salinity Status in the Nile Delta Soils (surface soils)

However, in soils of the south, salt accumulation has occurred from the irrigation system during the last century, since no action was taken for the construction of an adequate drainage system. Saline soils in the northern part have been affected by brackish water intrusion from the sea, the northern lakes and tidal marches. The flat topography and low land have accelerated this process by bringing the water table close to the soil's surface. (El-Nahal *et al.,* 1977).

Groundwater Table:

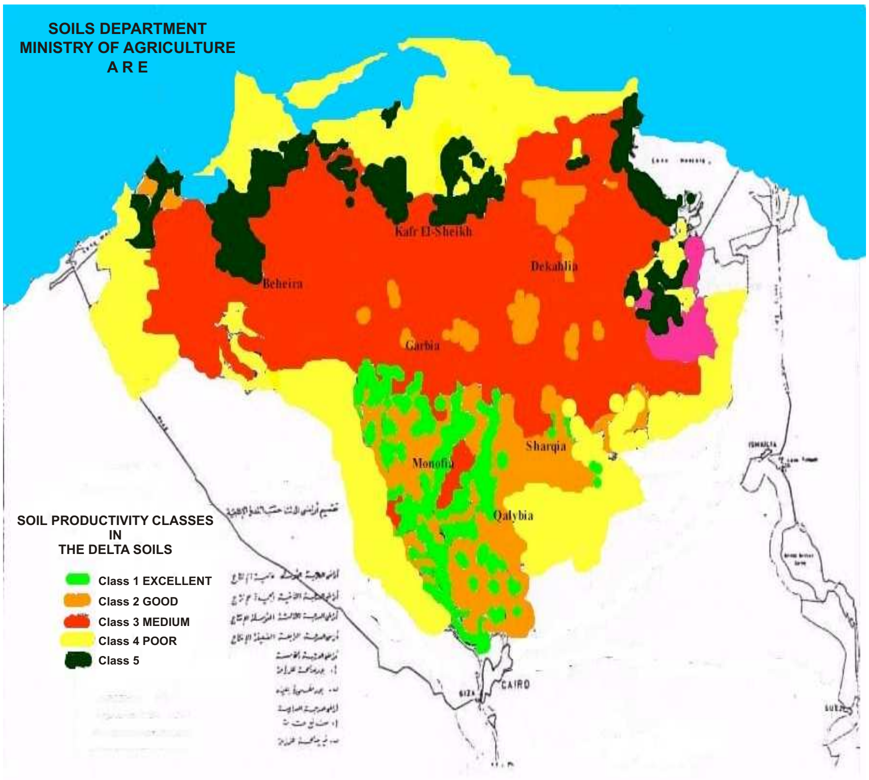
Map 2 shows that the water-table was deeper than 150 cm in the majority of the southern part, and was shallower in the northern part near the coastal lakes, reaching less than 20 cm from the soil surface and in some areas the soil was submerged under water. In all cases, however; the subsoil in the northern areas was quite wet and showing evidence of poor-aeration. The presence of reduced iron manganese concentration and colour mottling at different depths of the subsoil indicates poor drainage and anaerobic conditions.



Map 2. Water table depth in the Nile Delta soils

However, the depth of the ground showed in Map 3, reflects only the situation at the sampling time and does not represent seasonal variations. In some areas the measurement of ground water depth as well as other soil survey investigations were carried out during high ground water seasons. These records are considered as descriptive and could be used to give indication of the range in which the ground water in a certain area lies (El-Nahal *et al.,* 1977).

Shallow water table in the southern part of the Delta was found in areas subjected to water seepage from irrigation canals where drainage was lacking or proved to be inadequate. Ground water table was deep in areas where no seepage occurred or where drainage system was constructed. Khater *et al.,* (1997) and Zein *et al.,* (2000) found that values of electric conductivity and sodium adsorption ratio (SAR) for ground water table varied from one location to another.



Map 3. Soil productivity classes

Table 1 showed that higher values of electric conductivity and sodium absorption ratio for water-table in locations that used drainage water in irrigation, could be due to intrusion of seawater and the high level of salinity in drainage water used for irrigation compared to blending irrigation water.

Table 1. Electrical conductivity and SAR values of water-table in El-Hamoul and Balteim sites North Delta, Egypt (adapted from Zein *et al*., 2000)

Location	Water sources	Ec dSm^{-1}	SAR
El-Hamoul	Drainage Mixed	11.70 5.69	31.27 14.39
Baltiem	Drainage Mixed	12.50 6.50	23.34 11.55

Soil Productivity:

El-Nahal *et al.,* 1977 showed that the productivity classes of the Nile Delta soils as shown in Map 3. The first class soils cover only a small portion of the Nile Delta, about 4% mainly in Menofia and Qalybia Governorates in the southern part. These soils are suitable for all crops and give the highest yield. They are deep soil with medium texture and are well drained. They are non-saline and free of alkalinity.

The second class soils make up nearly 5% of the Delta area. The soils of this class differ from those of the first class only because they have heavier texture and are slightly saline.

They are located in large areas in Monofia, Qalybia and Garbia Governorates, and in small, scattered areas in the rest of the Delta.

The third class soils make up 33.5% of the Delta area. They are concentrated in large areas in Sharkia, Dekahlia, Kafr El-Sheikh, and Beheira Governorates, which occupy most of the northern part of the Delta.

The fourth class soils make up 7.8% of the Delta area. They are concentrated mainly in the newly reclaimed soils along the desert fringe, south of the northern lakes and along the sea coast. The fifth class soils (flooded land) make up 22.5% and the sixth class (public utilities) make up 7.4% of the Delta area.

Generally, the high salt content, high water table and the heavy or coarse texture are the main factors that restrict the productivity of the third and the fourth class soils.

Salinity and Sodicity Management:

Sometimes crops are exposed to conditions differing significantly from those for which the salt tolerant data were obtained. Several factors, including soil, crop and environmental conditions interact with salinity to cause a different yield response. Variety or hybrid and stage of growth are crop factors, which may modify the salinity response. Typically, crop breeding attempts to emphasise high productivity rather than salinity tolerance. Consequently, differences in salt tolerance between varieties or hybrids are not common among field and garden crops, with the exception of soybeans, where varieties can show large differences in salt tolerance.

Stage of plant growth is another factor in crop salt tolerance. While salinity may delay seed germination and seedling emergence, most crops are capable of germinating at higher salinity levels than they can tolerate during later stages of growth. Corn, for example, will germinate at a salinity level twice as high as the threshold for grain yield. Typically, crops are most sensitive as seedlings and tolerance increases as plants mature.

In Egypt, rainfall is the most critical environmental factor. Rainfall before and during the irrigation season makes it possible to use more saline irrigation water because salts will dilute in the root zone and leaching is increased. To calculate the average salinity of water, both rainfall and irrigation water should be considered. The average salinity of the applied water (Ca) can be calculated from:

$$Ca = [Cr\ Dr + Ci\ Di] \div [Dr + Di] \quad \textit{(Equation 1)}$$

Where:

C: electrical conductivity

D: depth

a: average applied

r: rainfall

i: irrigation water

The variable C can be expressed as concentration (mg L^{-1}) or electrical conductivity (dS m^{-1}). D is depth (cm). The subscripts a, r and i indicate average applied, rain and irrigation water, respectively. For example, in North Delta, if 6.7 cm of rainfall was totalled and 60 cm of irrigation water with a salt content of 2,500 mg L^{-1} were applied during the growing season, the resulting average salt concentration of the applied water would be:

Ca = [(0 x 6.7 cm.) + (2,500 mg L^{-1} x 60 cm.)] ÷ [6.7 cm + 60 cm.]

Ca = 2,249 mg L^{-1}

To convert these salt concentrations to electrical conductivity, divide Ca by 640. This results in an ECa of 3.5 dSm^{-1}. These values can be converted to soil salinity, assuming a leaching fraction of 0.15, by multiplying ECa by 1.5. Soil salinity, expressed as ECe, is 5.3 dSm^{-1}.

Could soil salinity cause a loss of yield?

The following equation could be used to calculate yield loss.

$$Yr= 100 \quad s\ (ECe \quad t) \quad \textit{(Equation 2)}$$

Where *Yr* is crop yield relative to the same conditions without salinity, *t* is the threshold salinity, *s* is the linear rate of yield loss with increasing salinity beyond the threshold and *ECe* represents the average root zone salinity measured as the electrical conductivity of a saturated soil extract.

Maas, (1986) has provided threshold values for salt tolerance of herbaceous crops. Using this reference, the threshold value (upper limit with no yield loss) for sugar beet yield is 7.0 dSm^{-1}. Using Equation 2, if leaching was 0.15, the sugar beet yield would be 90% percent:

$$Yr = 100 \quad 5.9\ (5.3 \quad 7.0)$$

How much salt adds to the soil without leaching requirements?

To convert this salt concentration to kg during growing season, divide Ca by 1,000,000, then multiply by 1,000 to get on kg of salt per m^3, since ET of sugar beet was 2,134 m^3 per feddan (feddan=0.24 hectare) using modified Penman (El-Marsafawy and Eid 1999), the salt added to the soil will be amounted 853.6 kg/feddan/season. It means that 853.6 kg (one ton approximately) of salt will be added when concentration of irrigation water is 2,500 mg L^{-1}.

Leaching Requirements:

To prevent salts from increasing to levels detrimental to crop production, water must drain through the crop root zone. In most instances, natural drainage is sufficient to leach salts from the crop root zone. If natural drainage is not adequate, however, a drainage system must be installed. Where salinity is a hazard, the length of time before productivity is reduced depends on water management, drainage and the area's hydrogeology.

The necessary leaching requirement (LR) can be estimated from the following equation Rhoades, (1974):

$$LR = ECw / (5\ (ECe)\ \ ECw) \quad \textit{(Equation 3)}$$

Where:

LR = the minimum leaching requirement needed to control salts within the tolerance (ECe) of the crop with ordinary surface methods of irrigation.

ECw = salinity of the applied irrigation water in ds/m

ECe = Average soil salinity tolerated by the crop as measured on a soil saturation extract.

Sodicity:

When the concentration of sodium becomes excessive in proportion to calcium plus magnesium, the soil is said to be sodic. Ramadan *et al.,* 1989 and Zein *et al.*, 1997 indicated that excessive sodium causes soil mineral particles to disperse and water penetration to decrease. High sodium concentrations become a problem when infiltration rate is reduced and the crop is not adequately supplied with water or when the hydraulic conductivity of the soil is too low to provide adequate drainage. Excess sodium may also add to cropping difficulties through crusting seed beds, temporary saturation of the soil surface, high pH, and the increased potential for disease, weeds, soil erosion, lack of oxygen and inadequate nutrient availability.

The permissible value of the SAR is a function of salinity. High salinity levels reduce swelling and aggregate breakdown (dispersion), promoting water penetration. High proportions of sodium, however, produce the opposite effect. Regardless of the sodium content, water with an electrical conductivity less than about 0.2 dSm^{-1}causes degradation of the soil structure, promotes soil crusting and reduces water penetration. Both salinity and the sodium adsorption ratio of the applied water must be considered when assessing the potential effect of water quality on soil water penetration.

Application of gypsum to the soil surface after tillage, or incorporation of gypsum into the soil up to 10 cm, is an effective method to improve infiltration rates. The application of gypsum to irrigation water to solve water related infiltration problem usually requires less gypsum per feddan than direct soil application. Gypsum is particularly effective when added to water if the water salinity is low (EC less than 0.5 dSm^{-1}). It is much less effective for higher salinity water because of the difficulty in applying and getting sufficient calcium into solution to counter the sodium present effectively.

Table 2. Relationship between applied water (m^3/feddan) and leaching requirements (LR) using polynomial and cubic equations for different crops in Egypt.

Crops	Polynomial and Cubic equations	R^2
Field crops	$AW = 4732.7\{LR\}^2 + 3005.33\{LR\} + 3189.5$	1.0
Cotton	$AW = 3390.2\{LR\}^3 + 3492\{LR\}^2 + 3139.9\{LR\} + 3185.3$	1.0
Sugar beet	$AW = 3214.4\{LR\}^2 + 2005.4\{LR\} + 2138$	1.0
	$AW = 3078.9\{LR\}^3 + 2087.6\{LR\}^2 + 2127.7\{LR\} + 2134.3$	1.0
Wheat	$AW = 2447.1\{LR\}^2 + 1533.6\{LR\} + 1637.5$	1.0
	$AW = 3845.3\{LR\}^3 + 1039.9\{LR\}^2 + 1686.2\{LR\} + 1632.7$	1.0
Corn	$AW = 8985.4\{LR\}^2 + 1086.3\{LR\} + 2378.2$	1.0
	$AW = 100920\{LR\}^3 + -27948\{LR\}^2 + 5093.4\{LR\} + 2252.6$	1.0
Vegetables crops:	$AW = 4334.4\{LR\}^2 + 2705.1\{LR\} + 2886.8$	1.0
Tomato	$AW = 3563.4\{LR\}^3 + 3030.3\{LR\}^2 + 2846.6\{LR\} + 2882.4$	1.0
Potato	$AW = 1984.98\{LR\}^2 + 1295.4\{LR\} + 1363$	1.0
	$AW = 2755.5\{LR\}^3 + 976.6\{LR\}^2 + 1404.8\{LR\} + 1359.5$	1.0
Pepper	$AW = 2369.8\{LR\}^2 + 1471.8\{LR\} + 1574.4$	1.0
	$AW = 2756.7\{LR\}^3 + 1361\{LR\}^2 + 1581.2\{LR\} + 1570$	1.0
Onion	$AW = 4765.8\{LR\}^2 + 3089.6\{LR\} + 3259.9$	1.0
	$AW = 5409.0\{LR\}^3 + 2786.3\{LR\}^2 + 3304.3\{LR\} + 3253.2$	1.0
Forage crops:		
Alfa alfa	$AW = 8866.2\{LR\}^2 + 5358.1\{LR\} + 5735.6$	1.0
	$AW = -19756.0\{LR\}^3 + 16096.0\{LR\}^2 + 4573.7\{LR\} + 5760.2$	1.0
Clover	$AW = 3605.0\{LR\}^2 + 2245.7\{LR\} + 2399.0$	1.0
	$AW = 4537.0\{LR\}^3 + 1944.6\{LR\}^2 + 2425.8\{LR\} + 2393.4$	1.0
Fruit crops:		
Date palm	$AW = 7442.6\{LR\}^2 + 4727.0\{LR\} + 5020.1$	1.0
	$AW = 7474.7\{LR\}^3 + 4707.1\{LR\}^2 + 5023.8\{LR\} + 5010.7$	1.0
Orange	$AW = 7442.6\{LR\}^2 + 4727.0\{LR\} + 5020.1$	1.0
	$AW = 7474.7\{LR\}^3 + 4707.1\{LR\}^2 + 5023.8\{LR\} + 5010.7$	1.0
Grape	$AW = 4716.7\{LR\}^2 + 2993.9\{LR\} + 3176.3$	1.0
	$AW = 5509.6\{LR\}^3 + 2700.3\{LR\}^2 + 3212.7\{LR\} + 3169.4$	1.0

Finely ground gypsum (less than 0.25 mm in diameter) dissolves much more rapidly. Therefore, the finely ground, usually purer grades of gypsum are generally more satisfactory for water application, (FAO, 1985).

Salt-crops Tolerance:

Excess salinity within the plants root zone has a general deleterious effect on plant growth, which is manifested as nearly equivalent reduction in the transpiration and growth rates (including cell enlargement and 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 this observation 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 root zone and to make the biochemistry adjustments necessary to survive under stress. This energy is diverted from the processes that lead to growth and yield.

Crops differ greatly in their response to salinity. The most distinct signs of injury from salinity is reduced crop growth and loss of yield. Crops can tolerate salinity up to certain levels without a measurable loss in yield (this is called the salinity threshold).

The more salt tolerant the crop, the higher the threshold level. At salinity levels greater than the threshold, crop yield reduces linearly as salinity increases, (see Equation 2.) Crops differ greatly in their values of both threshold (t) and slope (s). Values of threshold and slope for many crops are given by Maas (1986).

Egyptian Strategy to Use Drainage Water:

Egypt is a predominantly arid country and the scattered rain showers in the north can hardly support any agricultural crops. Agriculture thus depends mainly on irrigation from the River Nile (55.5 BCM (billion cubic metres) per year). The needed increase in food production to support the acceleration of population growth (2.7%), compels the country to use all sources of water (i.e. drainage water, groundwater and treated sewage water) for the expansion of irrigated agriculture.

The policy of the Egyptian Government is to use drainage water (up to salinity of 4.5 dSm^{-1}) after it is blended with fresh Nile water (if its salinity exceeds 1.0 dS/m) to form blended water of a salinity equivalent to 1.0 dSm^{-1}. The drainage water presently used for irrigation amounts to 4.7 BCM per annum and it is likely to continue to increase (see Table 3).

Table 3. Quantity of drainage water, salinity levels and estimated reuse in years 1988 and 1992 (adapted by Mashali based on data reported by Amer and Ridder (1988) and Rady (1990)

Regions	Quantity of drainage water in MCM					Total	Estimated reuse	
	Salinity levels EC in dSm^{-1}						Year 1988	Year 1992
	<1	1-2	2-3	3-4	>4			
Eastern Delta	949	1565	1055	310	433	4312	1130	2000
Middle Delta	330	1421	1832	273	1191	5047	686	1400
Western Delta	473	412	1291	901	1914	4991	554	1050
Total	1752	3398	4178	1484	3538	14350	2370	4450

In fact, direct use of drainage water for irrigation with salinity varying from 2 to 3 dSm^{-1}, is common in the districts of Northern Delta where there are no other alternatives or in areas of limited better water quality supply. Farmers in Beheira, Kafr-El-Sheikh, Damietta and Dakhlia Governorates have successfully used drainage water directly for periods of 25 years to irrigate over 10,000 ha of land, using traditional farming practices.

The soil texture ranges from sand, silt loam to clay with calcium carbonate content of 2 to 20 percent and very low in organic matter. The major crops include clover "Berseem", rice, wheat, barley, sugarbeet and cotton. Yield reductions of 25 to 30 percent are apparently acceptable to local farmers. Yield reductions observed are attributed to waterlogging and salinization resulting from over-irrigation and other forms of poor agricultural, soil and water management.

Pilot studies carried out in Kafr el Sheik and Beheira Governorates showed that by applying appropriate management practices (i.e. crop selection, use of soil amendments, deep ploughing, tillage for seedbed preparation, land levelling, fertilisation, minimum leaching requirements, mulching and organic manuring), drainage water of salinity 2 to 2.5 dSm^{-1} can be safely used for irrigation without long term hazardous consequences to crops or soils (see Table 4)

Table 4. Yields of dominant crops in Kafr el Sheikh and Beheira Governorates using drainage water for irrigation (after Mashali 1985)

Irrigation water		**Average yields**				
		Rice tons/ha	**Clover (berseem) tons/ha**	**Barley tons/ha**	**Cotton tons/ha**	**Squash kg/ha**
Drainage Water						
	Kafr El Sheikh	8.0	150	-	-	-
	(EC = 2-2.5 dS/m)					
Drainage water Beheira		8.2	155	3.7	1.9	330
Fresh Nile water		8.5	160	3.7	2.0	350
(EC = 0.4 dS/m)						

In Fayoum Governorate, the annual average volume of drainage water available amounts to 696 MCM, of which 350 MCM per year are used at present after blending with canal water. Results of pilot demonstrations in Ibshwai District during the period 1985 to 1987 on direct and cyclic use of drainage water (EC = 2.8 dSm^{-1}) with fresh Nile water are presented in Table 5.

Table 5. Effect of irrigation with different salinity levels on principal crops grown in the area (adapted by Mashali based on data reported by Rady 1990)

Source of irrigation water (EC in dS/m)	**Wheat Grain dry tons/ha**	**Onion tons/ha**	**Maize tons/ha**	**Summer tomato tons/ha**	**Winter tomato tons/ha**	**Pepper tons/ha**
Drainage water (2.8 dS/m with SAR 22)	5.0	6.5	1.8	2.5	8.0	12.5
Fresh Nile water for seedling establishment and then drainage water	3.0	6.5	2.0	4.0	8.7	20.0
Fresh Nile water (0.5 dS/m with SAR 4)	5.0	9.7	2.5	7.5	12.5	25.0

The following strategy emerged from these demonstrations: Irrigate sensitive crops (maize, pepper, onion, alfalfa, etc.) in the rotation with fresh Nile water and salt tolerant crops (wheat, cotton, sugarbeet, etc.) directly with drainage water. Moderately sensitive crops (tomato, lettuce, potato, sunflower, etc.) can be irrigated with drainage water but after seedling establishment with fresh Nile water. Based on these results, the Governorate is planning to reclaim 4,000 ha using the drainage water.

The estimated present annual abstraction from groundwater resources in the Nile Valley and Delta is about 2.6 BCM (for agricultural, municipal and industrial use) with an average salinity of 1.5 dSm^{-1} but ranging far higher, at least to 4.0 dSm^{-1} (the estimated use of this groundwater resource by the year 2010 is 4.9 BCM). Saline groundwaters ranging 2.0 to 4.0 dSm^{-1} have been successfully used for decades to irrigate a variety of crops in large areas of scattered farms in the Nile Valley and Delta.

Presently grown crops are mostly forage, cereals and vegetables. In the Delta, saline waters of EC 2.5 to 4 dSm^{-1} has been used successfully to grow vegetables under greenhouse conditions. In the New Valley (Oases, Siwa, Bahariya, Farafra, Dakhla and Kharga) there is the potential to irrigate about 60,000 ha utilising groundwater (salinity ranging from EC 0.5 $dSm^{-1}$to 6.0 dSm^{-1}), of which 17,000 ha are already under cultivation.

Siwa Oasis has the largest naturally flowing springs in the New Valley. Siwa once contained a thousand springs, of salinity ranging from EC 2 to 4 dSm^{-1}, which were used successfully to irrigate olive and date-palm orchards, with some scattered forage areas. At present 3,600 ha are irrigated from about 1,200 wells. Of these, 1,000 are hand dug to depths of 20-25m (salinity ranging from EC 3.5 to 5.0 dSm^{-1} and in some locations as much as 10 dS/m), and the remaining 200 wells were drilled deep (70-130 m) with salinity of EC 2.5-3.0 dSm^{-1}- the SAR values varying from 5 to 20.

Presently about 235 MCM/year is being used successfully to irrigate olive and date-palm orchards, alfalfa, cereals and wood trees (of which 60 MCM from continuing flowing springs). Due to over-irrigation without appropriate drainage facilities, seepage as well as run off to low lying land, salinity and waterlogging have developed in some lands of the oasis. To reduce drainage water volumes, minimise water pollution and safely dispose of the ultimate unusable final drainage water, new strategies are being developed and experimented by the Government authorities in Siwa Oasis (similar problems exist in Dakhla oasis).

These include:

- use of natural flowing springs to irrigate winter crops such as cereals and forage;
- use of saline water over 5 dS/m to irrigate salt tolerant crops like barley, vetches, Rhodes grass, sugar beet, etc.;
- use of biologically-active drainage water for the production of windbreak and growing wood trees;
- use of drainage water for stabilisation of sand dunes;
- reuse of drainage water (average salinity is EC 6.0 dSm^{-1} with SAR values of 10 to 15) after blending with good quality water (recently drilled deep well of salinity EC 0.4 dSm^{-1} with SAR of 5) or by alternating the drainage water with good water.

Irrigation management under saline conditions:

For proper management in scheduling irrigation it is important to:

1. improve the accuracy of the soil water balance components to calculate a reliable estimate of the leaching fraction;
2. estimate the leaching requirements and add that to the irrigation requirement;
3. consider the water distribution uniformity to decide which part of the field should receive at least the leaching fraction for salinity control;
4. take into account that leaching salts periodically is more practical than every irrigation;
5. consider that there is no need to increase irrigation frequency to control salt concentration except for drip irrigation; and
6. monitor the salinity of the root zone, especially prior to the times of periodic leaching. This would result in optimum salt control with minimum losses to deep percolation.

Appropriated irrigation systems may be necessary on problematic soils. Sprinklers are well adapted to sandy and loamy soils but less so to heavy or clayey soils. Drip or trickle irrigation system are better adapted to loamy or clayey soils and apply water through many small outlets (emitters) at a rate of 2 to 4 litters per hour. At these low rates they do not disperse the soil particles, as do sprinklers (FAO 1985).

Drip irrigation (Ragab et al., 1984) provides a greater opportunity for using saline water. Sprinkler irrigation may cause surface sealing (Ragab, 1983) and leaf burn of sensitive crops. Leaf burning can be reduced by night irrigation, and by irrigating continually rather than intermittently.

Basin irrigation has greater potential for uniform application than other methods of flooding such as border irrigation or wild-flooding irrigation provided that the basins are levelled and sized properly.

Furrow irrigation tends to accumulate salts in the seed beds because leaching occurs primarily below the furrows. The length of the furrow, the slope, size of the stream and time of application are factors that govern the depth and uniformity of application. Leaching and salinity control require a proper balance among these factors.

Seawater Agriculture:

Halophytes are able to osmotically adapted to; acquire mineral elements, especially potassium in the presence of sodium chloride, from saline soils; while preventing the toxic effects of salt ions (Flowers et al., 1977 and O'Leary, 1989). Halophytes have been used as forage in arid and semiarid areas for millennia (Johnson et al., 1992; Le Houe're, 1993).

The value of certain salt tolerant shrubs and grass species has been recognised by their incorporation in pasture-improvement programs in many salt affected regions throughout the world. There have been recent advances in selecting species with high boimass and protein levels in combination with their ability to survive a wide range of environmental conditions, including salinity (NAS, 1990 and Ulery *et al.*, 1998).

Halophytes suitable for production either as native stands or artificially established include the herbaceous species: *Elymus elongatus*, *Hedysarum carnosum*, *Cynodon dactylon* and *Puccinellia ciliata*, and the forage shrubs: *Atriplex halimus*, *Atriplex nummilaria, Atriplex canescens*, *Atriplex lentiformis*, *Atriplex semibaccata*, and *Atriplex glauca*.

The natural rangeland in Sinai region and the coastal parts of Egypt, for example, are dominated by several halophytes species. Palatable shrubs are suffering severely at present from overgrazing. The research policy has been geared towards optimum utilisation of the widely distributed unpalatable and less-palatable forage in feeding livestock.

The common halophytic species in Southern Sinai area varied widely in their chemical and mineral composition. They were relatively nutritious in winter season, particularly the palatable ones, i.e. *Suaeda fruticosa*, *Nitraria retusa* and *Salsola tetreandra*. Most of halophytic shrubs in Sinai contained moderate amount of crude protein and high levels of ash, silica and fiber constituents (Tadros, 1954 and Batanouny, 1986). Many halophytes survive saline stress by accumulation salt in their vegetative tissues.

The salt level in the leaves and stems of these plants can limit their direct consumption as food, but their seeds are relatively salt-free, which may allow production of starchy grains or oilseeds (Batanouny, 1993). *Distichlis palmeri* was developed into a crop with nutritional qualities, baking characteristics, and the taste of its flour compares very favorably with wheat flour (El-Shourbagy and Yensen, 1983; Yensen, 1993). *Salicornia* sp. has been experimented in Egypt as a source of vegetable oil (Charnock, 1988 and O'Leary, 1987).

Some of the most productive and salt-tolerant halophytes were shrub by species of *Salicornia* (glasswort), *Suaeda* (sea blite) and *Atriplex* (saltbush) from the family Chenopodiaceae, which contains about 20 percent of all halophyte species, Jaradat, 1999). Salt grasses such as *Distichlis* and *viny*, succulent-leaved ground covers such as *Batis* were also highly productive. (These plants are not Chenopodiaceae, though; they are members of the Poaceae and Batidaceae families, respectively.)

But to fulfill the first cost-effectiveness requirement for seawater agriculture, we had to show that halophytes could replace conventional crops for a specific use. Many halophytes have high levels of protein and digestible carbohydrates. Unfortunately, the plants also contain large amounts of salt; accumulating salt is one of the ways they adjust to a saline environment. Because salt has no calories yet takes up space, the high salt content of halophytes dilutes their nutritional value. The high salinity of halophytes also limits the amount an animal can eat. In open grazing situations, halophytes are usually considered "reserve-browse plants," to which animals turn only when more palatable plants are gone.

The most promising halophyte we have found thus far is *Salicornia bigelovii*. It is a leafless, succulent, annual salt-marsh plant that colonises new areas of mud flat through prolific seed production, (Glenn et al 1991). The seeds contain high levels of oil (30 percent) and protein (35 percent), much like soybeans and other oilseed crops, and the salt content is less than 3 percent. The oil is highly polyunsaturated and similar to sunflower oil in fatty-acid composition.

Seawater irrigation does not require special equipment. The large test farms we have helped build have used either flood irrigation of large basins or moving-boom sprinkler irrigation. Moving booms are used in many types of crop production. For seawater use, a plastic pipe is inserted in the boom so the seawater does not contact metal. *Salicornia* seeds have also been successfully harvested using ordinary combines set to maximise retention of the very small seeds, which are only roughly one milligram in weight.

Seawater farms can also be part of a solution to this problem if shrimp-farm effluent is recycled onto a halophyte farm instead of discharged directly to the sea. Halophytes grown on drain water in the valley take up enough selenium to make them useful as animal-feed supplements but not enough to make them toxic.

Will seawater agriculture ever be practised on a large scale? Our goal was to establish the feasibility of seawater agriculture; we expected to see commercial farming within upcoming 10 years. Twenty years later seawater agriculture is still at the prototype stage of commercial development. Several companies have established halophyte test farms of Salicornia or Atriplex in California, Mexico, Saudi Arabia, Egypt, Pakistan and India; however, to our knowledge, none have entered large-scale production. Our research experience convinces us of the feasibility of seawater agriculture. Whether the world ultimately turns to this alternative will depend on future food needs, socio-economics and to the extent to which freshwater ecosystems are withheld from further agricultural development.

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