Water saving potentialities through the use of saline water and the application of deficit irrigation

Hamdy A., Katerji N., Mastrorilli M., Dayyoub A.

in

Lamaddalena N. (ed.), Bogliotti C. (ed.), Todorovic M. (ed.), Scardigno A. (ed.).
Water saving in Mediterranean agriculture and future research needs [Vol. 2]

Bari : CIHEAM
Options Méditerranéennes : Série B. Etudes et Recherches; n. 56 Vol.II

2007
pages 45-59

Hamdy A., Katerji N., Mastrorilli M., Dayyoub A. **Water saving potentialities through the use of saline water and the application of deficit irrigation.** In : Lamaddalena N. (ed.), Bogliotti C. (ed.), Todorovic M. (ed.), Scardigno A. (ed.). *Water saving in Mediterranean agriculture and future research needs [Vol. 2].* Bari : CIHEAM, 2007. p. 45-59 (Options Méditerranéennes : Série B. Etudes et Recherches; n. 56 Vol.II)

WATER SAVING POTENTIALITIES THROUGH THE USE OF SALINE WATER AND THE APPLICATION OF DEFICIT IRRIGATION

A. Hamdy [*], N. Katerji [**], M. Mastrorilli [***] and A. Dayyoub [****]
[*] Professor Emeritus, CIHEAM-Mediterranean Agronomic Institute of Bari, Italy
E.mail: hamdy@iamb.it
[**] INRA, Station de Bioclimatologie, Thiverval-Grignon, France
[***] Istituto Sperimentale Agronomico, Bari, Italy
[****] Meditarranean Agronomic Institute of Bari, 70010 Valenzano (BA), Italy

SUMMARY- This work was conducted in the greenhouse of the Mediterranean Agronomic Institute of Bari, aiming to have further information characterizing the response of different durum wheat varieties to saline irrigation practices (5 and 10ds/m) using different irrigation regimes (100%, 60% and 40% of Etc). The presented data indicate clearly that the resistance to salt stress, as well as water stress varies greatly due to the variation in the studied wheat varieties. The findings show also that the vegetative growth and the grain yield production can tolerate salinity up to 5ds/m, which could be raised up to 10ds/m resulting in only 10% losses in the grain production. As a result, the apparent losses in the yield production under deficit irrigation using the saline water is fundamentally attributed to the water stress conditions. However, deficit irrigation with an appropriate Etc percentage and irrigation salinity level, is a win-win game as it provides good fresh water saving, acceptable yield production besides maintaining the soil salinity relatively low.

INTRODUCTION

In the arid and semi arid countries of the Mediterranean, the limited natural resources (land and water) in addition to the increase of population at a relatively high rate averaging to nearly 3 to 3.5% annually are putting immense difficulties for most of those developing countries to achieve water security, food security and environmental sustainability.

In spite of the major effects and the intensive programs carried out in those countries to improve the water productivity and water use efficiency in all water sectors particularly in the irrigation one, many countries are still far a way from achieving the goal of food security and water security (Hamdy and Katerji, 2006).

One of the approaches to be highly recommended is the use of the non-conventional water resources (saline brackish water and treated municipal waste water) as an additional water resources for irrigation to overcome the big gap in the cereals production (wheat, barley, maize), which are the fundamental crops having an important role on food security, fighting the poverty and alleviating hunger and mal nutrition.

Indeed 60% of cereals are produced under rain-fed agriculture conditions. This production is relatively low; representing nearly 20% of the one could be produced where irrigation is practiced due to the prevailing drought conditions at the critical growth stages (flowering and seed formation). Under such conditions there is a high potentiality to improve cereal production through supplemental irrigation at the critical growth stage with water having relatively high salt concentration level as most cereals can tolerate an Eci value lying between 6 ds/m and up to 8 ds/m.

Aware of the importance of the subject for most of arid and semi arid countries in the **MENA** and the Mediterranean region, an ample research program started 5 years ago between **CIHEAM-IAM**-Bari, **ICARDA**, **INRA** France and Agricultural university of Wageningen Holland where a part was directed to leguminous crops and other to the cereal crops in order to identify and distinguish between the different crop behaviors concerning their salt tolerance degree, in order to select the appropriate varieties with a higher salt resistance as a recommended varieties in the region.

The studies included in the research program were carried out in drainable Lysimeters and under controlled conditions in the **IAM-Bari** greenhouse, and covered the Leguminous crops, Beans, Check bees, Lentils and the cereals Barely, Durum Wheat and Bread Wheat.

The work presented in this study is a continuation of the research program, but the new in this research that it is not limited to elucidate just the impact of salinity, but also the effect of drought and water stress on the different plant growth stages and the yield.

The work presented in this paper is a part of this ample research program which has been carried out by the Mediterranean Agronomic Institute of Bari with INRA France and ICARDA, where, several varieties of durum wheat supplied by ICARDA will be under investigation with the main objectives of Investigating new ways of using the saline water for wheat production under arid and semi-arid conditions focusing on the salt tolerance degree of the durum wheat varieties, also to elucidate the behavior of the wheat growing parameters and the production under variable water stress and salt stress conditions.

MATERIAL AND METHODS

The experiment was conducted in the greenhouse of the Mediterranean Agronomic Institute in Valenzano, Bari (eastern south coast of Italy), during the year 2005-2006. The greenhouse where the experiment was conducted is covered with fiberglass sheet and is equipped with aeration and heating systems, thermostatically controlled to keep the temperature constantly around 20°C.

The experimental trail included two major parts:

- ➢ The first, where soils were kept during the whole cropping period at field capacity. At each irrigation the volume of water applied corresponds to the depleted water due to evapotranspiration.
- ➢ The second, where the plants were subjected to deficit irrigation receiving at each irrigation a volume of water equal to 60% and 40% respectively of the water lost due to evapotranspiration.

Following variables were studied:

- Durum wheat: three varieties under investigation (*Table 1*).
- Three salinity levels for irrigation water: fresh water of EC 1ds/m (control treatment) and two salinity levels 5ds/m and 10ds/m.
- Three irrigation regimes:
  - ➢ 100% of evapotranspiration (Trial A)
  - ➢ 60% of evapotranspiration (Trial B).
  - ➢ 40% of evapotranspiration (Trial B).

Table 1. Agronomic characteristics of the investigated cultivars tested in the green house.

Symbol	Name	Origin	Some agronomical characters
V1	CHAM -1	CIMIT-ICARDA	High yielding, good performance under higher rainfall and supplementary irrigation
V2	HAURANI	Syria	Landrace
V3	HUGLA	ICARDA	Showing salt tolerance

Source: ICARDA, plant breeding sector.

Table 2. Chemical analysis of irrigation water

EC (ds/m)	pH	Soluble anions (meq/l)			Soluble cations (meq/l)				SAR
		HCO_3^-	CL^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+	
F.W	7.35	3.70	1.20	6.80	7.20	2.80	1.57	0.13	0.70
5.00	7.52	3.25	21.30	15.20	7.10	11.30	21.70	1.16	6.85
10.00	7.41	3.60	46.80	27.11	7.40	22.40	45.71	2	11.84

The set-up consists of 162 lysimeter, made of polyvinyl chloride (PVC) with a volume of 0.07m3 (diameters of 0.40m and depth of 0.60m). The bottom of the tube was sealed with plastic tent 0.2 mesh in diameter and placed at the bottom of lysimeter 5 cm of coarse gravel for maintaining the proper drainage. At the upper part of the lysimeter depth of about 10-cm was left empty for the accommodation of irrigation water. Three porous cup tubes were located at different depth (15,30 and 45 cm) for soil water sampling by suction. Each lysimeter was placed inside a plastic container to collect the drainage water. The lysimeter dimensions and its technical specification are illustrated in Fig.1.

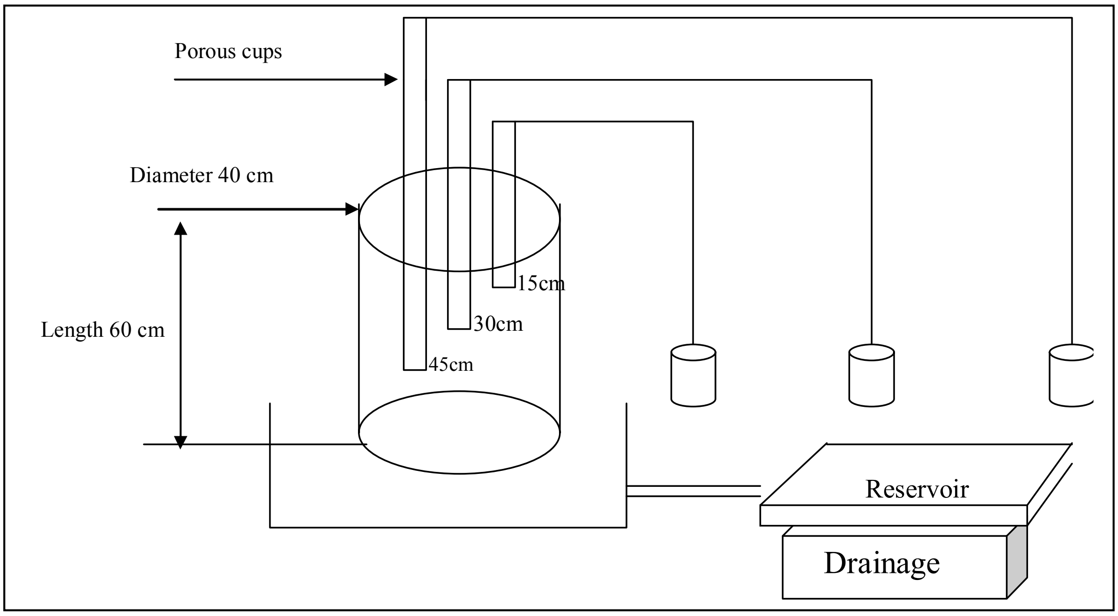

Fig. 1. Scheme of Lysimeter with Porous cups and drainage reservoir

Surface irrigation system was used before sowing; the volume of the water needed to bring the contained soil in the lysimeter to field capacity was calculated using the irrigation indicator lysimeter line. After sowing each lysimeter was irrigated with a constant volume of water previously calculated. To ensure a good germination percentage and healthy well developed seedling both stages were performed using fresh water.

Irrigation with saline water started at the end of seedling establishment stage where seedling thinning took place. Irrigation was practiced when 30% of the available water was depleted due to evapotranspiration; this was calculated by the aid of a class A pan installed inside the green house. To calculate the volume of water to be applied at each irrigation to compensate the water losses due to the evapotranspiration, one replicate of each treatment “the irrigation guide line “at the irrigation time was watered, and the excess drained water accumulated in the bottom the plastic container was collected and measured. Differences between the applied water and that sucked from the plastic container gave the amount of evapotranspiration corresponding to water amount to be applied at each irrigation practice for the rest of application. Such technique was followed for both fresh water (control treatment) and the saline irrigation treatment (5 and 10ds/m).

The volume of water calculated under each investigated salinity level was added in full to the 100% irrigation trial, where as for the deficit irrigation trials only 60% and 40% of the volume was applied

After complete maturity of wheat the plants were harvested and divided into four main parts (roots, shoots and grains). The plant components were oven dried at 70ºC for 48 hours and the oven dry weight were recorded for each replicate in the investigated treatment.

Immediately after harvesting, representative soil samples were taken from the upper layer (0-15 cm), from the intermediate layer (15-30 cm) and from the bottom layer (30-45 cm). All soil samples were analyzed for their salt content.

RESULTS AND DISCUSSION

Water saving potentiality under deficit irrigation and irrigation with saline water

One of the major constraints, most arid and semi arid countries particularly those of the Mediterranean are now facing for achieving food security and agricultural development, is the chronic shortage in the available water resources. The increase in population at a relatively high rate, the very rapid urbanization on one hand, and the economical industrial development on the other hand, all are now raising up further problems beside the complex one, already are existing.

The policies of most of those countries in achieving both water and food security in their countries is mainly directed towards improving the management and use of water in agricultural sector which consumes more than 80% of the available water resources, but with a relatively high water losses and very poor water use efficiency not exceeding the 50%.

Politically and technically, it is now well recognized that the key in solving the water problems lies in the agricultural sector through improving crop water productivity, avoiding water losses and increasing the irrigation water use efficiency. However, this to be achieved necessitates the implementation of effective programs for water saving in the agricultural sector. Indeed, there are several approaches for water saving in this sector, among them the deficit irrigation practices and the use of the non conventional water resources, the saline one as an alternative water source for irrigation.

The question is what is the potentiality of water saving in the agricultural sector using such approaches?

The volumes of water applied during the whole cropping period under the different irrigation regimes using water of different salinity levels in both A and B trials are presented in *Table 3*.

Table 3. Water volumes m^3/ha and saline water as percentages of total water applied during the cropping period

ET (m3/ha)											
	Trial A - 100% irrigation										
	Irrigation salinity level										
	FW				**5 ds/m**				**10 ds/m**		
	FW (m3/ha)	**SW (m3/ha)**	**Tot.**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**SW%**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**SW%**
V1	3991.0	0.0	3991.0	891.0	2809.2	3700.2	0.8	891.0	2596.2	3487.2	0.7
V2	4344.8	0.0	4344.8	891.0	3250.8	4141.8	0.8	891.0	3143.1	4034.1	0.8
V3	4247.9	0.0	4247.9	891.0	3153.8	4044.8	0.8	891.0	2840	3731.0	0.8
Avg.	4194.6	0.0	4194.6	891.0	3071.3	3962.3	0.8	891.0	2859.7	3750.7	0.8
	Trial B - 60% irrigation										
	FW				**5 ds/m**				**10 ds/m**		
	FW (m3/ha)	**SW (m3/ha)**	**Tot.**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**SW%**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**SW%**
V1	2593.2	0.0	2593.2	891.0	1523.3	2414.3	0.6	891.0	1497.6	2388.6	0.6
V2	2868.2	0.0	2868.2	891.0	1902.5	2793.5	0.7	891.0	1692	2583.0	0.7
V3	2587.0	0.0	2587.0	891.0	1592.9	2483.9	0.6	891.0	1472.9	2363.9	0.6
Avg.	2682.8	0.0	2682.8	891.0	1672.9	2563.9	0.7	891.0	1554.2	2445.2	0.6
	Trial B - 40% irrigation										
	FW				**5 ds/m**				**10 ds/m**		
	FW (m3/ha)	**SW (m3/ha)**	**Tot.**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**SW%**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**SW%**
V1	2451.9	0.0	2451.9	891.0	1397.9	2288.8	0.6	891.0	1326.2	2217.2	0.6
V2	2157.5	0.0	2157.5	891.0	1189.5	2080.5	0.6	891.0	1119.4	2010.4	0.6
V3	2144.5	0.0	2144.5	891.0	1200.6	2091.6	0.6	891.0	1048	1939.0	0.5
Avg.	2251.3	0.0	2251.3	891.0	1262.7	2153.7	0.6	891.0	1164.5	2055.5	0.6

Under the A-Trial, the 100% irrigation with fresh water showed volumes of water 6% and 11% greater than the ones under the 5 ds/m and the 10 ds/m salinity levels respectively. Here, we would like to keep in mind that under saline irrigation treatments of the ECi 5 and 10 ds/m in both A and B trials, the volume of applied water is not totally saline water, as a portion of it was practiced with fresh water during the germination and the seedling establishment to assure high germination percentage and healthy seedlings. The volume of fresh water with respect to the total volume applied varied with the variation of the irrigation regime and accounted to 20, 30 and 40% of the total volume under 100, 60 and 40% irrigation treatments respectively.

Regarding the deficit irrigation treatments, the data shows clearly that for the fresh water and irrigation with only 60% of the crop evapotranspiration demands resulted in nearly 36% water saving, whereas, under the 40% irrigation treatment, actually around 46% was the saving in the applied water.

In this regard, the data also declares that the irrigation with the saline water instead of the fresh one, starting from the end of the seedling stage till the full maturity, we can have enormous saving in the fresh water amounting to nearly 80% under the 100% irrigation treatment. The deficit irrigation and the irrigation with saline water is a win win game: such approach, besides reducing the volume of water applied by 40 and 60% of that under 100% irrigation, which has its beneficial effect in reducing the accumulated salts in the active root zone, and consequently diminishing the leaching requirements. Furthermore, as it substitutes the fresh water for irrigation, it provides from 60% up to 70% saving in fresh water.

Such data evidently indicates that through deficit irrigation and irrigation with saline water, there is a high potentiality of fresh water saving in the irrigated agriculture.

However, the crucial question: what is the impact of both approaches on the cereals production and particularly the wheat? The answer to this question can be provided by analyzing the status of the grains yield of the investigated varieties under both approaches previously mentioned either individually and/or in combination (Fig.2) and (*Table 4*).

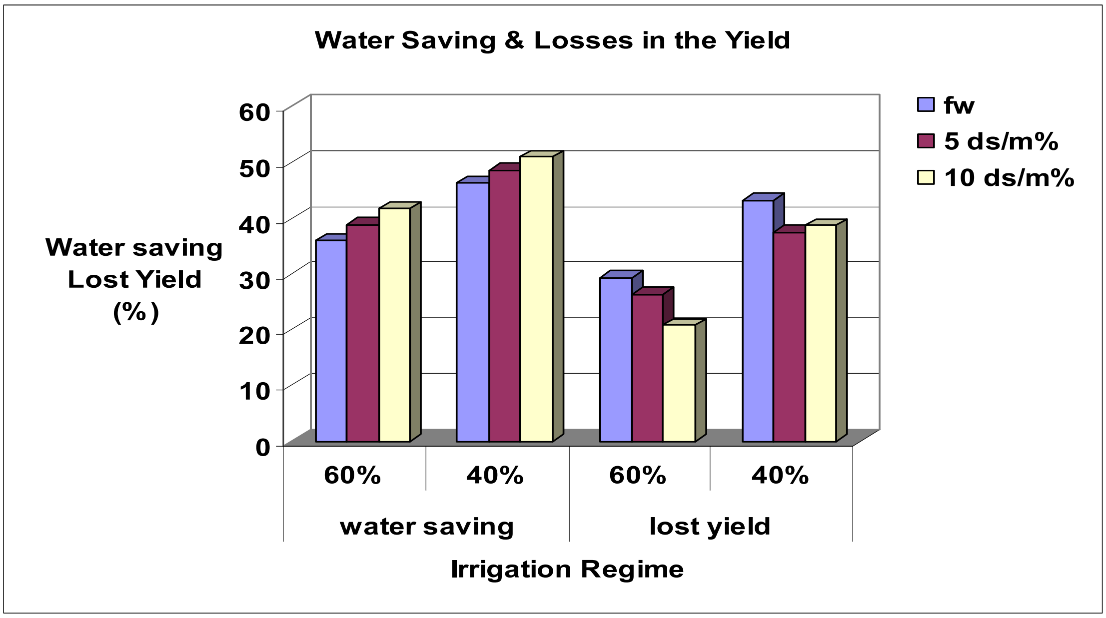

Fig. 2. Water saving and the losses in the yield related to deficit irrigation

Table 4. Water volumes m^3/ha and grain yield ton/ha under investigated irrigation treatments

ET (m3/ha)												
	Trial A - 100% irrigation											
	Irrigation salinity level											
	FW				**5ds/m**				**10ds/m**			
	FW (m3/ha)	**SW (m3/ha)**	**Tot.**	**Yield (ton/ha)**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**Yield (ton/ha)**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**Yield (ton/ha)**
V1	3991.0	0.0	3991.0	5.4	891	2809.2	3700.2	5.1	891	2596.2	3487.2	4.9
V2	4344.8	0.0	4344.8	5.5	891	3250.8	4141.8	5.7	891	3143.1	4034.1	5.5
V3	4247.9	0.0	4247.9	6.3	891	3153.8	4044.8	6.3	891	2840.0	3731.0	5.7
Avg	4194.6	0.0	4194.6	**5.7**	891.0	3071.3	3962.3	**5.7**	891.0	2859.7	3750.7	**5.4**
	Trial B - 60% irrigation											
	FW				**5ds/m**				**10ds/m**			
	FW (m3/ha)	**SW (m3/ha)**	**Tot.**	**Yield (ton/ha)**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**Yield (ton/ha)**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**Yield (ton/ha)**
V1	2593.2	0.0	2593.2	4.3	891	1523.3	2414.3	4.3	891	1497.6	2388.6	4.4
V2	2868.2	0.0	2868.2	3.7	891	1902.5	2793.5	4.0	891	1692.0	2583.0	4.2
V3	2587.0	0.0	2587.0	4.2	891	1592.9	2483.9	4.5	891	1472.9	2363.9	5.0
Avg.	2682.8	0.0	2682.8	**4.1**	891.0	1672.9	2563.9	**4.2**	891.0	1554.2	2445.2	**4.5**
	Trial B - 40% irrigation											
	FW				**5ds/m**				**10ds/m**			
	FW (m3/ha)	**SW (m3/ha)**	**Tot.**	**Yield (ton/ha)**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**Yield (ton/ha)**	**FW (m3/ha)**	**SW (m3/ha)**	**Tot.**	**Yield (ton/ha)**
V1	2451.9	0.0	2451.9	3.6	891	1397.8	2288.8	3.7	891	1326.2	2217.2	3.6
V2	2157.5	0.0	2157.5	2.9	891	1189.5	2080.5	3.2	891	1119.4	2010.4	3.2
V3	2144.5	0.0	2144.5	3.3	891	1200.6	2091.6	3.7	891	1048.0	1939.0	3.7
Avg.	2251.3	0.0	2251.3	**3.3**	891.0	1262.7	2153.7	**3.6**	891.0	1164.5	2055.5	**3.5**

The presented data indicate that there is a high potentiality of using saline water for irrigation, even with relatively high salinity level up to 10 ds/m substituting the fresh water. Under the 100% irrigation treatment, the use of saline water leads to around 80% saving in the fresh water besides the advantage of having a yield production even with the relatively high salinity level (10 ds/m) of an average 5.4 tons/ha which is more or less equal to the one obtained under the fresh water irrigation treatment with only differences 0.3 ton/ha between both irrigation with fresh water and the 100% saline one.

However, the disadvantage could be related to the increase in the accumulated salts in the active root zone exceeding the salinity level which the wheat could tolerate, and thereby leaching should be practiced with fresh water to avoid the deterioration in the soil productivity. However, under such situation, leaching is normally carried using nearly 15% leaching fraction, which indeed represents a small portion of fresh water already saved (Van Hoorn *et al.*, 1993; Katerji *et al.*, 2005).

To avoid such raise up in salinity level in the active root zone, as a promising solution is to stop irrigation with saline water, and to irrigate and leach with fresh water particularly at the sensitive growth stages (flowering and seed filling).

As shown in *Table 4*, the use of the 5 ds/m saline water besides saving 80% of the fresh water showed a grain yield identical to the one where fresh water was practiced. However, we shall be still faced with a relatively raise up in the salinity level in the active root zone, but with relatively lower values not exceeding the 5 ds/m and such accumulated salts to be leached will require small fresh water volumes.

To use saline water successfully for cereals production, the case of wheat, and to avoid losses in the yield production, it is of paramount importance having a high germination percentage and a well developed healthy seedlings. Equally the salinity of the irrigation water should be decided in view of the salt tolerance degree of the growing crop and particularly the sensitive growth stages, and therefore the selection of the crop variety should be carefully considered (Hamdy, 1990a,b; Hamdy *et al.*,1993 and Hamdy, 1994).).

What we want to add here is that sustainable use of saline water for irrigation implies not only avoiding losses in the yield production but, equally, keeping the soil at high productivity without any deterioration, and that is the reason behind having a good quality water source, the fresh water, beside the saline one to be used at the sensitive growth stages and to satisfy the leaching requirements (Hamdy, 1996).

Returning again to analysis (*Table 4*), the data concerning the yield production under deficit irrigation treatments using fresh water, the presented data indicates that the 60% irrigation treatment provided 36% fresh water saving besides giving a yield corresponding to 72% of that obtained under the 100% irrigation with an average 28% yield losses.

Following the same trend under the sever deficit irrigation the 40% irrigation treatment, the saving in the fresh water amounted to 1943 m^3/ha which is nearly 50% the volume applied under the 100% irrigation treatment, but, in the mean time the losses in the grain yield were substantially high, nearly 42% of that under full irrigation treatment. Such data indicates clearly that under deficit irrigation, the lower is the volume of applied water, the greater will be the fresh water saving, and the higher will be the losses in the yield production.

Now to decide which irrigation regime we have to follow, we have to put on balance the fresh water saving on the right side, and the yield production on the other side.

Indeed, to take the decision is not any easy one, as it is fundamentally depending on the availability of the fresh water resources, and the surrounding water problems, the prevailing socio economic conditions, the water allocation policies, as well as the food security achievements. All those factors, either separately, or combined together, play an important role on the decision to be taken which will greatly vary from one country to the other in view of the existing conditions.

Some countries will favor deficit irrigation practices, but only at 60% irrigation level accepting the 30% losses in grain production, and having around 40% saving in the fresh water to be allocated to other sectorial water uses suffering water shortages, and or to increase the irrigated area.

Other countries, those characterized with acute shortages in available water resources could accept higher water saving and greater losses in the grain yield provided by the severe deficit irrigation, the 40% treatment and to use such saved water in other sectors of a relatively high return than the agriculture, like industry and tourism, and by satisfying the needs of wheat through foreign markets.

Other countries, which have major interest in not only saving more water from the agricultural sector, but, in the mean time to have a high level of cereals production. Such countries can implement the deficit irrigation approach but through irrigation with 80% volumes of water which is the intermediate level between the 100% and the 60% irrigation regimes.

Returning again to *Table 3*, where deficit irrigation was practiced using saline water of different salinity levels, the presented data concerning the water saving indicates that through such approach nearly 40% and 50% of the fresh water are saved under the 60% and 40% irrigation treatments respectively. On the other hand, concerning the grain yield production under the 60% irrigation treatments showed values of an average equal or slightly higher than that where 100% irrigation was practiced. However, under this deficit irrigation level, the yield was subjected to some losses of an average nearly 20% lower than that obtained under the 100% irrigation regime.

Taking into consideration the salinity level of the irrigation water, it could be seen clearly that: for both ECi-values of 5 ds/m and 10 ds/m, no significant differences occurred, neither in fresh water saving percentages, nor in the grain yield production.

Accordingly, the 60% deficit irrigation with the 5 ds/m salinity level is the one to be recommended, as it has several advantages as compared with the other irrigation treatments in providing a high water saving percentage in the fresh water, a convenient yield production corresponding to 80% of that under full irrigation, beside, having an active root zone with a lower ECi-value than that expected under the 100% irrigation treatment as well as the one with the high salinity level, the 10 ds/m.

Regarding the 40% irrigation regime with saline water (*Table 3*), the data shows that under both investigated salinity levels, the 5 and the 10 ds/m, the fresh water saving as well as the yield production were more or less having the same values. However, under deficit irrigation treatment, the 40% in spite of its advantage in providing more water saving than the 60% treatment, yet, the grain yield was subjected to further losses nearly with values 20% lower with respect to the 60% irrigation treatment.

The other point which should be carefully considered is the degree of salt accumulation in the active root zone and which will require under the 40% irrigation more fresh water for leaching as it is expected. That salts will be accumulated in excess in the active root zone with respect to the 60% irrigation treatment, particularly when irrigation is practiced with a higher ECI-values exceeding the 5 ds/m.

Such data again gives the evidence that among the investigated irrigation treatments the 60% irrigation with saline water of an ECi-value 5 ds/m is the one to be recommended as it satisfies our major objective in achieving a good fresh water saving, convenient wheat production, and keeping the soil at high productivity through appropriate leaching management using a relatively low leaching fraction.

Average EC-values (ds/m) in the active root zoon (0-45cm) at the critical growth stages

At the critical growth stages, water samples representing the soil solution in circulation were sucked after each irrigation from the different soil layers by the aid of a vacuum pump, through the porous cups inserted at the depths 7.5, 22.5 and 37.5 cm. (Fig. 1). Average EC values in the different soil layers for the A trials under the two salinity levels (5 and 10ds/m) for the investigated varieties are given in *Table 5*.

Table 5. Salt accumulation and its distribution under 100% successive irrigation practices during the cropping period of the investigated wheat varieties

Salinity level	No. of irrigation	Wheat growing stage	EC ds/m			
			Soil layer depth			avg.
			0-15	15-30	30-45	
FW	1st	Germination & seedling	0.87	0.85	0.87	0.86
	2nd	Early vegetative growth	0.87	0.88	1.00	0.92
	3rd	Full vegetative growth	0.84	0.74	0.73	0.77
	4th	Flowering	1.20	0.93	0.93	1.02
	5th	Seed filling & maturity	1.12	0.95	0.94	1.00

Salinity level	No. of irrigation	Wheat growing stage	EC ds/m			
			Soil layer depth			avg.
			0-15	15-30	30-45	
5ds/m	1st	Germination & seedling	0.87	0.85	0.87	0.86
	2nd	Early vegetative growth	1.54	1.47	1.10	1.37
	3rd	Full vegetative growth	5.55	4.76	3.49	4.60
	4th	Flowering	7.57	7.57	7.81	7.65
	5th	Seed filling & maturity	8.82	8.12	8.85	8.59

Salinity level	No. of irrigation	Wheat growing stage	EC ds/m			
			Soil layer depth			avg.
			0-15	15-30	30-45	
10ds/m	1st	Germination & seedling	0.87	0.85	0.87	0.86
	2nd	Early vegetative growth	3.20	2.37	1.17	2.24
	3rd	Full vegetative growth	10.81	9.70	6.63	9.05
	4th	Flowering	13.73	13.41	14.14	13.76
	5th	Seed filling & maturity	16.21	15.85	17.80	16.62

It is worthy to repeat again that both the germination and seedling establishment stages were developed using only fresh water for irrigation. The end of the seedling stage i.e. the early vegetative growth 36 days from sowing started the irrigation with the saline water of 5 and 10 ds/m.

Regarding the 100% fresh water irrigation treatment, it could be observed that for the investigated varieties successive irrigation with fresh water did not result in any increase in the salinity level of the whole soil profile as well as in the salt distribution within the different soil layers.

Under the 100% irrigation with saline water of an ECi equals to 5 ds/m (*Table 5.*), the represented data indicates that there is a gradual increments in the accumulated salts in the different soil layers with increasing the number of irrigations.

In the early vegetative growth, the EC for the whole soil profile under the investigated wheat varieties showed an average value around 1.36 ds/m which is very near to the one where irrigation was practiced with fresh water. However, at the end of the vegetative growth and the start of the flowering stage where the leaf area reached its maximum value there was a notable increase in the EC, being with an average value 4.15 ds/m, nearly three times greater than the one measured after the previous irrigation. It is well recognized that for the cereal crops, in our case the wheat, both flowering and seed filling stages are very sensitive ones to salinity.

Regarding the data obtained, it could be concluded that irrigation with saline water up to 5 ds/m could be used safely, hence, the successive irrigation with such salinity level up to the flowering stage, the most sensitive one, the accumulated salts were of an average value around 4 ds/m which is at a level still below the one which the investigated wheat varieties could tolerate.

Concerning the soil salinity management, in view of soil salinity data obtained, the leaching of accumulated salts frequently with each irrigation is not recommended. Leaching should be practiced at the end of the cropping period after harvesting, hence, as shown in (*Table 5.*), at the wheat ripening period, the accumulated salts were of an average value around 7.63 ds/m which is exceeding the threshold value which the investigated wheat varieties could tolerate.

Doubling the irrigation salinity level up to 10 ds/m another picture appeared (*Table 5.*). As a general trend the salts were accumulated at the different soil depths as well as within the whole soil profile with values more or less the double of the ones recorded under the 5 ds/m irrigation treatment.

In our study, irrigation with 10 ds/m saline water, the flowering stage, accumulated salts were of an EC-value around 9 ds/m which is relatively a high value exceeding the one that wheat could tolerate. The presence of accumulated salts with relatively high EC–value at this sensitive stage requires immediate leaching of the accumulated salts to avoid the negative salinity impact on the next sensitive growth stage i.e. the seed filling stage.

Such data indicate that the degree of accumulated salts in the active root zone will differ according to the variation in the salinity level of irrigation water. In this regard, monitoring and following up the soil EC–values during the cropping period particularly at the critical growth stages is of paramount importance to decide on when to leach and what should be the leaching fraction.

Soil salinity after wheat harvesting

After harvesting, the soil samples packed in the lysimeter were divided into the following soil layer depths: (0-15 cm) the upper layer, (15-30 cm) the intermediate layer and (30-45 cm) the bottom layer. EC of the above mentioned investigated layers was determined using the saturation paste technique (*Table 6*).

Table 6. Electrical conductivity (ds/m) of the different soil layers measured in the soil saturation paste after harvest

Electrical conductivity (ds/m) of different soil layers					
		Wheat varieties			
Treatment (ds/m)	**Soil layer**	V1	V2	V3	**Avg.**
		Trial A (100% irr. treatment)			
FW	**0 - 15**	0.94	1.02	0.94	**0.97**
	15 - 30	0.80	0.80	0.75	**0.79**
	30 - 45	0.90	0.71	0.80	**0.80**
	Avg.	**0.88**	**0.84**	**0.83**	**0.85**
5 ds/m	**0 - 15**	6.59	6.36	5.51	**6.15**
	15 - 30	3.59	4.95	4.66	**4.40**
	30 - 45	3.81	4.47	4.66	**4.31**
	Avg.	**4.66**	**5.26**	**4.94**	**4.95**
10 ds/m	**0 - 15**	9.95	11.09	7.74	**9.59**
	15 - 30	6.48	9.00	7.28	**7.59**
	30 - 45	7.17	9.55	8.31	**8.34**
	Avg.	**7.86**	**9.88**	**7.78**	**8.51**
		Trial B (60% irr. treatment)			
FW	**0 - 15**	1.15	1.04	1.09	**1.09**
	15 - 30	0.90	0.74	0.71	**0.78**
	30 - 45	0.92	0.81	0.89	**0.87**
	Avg.	**0.99**	**0.86**	**0.89**	**0.92**
5 ds/m	**0 - 15**	5.58	5.34	4.54	**5.15**
	15 - 30	3.58	4.53	3.21	**3.77**
	30 - 45	3.60	4.24	3.07	**3.63**
	Avg.	**4.25**	**4.70**	**3.60**	**4.19**
10 ds/m	**0 - 15**	7.97	10.41	10.16	**9.51**
	15 - 30	6.34	9.61	6.30	**7.42**
	30 - 45	6.90	7.69	6.37	**6.98**
	Avg.	**7.07**	**9.24**	**7.61**	**7.97**
		Trial B (40% irr. treatment)			
FW	**0 - 15**	1.19	0.80	0.85	**0.95**
	15 - 30	0.77	0.78	0.79	**0.78**
	30 - 45	0.90	0.80	0.81	**0.84**
	Avg.	**0.95**	**0.79**	**0.82**	**0.85**
5 ds/m	**0 - 15**	3.86	3.37	2.98	**3.40**
	15 - 30	3.10	3.58	2.87	**3.18**
	30 - 45	3.39	3.44	2.91	**3.25**
	Avg.	**3.45**	**3.46**	**2.92**	**3.28**
10 ds/m	**0 - 15**	8.89	8.37	7.45	**8.24**
	15 - 30	6.68	7.01	7.31	**7.00**
	30 - 45	6.36	7.86	7.60	**7.27**
	Avg.	**7.31**	**7.74**	**7.45**	**7.50**

As shown in *Table 6*, keeping the salt concentration level of the irrigation water constant and changing the wheat varieties, the degree of salt accumulation in the different soil layers as well as the average salt concentration level within the whole soil profile were more or less of similar values, with only slight difference between the investigated varieties. On the other hand, considering the degree of salt accumulation within the whole soil profile as well as in the different soil layers, the data shows that there was a gradual increase in the salinity concentration with the gradual increments of the ECi values.

Considering the average electrical conductivity values within the whole soil profile, it is noticed that under the 100% successive irrigation with saline water of 5 ds/m from seedling stage till maturity brought the accumulated salts in the whole soil profile to an average Ec-value of 4.95 ds/m. Doubling the Eci from 5 to 10 ds/m resulted in a 72% increase in the accumulated salts with an average value of 8.51 ds/m.

Under trial A, considering the active root zone where the wheat roots penetrate is of depth lying between 30 and 45 cm it can be observed that under successive irrigation with the low salinity level 5 ds/m, the accumulated salts in the active root zone up to 45 cm reached after harvesting an average Ec-value around 5 ds/m which the crop wheat with its investigated varieties could tolerate (Hamdy,1999). This clearly explains the reason behind having a grain yield production under the 5 ds/m irrigation treatment more or less equal to the one obtained under irrigation with fresh water. This again confirm, that for the investigated wheat varieties, irrigation with saline water up to 5 ds/m can be used safely without having any significant losses in the grain yield.

In this regard and concerning saline irrigation management, it could be wisely said that it is not necessary to leach the accumulated salts at the previous sensitive growth stage (flowering and seed filling), hence, the accumulated salts at both stages will be of an Ec-value substantially lower than the ones at the harvest time and therefore, it is recommended that leaching be carried out at the end of the cropping period after the yield harvest.

This is not the case, where irrigation was practiced with water of salinity level 10 ds/m. The accumulated salts in the active root zone (0-45 cm) were of an average value 8.5 ds/m which is relatively higher than the one that wheat sensitive growth stages can tolerate. To avoid the negative impact of salts being accumulated in excess in the active root zone on the grain production, it is advisable that leaching to be carried out before reaching such relatively high soil salinity levels particularly at the sensitive growth stages.

Concerning the salt distribution and accumulation in the different soil layers, the presented data (*Table 6.*)indicates that for the investigated Eci-values including the fresh water, there is a general trend characterizing the salt accumulation with the different soil depths, showing the higher Eci-value at the upper layer (0-15 cm), followed by the bottom one (30-45 cm), while the intermediate layer (15-30 cm) was the lowest in its accumulated salts. The intermediate soil layer being with an Eci-value lower than in the ones of both upper and bottom layer could be explained on the ground that the intermediate layer is subjected to two processes both leading to the removal of salts from this layer: The first, during the irrigation and the downward water movement leaching salts from this layer to the bottom one, the second, during the drying and the upward movement of water by capillary rise carrying with it the salts to upper surface layer.

Regarding the Trial-b (*Table 6*), where deficit irrigation was practiced, the presented data indicates that under both investigated Eci, the accumulated salts as well as its distribution in the different soil layers followed a trend identical to the one under the A-Trial. However, as presented in Fig. 3.

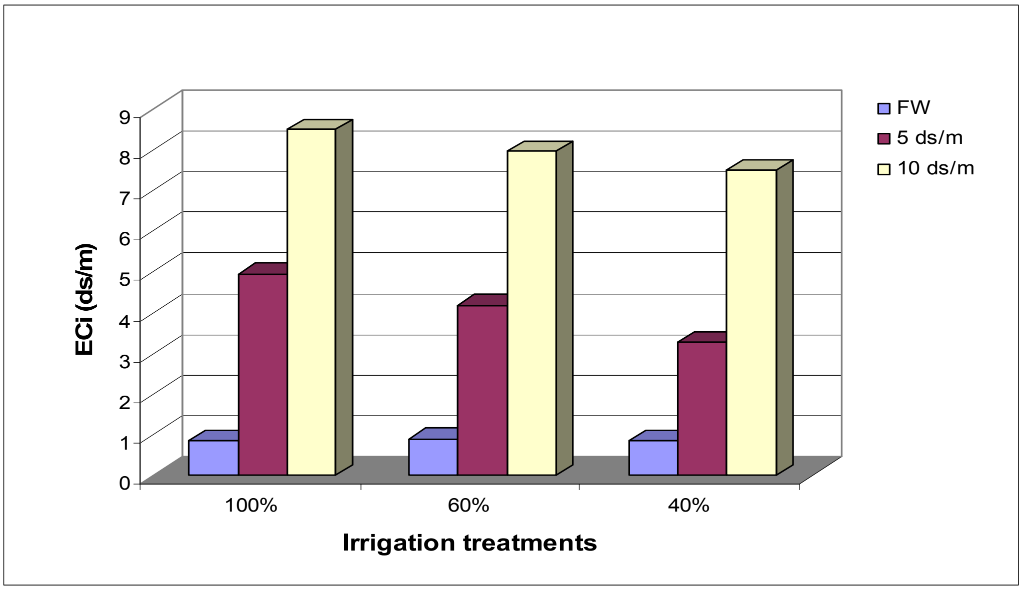

Fig. 3. The distribution of salts in the different soil layers at the end of the cropping period

Under deficit irrigation (Trial-B), the accumulated salts with the whole soil profile as well as in the different soil layers, were of lower values than the ones measured under the 100% irrigation treatments. Under the 60% irrigation treatment with the 5 ds/m saline water, the soil profile was of an Eci-value 4.19 ds/m with nearly 15% reduction in the accumulated salts observed under the 100% irrigation treatment.

This was also the case with the relatively high salinity level 10 ds/m, where the accumulated salts were of values nearly 10 % lower than the ones corresponding to the 100% irrigation treatment.

Under sever water stress, the 40% irrigation treatment, the accumulated salts were found with an average values lower than the ones related to the 60% irrigation treatment and corresponded to 66% and 88% of the Eci-values obtained under the 100% irrigation for the 5 and 10 ds/m irrigation salinity level respectively.

CONCLUSIONS

In view of the presented data and results obtained, we can come up to some important conclusions, among them the following to be highlighted:

- Irrigation with saline water up to 5 ds/m could be used safely, hence, the successive irrigation with such salinity level up to the flowering stage, the most sensitive one, the accumulated salts were of an average value around 4 ds/m which is at a level still below the threshold value which the investigated wheat varieties could tolerate.
  For wheat varieties under investigation, irrigation salinity level could be raised up to 10ds/m resulting in only around 10% losses in the grain yield production.

- The presented data show that the higher is the salinity level of irrigation water; the lower will be the consumptive water use, and the greater will be the biomass and the grain water use efficiencies. This also holds true under deficit irrigation using saline water. The smaller is the volume of water applied and the higher is its salinity level; the better will be the improvement in both biomass and grain water use efficiencies.

- Among the investigated irrigation treatments the 60% irrigation with saline water of an ECi-value 5 ds/m is the one to be recommended as it satisfies our major objective in achieving a good fresh water saving, convenient wheat production, as well as keeping the soil at a relatively low salinity level could be easily leached by precipitation and or by relatively small fresh water volumes and thereby bringing the soil again to its original productivity level.

REFERENCES

Bernstein, L. and François, L.E. (1973). Comparison of drip, furrow and sprinkler irrigation, Soil Sci 115:73-86.

François, L.F. (1981). Alfalfa management under saline condition with zero leaching. Agronomy Journal, 73-1042.1946.

Hamdy, A. (1990a). Management practices under saline water irrigation. Symp. On Scheduling of irrigation for vegetable crops under field condition. Acta Horticulture, vol. 2, N° 278.

Hamdy, A. (1990b). Crop management under saline irrigation practices. In: Water, soil and crop management relating to the use of saline water. A. Kandiah (ed.) FAO,AGL/MISC/16/90, 108-116.

Hamdy, A. (1990c). Saline irrigation practices: leaching management. Proceedings of The Water and Wastewater. Conference, 24-27 April, 1990. Barcelona, Spain.

Hamdy, A. and Nassar, A. (1991). Saline irrigation practices and management: modes of water application and leaching (in press).

Hamdy A. and Lacirignola, C. (1993). An overview of water resources in the Mediterranean countries. Cahiers Options Méditerranéennes, Vol. I, n°1: Water resources development and management in Mediterranean countries. Pp. 1.1-1.32.

Hamdy, A., Abdel-Dayem, S. and Abu-Zeid, M. (1993). Saline water management for optimum crop production. Agricultural water management 24:189-203.

Hamdy, A. (1994). Use and management of saline water for irrigation towards sustainable development. In: Sustainability of irrigated agriculture. (eds) Pereira L.

Hamdy, A. (1996). Saline irrigation: assessment and management techniques. In: Choukr-Allah, R.; Malcom, L.V.; Hamdy A. (eds). Halophytes and Biosaline Agriculture. Dekker, New York, pp. 147-181.

Hamdy, A. (1999). Saline irrigation assessment and management for a sustainable use. Proceedings: special session on: Non-conventional resources management and practices.UWRM Sub-network. Annual meeting. IAV Hassan II, Rabat, Morocco, 28 October, 1999. pp. 3-69.

Hamdy, A. and Katerji, N. (2006). Water crisis in the Arab World. Analysis and Solutions. CIHEAM/MAIB publication, pp. 60.

Van Hoorn, J.W.; Katerji, N.; Hamdy, A. and Mastrorilli, M. (1993). Effect of saline water on soil salinity and on water stress, growth and yield of wheat and potatoes. Agr. Water Management 23, 247-255.

Katerji, N.; Van Hoorn, J.W.; Hamdy, A.; Mastrorilli, M.; Nachit, M.M. and Oweis, T. (2005). Salt tolerance analysis of chick-pea, fababean and drum wheat varieties. II Durum Wheal. Agric. Water Management 72, 192-207.