THE USE OF SALINE WATER FROM THE CASPIAN SEA FOR IRRIGATION AND BARLEY PRODUCTION IN NORTHERN IRAN

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Abstract
Saline water was previously considered unusable for irrigation but some researches have shown that these waters can be used successfully to grow crops under certain conditions. The impact of irrigation, using Caspian Sea water mixed with well water, on barley growth/yield and soil characteristics was investigated. Pot experiments were carried out using three irrigation regimes: well water; Caspian Sea water diluted with the well water at a 1:1 ratio and used either at stem elongation or at ear formation. Results show that a 1:1 mixture of Caspian Sea and well water can be used for irrigation without a significant reduction in barley yield, provided this is applied at ear formation. However, when applied at stem elongation, significant yield reduction occurs. Soil analysis after harvest showed that the EC had increased significantly, especially with irrigation applied at stem elongation. This study shows that the supplementary irrigation of barley with a mixture of well and sea waters at the time of ear formation appears promising and could lead to an increase in barley yield in northern Iran.

Additional Keywords: sea water, salinity, Caspian Sea

Introduction
A rapid increase in the population of Iran during the past two decades has significantly increased the country's need for food and fibre and has put its land and water resources under severe stress. Freshwater resources of the country, both surface and ground water, has been over-exploited, often at the expense of deteriorating water and land quality. With limited room for expanding irrigation agriculture due to the lack of extra capacity in the country's freshwater resources, the possible use of Caspian Sea water, whose salinity is well below that of the open seas and oceans, has some appeal (Dordipour 2000). Saline water was used to be considered unusable for irrigation but research efforts during the past two decades have brought into practice some large irrigation schemes which depend on saline water (Hamdy *et al.*1993). However, with its potential hazard of increasing land and ground-water salinity as well as possible deterioration of soil physical, chemical and biological characteristics, the issue needs to be thoroughly researched. The sustainability of irrigated agriculture in arid and semi-arid areas depends on maintenance of salt balance within the soil profile and disposal of shallow groundwater is a necessity. Saline drainage waters can be used for irrigation of certain crops and their use lessens drainage disposal requirements and water pollution (Rhoades 1980). Rhoades *et al.* (1989) further demonstrated a strategy for using saline and non-saline water in rotation, which caused no reduction in yield providing there was a good stand.

Salinity generally affects the growth of plants by either ion excess or by water deficits in the expanded leaves (Greenway and Munns 1980). Water uptake is restricted by salinity due to the high osmotic potential in the soil and high concentrations of specific ions that may cause physiological disorders in the plant tissues (Feigin 1985) and reduce yields (Verma and Neue 1984). However, some crops such as wheat and barley can be tolerant of saline irrigation water and selection and breeding are likely to improve the performance of these crops under highly saline regimes (Yazdani 1991; Norlyn and Epstein 1982). Research suggests that irrigation of barley with up to two-thirds seawater is feasible and may result in economically significant yields. This study therefore examines growth and yield of barley in irrigated pot experiments using a mixture of Caspian Sea water and well water. Field trials are described elsewhere (Dordipour 2004). The effect of the application of saline water on soil properties is also examined together with an assessment of overall water use and water use efficiencies in different irrigation regimes.

Materials and Methods
Barley (Hordeum vulgare (L.) cv. 'LB') was grown on a silty loam soil of the Agh-ghala series in plastic pots (20-25 cm diameter and 31 cm height) under a plastic green house at Tarbiat Modarres University (TMU). Irrigation water was provided from the Caspian Sea and from a well located at TMU. The basic physico-chemical properties of the soil and waters were determined with standard techniques (Sparks et al. 1996; Page et al. 1982; Richards 1954). Some chemical data for the irrigation waters are presented in Table 1. The sea water was considerably more saline than the well water and salt concentrations varied slightly with season.

Table 1. Chemical data for irrigation waters used in the experiments

Property	Caspian Sea water (spring)	Caspian Sea water (summer)	Well water
Electrical Conductivity (dS/m)	21.5	23.0	0.8
Soil pH	7.3	7.0	7.5
Sodium ($mmoles_+$/l)	160	150	2
Calcium ($mmoles_+$/l)	80	68	5
Magnesium ($mmoles_+$/l)	0	18	1
Cl ($mmoles_-$/l)	180	165	2
HCO_3 ($mmoles_-$/l)	2.0	3.6	2.7
SO_4 ($mmoles_-$/l)	58.0	67.0	3.2

Pots (with drainage holes) were packed with 16.95 kg air-dried soil in 5 x 5 cm uniformly compressed increments over 2 cm of gravel/sand (Homaee 1999). The soil contained 12%, 64% and 24% sand, silt and clay respectively and was classed as a silty loam texture. The bulk density and organic carbon content were 1.4 g/cm and 0.59% respectively. A completely randomized factorial design was used with three irrigation and nine fertilizer regimes and three replications. The three irrigation regimes consisted of: (I_0) well water with an EC of 0.802 dS/m, (I_1) Caspian Sea water with an EC of 21.5 dS/m, diluted with the well water at a 1:1 ratio and used at the stem elongation stage and (I_2) the same as (I_1), used at the ear formation, respectively. The surface of each pot was divided into concentric circles, in which 40 barley seeds were sown on January 22, 2001. They were thinned to 20 plants after germination and full establishment of seedlings. Ten plants were used for measurement and sampling in the tillering and heading stages to determine quantity of fresh and dry matter production and the 10 remaining plants used for yield and its components, dry matter, nutrient contents, height, and so on. The pots were irrigated with well water for germination and establishment of seedlings. The irrigation then continued according to water requirement, until the respective irrigation treatments were applied. Three pots from each treatment were weighed before every irrigation and the required quantity of water was calculated from the difference between " pot capacity" (analogous to field capacity) and the actual weight minus plant weight, plus about 30% leaching fraction. Pot capacity was determined by adding excess water to pots with soil. The pots were then covered by plastic sheets to prevent evaporation and weighed over a few days until an equilibrium weight was attained. The irrigation cycle was adjusted according to the depletion of 50% available water from the pot soil (Marcelis and Van Hooijdonk 1999; Bar-Tal *et al.* 1991). Nitrogen was applied to all pots (300 kg/ha of urea: one third before planting, one third at the tillering and one third at the heading stage). Each treatment also received 75 kg P_2O_5/ha as $NH_4H_2PO_4$. Further fertilizer treatments consisting of all possible combinations of three levels of K and three levels of Zn. Fertilizer treatment results are reported elsewhere (Dordipour 2004). At harvest, the plants were divided into tops (head, leaf and shoot) and roots (in two depth intervals of 0-10 and 10-20 cm) and their fresh and oven-dry weights (60 °C for 24 hr) were determined. After harvest, the soil from all the pots was divided into two horizontal layers (0-10 and 10-25 cm) and analysed. Statistical analysis and mean comparisons test of main effects and interactions on the yield and its components, fresh and dry matter, soil and another parameters of plant were analyzed by the SAS-ANOVA and SAS-MEANS procedures, separately (SAS 1992).

Results and Discussion

Effect of irrigation on growth and yield of barley

Growth and yield were best in treatment I_o (control) as indicated in Table 2. Addition of sea water at stem elongation (Treatment I_1) decreased yield by 62% but when applied at ear formation it did not significantly affect yield compared to the control. This is in accord with Francois *et al.* (1994) who demonstrated that the time or stage of salinity stress had a significant effect on grain-weight of wheat. Visual observations of growth indicated that chlorosis, necrosis and margin/tip burns of leaves appeared at early growth stages and developed as growth progressed. Symptoms were more evident in I_1.

Table 2. Growth and yield of barley at harvest in pots as affected by irrigation treatment

Irrigation Treatment	Yield (g/pot)	Dry weight head (g/pot)	Dry weight leaf (g/pot)	Dry weight shoot (g/pot)	Dry weight root (0-25cm) (g/pot)
I_o	23.06 A*	27.22 A	8.59 A	17.72 A	5.49 A
I_1	8.71 B	10.95 B	4.66 C	6.59 C	1.27 C
I_2	22.26 A	26.54 A	7.75 B	16.45 B	3.53 B

*Means within each column followed by the same letter are not significantly different at p= 0.05 (Duncan's range test)

Examination of ratio of dry/fresh weights of leaf, head and shoot showed that fresh weight growth was reduced more than dry weight growth indicating a water deficit at high salinity (Marcelis and Van Hooijdonk,1999). Irrigation with sea water resulted in a decline in fresh and dry weights of roots for all soil depths and at different growth stages (Figure 1). The ratio of dry root/shoot weights also decreased by ~30% for treatments I_1 and I_2 in comparison to I_0.

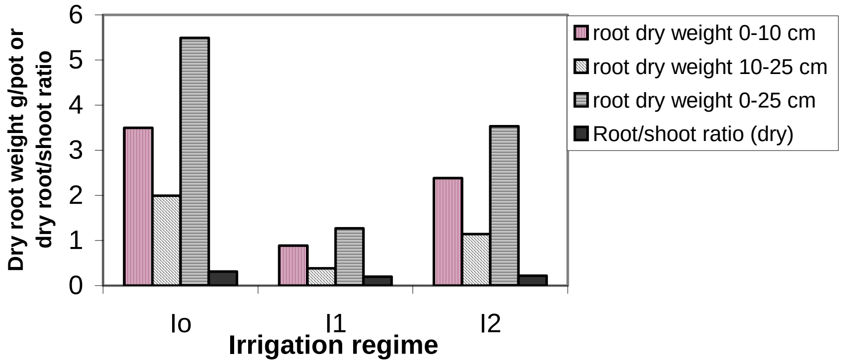

Figure 1. Variation of root parameters with irrigation regime and soil depth

Effect of irrigation on soil quality

Mean comparison tests between irrigation treatments, indicate that irrigation treatment I_1 significantly increased soil salinity levels (Table 3) compared to the control irrigation (I_o), particularly in the topsoil (0-10 cm) (Figure 2). There were also significantly increased levels of soluble sodium, calcium and magnesium due to the addition of sea water in the irrigation. This indicated that the applied leaching fraction (30%) was not efficient at removing salts in the pots and further work needs to be done in order to assess the ideal leaching regime**.**

Table 3. Soil data before and after pot experiments

Soil Analyses (measured on saturation extract)	Soil before experiment	Soil after experiment (mean of 0-25 cm)		
		Treatment I_o	Treatment I_1	Treatment I_2
Electrical Conductivity (dS/m)	16.2	10.0	23.7	21.4
Sodium Adsorption Ratio	19	12	23	20
Sodium (mmoles+/l)	112	63	157	132
Calcium (mmoles+/l)	39	28	33	41
Magnesium (mmoles+/l)	29	25	59	47
HCO_3^-(mmoles-/l)	4	3	2	2
Cl^-(mmoles-/l)	101	51	176	151
SO_4^{2-}(mmoles-/l)	57	64	74	64

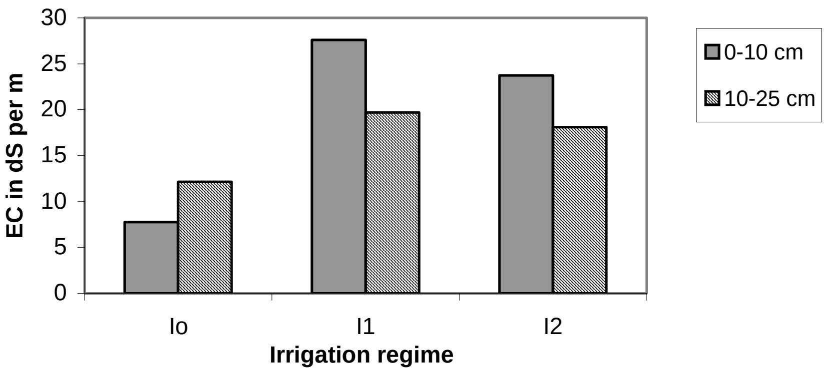

Figure 2. Variation of soil electrical conductivity with irrigation regime and soil depth

Water use efficiencies

Total water use and water use efficiencies WUE (cm^3 per g of yield) for the different irrigation regimes are illustrated in Figure 3. Water consumption decreased with increasing soil salinity and significant differences occurred in WUE between treatment I_1 and I_0**.**

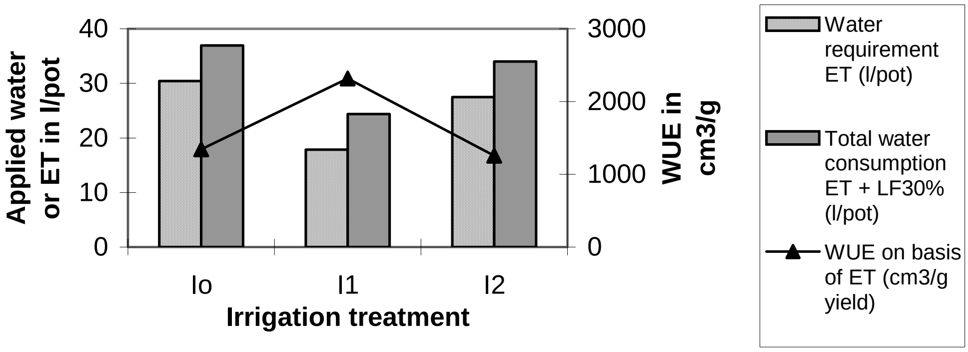

Figure 3. Applied water, evapotranspiration (ET) and water use efficiency (WUE) during pot experiments

Conclusion

Irrigation with a 1:1 mixture of sea/well water at the stem elongation stage of barley (I_1 treatment) adversely affected yield, aerial biomass and root growth in comparison to irrigation with well water (I_0) alone and also increased soil salinity. However, irrigation with the same water at the heading stage (I_2 treatment), had less effect on the barley, especially grain yield and aerial biomass and most importantly, did not cause an economic reduction in yield compared to the I_0 treatment. Use of seawater for supplementary irrigation could thus substantially reduce the pressure on limited groundwater resources. However, the increased soil salinity will result in problems for future germination and seedling growth when the plants are more susceptible to salinity. If the leaching of excessive salt from root zone is possible, particularly at early stages of growth, this should increase yield. Supplementary irrigation can therefore be applied at the last stages of barley growth (when water resources are restricted), provided that fresh water, low saline water or precipitation can be applied to control the soil salinity at the early stages of growth of the next crop. Further experiments with different mixing rates of Caspian Sea water and well water and the calculation of a suitable Leaching Ratio (LR) to stabilize soil salinity are in progress. The option of establishing a drainage system to remove excess salts from the profile either by rain or by adding the calculated LR to volume of irrigation water is under investigation.

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