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B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
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Wheat yield response and seasonal salt profile evolution under irrigation with saline waters in a semi-arid region

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Abstract

Scarcity of fresh water resources is the major constraint for agricultural development in Iran as in many other regions with arid and semi-arid climate. With the pressure on fresh water resources, the use of un-conventional water resources including brackish, saline and sewage water has received greater attentions in recent years. The objective of this study was to assess the impact of farmers' practices using saline groundwater on wheat yield and soil salinity in a Mediterranean climate of Fars province in southern Iran. The study was carried out in several commercial wheat production regions for two years. Chemical analysis of irrigation waters, volume of applied irrigation water, electrical conductivity of soil saturation extract (*ECe*) and yield were measured in each field. General information on agronomic practices was also collected using a questionnaire. Results demonstrate that waters with salinities higher than what has been classified as "suitable for irrigation" are being used for the production of wheat crop. Analysis of wheat yield response to saline irrigation water showed that for water salinities up to 10.7 $mS \cdot cm^{-1}$ (threshold value) variation in yield was relatively minor, above which wheat yield decreased at a greater rate. Root zone salinity profiles showed the effect of winter rainfall in reducing soil salinity. It is concluded that although acceptable yields are obtained with some of the highly brackish waters, over application of these waters would threaten the sustainability of crop production in the region.

Key words: *saline water, soil salinity, wheat yield, rainfall, leaching fraction*

INTRODUCTION

Scarcity of fresh water resources is the major constraint for agricultural development in Iran as in many other regions with arid and semi-arid climate. With the pressure on fresh water resources, the use of un-conventional water resources including brackish, saline and sewage water has received greater attentions in recent years. In Iran, as in many other countries, there are large volumes of saline waters, which could be used for irrigation. The volume of saline surface water resources whose total dissolved salts (TDS) in most of the year is greater than 1500 $mg \cdot dm^{-3}$ is equal to 12.88 km^3 which is about 12% of the potential of renewable surface water resources of the country [Yekom Consulting Engineers 2008]. Of the total saline surface water resources 8.61 km^3 (about 67%) flows in the Persian Gulf and the Gulf of Oman basin, and 2.84 km^3 (about 22.1%) in the Central Plateau basin. The total area of brackish groundwater resources is 350,222 km^2 with yearly exploiting volume of 13.7 km^3. In other words, considering yearly withdrawal of 53.8 km^3 from alluvial aquifers (qanats and wells), 25% of total withdrawal is from saline water zones. Central plateau basin with exploiting volume of 9.9 km^3 (72% of total exploiting volume) has the most withdrawal volume among the six major basins of the country.

In the arid and semi-arid region of Iran, saline waters are used in the production of a number of crops including cereals, cotton, sugar beet, alfalfa, canola and pistachios. Fars province, the site of this study, is the main region for wheat production and ranks first in wheat production and harvested yield in the country. The area under wheat in the province is about 600 thous. ha which is about 40% of the total cultivated area of the province.

Wheat is known to have a moderate degree of salt tolerance [MAAS, HOFFMAN 1977]. Salt tolerance of wheat is 6 mS·cm^{-1} with approximately 7% decrease in yield for each 1 mS·cm^{-1} increase in the electrical conductivity of the soil's saturation extract, *ECe* [MAAS, HOFFMAN 1977]. Response of wheat to irrigation with saline water has been studied by several researchers (JURY *et al*. [1978]; RHOADES *et al*. [1989]; SHARMA *et al*. [1991]; KHOSLA and GUPTA [1997]; MA *et al*. [2008]; GHANE *et al*. [2009]; JIANG *et al*. [2012]; JIANG *et al*. [2013]; OUDA *et al*. [2015]; ABEDINPOUR, [2017]). JURY *et al*. [1978] found no detrimental effect of salinity on wheat yield irrigated with water salinities up to 7.1 mS·cm^{-1}. RHOADES *et al*. [1989] showed that irrigation using substantial amount of water with salinity 4 mS·cm^{-1} caused little reduction in yield in their experiment. JIANG *et al*. [2012; 2013] studied the effects of irrigation water quantity and salinity on spring wheat yield, evapotranspiration and water use efficiency in an arid region of northern China. They concluded that irrigation water amount of 300 mm at salinity level of 3.2 mS·cm^{-1} is suitable for this area giving the highest water use efficiency of 1.25–1.63 kg·m^{-3}.

Use of saline water for crop production has a long history in the arid and semi-arid areas of the country. The suitability of highly saline waters used for irrigation in these regions is of concern based on the guidelines given by the FAO (FAO 29). However, as experiences and experimentations over the years have shown, evaluation of water quality depends on its specific conditions of use which includes the type of crop, properties of soil, irrigation management and cultural practices, climatic factors and economics [PRATT, SUAREZ 1990; RHOADES *et al*. 1992]. Many examples of experiences in using saline water for irrigation are reported by RHOADES *et al*. [1992]. Based on these experiences they questioned the limits proposed earlier for irrigation water quality classification. The general guideline by the FAO (FAO 29) has recently been reevaluated and it has been shown that it overestimates the negative consequence of irrigation with saline waters [LETEY *et al*. 2011]. There are no guidelines available for assessment of quality of irrigation waters tailored to specific condition of use in Iran at present. As a first step, where this study was carried out needed a more thorough examination of the use of saline water for crop production.

The objective of this study was to assess the impact of farmers' practices using saline groundwater on wheat yield and soil salinity in a Mediterranean climate of Fars province in southern Iran. The evaluation should serve as the bases for future studies to improve management practices for sustainable use of saline water.

METHODS

DESCRIPTION OF THE STUDY SITE

The study was carried out for two growing seasons (i.e. 2010–2012) in several commercial wheat production regions in Fars Province in southern part of Iran (Fig. 1). Wheat fields are surface irrigated in relatively small plots. Local wheat varieties namely, Marvdasht, Shiraz, Kavir, and Falat are grown. Wheat is planted in November and is harvested in June. These agricultural production areas are located in intermountain valleys which drain into salt lakes or playas. Source of water is from unconfined aquifers. The aquifers are made of Quaternary alluvium that consist of medium to fine-grained material brought about by stream and flood wash of the surrounding geological units. Many of the aquifers are becoming depleted at a fast rate due to over-exploitation and continuing drought. The quality of groundwater is generally poor being mainly affected by the surrounding geological formations. Of importance in this regard is the existence of many salt domes scattered in the province [RAEISSI, MOORE 1993].

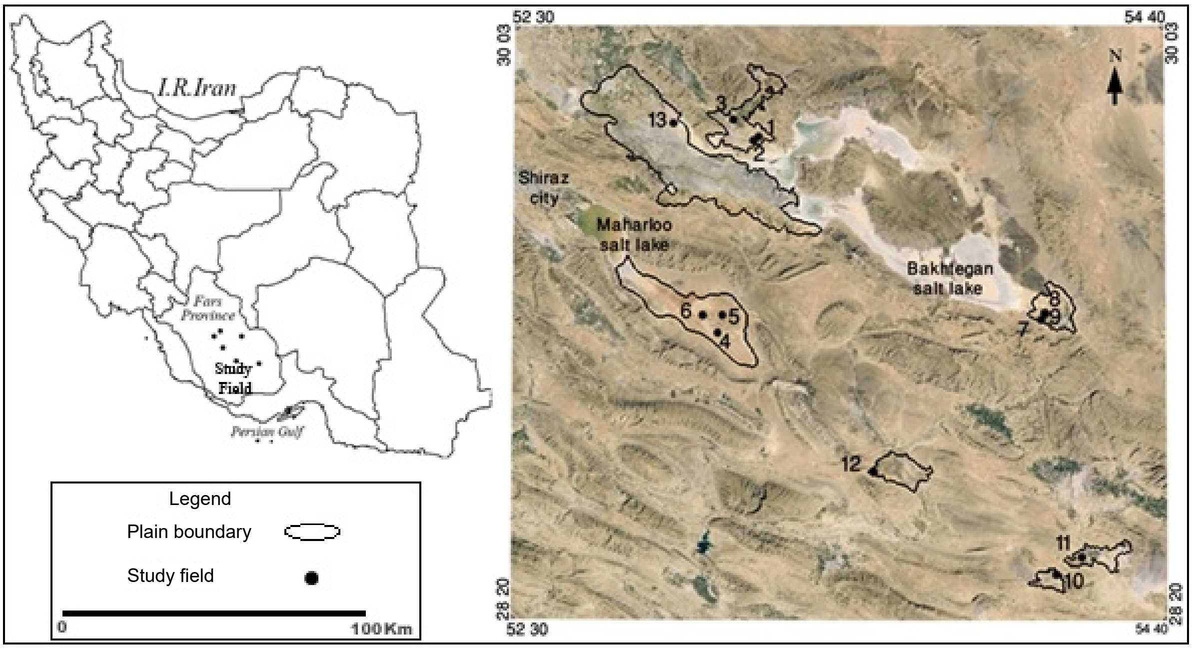

Fig. 1. Location of the study site; source: own elaboration

The soils are calcareous with a calcium carbonate content of 30–50% with very low in organic matter. The soil texture ranges from loam to silty clay loam. Soil infiltration rates average about 1 cm per hour ranging between 0.3 and 1.35 $cm \cdot h^{-1}$. Internal soil drainage is good with very deep water tables.

There are three distinct climatic regions in the province, including the mountainous area of the North and North-West with moderate cold winters and mild summers, the central regions, with relatively rainy mild winters, and hot dry summers, and the southern part which has moderate winters with very hot summers. Mean annual precipitation in normal years is about 300 mm, mainly occurring during November till April, the growing season for wheat crop. The central region is the main place for irrigated wheat production where this study was carried out.

AGRONOMIC PRACTICES

Management practices employed by the farmers in using these waters are similar to those practiced with the use of non-saline waters. In general, production of wheat in these regions is based on using high inputs of seeds, fertilizer and water. Most of the farmers use seeding rate of about 300–350 $kg \cdot ha^{-1}$. This is compared to the recommended amount of seeding rate of 150 $kg \cdot ha^{-1}$. Increasing the seeding rate is partly done to compensate for low germination rate caused by high salinity of the seed bed. Although high amount of seed is planted, the percentage of emergence is low in some of the field which is due to improper preparation of seedbed. Agronomic practices such as land preparation, irrigation method and crop rotation are suboptimal.

On-farm water application rates are generally high in the province. Seasonal applied water for some of the farms shows an average of 6700 $m^3 \cdot ha^{-1}$ (about 2000 m^3 for the first irrigation). This water is applied in 5 to 6 irrigations during the season with the first one after planting time in November and the rest after the rainfalls in March through May in 10 to 15 days irrigation interval.

The main reason for high irrigation losses is the ineffective surface irrigation methods used by the farmers. This results in poor uniformity and large application of irrigation water. With the introduction of laser-controlled land levelling and modern agricultural machinery farmers are expected to adopt modern surface irrigation methods. Adoption of such irrigation practices would reduce labour and energy costs, improve uniformity of application, lower water application, increases efficiency, reduces nutritional losses, improve crop yield and prevent environmental degradation. Moreover, it ensures sustainable production when scarcity of water becomes severe as it has occurred recently due to the long period of drought and overexploitation of groundwater

DATA COLLECTION

In total 13 farms were surveyed in different regions during the study period. Chemical analysis of irrigation waters, volume of applied irrigation water, electrical conductivity of soil saturation extract (*ECe*) and yield were measured for each field. Among the water chemical parameters determined was pH, *EC*, while major ions included Mg, Ca, Na, K, Cl, HCO_3, and SO_4. Chemical composition of irrigation waters and salinity of soil saturated extract were measured in the laboratory according to USSL Handbook No. 60 [RICHARDS (ed.) 1954]. For soil salinity measurement, soil samples were collected to a depth of 90 cm at 30-cm depth interval in the root zone at the upper, middle and lower end of each field. This was repeated five to six times during the growth season. For each field average yield mass per area was calculated as the total yield mass divided by the total area. General information on agronomic practices including the amount of seed rate and fertilizer used, planting date, crop rotation, number of irrigations, depth to water table were collected using a questionnaire.

DATA ANALYSIS

Response of crop yield to salinity of irrigation water was analyzed using the segmented linear regression model [OOSTERBAAN *et al.* 1990]. Irrigation water salinities data are grouped into two sets from which the threshold value of salinity of irrigation waters and the rate of decrease in yield above the threshold is determined. The regression equations for fitted line are as follows:

$$Y = Cs \quad \text{for } X < B \tag{1}$$

$$Y = Ag(X - Xg) + Cg \quad \text{for } X > B \tag{2}$$

Where: Y is yield, X is salinity of irrigation water, B is the break-point of salinity, Cs is the average yield for data with $X < B$, Ag is the slope of the production function for data with $X > B$, Xg is the average water salinity for data with $X < B$ and Cg is the average yield for data with $X > B$.

The selection of the best breakpoint is based on maximizing the statistical coefficient of explanation, and performing tests of significance.

An estimate of leaching fraction was made for irrigation events in the later part of the season using the model developed by HOFFMAN and VAN GENUCHTEN [1983]. The model predicts average root zone salinity based on irrigation water salinity, leaching fraction and root water uptake model. Assuming an exponential root water uptake the following equation was derived to compute linearly averaged root zone salinity (C):

$$\frac{C}{CI} = \frac{1}{L} + \frac{\delta}{ZL} \ln\left[L + (1 - L)\exp\left(\frac{-Z}{\delta}\right)\right] \tag{3}$$

Where: CI is irrigation water salinity, L is leaching fraction, Z is depth of the root zone, δ is an empirical constant set to $0.2Z$.

With a given irrigation water salinity quality of irrigation waters was assessed based on the guidelines given by the FAO [AYERS, WESCOT 1985; RHOADES *et al.* 1992] in regard to their effect on crop and soil.

RESULTS AND DISCUSSION

Chemical composition of the well waters used for crop production in the studied farms is given in Table 1. According to the criteria given by FAO [AYERS, WESCOT 1985; RHOADES *et al*. 1992], these waters are considered as moderately to highly saline with severe limitations on use. One of the main concerns and limitations of irrigation with saline water is the effect on crop growth. Based on salt tolerance of wheat crop [MAAS, HOFFMAN 1977], it is expected that relative wheat yield decreases up to 75% with the use of these waters. However, as shown below relatively good crop yield is obtained using these waters which emphasizes the point that suitability of saline irrigation water should be evaluated on the basis of specific conditions of the locality where it is to be used including irrigation management, soil properties, cultural practices, climatic factors and economics.

The sodicity hazard of irrigation waters is evaluated based on the SAR and salinity. Although SAR values for some of the waters are high (Tab. 1), but due to their high electrolyte concentration soil dispersion and surface sealing should not impose major problem [RHOADES *et al*. 1992]. The potential hazard with the use of these waters is when rain events occur during the germination and seedling stage, which could result in poor crop stand as a result of surface crusting.

With highly saline waters, assessment of irrigation water quality should also include ion ratios as well as toxicity factors for specific crops [PRATT, SUAREZ 1990]. Based on this, Ca deficiency may be of concern with some of the waters used here with high Mg:Ca ratio. In this regard, Ca deficiency associated with high Mg:Ca ratio and Na is of special concern. Under non-saline conditions Ca requirement of plants is considered to be 0.7–1.5 mmol·dm^{-3}. The calcium requirement becomes greater under saline conditions since sodium can reduce calcium mobility in the plant to young, developing tissues [GRATTAN, GRIEVE 1998]. Calcium deficiency problem has been observed to develop at Mg:Ca > 1 for some crops such as barley [CARTER *et al*. 1979] independent of salinity or absolute Ca concentrations.

These waters are generally saturated with calcium carbonate but unsaturated with gypsum and consequently calcite is expected to precipitate at low leaching fraction throughout the root zone. At higher leaching fractions, the case of many farms in this study, calcite and gypsum is predicted to precipitate at lower depths.

ROOT ZONE SALINIY

Average root zone salinity of the wheat fields during the two growing seasons is shown in Figure 2. Soil salinity

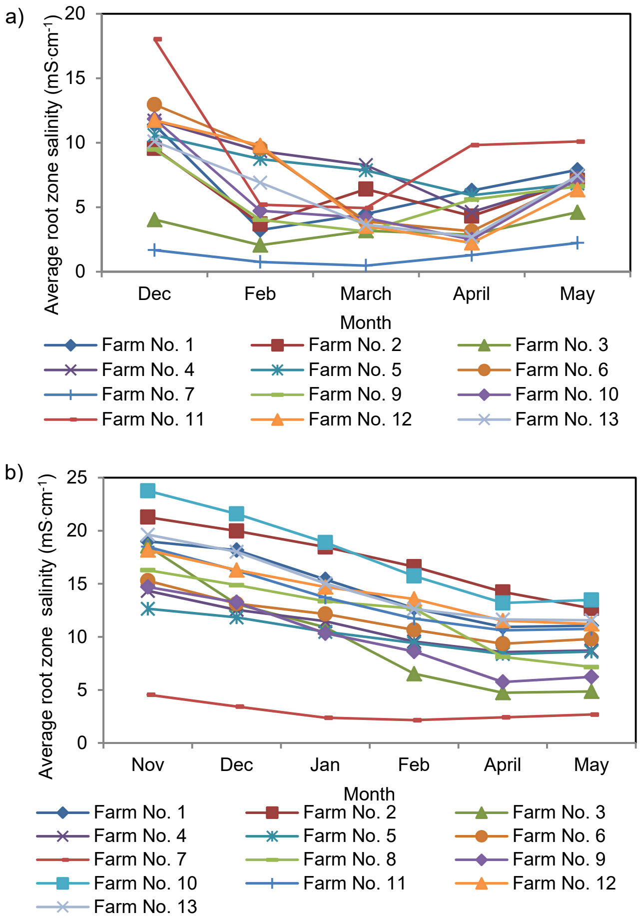

Fig. 2. Average root zone salinity during growing seasons in the studied fields: a) first season, b) second season; source: own study

Table 1. Chemical composition of irrigation waters used in the studied fields

Region	Field No.	*EC* (mS·cm^{-1})	pH	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	SAR	Mg:Ca
				mmol·dm^{-3}							
Arsenjan	1	11.50	7.17	73.5	24.0	20.0	92.5	17.0	10.0	12.61	0.83
	2	11.00	7.96	85.0	20.0	10.0	88.7	25.0	4.8	17.00	0.50
	3	8.80	7.79	42.0	25.0	16.0	48.0	23.7	7.0	7.31	0.64
Sarvestan	4	6.80	7.60	20.0	16.0	24.0	35.0	23.2	1.8	3.78	0.67
	5	6.00	7.30	36.0	9.0	24.0	60.0	7.0	2.0	7.86	2.70
	6	8.22	7.50	51.0	10.0	24.0	57.5	51.9	5.0	10.87	2.40
Neyriz	7	1.30	8.26	0.8	4.8	0.2	0.95	1.2	4.0	0.36	0.04
	8	9.70	7.10	70.0	25.0	8.0	85.0	6.8	5.0	13.00	0.32
	9	10.40	7.11	50.0	24.5	50.5	59.0	50.5	6.0	7.09	2.06
Darab	10	10.21	7.85	60.0	30.0	21.0	68.0	32.3	8.0	9.43	0.70
	11	6.80	7.53	28.0	20.0	20.0	35.0	18.0	9.8	5.11	1.00
Fasa	12	9.18	7.77	48.5	32.5	22.5	57.5	36.5	7.5	7.33	0.69
Marvdasht	13	9.80	7.30	64.0	15.0	15.0	84.0	8.0	2.4	13.49	1.00

Source: own study.

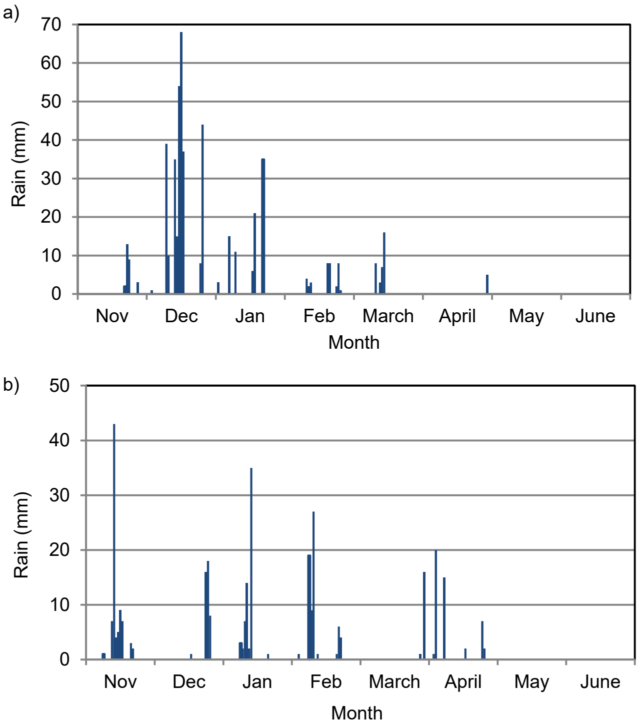

Fig. 3. Distribution of rainfall during a) first and b) second growing seasons; source: own elaboration

in the root zone is at its maximum during the planting time in November. It decreases during the raining season in winter and early spring when most of the rainfall occurs. During this period wheat is in its early development stage with low evapotranspiration requirements. Therefore, rainfall effectively leaches salts from the root zone. Then, soil salinity starts to increase again as the crop grows and its water requirement is furnished with application of saline irrigation waters. The level of soil salinity in the root zone depends on the amount and temporal distribution of rain (Fig. 3). In the first season total rainfall of 415 mm occurred compared to 320 mm in the second season. Also in the first season most of the rainfall occurred in December, while in the second year it was more uniformly distributed. To further demonstrate the effect of rainfall on leaching salts from the profile, evolution of salt profile in several individual fields in both seasons is presented in Figures 4 and 5. It is seen that soil salinity profile is decreasing as the season progresses which is concomitant with the occurrence of rainfall. During the first season, soil salinity reaches below 5 mS·cm^{-1} in March and April, when wheat crop is in its active growth stage. Then, soil salinity starts to increase with application of saline irrigation waters to meet the crop water requirement. The same process is repeated in the second, although as seen in the figures soil salinity reached a much lower magnitude in first season compared to that in the second cropping season. These data clearly show the effect of rainfall in reducing the impact of irrigation with saline waters. ISIDORO and GRATTAN [2010] using a simulation model also showed the effect of rainfall and its temporal effect on soil salinity. Their analysis indicated that winter rainfall could be more effective in reducing soil salinity than evenly distributed rainfall throughout the year.

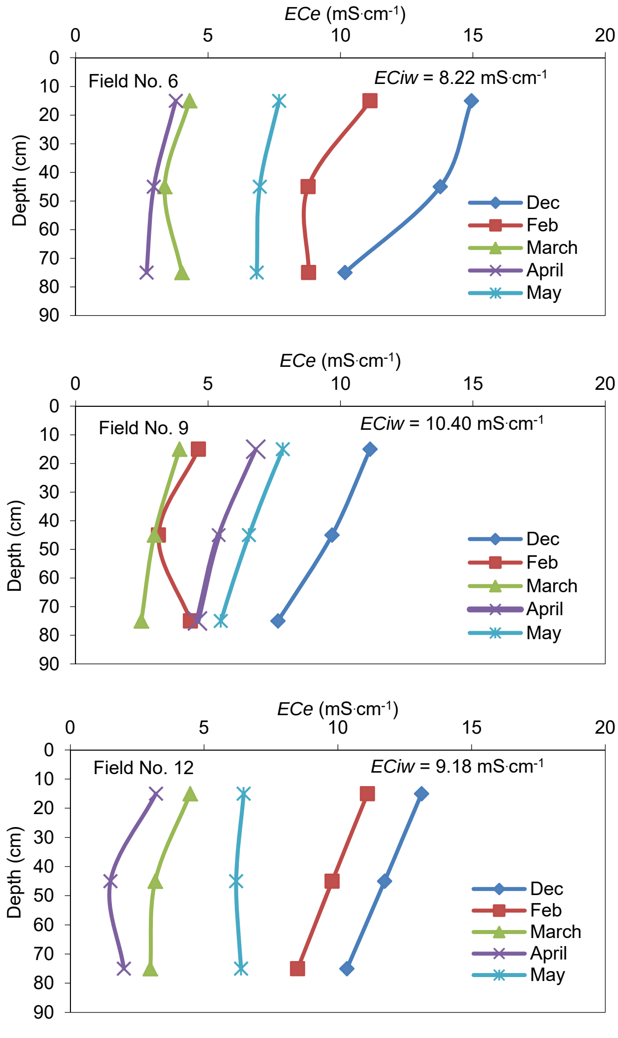

Fig. 4. Seasonal evolution of soil salinity profile during the first growing season in the studied fields; source: own study

YIELD ASSESSMENT

Relatively good yields are obtained with the use of quite saline waters in these regions as shown in Figure 6. Wheat yield as high as 6500 kg·ha^{-1} is produced with water salinity of 10.20 mS·cm^{-1}. Average wheat grain yield during the studied period was about 5000 kg·ha^{-1} in comparison to the average yield of 7780 kg·ha^{-1} obtained under non-saline condition in the same regions. This illustrates the high potential available for using saline waters for irrigation in regions which receive sufficient rainfall to prevent the build-up of excessive soil salinity over time.

Wheat yield decreases with increasing water salinity; however, for water salinities up to about 10 mS·cm^{-1} variation in yield is relatively minor. For irrigation water salinities above 10 mS·cm^{-1}, wheat yield decreases at a greater rate. There is a range of yield obtained with the same salinity of irrigation waters indicating that other factors are also involved. Some of these factors responsible for the differences in yield among farms are soil type, climate, management practices, and crop variety. OOSTERBAAN *et al.* [1990] also observed considerable scattering in field data when yield was plotted against soil salinity. They reasoned

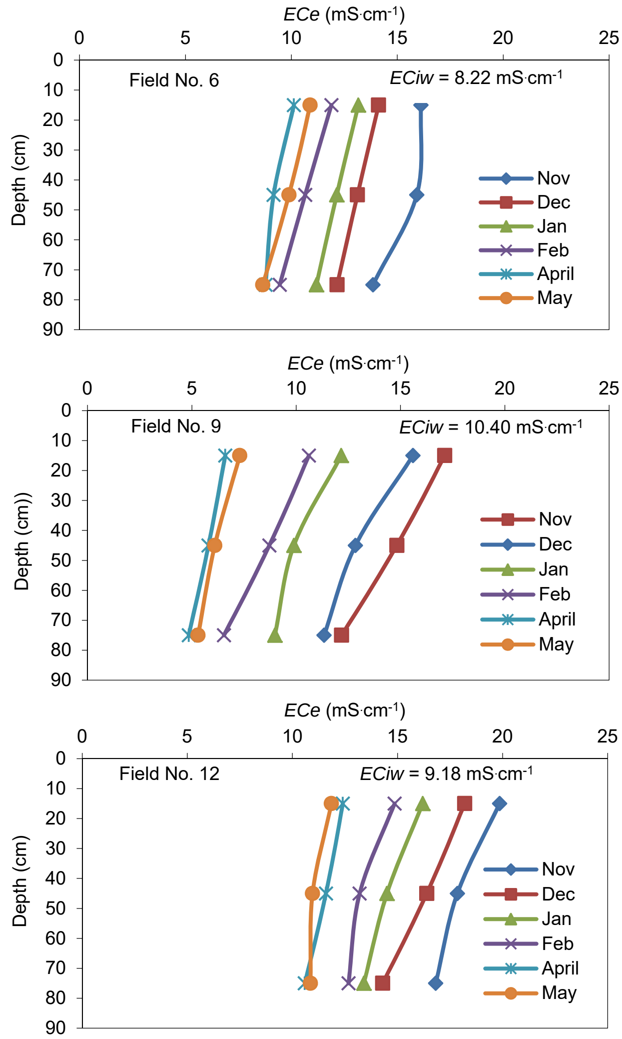

Fig. 5. Seasonal evolution of soil salinity profile during the second growing season in the studied fields; source: own study

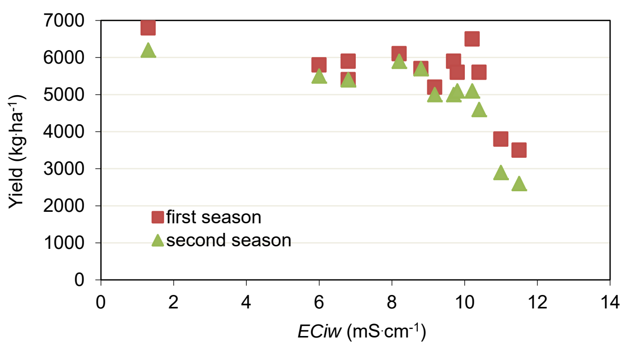

Fig. 6. Wheat grain yield obtained with different irrigation water salinities; source: own study

that the scatter is due to the presence of many production factors in agriculture, which cannot be all accounted for. Regardless of the scattering in data points, the general trend of the data is such that the change in yield with increasing salinity up to a point is relatively constant (breaking point) and then starts to decrease. Based on this figure, it appears that salinity of irrigation water has a significant effect on yield and despite some scattering in data points a relation between yield and irrigation water salinity could be obtained. For this purpose, segmented linear regression was employed to define this relation. Based on this analysis the value of breaking point (B) is equal to 10.7 mS cm^{-1} and values of parameters *Ag*, *Xg*, *Cs* and *Cg* are: $-1.93 \cdot 10^3$, 11.25 mS·cm^{-1}, $5.75 \cdot 10^3$ kg·ha^{-1}, and $3.22 \cdot 10^3$ kg·ha^{-1}, respectively.

LEACHING FRACTION ESTIMATIOM

These data show the transient nature of salinity in the field and the contribution of rainfall in this regard. To simulate such situations transient models that include amount of rain and saline irrigation water consistent with actual conditions is required [LETEY *et al.* 2011]. These models, however, have had limited field tests due to enormous data acquisition and variability of field properties among others. On the other hand, steady state models could be used with relatively simple data when conditions are close to meet their assumptions. In the irrigated fields studied here, uniformity of water distribution is poor, and fields are irrigated to supply crop water requirement for the areas receiving the least water. Therefore, heavy irrigations are applied and the change from steady state caused by the rains is rectified with each irrigation. To estimate leaching fraction equation four was solved for average root zone salinity by adjusting the leaching fraction until good agreement was found between the measured and calculated soil salinity. At a leaching fraction of 45% a significant correlation was observed between measured and calculated soil salinity for irrigation episodes at the end of the season when rainfall had ceased for some time (Fig. 7). The uniform shapes of the soil salinity profiles with depth also give an indication of high leaching fraction as shown in Figures 4 and 5 for some of the fields in the two growing seasons.

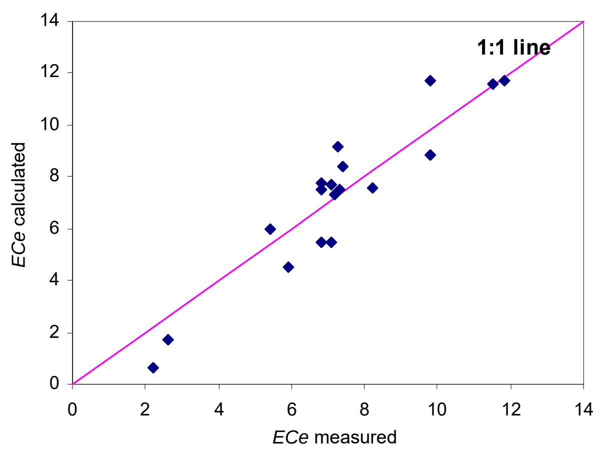

Fig. 7. Measured versus predicted soil salinity expressed by electrical conductivity of soil saturation extract (*ECe*) at 45% leaching fraction; source: own study

CONCLUSIONS

Based on the results obtained in this study it is concluded that relatively good crop yield could be obtained using highly saline waters in regions which receive sufficient rainfall (above 300 mm) to prevent the build-up of excessive soil salinity over time. Some of the main issues emerging from this study are listed below.

1. At present, no guidelines are available which could be practically used in the field. A water quality guideline for assessment of quality of water for irrigation is required. It should consider local factors such as the soil physical and chemical properties, climate, and management practices. It should be based on the experiences and scientific knowledge accumulated in the country from the use of brackish waters.

2. Although acceptable yields are obtained with some of the highly brackish waters, over application of these waters would threaten the sustainability of crop production in the region.

3. Uniformity of water application is very low in many of the surface irrigated field. This is often the reason for high application rates, especially during first irrigation when up to 2000 $m^3 \, ha^{-1}$·is used. With popularity of laser-controlled land levelling, surface irrigation systems should be properly designed. Technical guidelines for modern surface irrigation methods are not available at present.

4. The ionic composition of brackish irrigation water is becoming of concern. The effect of high ratios of Mg:Ca on soils and crops is not well understood. This should become one of the main research programs for research institutes in the country.

5. Evaluation of management practices reveals that there are other factors besides salinity that limit yield of crops. An important factor is soil tillage for seedbed preparation. Seedbed shape and seed location should be managed to minimize high salt affects.

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