Research Journal of Agronomy 2 (3): 90-95, 2008
ISSN: 1815-9354

Soil Salinity and Barley Production under Full and Deficit Irrigation with Saline Water in Arid Conditions of Southern Tunisia

[1]Kamel Nagaz, [1]Ines Toumi, [2]Mohamed Moncef Masmoudi and [2]Netij Ben Mechlia
[1]Institut Des Régions Arides, 4119 Médenine, Tunisia
[2]INAT, 43 Avenue Charles Nicolle, 2083 Tunis, Tunisia

Abstract: Field study was conducted during 2001-2002 on a sandy soil to determine the effect of full and deficit irrigation on soil salinity, yield and water use efficiency of barley (*Hordeum vulgare* L. cv. Ardhaoui). Four irrigation treatments were applied. These consisted in water replacements of accumulated crop evapotranspiration (ETc) at levels of 100% (Full irrigation, 100-ETc), 85, 70 and 50% (Deficit irrigation 85-ETc, 70-ETc and 50-ETc) with fixed irrigation intervals of 10 days. Well water with an ECi of 11.7 dS m^{-1} was used for irrigation. Yield, yield components, water supply and soil salinity were measured. The results showed that soil salinity values remained lower than those of ECiw and were significantly affected by irrigation treatments. Higher soil salinity was maintained in the root zone with deficit (50-ETc and 70-ETc) than full irrigation (100-ETc). No significant differences were observed in grain yield, dry matter and 1000-seed weight, seed per spike and spike per m^2 from the comparison between full irrigation (100-ETc) and 85-ETc deficit irrigation treatments. However, the 70-ETc and 50-ETc deficit irrigation treatments caused significant reductions in the five parameters considered (in comparison with full irrigation). Water-use efficiency (WUE) obtained in this experiment corresponds with values reported in the literature and was affected by irrigation treatments. The lowest WUE values occurred under the 100-ETc treatment, while the highest values were obtained under 50-ETc deficit irrigation treatment. The full irrigation (100-ETc) and deficit irrigation (85-ETc) strategies were found to be a useful practice for scheduling barley irrigation with saline water under the arid Mediterranean conditions of southern Tunisia.

Key words: Arid, salinity, deficit irrigation, barley, yield, water use efficiency

INTRODUCTION

Lack of adequate water is the limiting factor to crop production in the arid regions of southern Tunisia. However, most of the waters available for irrigation is frequently saline. These saline waters must be used in this region, where supplemental water is needed to intensify agriculture. Strategic options for achieving sustainable agriculture include alternate cropping patterns (cultivating low water demand crop), water conserving irrigation scheduling and developing of stress/drought tolerant crop varieties (Qadir *et al*., 2003). Deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (English and Nakamura, 1989; English and Raja, 1996; Mugabe and Nyakatawa, 2000; Ghinassi and Trucchi, 2001; Kirda, 2002; Mao *et al*., 2003; Panda *et al*., 2003; Zhang *et al*., 2004). In this method, the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season. The expectation is that any yield reduction (especially in water-limiting situations) will be compensated by increased production from the additional irrigated area with the water saved by deficit irrigation (Bazza, 1999; Kirnak *et al*., 2002; Ali *et al*., 2007).

Hassan *et al.* (2000) investigated the impact of deficit irrigation strategies on wheat yield and water savings. They reported that moderate deficit irrigation produced relatively high yield and saved 34% of irrigation water compared to full irrigation. Mugabe and Nyakatawa (2000) observed that applying 75 and 50% of crop water requirements resulted in yield decreases of 12 and 20% in 2 years, respectively. Zhang *et al.* (2004) found that severe soil water deficit (SWD) decreased grain yield of winter wheat, while slight SWD throughout the growing season did not reduce grain yield or water use efficiency. This result indicates that water supply can be reduced somewhat without significantly decreasing grain yield. Bekele and Tilahun (2007) reported that deficit irrigation throughout the growing season of onion as 50 and 75% of ETc reduced yields from full irrigation and resulted in

Corresponding Author: Kamel Nagaz, Institut Des Régions Arides, 4119 Médenine, Tunisia

the highest water saving and crop water use efficiency. Experiments with barley (Khalil *et al*., 2007) showed that yield reduction under deficit irrigation during the entire growing season was about 5 and 20% of the total irrigation water was saved.

Barley is one of the important cereal crops in arid regions of Tunisia and occupies a large cultivated area during the winter and has been classified as a tolerant plant (Maas and Hoffman, 1977). However, productivity is usually low and irrigation with waters having an ECi more than 3 dS m^{-1} is commonly practiced on a routine basis without scheduling and provision drainage and it carries the danger of a rapid soil salinization because of increased salt input.

Due to chronic water shortage and soil degradation hazards in irrigated areas, there is a need to develop strategies that may help to save water and control salinity. In the absence of drainage systems and under conditions of high evaporative demand and chronic shortages of water, techniques based on irrigation restrictions during the whole growing period without substantially affecting yields seem to be reasonably appropriate. Thus, various deficit irrigation strategies have been applied to barley crop.

The objective of the present study was to make quantitative assessments of both salt accumulation in the soil and yield response to full and deficit irrigation strategies with saline water in order to derive an irrigation strategy that save water in irrigated barley, reduce salt input and improve water productivity under the arid Mediterranean conditions of southern Tunisia.

MATERIALS AND METHODS

A field experiment was carried out at the experimental station of the Arid Lands Institute, Médenine, Tunisia, during the period 2001-2002. The experimental soil was sandy with an ECe range of 1.0-1.65 dS m^{-1} on whole profile basis (0-70 cm depth of soil) and organic matter concentration of 6.6 g kg^{-1}. The total soil water, calculated between field capacity and wilting point, is 60 mm. The climate of the region is typical of arid areas.

The values of ten days reference evapotranspiration (ETo) which define the weather conditions prevailing during the study are shown in Fig. 1. These data are compared to the average values for the period 1983-98. The evolution of ten days ETo was similar, though with slightly higher values for the period 1983-98, with a total of 669 mm as compared to 645 mm, the ETo during the period under experiment for 2001-2002. Maximum ten days ETo occurred during June-August, when the field remained fallow. The annual distribution of rainfall during

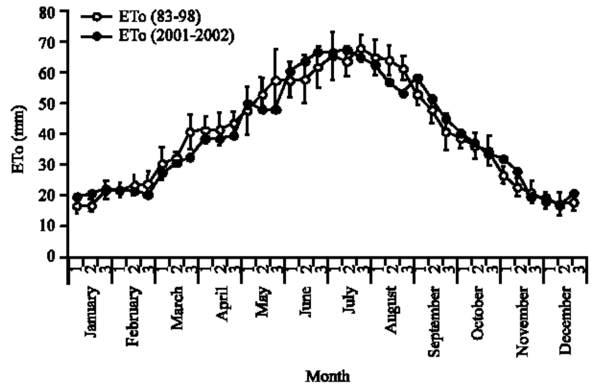

Fig. 1: Ten days reference Evapotranspiration (ETo) for 2001-2002 and period 1983-1998

Table 1: Monthly values of rainfall for 2001-2002

Month	Rainfall (mm)
November 2001	5
December 2001	10
January 2002	30
February 2002	15
March 2002	24.5
April 2002	18
May 2002	-
June 2002	-

Table 2: Composition of irrigation water (meq L^{-1})

Eci (dS m^{-1})	$Ca^{++}+Mg^{++}$	Na^{+}	K^{+}	Cl^{-}	So_4^{--}	$Co_3^{-}+HCo_3^{-}$	SARiw
11.7	43.5	71.5	2.0	74.0	40.0	3.0	15.31

2001-2002 is given in Table 1. Most of the rainfall occurred during the monsoon season from the beginning of November to the end of April.

Four irrigation treatments were set up in a in a randomized complete block design with three replicates. The experimental area was divided into three blocks with four elementary plots per block. The plot size was 4×4 m^2. All plots were surface irrigated with water from a well having an ECi of 11.7 dS m^{-1} (Table 2). Water for each block passed through a water meter and gate valve. Measured amounts of water were delivered to the plots using a hosepipe and water meters. The irrigation treatments were defined as follow: The full irrigation treatment (100-ETc) was irrigated with a quantity equal to 100% of cumulative crop evapotranspiration (ETc); The other three treatments were irrigated at the same frequency as treatment 100-ETc, but with quantities equal to 50, 70 and 85% of accumulated ETc, respectively (50-ETc, 70-ETc and 85-ETc). These treatments were identified as deficit irrigation treatments. Since irrigation of barley at the study area is on a weekly basis and barley is a drought-resistant crop, extension of irrigation to 10 days is a possibility. Therefore, an irrigation frequency of 10 days was adopted in this study.

The FAO-56 method given in Allen *et al.* (1998) was used as an estimate of crop evapotranspiration. The crop Evapotranspiration (ETc) was estimated by using reference Evapotranspiration (ETo) combined with a barley crop coefficient (Kc). The ETo was estimated from daily climatic data collected from the Institute meteorological station, located near the experimental site (data not presented) by means of the FAO-56 Penman-Monteith method given in Allen *et al.* (1998). The barley crop coefficient (Kc) was computed following the single crop coefficient approach. It was assumed that actual crop Evapotranspiration (ETa) between two successive irrigation was calculated by the formula Eta = Iw+Ra-Dw, where Iw was the amount of irrigations water applied, Ra is amount of precipitation and Dw was the amount of water drained at the soil depth of 70 cm. No attempt was made to directly measure the soil water content. Soil depth is up 70 cm because of a cracked roky layer which ensures optimal drainage of excess water. The follow-up of the irrigation water supplies by water meter during the growing season of barley showed that the irrigation water applied at each irrigation under full treatment allows soil to reach only its field capacity. Therefore, the water losses as deep percolation were restricted and drainage at the depth of 70 cm was considered as negligible. Thus, actual crop evapotranspiration was equal to the amount of irrigation water and rainfall since drainage was zero at the soil depth of 70 cm. Irrigations were applied for ten days time step. The water use by the crop included the irrigation water added and the growing season rainfall, which is referred to as total water applied.

Barley (*Hordeum vulgare* L. cv. *Ardhaoui*) was planted at a seeding rate of 120 kg ha^{-1} in the third week of November and harvested in the first week of June. After preparing the seedbed, 175 kg N, 125 kg K and 100 kg P per ha were drilled in all the plots. At tillering stage, crops received a basal dose of 40 kg N per ha. For each treatment, yield was evaluated on three sample areas. The criteria for analyzing yield were: final dry matter biomass of the aerial parts of plants, grain yield, 1000-seed weight, seed per spike and spike per m^2.

The evaluation of WUEb at crop production level was based on the relation between evapotranspiration (ET) and dry biomass (Bos, 1985). In practice, water use (ET) was estimated from the amounts of irrigation water, rainfall and the changes in the soil water content. When plotting total above-ground dry matter yield vs. ET, a linear relationship is generally found; the slope, determined from field experiments, represents the WUEb (Feddes, 1985) or the biomass water ratio according to Monteith (1993). The ratio between grain yield (at 0% humidity) and ET could be retained as the agronomic WUEg. Water use efficiency (WUEb, WUEg) was expressed as the ratio of yield to that of the water use:

$$\text{WUE} = \text{Yield (kg ha}^{-1}\text{)/Water use (mm)}$$

Soil samples were collected after harvest. The soil was sampled with a 4 cm auger every 15 cm to a depth of 60 cm. Samples were air-dried and ground to pass a mesh of 2 mm size and were analyzed for ECe.

Analysis of variance was performed to evaluate the statistical effect of irrigation treatments on barley yield, barley components, WUE and soil salinity using the STATGRAPHICS *Plus* 5.1 (www.statgraphics.com). LSD test was used to find any significant difference between treatment means.

RESULTS AND DISCUSSION

Soil salinity: The final average ECe values (0-60 cm soil depth) under different treatments are presented in Fig. 2. Initial soil salinity determined at the time of planting was 1.35 dS m^{-1}. After the crop harvest, ECe increased under all irrigation treatments. However, higher soil salinity was observed in case of deficit irrigation treatments than full irrigation (100-ETc) (Fig. 2). ECe values were, in a decreasing order, 50-ETc > 70-ETc > 85-ETc > 100-ETc. The reason for the higher soil salinity obtained for deficit irrigation treatments may be attributed to little leaching of the soil expected under deficit irrigation conditions. Schoups *et al.* (2005) reported that one consequence of reducing irrigation water use by deficit irrigation is the greater risk of increased soil salinity due to reduced leaching.

The ECe values obtained under all irrigation treatments were lower than the EC of the irrigation water used. Singh and Bhumbla (1968) observed that the extent of salt accumulation depended on soil texture and reported that in soils containing less than 10% clay the ECe values remained lower than those of ECiw. Low values of ECe under the prevailing climatic conditions were due to the leaching of soluble salts with the received rainfall (Table 1). The leaching by rain water occurred during November, December and January-April.

Yield and yield components: For analyzing the effect of full and deficit irrigation treatments on the final yield, five criteria were retained: final dry matter biomass of the aerial parts of plants, grain yield, spike number m^{-2}, seed number/spike and 1000-seeds weight. The data concerning the five parameters considered, observed for all irrigation strategies, are presented in Table 3.

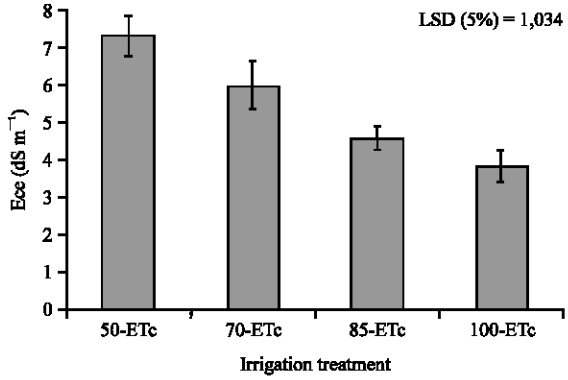

Fig. 2: Mean soil salinity (ECe, dS m^{-1}) values under full and deficit irrigation treatments

Barley grain yield was less in the 70-ETc and 85-ETc treatments than 100-ETc treatment (Table 3). Dry matter production was not significantly affected by irrigation treatment. The decreased grain yields in the 70-ETc and 85-ETc deficit irrigation treatments compared to the full treatment (100-ETc) were associated with lower spike number m^{-2}, seed number/spike and seed weight (Table 4) as a consequence of water shortage during jointing, flowering and grain filling. Therefore, the increasing water stress caused a reduction in the number of tillers and subsequently a reduction in the number of spikes per m^2. Also, reduction in 1000-seeds weight was noticed and could be attributed to grain filling failure as a consequence of water supply shortage. Thus, the increase in yield under full irrigation (100-ETc) was attributed to improved growth and yield components due to water supply. A further reduction in both grain and dry matter yields occurred with the 50-ETc treatment. The grain yield and dry matter production for the 50-ETc treatment in relation to the 100-ETc treatment were 30 and 32%, respectively. The difference in barley grain yield was not significant between the 50-ETc and 70-ETc treatments ($p<0.05$).

The differences in grain yield and yield components under 70-ETc and 85-ETc treatments were significant ($p<0.05$). Due to its effect of reducing the build-up of salinity the 85-ETc treatment resulted in barley yields comparable with those obtained under 100-ETc treatment. Barley crop productivity is most sensitive to water stress during jointing, flowering and grain filling (Sepaskhah, 1978; Weltzien and Srivastava, 1981; Ceccarelli, 1987; Baheri *et al*., 2005). Note that the 50-ETc and 70-ETc deficit irrigation strategies result in higher salinity in the rooting zone than the 85-ETc and 100-ETc strategies (Fig. 2). The higher salinity associated with deficit irrigation strategies (50-ETc and 70-ETc) were sufficient to cause reduction in yield of barley. These results obtained under the prevailing climatic conditions

Table 3: Yield under different irrigation treatments

Irrigation treatment	Grain yield (q ha^{-1})	Dry matter (q ha^{-1})
50-ETc	24.320	41.430
70-ETc	27.430	49.110
85-ETc	31.740	56.340
100-ETc	35.240	60.410
LSD (5%)	4.159	25.152

Table 4: Yield components under different irrigation treatments

Irrigation treatment	1000-seeds weight (g)	Seed per spike	Spike per m^2
50-ETc	43.170	40.330	189.330
70-ETc	44.400	42.130	201.000
85-ETc	46.670	46.000	208.670
100-ETc	48.000	47.930	219.330
LSD (5%)	1.630	3.561	18.084

support the practicality of the 85-ETc and 100-ETc strategies to facilitate the use of saline water for irrigation of barley.

Water deficit conditions can aggravated the stress placed on plants growing under saline conditions. Successful use of saline waters for irrigation purposes will be linked to irrigation management that eliminates soil moisture deficit conditions (Bresler *et al*., 1982; Shalhevet, 1994). Barley has been described as a highly salt-tolerant crop (Maas and Hoffman, 1977). Therefore, barley can be grown with acceptable yield using water that has a salinity level as high as 11.7 dS m^{-1}, if irrigation management practices maintain the fraction of ETc applied above the value of 85%.

Water use efficiency: Amounts of irrigation water supply for each irrigation treatments are presented in Table 5. For all treatments, irrigation water supply ranged from about 180 to 340 mm. The amount of irrigation water for full irrigation treatment was comparable to that reported by Nagaz and Ben Mechlia (1998, 2000) and Khalil *et al*. (2007).

The WUE expressed as the ratio of barley yield to water use from planting to harvest is presented in Table 5. The WUEs values obtained are comparable with those obtained in other field studies (Bhutia and Singh, 1990; Hussain and Al-Jaloud, 1998; Nagaz and Ben Mechlia, 1998, 2000) and were affected by the irrigation treatments.

The WUE for grain yield and dry matter production was the lowest under 100-ETc treatment and the highest under 50-L treatments. The deficit irrigation treatment 40-L gave a higher WUE because yield reduction (30 for grain yield and 32% for dry matter) was less than the water use (36%). The WUEg with 50-ETc was significantly different from that obtained with 100-ETc, 85-ETc and 70-ETc treatments ($p<0.05$). These three last treatments did not show a statistical difference between them. However, the

Table 5: Water supply (mm) and water use efficiency (kg/ha/mm) under different irrigation treatments

Irrigation treatment	Irrigation* (mm)	Rainfall (mm)	Total water applied (mm)	WUEg (kg/ha/mm)	WUEb (kg/ha/mm)
50-ETc	180	102.5	283	8.590	14.64
70-ETc	243	102.5	346	7.940	14.19
85-ETc	291	102.5	394	8.040	14.26
100-ETc	340	102.5	443	7.950	13.64
LSD (5%)	-	-	-	0.449	3.039

*an irrigation of 60 mm supplied just before planting is not included in these totals

values of WUE, based on dry matter, were not significantly different between the four treatments ($p<0.05$).

CONCLUSION

Results of this study indicate that the full irrigation treatment (100-ETc) decreased the soil salinity. Higher soil salinity was maintained in the root zone with 50-ETc and 70-ETc deficit irrigation strategies. Barley yields were influenced by irrigation treatments. Barley grain yields of deficit irrigated treatments (50-ETc and 70-ETc) were significantly lower than those in full irrigation treatment (100-ETc). Treatment 85-ETc gave also good yields. Note that the deficit irrigation treatments gave lower yields and resulted in higher salinity in the rooting zone than the full irrigation (100-ETc). The data show that factors such as spike per m^2, number of seed per spike and 1000-seeds weight are significant for grain yield. Dry matter production was affected by the irrigation treatments although, no significant difference was observed between the irrigation treatments. The higher salinity associated with the deficit irrigation treatments were sufficient to cause reduction in barley yield and yield components. The water use efficiency (WUE) for grain yield was significantly affected by irrigation treatments. The lowest values occurred under the 100-ETc treatment, while the highest values were obtained under 50-ETc deficit irrigation treatment. Although high efficiencies were observed for the most severe restrictions (50-ETc and 70-ETc), the yield and quality obtained under these treatments do not allow opting for such important reductions. The relatively high yields and water use efficiency values noted under 85-ETc treatment indicate the high potential of the barley crop to valorize irrigation waters of limited quality under mild water deficit conditions.

Based on results, it can be concluded that the full irrigation (100-ETc) and deficit irrigation (85-ETc) strategies offer significant advantage for both barley yields and WUE and reduce the build-up of salinity compared to the 50-ETc and 70-ETc irrigation practices in barley production under arid conditions. As a result of this research, full irrigation 100-ETc is recommended for irrigation of barley crop under the arid climate of southern Tunisia. In case of situations where water supply is limited, irrigation of barley could be scheduled using 85-ETc, deficit irrigation strategy.

REFERENCES

Ali, M.H., M.R. Hoque, A.A. Hassan and A. Khair, 2007. Effects of deficit irrigation on yield, water productivity and economic returns of wheat. Agric. Water Manage., 92: 151-161.

Allen, R.G., L.S. Perreira, D. Raes and M. Smith, 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper N° 56, FAO, Rome, Italy, pp: 300.

Baheri, S.F., A. Javanshir, H. Kazemi and S. Aharizad, 2005. Effects of irrigation at different phenological stages on some traits in spring barley genotypes. Iranian J. Agric. Sci., 36 (1): 169-176.

Bazza, M., 1999. Improving irrigation management practices with water-deficit irrigation. In: Kirda, C., Moutonner, P., Hera, C., Nielsen, D.R. (Eds.), Crop Yield Response to Deficit Irrigation, Developments in Plant and Soil Sciences. Kluwer Academic Publishers, 84: 21-38.

Bekele, S. and K. Tilahun, 2007. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. Agric. Water Manage., 89: 148-152.

Bhutia, N.K. and G.D. Singh, 1990. Study on yield and water use efficiency of barley in response to moisture regimes and sources of nitrogen. Haryana J. Agron., 6 (1): 76-77.

Bos, M.G., 1985. Summary of ICID definitions on irrigation efficiencies. In: A. Perrier and Ch. Riou (Eds.), Crop Water Requirements. Int. Conf., Paris, INRA, Paris, pp: 899-911.

Bresler, E., B.L. McNeal and D.L. Carter, 1982. Saline and sodic soils: Principals dynamics-modelling. Irrig. Sci., 13: 157-164.

Ceccarelli, S., 1987. Yield potential and drought tolerance of segregating population of barley in contrasting environments. Euphetica, 36: 265-273.

English, M. and B. Nakamura, 1989. Effects of deficit irrigation and irrigation frequency on wheat yields. J. Irrig. Drain. Eng., 115 (2): 172-184.

English, M. and S.N. Raja, 1996. Perspectives on deficit irrigation. Agric. Water Manage., 32 (1): 1-14.

Feddes, R.A., 1985. Crop water use and dry matter production: state of the art. In: A. Perrier and Ch. Riou (Editors), Crop Water Requirements. Int. Conf., Paris, INRA, Paris, pp: 211-234.

Ghinassi, G. and P. Trucchi, 2001. Deficit irrigation trials on maize in a Mediterranean semi-arid environment. Int. Water Irrig., 21 (1): 12-17.

Hassan, A.A., A.A. Sarkar, N.N. Karim, M.H. Ali, 2000. Irrigation schedule and deficit irrigation for wheat cultivation. Bangladesh J. Agric., 25 (1/2): 43-50.

Hussain, G. and A. AL-Jaloud, 1998. Effect of irrigation and nitrogen on yield, yield components and water use of barley in Saudi Arabia. Agric. Water Manage., 36: 55-70.

Khalil, F.A., S.A. Ouda and M.M. Tantawy, 2007. Predicting the effect of optimum irrigation and water stress on yield and water use of barley crop. J. Applied Sci. Res., 3 (1): 1-6.

Kirda, C.R., 2002. Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. In: Deficit Irrigation Practices, FAO Water Reports, 22: 3-10.

Kirnak, H., I. Tas, C. Kaya and D. Higgs, 2002. Effects of deficit irrigation on growth, yield and fruit quality of eggplant under semi-arid conditions. Austr. J. Agric. Res., 53: 1367-1373.

Maas, E.V. and G.J. Hoffman, 1977. Crop salt tolerance: current assessment. J. Irrig. Div. Am. Soc. Civ. Eng., 103: 115-134.

Mao, X., M. Liu, X. Wang, C. Liu, Z. Hou and J. Shi, 2003. Effects of deficit irrigation on yield and water use of greenhouse grown cucumber in the North China Plain. Agric. Water Manage., 61: 219-228.

Monteith, J.L., 1993. The exchange of water and carbon by crops in a Mediterranean climate. Irrig. Sci., 14: 85-91.

Mugabe, F.T. and E.Z. Nyakatawa, 2000. Effect of deficit irrigation on wheat and opportunities of growing wheat on residual soil moisture in southeast Zimbabwe. Agric. Water Manage., 46: 111-119.

Nagaz, K. and N. Ben Mechlia, 1998. Barley production under different irrigation regimes with two water qualities. Agricoltura Mediterranea. Int. J. Agric. Sci., 128 (1): 28-33.

Nagaz, K. and N. Ben Mechlia, 2000. Nitrogen and water quality effects on yield and water use efficiency of barley (*Hordeum vulgare* L. cv. *Ardhaoui*) in the arid climate of southern Tunisia. Agricoltura Mediterranea. Int. J. Agric. Sci., 130 (1): 11-17.

Panda, R.K., S.K. Behera and P.S. Kashyap, 2003. Effective management of irrigation water for wheat under stressed conditions. Agric. Water Manage., 63 (1): 37-56.

Qadir, M., Th. M. Bores, S. Schubert, A. Ghafoor and G. Murtaza, 2003. Agricultural water management in water-starved countries: challenges and opportunities. Agric. Water Manage., 62: 165-185.

Schoups, G., J.W. Hopmans, C.A. Young, J.A. Vrugt, W.W. Wallender, K.K. Tanji and S. Panday, 2005. Sustainability of irrigated agriculture in the San Joaquin Valley, California. Proceed. National Acad. Sci., USA, 102: 15352-15356.

Sepaskhah, A.R., 1978. Time and frequency of irrigation in relation to growth stages of barley. Agron. J., 70: 731-734.

Shalhevet, J., 1994. Using water of marginal quality for crop production: major issues. Agric. Water Manage., 25: 233-269.

Singh, B. and D.R. Bhumbla, 1968. Effect of quality of irrigation water on soil properties. J. Res. Punjab Agric Univ., 5: 166-172.

Weltzien, H.C. and J.P. Srivastava, 1981. Applications in breeding strategies, ICARDA, Aleppo (Syria). In barley genetics IV, Fouth. Int. Barley Generics Symposium, Edinburgh, Scotland, pp: 351-369.

Zhang, Y., E. Kendy, Y. Qiang, L. Changming, S. Yanjun and S. Hongyong, 2004. Effect of soil water deficit on evapotranspiration, crop yield and water use efficiency in the North China Plain. Agric. Water Manage., 64: 107-122.