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Millet Production under Different Irrigation Strategies with Saline Water in Arid Conditions of Tunisia

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Abstract: A field study was conducted in Southern Tunisia to evaluate the effects of irrigation strategies with saline water (7.0 dS m^{-1}) on soil salinity, yield and water use efficiency of Pearl millet (*Pennisetum glaucum* (L.) R.Br.). Millet was grown on a sandy loam soil under four irrigation treatments as low frequency irrigation for the whole season (L); high frequency irrigation for the whole season (H); low frequency irrigation until the beginning of flowering, high frequency irrigation during flowering and grain filling stages and low frequency irrigation after flowering and grain filling (LHL) and high frequency irrigation until the beginning of flowering, low frequency irrigation during flowering and grain filling stages and high frequency irrigation after flowering and grain filling (HLH). The actual irrigation frequencies for the treatments L and H were dictated by the degree of soil water depletion within the root zone before the next irrigation. Irrigations were applied when 70 and 40% of the total available water in root zone had been depleted, respectively, for L and H treatments. Yield, yield components, water supply and soil salinity were measured. The results showed that soil salinity values remained lower than that of ECiw and were significantly affected by irrigation treatments. Higher soil salinity was maintained in the root zone with H and HLH than L and LHL irrigation treatments. Millet yields were maximized under the L treatment and yields in this treatment averaged 22 and 12.4% more grain and dry matter than the H treatment, respectively. No significant differences were observed in grain yield, dry matter production, panicle no m^{-2}, kernel number/panicle and 1000-kernel weight from the comparison between L and LHL treatments. With L and LHL treatments, 17.9 and 13.5% of the irrigation water was saved in comparison with H irrigation treatment and WUEg increased by 35 and 26% compared with that of H irrigation treatment. L and LHL irrigation treatments provide significant advantage for both yield and WUE and reduce the build-up of salinity compared to the H and HLH irrigation practices in millet production under experimental conditions. For water-saving purposes, the L and LHL irrigation strategies were found to be a useful practice for scheduling millet irrigation with saline under the arid Mediterranean conditions of Southern Tunisia.

Key words: Arid, millet, yield, water use efficiency, irrigation frequency, water management, salinity

INTRODUCTION

One of the major problems confronting irrigated agriculture nowadays throughout the world is the lack of adequate water resources. In many countries and regions, adequate water is relatively scarce, but there are considerable resources of saline water, which could be utilized for irrigation if proper crops, soil and water management practices were established (Mantell *et al*., 1985; Rhoades *et al*., 1992). In arid regions of Tunisia, restricted supply of good quality water is the most important factor limiting crop production and irrigation of a wide range of crops is expanding around shallow wells having a salinity ranging from 3-9 dS m^{-1}. The efficient use of saline water for irrigation is to undertake appropriate management of irrigation to preserve water resources and prevent the development of excessive soil salinization for crop production. Irrigation frequency is one of the most important factors in irrigation scheduling for controlling soil salinity and therefore, developing best management practices for irrigated areas (Al-Tahir *et al*., 1997; Wang *et al*., 2006). Earlier reports by Hunsaker *et al*. (1998), Imtiyaz *et al*. (2000), Camposeo and Rubino (2003), Hassan *et al*. (2005), Sensoy *et al*. (2007) and Wan *et al*. (2007) show that highest yields of cotton, pepper, tomato, sugar beet, melon, cabbage, spinach, carrot and onion were obtained from the treatment employing the greatest frequency.

Results from experiments testing the recommendation to increase the irrigation frequency, when saline water is used (Hoffman *et al*., 1983; Kafkafi, 1984), however are contradictory. Experiments with barley (Al-Tahir *et al*.,

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1997) and with alfalfa (Helalia *et al.*, 1996) showed a distinct advantage to high frequency irrigation. Ayers and Westcot (1976) and Sharma *et al.* (1977) found also that irrigation frequency must be increased to minimize salt accumulation and optimize crop yield. Experiments with other crops i.e., with beans (Bernstein and Francois, 1975), with eggplant and corn (Shalhevet *et al.*, 1983, 1986), with tall fescue (Hoffman *et al.*, 1983) and with potato (Nagaz *et al.*, 2007) have shown no advantage of increasing frequency of irrigation with saline water. Some results for pepper (Bernstein and Francois, 1975) and for barley (Wagenet *et al.*, 1980) actually showed a damaging rather than beneficial effect of increasing frequency of irrigation with saline water. The effects of irrigation frequency strategies on yield have been investigated for various crops but rarely for pearl millet crop in the context of arid areas.

Pearl millet (*Pennisetum glaucum* (L.) R.Br.) is a major summer crop in the irrigated areas of Southern Tunisia and covers 13% of the irrigated agricultural land. However, productivity is usually low and irrigation with waters having an ECi >3 dS m^{-1} is commonly practiced on a routine basis without scheduling strategy and provision drainage and it carries the danger of a rapid soil salinization because of increased salt input. Pearl millet productivity is most sensitive to water stress during flowering and grain filling stages (Mahalakshmi and Bidinger, 1985; Hattendorf *et al.*, 1988; Mahalakshmi *et al.*, 1988). Both timing of stress in relation to flowering and intensity of stress determine the reduction in grain yield (Mahalakshmi *et al.*, 1988). Therefore, irrigation must be scheduled to avoid excessive moisture or water stress that can lead to reduced yield and lower quality. Thus, various irrigation strategies have been applied to pearl millet crop considered as moderately tolerant to water stress caused by deficit irrigation or salinity (Hajor *et al.*, 1996).

The objective of the present study was to determine irrigation water requirements of millet crop and to make quantitative assessments of both salt accumulation in the soil and yield response to saline irrigation strategies in order to derive an irrigation strategy that save water in irrigated millets, reduce salt input and improve water productivity.

MATERIALS AND METHODS

Experimental site and climate: Experiment was carried out during summer crop growing season of 2001 at CFRA Médenine near the "Institut des Régions Arides de Médenine" in the Southern East of Tunisia. Pearl Millet (*Pennisetum glaucum* (L.) R.Br.), native of the region, was planted on a sandy loam soil with low organic matter content and an ECe of 2.30 dS m^{-1} (0-70 cm depth of soil). The total soil available water calculated between field capacity and wilting point for an assumed millet root extracting depth of 0.70 m, was 72.5 mm. The climate of the region is typical of arid conditions with an annual precipitation of 200 mm and annual reference Evapotranspiration (ETo) of 1465 mm. The average values of ten days Eto for the period 1983-98 are shown in Fig. 1. These data cover only the period, when experiment took place.

Crop management and experimental design: Pearl millet was sown in the third week of May 2001, 7×3 m plots separated from each other, in a randomized complete block design with four replicates and four irrigation treatments. The experimental area was divided into four blocks with four elementary plots per block. Each elementary plot consisted of twelve rows of millet. All plots were surface irrigated with water from a well having an Eci of 7.0 dS m^{-1} (Table 1). Water for each block passed through a water meter and gate valve. Each plot was feed individually. Measured amounts of water were delivered to the plots using a hosepipe and water meters.

Before planting, soil was spread with 13 t ha^{-1} of organic manure. Nutrient supply included N, P and K at rates of 180, 100 and 100 kg ha^{-1}, respectively. The P and K fertilizers were applied as basal dose before planting. Nitrogen was divided and applied in all treatments during early vegetative growth.

Four distinct water treatments were applied. The treatments were defined as low frequency irrigation for the whole season (L); high frequency irrigation for the whole season (H); low frequency irrigation until the beginning of flowering, high frequency irrigation during flowering and grain filling stages and low frequency irrigation after

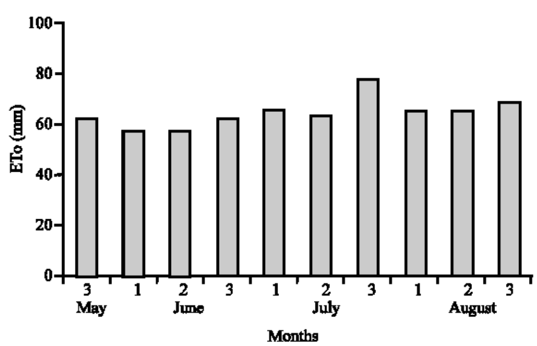

Fig. 1: Ten days reference Evapotranspiration (ETo), period 1983-1998

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

ECi (dS.m^{-1})	$Ca^{++}+Mg^{++}$	Na^+	K^+	Cl^-	So_4^{--}	$Co_3^{-}+HCo_3^{-}$	SARiw
7.0	34.4	34.8	0.8	38.5	28.5	3.0	8.4

flowering and grain filling (LHL) and high frequency irrigation until the beginning of flowering, low frequency irrigation during flowering and grain filling stages and high frequency irrigation after flowering and grain filling (HLH). The actual irrigation frequencies for the treatments were dictated by the degree of available soil water depletion allowed within the root zone before the next irrigation. In treatments L and H, irrigation was applied, when approximately 70 and 40% of the total available water had been depleted from the root zone. Treatments HLH and LHL represented a scheduling practices aimed at avoiding water stress during the period considered to be the most critical to yield. For the HLH and LHL treatments, the change of irrigation regime occurred at the beginning of flowering. For scheduling irrigation, the gravimetric method was used to estimate the day when the target soil water depletion for each treatment would be reached and the amount of irrigation water needed to replenish the soil profile to field capacity.

Measurements and water-use efficiency: For determining soil water content by the gravimetric method (θ_g), the weight of wet and dry soil has to be known. Samples were taken with a 4 cm auger prior and after each irrigation and at intermediate dates between irrigation intervals and each elementary plot were sampled at two points within homogeneous areas from four depths (0-0.20; 0.20-0.40; 0.40-0.60; 0.60-0.70 m in depth). After the sampling, the wet mass of the soil was immediately determined. Therefore, soil samples were dried for 48 h at 105°C and θ_g calculated. Undisturbed soil samples were taken at the beginning of the trial in order to calculate the bulk density, which was used for determining volumetric (θ_v) soil water content. The dried soil samples were ground to pass a mesh of 2 mm size and were analyzed for ECe.

Millet was harvested by hand on the third week of August. For each treatment, yield was evaluated on four sample areas. The criteria for analysing yield were: final dry matter biomass of the aerial parts of plants, grain yield, panicle number m^{-2}, kernel number/panicle and 1000-kernel weight.

Water-Use Efficiency (WUE) is defined as the yield obtained per unit of irrigation water applied. The WUE was calculated as follow: WUE (kg/ha/mm) = Yield (kg ha^{-1})/total irrigation water applied (mm) from planting to harvest; an irrigation of 72 mm applied before planting is not included in the total.

Statistical analysis: Analysis of variance was performed to evaluate the statistical effect of irrigation treatments on millet yields and components, WUE and soil salinity using the STATGRAPHICS Plus 5.1 (www.statgraphics.com). LSD test at 5% level was used to find any significant difference between treatment means.

RESULTS AND DISCUSSION

Soil salinity: The average ECe values (0-70 cm soil depth) under different irrigation treatments are presented in Fig. 2. Initial soil salinity determined at the time of planting was 2.3 dS m^{-1}. Under all irrigation treatments, ECe increased and reached its highest value at crop harvest. The ECe was directly related to the irrigation treatments. ECe values under high frequency irrigation treatment (H) were higher than under low frequency irrigation treatment (L). Applying frequent irrigation to the crop only during the period of flowering and grains filling (treatment LHL) increased slightly ECe values over the low frequency irrigation (L). However, HLH treatment decreased insignificantly ECe in comparison with high frequency irrigation treatment (H). The difference between treatments in ECe became significant 25 days after planting. Average salinity values during the experimental period were, in a decreasing order, H>HLH>LHL>L. The reason for the higher soil salinity obtained for H and HLH treatments may be attributed to the fact that more frequent irrigation would result in higher direct evaporation rates leading to an increase in salt accumulation in the soil. Earlier reports by Hoffman *et al.* (1983), Hamdy (1991, 1996), Shalhevet *et al.* (1986) and Shalhevert (1994) show that lower soil salinity was observed in case of low frequency irrigation than frequent irrigation regime. The lowest salinity levels maintained by using low frequency irrigation have significant agronomic relevance particularly in arid areas characterized by high evaporative demand and scarce and irregular rains.

The average ECe values under the different irrigation treatments were lower than the EC of the irrigation water used (Fig. 2). Singh and Bhumbla (1968) observed that the extent of salt accumulation depended on soil texture and reported that in soils containing <10% clay

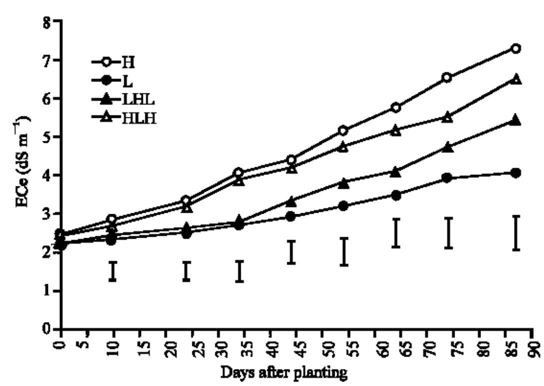

Fig. 2: Soil salinity (ECe, dS m^{-1}) under the different irrigation treatments. Vertical bar indicates the LSD (5%) value

Table 2: Yield and its components for different irrigation scheduling strategies

Treatments	Grain yield (q ha^{-1})	Final dry matter (q ha^{-1})	Panicle number m^{-2}	Kernel number/panicle	1000-kernel weight (g)
L	26.400	116.070	87.000	259.000	12.600
H	20.670	101.670	75.000	229.000	11.180
LHL	24.020	111.410	83.000	244.000	12.150
HLH	22.490	106.670	78.000	235.000	11.840
LSD (5%)	2.531	7.447	7.615	27.677	0.429

the ECe values remained lower than ECiw. Low values of ECe under the prevailing climatic conditions were also due to the low initial soil salinity (2.30 dS m^{-1}).

Yield and its components: For analyzing the effect of irrigation treatments on the final yield, five criteria were retained: final dry matter biomass of the aerial parts of plants, grain yield, panicle no m^{-2}, kernel number/panicle and 1000-kernel weight. The data concerning the five parameters considered, observed for all irrigation scheduling strategies, are shown in Table 2.

Millet grain yield was less in the H and HLH treatments than L treatment (Table 2). Dry matter production was affected by irrigation treatment. The decreased grain yields in the H and HLH treatments compared to the L treatment were associated with lower panicle no m^{-2}, kernel number/panicle and kernel weight (Table 2) caused by saline stress (Fig. 2). A further reduction in both parameters occurred with the H treatment. The grain yield and dry matter production for the H treatment in relation to the L treatment were 22 and 12.4%, respectively, indicating that saline stress had a larger effect on the grain yield than on the dry matter. The difference was significant between the L and H treatments ($p<0.05$). The differences in yield and its components under L and LHL treatments were not significant ($p<0.05$). Due to its effect of reducing the build-up of salinity the LHL treatment resulted in millet yields comparable with those obtained under L treatment. Millet crop productivity is most sensitive to water stress during flowering and grain filling (Mahalakshmi and Bidinger, 1985; Hattendorf *et al*., 1988; Mahalakshmi *et al*., 1988). Note that the H and HLH irrigation strategies result in higher salinity in the rooting zone than the L and LHL strategies (Fig. 2).

The higher salinity associated with the H and HLH strategies were sufficient to cause reduction in yield of Millet. These results obtained under the prevailing climatic conditions support the practicality of the L and LHL strategies to facilitate the use of saline water for irrigation.

Water supply and water use efficiency: Amounts of irrigation water supply for each irrigation treatments are shown in Fig. 3. The irrigation water supply for the H treatment (392 mm) was 17.9% greater than that for the L treatment (322 mm), whereas it was 9 and 5% greater than the L in the HLH and LHL treatments (354 and 339 mm). The L and LHL irrigation strategies required less water than the H and HLH irrigation strategies.

Table 3: Water use efficiency (kg/ha/mm) under different irrigation treatments

Treatments	WUEg	WUEb
L	8.200	36.050
H	5.270	25.940
LHL	7.090	32.860
HLH	6.350	30.130
LSD (5%)	2.119	2.024

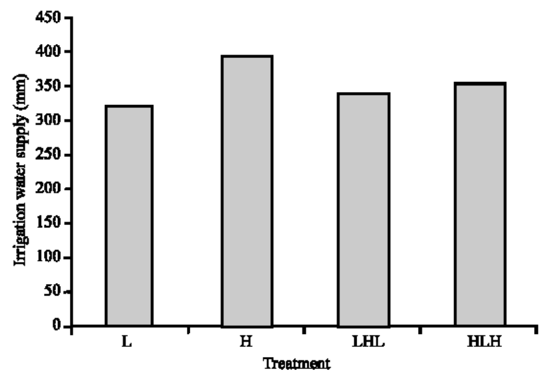

Fig. 3: Irrigation water supply under different irrigation treatments

The WUE expressed as the ratio of the millet yield to irrigation water received from planting to harvest is presented in Table 3. The WUE values were comparable with those reported by Maman *et al.* (2003), Hattendorf *et al.* (1988), Chaudhuri and Kanemasu (1985) and Kanemasu *et al.* (1982). Comparison of the treatment Water Use Efficiency (WUE) suggests that the L and LHL treatments achieved more efficient utilization of the irrigation water in yield production. The WUEg for the H treatment was 5.27 kg/ha/mm but was 35% (8.20 kg/ha/mm) and 26% (7.09 kg/ha/mm) higher for the L and LHL treatments, respectively. The WUEb was 28 and 21% higher for the L (36.05 kg ha^{-1} m^{-1}) and LHL (32.86 kg/ha/mm) than the H (25.94 kg/ha/mm), respectively. WUE for grain and dry matter production of HLH treatment (6.35 and 30.13 kg/ha/mm) differed significantly from L treatment ($p<0.05$). Thus, for the conditions in this study, the use of high frequency irrigation for the whole season resulted in crop stress sufficient to reduce both millet yields and crop water use efficiency. Higher WUE under L and LHL irrigation treatments was obviously due to higher yield accompanied by saving of irrigation water as compared to H and HLH irrigation treatments.

CONCLUSION

Less frequent irrigation for millet was found to increase crop dry matter and grain yield production in this study on a sandy loam soil in the arid conditions of southern Tunisia. Higher soil salinity was maintained in the root zone with H and HLH than L and LHL irrigation strategies.

As the salinity increased, there was a considerable reduction in crop yield under H and HLH than L and LHL irrigation strategies. In this climatic setting, millet yields were maximized for treatment L. Grain yield for treatment L was significantly greater than that for treatment H. Comparison of treatment L with treatment H indicates that the L irrigation strategy resulted in a 12.4% increase in dry matter production and a 22% increase in grain yield over the H irrigation strategy. The increased crop production for the L over the H treatment was realized with a large saving in the irrigation water (17.9%) and the WUEs for grain yield and dry matter production were 35 and 28% higher.

Applying frequent irrigation to the millet crop only during the period of flowering and grain filling (treatment LHL) increased dry matter 9% and grain yield 14% over the high frequency irrigation treatment (H). The differences in millet grain yield and dry matter production between the LHL and L treatments were not significant. The increased crop production for the LHL over the H treatment was associated with 13.5% less irrigation water and significantly higher WUE.

Based on results, it can be concluded that the full season low frequency (L) and LHL irrigation strategies offer significant advantage for both yield and WUE and reduce the build-up of salinity compared to the H and HLH irrigation practices in millet production under arid conditions. This conclusion is consistent with the experimental results of Wagenet *et al.* (1980), Hoffman *et al.* (1983) and Shalhevert (1994) and confirms the credibility of the recommended low frequency irrigation strategy to facilitate the use of saline water for irrigation.

A comparison of these two strategies (low frequency versus high frequency irrigation) is also discussed by Hamdy and Lacirignola (1999) and Savvas *et al.* (2007). As a result of this research, low frequency (L) and LHL irrigation strategies are recommended for irrigation of millet cultivation.

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