Journal of Agricultural Science; Vol. 15, No. 5; 2023
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Impact of Saline Water Irrigation (SWI) on Water Use Efficiency of Quinoa (*Chenopodium quinoa* Willd.) Under Tunisian Semi-arid Conditions

Mourad Rezig[1], Neserine Ben Yahia[1], Mohamed Allani[2], Hassouna Bahrouni[1], Ali Sahli[2] & Mohamed Ali Ben Abdallah[1]

[1] Institut National de Recherches en Génie Rural Eaux et Forêts, Tunisie

[2] Institut National Agronomique de Tunisie, Tunisie

Correspondence: Mourad Rezig, Institut National de Recherches en Génie Rural Eaux et Forêts, Rue Hédi Elkarray, Ariana, Tunisie. Tel: 216-98-576-500. E-mail: rezigue_mourad@yahoo.fr

Received: January 18, 2023 Accepted: March 4, 2023 Online Published: April 15, 2023

doi:10.5539/jas.v15n5p57 URL: https://doi.org/10.5539/jas.v15n5p57

Abstract

This study was carried out in Cherfech Tunisia, at the experimental station of the National Research Institute of Rural Engineering, Water and Forests (INRGREF) during the growing season 2015. The main objectives are quantifying and valuing the Water consumption (WC) and Water Use Efficiency of quinoa (*Chenopodium quinoa* Willd.), under saline water irrigation at different concentrations (T_0 = 1.2 dS m^{-1}, T_1 = 9.2 dS m^{-1} and T_2 = 18 dS m^{-1}). The TDM decreased from 6.7 to 13.4% due to the increase in the salt concentration of the irrigation water from 9.2 to 18 dS m^{-1}. A reduction of 9.8 to 12.6% was marked for treatments T_1 and T_2. Also, the WUE $_{PR}$-anthesis has registered a decrease of 8 and 12.5% respectively for T_1 (WUE_{PR} = 10.3 kg m^{-3}) and T_2 (WUE_{PR} = 9.8 kg m^{-3}) compared with the control T_0 (WUE_{PR} =11.2 kg m^{-3}). However, irrigation water salinity showed no effect on the WUE post-anthesis T_0 and T_1 (WUE_{PS} = 3 kg m^{-3}). Nevertheless, a decrease about 15% was recorded in the T_2 (WUE_{PS} = 2.5 kg m^{-3}). At harvest, the highest, WUE_{TDM} (5.43 kg m^{-3}) was recorded under T_0. However, the lowest WUE_{TDM} (5 kg m^{-3}) was marked under T_2; a decline of 7.9% was marked. Besides, the uppermost WUE_{GY} (2.09 kg m^{-3}) was recorded under T_0. However, the smallest amount of WUE_{GY} (1.1 kg m^{-3}) was recorded under T_2. A lessen of 47.4% was manifested on WUE_{GY} due to the height reduction on yield in the T_2.

Keywords: irrigation saline water, water use, water use efficiency, quinoa

1. Introduction

Quinoa is a pseudo cereal native to the Andian regions of South America (Matiacevich et al., 2006); it can be used in a similar way as wheat and rice (Gómez-Caravaca et al., 2012). Quinoa has been cultivated in many countries like Tunisia, Morocco, Algeria, USA, Canada, India, England, Denmark, Greece and Italy (Bhargava et al., 2006; Pulvento et al., 2010) below different climatic situation. It is distinct by a high tolerance to drought and salinity (Gomez-Pando et al., 2010, Razzaghi et al., 2011a, Adolf et al., 2013). Quinoa is able to tolerate high salinity levels as in sea water (Hariadi et al., 2011; Adolf et al., 2013).

Wilson et al., (2002) affirmed that there isn't any effect in plant height, leaf area and fresh weight, till 11 dSm^{-1}. They observed an increase in leaf area and dry weight grown at 11 dSm^{-1} compared to those grown at 3 dSm^{-1}.

Jacobsen et al. (2005) observed that quinoa biomass production, seed yield and harvest index were higher under moderately saline conditions (10-20 dSm^{-1}) than that under non-saline conditions.

Numerous researchers have studied the effect of salinity on quinoa germination and plant growth (Koyro & Eisa, 2008; Hariadi et al., 2011; Ruiz-Carrasco et al., 2011), on physiological and morphological characteristics (Cocozza et al., 2012; Pulvento et al., 2012; Adolf et al., 2012). However, there is a few of research in relation to the effect of salinity on water use efficiency before and after quinoa grain filling.

2. Methodology

2.1 Location

The study was conducted at INRGREF, located in Cherfech, Ariana (Tunisia, 10° Est, 37° N, Alt. 10.5 m), during the growing season 2015. The climate of the region is semi arid.

The annual average rainfall is about 450 mm with unequal distribution.

The highest and least temperatures were 33±4 °C and 20±3 °C, and the most and lowest percentage of relative humidity were 44±3% and 22±1%, respectively. The texture was clay-loam and characterized by a hydraulic conductivity at saturation of 1 m d^{-1}.

The water content at field capacity varies from 45.2 to 47.9 % and at the wilting point ranges from 25.7 to 27.1% from the surface to the depth. The total available water was 188 mm m^{-1}. The bulk density sited from 1.56 to 1.67.

2.2 Plant Material

Plant material consisted of one quinoa variety (*Chenopodium quinoa* Willd.). The planting was carried out on March 2, 2015.

2.3 Irrigation Treatment

Three levels of water salinity were applied; T_0: irrigation with low salt water (T_0 = 1.2 dS m^{-1}); T_1: treatment with medium salt water (T_1 = 9.2 dS m^{-1}) and T_2: irrigation with salt water (T_2 = 18 ds m^{-1}).

All irrigation treatments (T_0; T_1 and T_2) received 100% of ETc. Salt application was initiated on April 15; 2015. The experimental design adopted was a complete randomized block with three replicates.

Each elementary plot had 2.5 m length and 5 m width (Figure 1). Indeed, each treatment (T_0, T_1 and T_2) was composed with 6 lines of 2.5 m length (Figure 1). The distance among plants was 0.33 m and 1 m between crop lines.

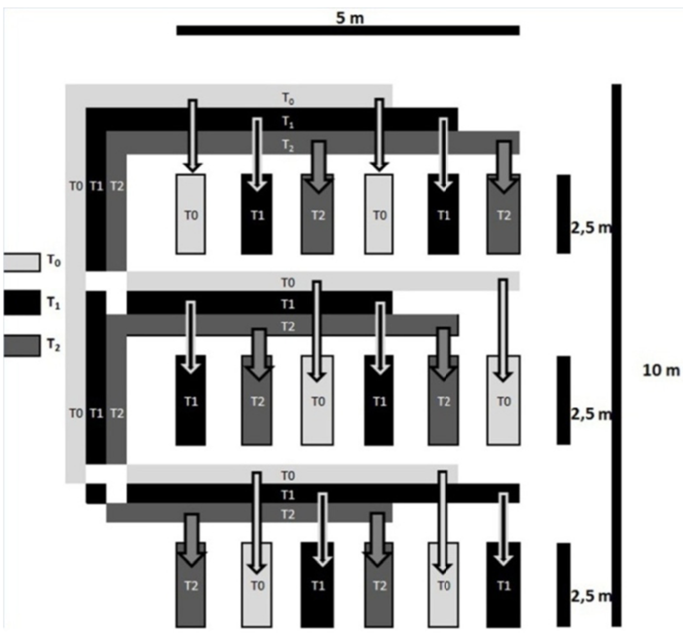

Figure 1. Experimental plot

2.4 Field Measurements

2.4.1 Total Dry Biomass (TDM)

For this purpose, twelve samples were taken throughout the quinoa crop cycle. At each sampling, three plants per treatment (T_0 = 1.2 dS m^{-1}, T_1 = 9.2 dS m^{-1} and T_2 = 18 dS m^{-1}) were taken from each plot, a total of nine plants per sample. After separation of the various parts, the quantity of fresh material was determined immediately. The dry biomass was calculated after drying at 80 °C to a constant weight.

2.5 Formulations

2.5.1 Evapotranspiration Under Greenhouse (ET0)

Evapotranspiration greenhouse $ET0_G$ was considered with the method (Bellouch et al, 2007):

$$ET0_G = RG\cdot(0.67\cdot K_P)/L \tag{1}$$

where, RG: Global Radiation (Joule/cm^2); 0.67: the active energy for evapotranspiration relative to the total received (about 67%); Kp: wall transmission coefficient (single wall 70%); L: 251 (Joule/cm^2) is the latent heat of water vaporization.

2.5.2 Estimation of Crop Evapotranspiration (ET_C)

The Estimation of water requirements ET_C was carried out using the following relationship:

$$ET_C = K_C\cdot ET0_G \tag{2}$$

For the ET_C calculation, we used the K_C values adopted by FAO (Doorenbos & Pruitt, 1986; Allen et al., 1998):

$K_{C\ ini}$ = 0.52 (where vegetation is less than 10%); $K_{C\ med}$ = 1 (where vegetation reaches its maximum development of more than 80%); $K_{C\ end}$ = 0.70 (the stage of maturation where the crop loses its leaves). Where $ET0_G$ is the potential evapotranspiration under greenhouse.

2.5.3 Estimation of Water Consumption (WC)

The soil moisture was monitored on eighteen experimental units and the WC was determined over the entire quinoa cycle. The TDR method was used. We have installed 9 probes at different depths (20; 40 and 60 cm) for the T_0 and 18 salinity-proof probes for the T_1 and T_2. The initial water stock was measured by the TDR up to 60 cm for the various experimental units.

As well, in each test unit, soil samples were collected every 20 cm to 60 cm deep, and TDR measurements every 20 cm were also carried out to establish the calibration equation.

Water consumption (WC) is estimated with soil water balance equation as follows (Hillel, 1998):

$$WC = P + I + U\ (+/-)\ R - D_W - D_S \tag{3}$$

where, P: effective rainfall (mm); I: irrigation (mm); U: the upward capillary flow into the root zone (mm); R: the runoff (mm); D_w: was the downward drainage out the root zone (mm); D_S: the change of soil water stored in soil layer of 0-60 cm (mm).

The upward and downward flow was estimated using Darcy's law (Kar et al., 2007; De Medeiros et al., 2005). Results indicated that the two items were insignificant at the experimental site.

Runoff was also insignificant during the growing season. Soil water content was measured each month with gravimetrically method. Soil water content data were collected for every 20 cm interval in soil depth. Some measurements were added before and after irrigation.

2.5.4 Estimation of the Water Use Efficiency

WUE of total dry matter (WUE_{TDM}) and WUE of grain yields (WUE_{GY}) were calculated using the following equations:

$$WUE_{TDM}\ (kg\ m^{-3}) = TDM/WC \tag{4}$$

$$WUE_{GY}\ (kg\ m^{-3}) = GY/WC \tag{5}$$

where, WUE is the water use efficiency (kg m^{-3}), TDM is the total dry biomass (g m^{-2}), GY is the grain yields (kg) and WC is the total water consumption over the whole growing season (mm).

2.6 Statistical Analysis

The results were subjected to variance analysis of one factor by General Linear Model (GLM). This analysis was performed using SPSS 20.0 software. The ensemble was completed by multiple comparisons of means with Student Newman Keuls test (S-N-K).

3. Results

3.1 Impact of Salinity on the Total Dry Biomass (TDM)

The impact of treatment (T_0, T_1 and T_2) on Total Dry Biomass (TDM) of Quinoa was given in Figure 2.

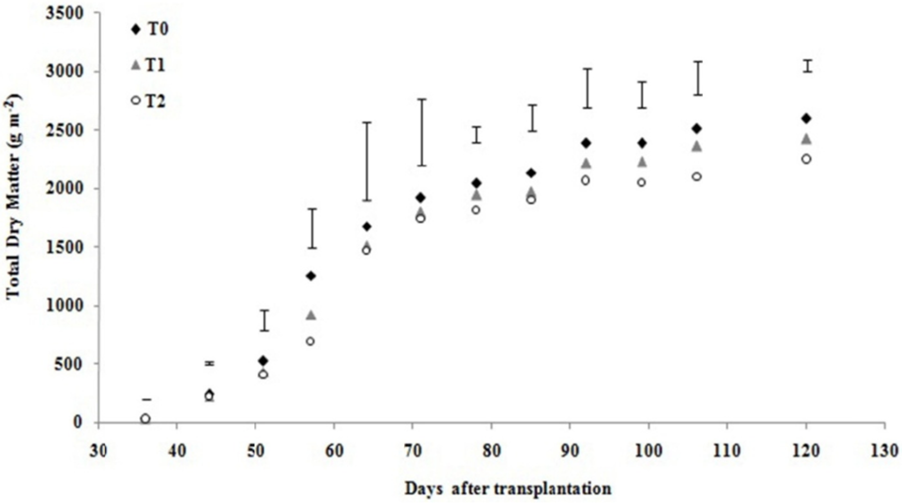

Figure 2. The Total dry biomass (TDM) of quinoa under the three treatments (T_0, T_1 and T_2)

The results showed that the TDM was higher in (T_0) than that in (T_1 and T_2) treatments. In detail, the maximum amount of TDM was observed in the treatment T_0 (2598.47 g m^{-2}) and in the T_1 (2423.06 g m^{-2}). Conversely, the minimum TDM accumulation was registered in T_2 (2251.25 g m^{-2}). At maximum growth, T_0 increased respectively the TDM by (6.75 and 13.4%) compared to T_1 and T_2. Similarly, the variance analysis showed a significant effect ($P< 0.05$) of irrigation with saline waters on the TDM and the S-N-K test showed that the three treatments (T_0, T_1 and T_2) were statistically heterogeneous. These results are in agreement with those of Morales et al. (2011), El Youssfi (2013), Hirich et al. (2014a), and Algosaibi et al. (2015), these authors found that salt stress decreases the quinoa total dry matter accumulation.

3.2 Impact of Salinity on the Water Consumption

Figure 3 illustrates the daily monitoring of quinoa water consumption and water requirements for the three treatments T_0 (a), T_1 (b) and T_2 (c). It was observed that the quinoa daily water consumption for the three treatments (T_0, T_1 and T_2) were low at the growth stage and then increased during the mid-season stage and decreased at the end of the cycle but remained higher compared to the beginning of the transplant cycle. The increased water consumption at the flowering and ripening stages was necessary for the grain filling. Similar to cereals, maximum water requirements were registered during flowering and maturing stages (Mariscal, 1992). Similarly, figure (3.a) shows that for the treatment (T_0) at the beginning of quinoa development cycle, the daily water consumption (ETR) and the water needs (ET_C) follow the same pace. However, from 79 days after transplantation (DAT) the ETR becalmed slightly lower than the ET_C. Consequently, all through the growth cycle the quinoa has consumed 478.1 mm with respect to an ET_C equal to 508.8 mm, *i.e.*, a reduction of the order of 6%. Likewise, for the treatment T_1 (Figure 3b), the ETR and the ET_C appeared to be identical until the 79^{th} DAT, from this date, the quinoa daily water consumption becomes less than the water requirement of the crop. Thus, the overall water consumption was about 459.1 mm against ET_C equivalent to 508.8 mm; a reduction of 9.8% was noticed. Besides, the daily water consumption (ETR) and the water requirements of the quinoa (ET_C) at the T_2 treatment (Figure 3c) showed that the two curves appear to be similar only during the early phases of quinoa development, but from 79 DAT, the daily quinoa ETR decreased compared to the ET_C. The cumulative water consumption was about 444.9 mm; a decrease of 12.6% was recorded.

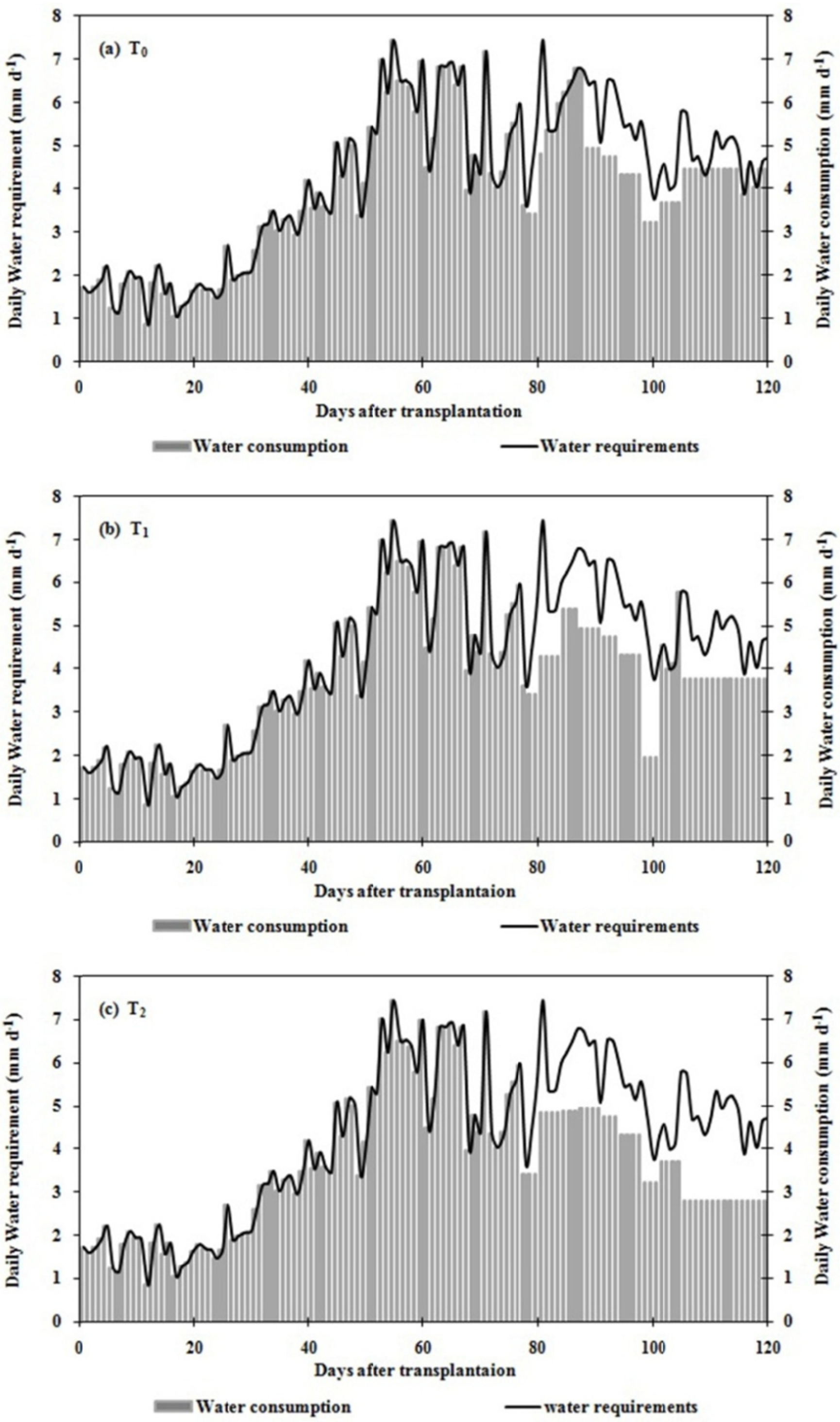

Figure 3. The Daily water requirement (WR) and consumption (WC) of Quinoa under the three treatmentsT_0 (a), T_1 (b) and T_2 (c)

3.4 Impact of Salinity on the Water Use Efficiency

The Water Use Efficiency pre-anthesis and post-anthesis (WUE_{PR} and WUE_{PS}) of quinoa under the three treatments (T_0, T_1 and T_2) are shown in Figure 4.

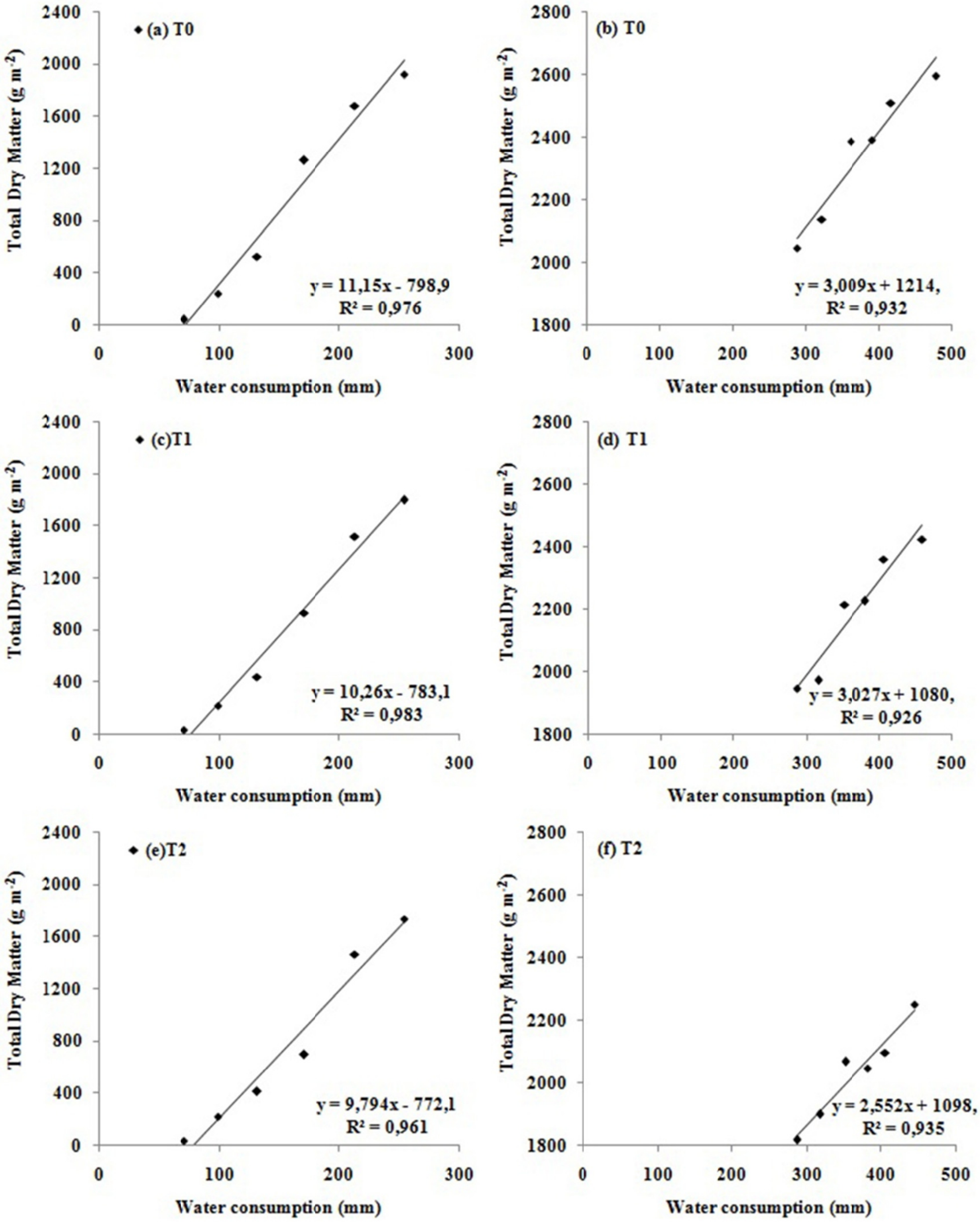

Figure 4. The Water Use Efficiency pre-anthesis and post-anthesis (WUE_{PR} and WUE_{PS}) of Quinoa under the three treatments T_0 (a and b), T_1 (c and d) and T_2 (e and f)

Data analysis shows that the throughout quinoa growing cycle, the relation between water consumption and total dry biomass (*i.e.*, water use efficiency) aren't a linear relation. Moreover, we observed that it has an inflection point at the anthesis stage and divides the curve into two separate lines, one is pre-anthesis and the other one is post-anthesis. The slope of each line expresses the water use efficiency for the total dry biomass before and after anthesis.

In fact, the WUE_{PR} varied from 11.2 kg m^{-3} in the control treatment T_0 (Figure 4a) to 10.3 kg m^{-3} for the treatment T_1 (Figure 4c). For T_2, it was equal to 9.8 kg m^{-3} (Figure 4e).

As for the WUE_{PS}, it was equal to 3 kg m^{-3} for the two treatments T_0 (Figure 4b) and T_1 (Figure 4d). However, for the treatment T_2 it has been reduced to 2.6 kg m^{-3} (Figure 4f).

The WUE_{TDM} and the WUE_{GY} for the three treatments (T_1, T_2 and T_3) were presented in Table 1.

Table 1. The WUE_{TDM} and the WUE_{GY} under the three treatments (T_1, T_2 and T_3) at harvest

Treatments	**WC**	**TDM**	**GY**	**WUE_{TDM} (kg m^{-3})**	**WUE_{GY} (kg m^{-3})**
T0	478.1	2598.5 a	999.7 a	5.43 a	2.09 a
T1	459.1	2423.1 b	703.7 b	5.27 ab	1.53 b
T2	449.9	2251.3 c	498.2 c	5 b	1.11 c
LSD (5%)		107.3	98	0.27	0.3

Note. WC: Water consumption, TDM: Total dry biomass, GY: Grain yield, LSD: Least Significant Difference (5%).

Statistical analysis (Table 1) shows that at the grain filling, the WUE_{TDM} and WUE_{GY} were significantly ($P < 0.05$) affected by the irrigation water salinity (T_0 = 1.2 dS m^{-1}, T_1 = 9.2 dS m^{-1} and T_2 = 18 dS m^{-1}). However, no significant difference ($P > 0.05$) was observed between T_1 and T_2 with respect to WUE_{TDM}.

In consequence, the highest WUE_{TDM} were recorded under the two treatmentsT_0 and T_1 (5.43 kg m^{-3} and 5.27 kg m^{-3}), respectively. Nevertheless, the lowest was marked beneath T_2 (5 kg m^{-3}).

However, for WUE_{GY} ANOVA analysis showed significant difference at 5% between the three treatments (T_0, T_1 and T_2). The maximum WUE_{GY} was noted in T_0 (2.09 kg m^{-3}) followed by the T_1 (1.53 kg m^{-3}) and the minimum WUE_{GY} (1.11 kg m^{-3}) was observed in T_2 (18 dS m^{-1}) with high salinity.

4. Discussion

The impact of salinity (T_0 = 1.2 dS m^{-1}, T_1 = 9.2 dS m^{-1} and T_2 = 18 dS m^{-1}) on the daily WC, the TDM, the correlation connecting water use and total dry biomass before and after anthesis were investigated.

The Figure 2 showed that the saline water had a negative influence on the quinoa total dry biomass, a decrease was recorded compared to the T_0 (control) in the order of 6.8 and 13.4% respectively for T_1 and T_2. In fact, El Youssfi (2013) studied the performance of three varieties of quinoa in irrigation with three concentrations of NaCl (S_1 = 0.92 dS m^{-1}, S_2 = 3 dS m^{-1} and S_3 = 6 dS m^{-1}) and found that the two treatments (S_2 and S_3) influence the production of dry biomass. Similarly, Hirich et al. (2014b) showed that the total dry biomass of quinoa decreased significantly with higher salinity and that the maximum amount of total dry biomass were found at control level (1 dS m^{-1}).

Algosaibi et al. (2015) studied the effect of salt on quinoa development. These authors found that the dry biomass decreased slightly with increased salinity. Also, Morales et al. (2011) found that irrigation with a salinity of more than 15 dS m^{-1} of NaCl leads to a reduction of the total fresh matter of quinoa from 100% to 25% and even to 5%. Similarly, Talebnejad and Sepaskhah (2015a) observed a decrease in dry weight of the above ground part of the plant (198.7, 153.3, 135.1 and 117.7 g column^{-1}) respectively for concentrations of Na cl (10; 20; 30 and 40 dS m^{-1}), similar, the dry weight of the roots marked a remarkable decrease from 20 dS m^{-1}. Definitely, our results are in agreement with numerous researchers. These authors found that the salt stress decreased the accumulation of total dry biomass accumulation.

Also, the saline water causes a reduction in the assimilates flow to meristematic tissues, leading to a decrease in fresh and dry leaf and stem and root matter (Hernandez et al., 2000). Salinity reduces crop growth by modifying the water and ion balance of tissues (Greenway & Munns, 1980; Ouerghi et al., 1998) and by limiting the nutrient uptake necessary for growth (Yeo, 1983; Zhu, 2002).

Likewise, the results obtained (Figure 3), illustrated that the quinoa water consumption decreased by 4 and 7% respectively for T_1 and T_2 refer to the control T_0. Talebnejad and Sepaskhah (2015) reported that the application of salt stress affected evapotranspiration. In fact, ETR declined with increasing NaCl concentrations.

Our results are in conformity with those of Razzaghi et al. (2011b); Ince Kaya et al. (2015); Talebnejad and Sepaskhah (2015). They affirmed that the soil salinity reduced the quinoa water consumption.

As shown by our results (Figure 4), the treatment effect (salt water irrigation) resulted in a reduction in the WUE pre-anthesis (from transplanting to anthesis) of 8 and 12.5% respectively for T_1 (WUE_{PR} = 10.3 kg m^{-3}) and T_2 (WUE_{PR} = 9.8 kg m^{-3}) compared with the control T_0 (WUE_{PR} = 11.2 kg m^{-3}). However, irrigation water quality (salinity level) showed no effect on the WUE post-anthesis (from anthesis to harvest) of the two treatments T_0 and T_1 (WUE_{PS} = 3 kg m^{-3}). Nevertheless, a decrease about 15% was recorded in the T_2 treatment (WUE_{PS} = 2.5

kg m^{-3}). The obtained results in Table 1 proved that WUE_{TDM} was significantly affected ($P < 0.05$) by irrigation water salinity (T_0, T_1, and T_2). However, no significant difference ($P > 0.05$) was observed between T_0, and T_1. The WUE_{TDM} gradually decreased when salinity increased. The highest, WUE_{TDM} (5.43 kg m^{-3}) was recorded under control treatment (T_0). However, the lowest WUE_{TDM} (5 kg m^{-3}) was obtained under T_2 treatment (S = 18 dS m^{-1}). A decline of 7.9% was marked on WUE_{TDM} due to the reduction on TDM and on cumulative water consumption from T_0 (S = 1.2 dS m^{-1}) to T_2 (S = 18 dS m^{-1}). Also, The WUE_{GY} decline when salinity amplified. The uppermost WUE_{GY} (2.09 kg m^{-3}) was recorded under control treatment (T_0). However, the lowest WUE_{TDM} (1.1 kg m^{-3}) was obtained under T_2 treatment. A decrease of 47.4% was marked on WUE_{GY} due to the height reduction on yield in the T_2 treatment. Talebnejad and Sepaskhah (2015a) found a decrease in the WUE (0.38, 0.31, 0.27 and 0.15 kg m^{-3}) respectively for high concentrations of NaCl (10; 20; 30 and 40 dS m^{-1}). Gowing et al. (2009) showed that the WUE of wheat reduced with height salinity. However, Razzaghi et al. (2012) showed that salt stress significantly improved water productivity (2.66, 2.70, 3.12, 3.46 and 3.46 g l^{-1}), respectively for NaCl concentrations of (0; 10; 20; 30; and 40 dS m^{-1}). Ince Kaya et al. (2015) for the same concentrations of NaCl, declared that there was a small enhance in the water use efficiency of quinoa.

5. Conclusions

The results indicated that the salinity reduced significantly the water use, total dry biomass, grain yield and WUE. However, this distress was irregular between the treatments. The cumulative water consumption decreased gradually, with increasing salt concentrations of water as of 9.2 to 18 ds m^{-1}. Also, the WUE pre-anthesis has decreased respectively for T_1 and T_2 related to T_0. However, irrigation water salinity showed no effect on the WUE at post-anthesis for the two treatments T_0 and T_1. Nevertheless, a decrease was recorded in the T_2. At harvest, the highest WUE_{TDM} was recorded under T_0. However, the lowest WUE_{TDM} was obtained under T_2. As well, the upper most WUE_{GY} was recorded under T_0. Though, the lowest WUE_{GY} was obtained under T_2.

References

Adolf, V. I., Jacobsen, S.-E., & Shabala, S. (2013). Salt tolerance mechanisms in quinoa (*Chenopodium quinoa* Willd.). *Environ Exp Bot, 92*, 43-54. https://doi.org/10.1016/j.envexpbot.2012.07.004

Adolf, V. L., Shabaha, S., Anderson, M., Razzaghi, F., & Jacobsen, S. V. (2012). Varietal differences of quinoa's tolerance to saline conditions. *Plant Soil, 357*, 117-129. https://doi.org/10.1007/s11104-012-1133-7

Algosaibi, A. M., El-Garawany, M. M., Badran, A. E., & Alamadini, A. M. (2015). Effect of irrigation water salinity on the growth of quinoa plant seedling. *Journal of Agricultural Science, 7*(8), 205. https://doi.org/10.5539/jas.v7n8p205

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop Evapotranspiration Guidelines for Computing Crop Water Requirements. *Irrigation and Drainage* (Paper No. 56). FAO, Rome, Italy.

Bellouch, H., Baroud, A., Taoura, M., & Sirat, B. (2007). Pilotage de l'irrigation par la méthode du rayonnement global. In N. Lamaddalen, C. Bogliotti, M. Todorovic, & A. Scardign (Eds.), Water saving in Mediterranean agriculture and future research needs (Vol. 2, pp. 287-292). Bari: CIHEAM.

Bhargava, A., Shukla, S., & Ohri, D. (2006). *Chenopodium quinoa*—An Indian perspective. *Ind Crops Prod, 23*, 73-87. https://doi.org/10.1016/j.indcrop.2005.04.002

Cocozza, C., Pulvento, C., Lavini, A., Riccardi, M., Andria, R., & Tognetti, R. (2012). Effects of increasing salinity stress and decreasing water availability on ecophysiological traits of quinoa (*Chenopodium quinoa* Willd.) grown in a Mediterranean-type agro ecosystem. *J. Agron. Crop Sci., 199*(4), 229-240. https://doi.org/10.1111/jac.12012

De Medeiros, G. A., Arruda, F. B., & Sakai, E. (2005). Crop coefficient for irrigation beans derived using three refrence evaporation methods. *Agric. For. Meteorol., 115*, 135-143. https://doi.org/10.1016/j.agrformet.2005.11.010

Doorenbos, J., & Pruitt, W. O. (1986). *Crop water requirements* (FAO Irrigation and Drainage Paper No. 24). Rome, Italy.

El Youssfi, L. (2013). *Durabilité d'un système de cultures non conventionnel irrigué par les eaux usées traités dans la région d'Agadir* (p. 163, Thèse de Doctorat, Centre des Études Doctorales Ibn Zohr).

Gómez-Caravaca, A. M., Iafelice, G., Lavini, A., Pulvento, C., Caboni, M. F., & Marconi, E. (2012). Phenolic compound and saponins in quinoa samples (*Chenopodium quinoa* Willd.) grown under different saline and nonsaline irrigation regimes. *Journal of Agricultural and Food Chemistry, 60*(18), 4620-4627. https://doi.org/10.1021/jf3002125

Gomez-Pando, L. R., Alvarez-Castro, R., & Eguiluz-de Ia Barra, A. (2010). Effect of salt stress on Peruvian germplasm of *Chenopodium quinoa* Willd.: A promising crop. *J. Agron. Crop Sci., 196*, 391-396. https://doi.org/10.1111/j.1439-037X.2010.00429.x

Gowing, D. J., Rose, W. A., & Ghamarnia, H. (2009). The effect of salinity on water productivity of wheat under deficit irrigation above shallow groundwater. *Agricultural Water Management, 96*, 517-524. https://doi.org/10.1016/j.agwat.2008.09.024

Greenway, H., & Munns, R. (1980). Mechanisms of salt tolerance in nonhalophytes. *Annu. Rev. Plant Physiol., 31*, 149-190. https://doi.org/10.1146/annurev.pp.31.060180.001053

Hariadi, Y., Marandon, K., Tian, Y., Jacobsen, S. E., & Shabala, S. (2011). Ionic and osmotic relations in quinoa (*Chenopodium quinoa* Willd.) plants grown at various salinity levels. *J. Exp. Bot., 62*, 185-193. https://doi.org/10.1093/jxb/erq257

Hernandez, J., Jimenez, A., Mullineaux, P., & Sevilia, F. (2000). Tolerance of pea (*Pisum sativum* L.) to long-term salt stress is associated with induction of antioxidant defences. *Plant, Cell & Environment, 23*(8), 853-862. https://doi.org/10.1046/j.1365-3040.2000.00602.x

Hillel, D. (1998). *Environmental Soil Physics*. Academics Press, London.

Hirich, A., Choukr-allah, R., & Jacobsen, S.-E. (2014a). Deficit irrigation and organic compost improve growth and yield of quioa and pea. *J Agro Crop Sci, 200*(5), 390-398. https://doi.org/10.1111/jac.12073

Hirich, A., Jelloul, A., Choukr-allah, R., & Jacobsen, S.-E. (2014b). Saline water irrigation of quinoa and chickpea: Seedling rate, stomatal conductance and yield responses. *J Agro Crop Sci, 200*(5), 378-389. https://doi.org/10.1111/jac.12072

Ince Kaya, C., Yazar, A., & Metin Sezen, S. (2015). SALTMED Model Performance on Simulation of Soil Moisture and Crop Yield for Quinoa Irrigated Using Different Irrigation Systems Irrigation Strategies and Water Qualities in Turkey. *Agriculture and Agricultural Science Procedia, 4*, 108-11. https://doi.org/10.1016/j.aaspro.2015.03.013

Jacobsen, S. E., Mauteros, C., Christiansen, J. L., Bravo, L. A., Corcuera, L. J., & Mujica, A. (2005). Plant responses of quinoa (*Chenopodium quinoa*) to frost at various phonological stages. *Eur. J. Agron., 22*, 131-139. https://doi.org/10.1016/j.eja.2004.01.003

Kar, G., Kumar, A., & Martha, M. (2007). Water use Efficiency and crop coefficient of dry season oilseed crops. *Agric. Water Manage., 87*, 73-82. https://doi.org/10.1016/j.agwat.2006.06.002

Koyro, H. W., & Eisa, S. S. (2008). Effect of salinity on composition, viability and germination of seeds of *Chenopodium quinoa* Willd. *Plant and Soil, 302*, 79-90. https://doi.org/10.1007/s11104-007-9457-4

Mariscal, A. (1992). *Agroclimatologia*. Universidad Autonoma Tomas Frias, Potosı, Bolivia.

Matiacevich, S. B., Castellion, M. L., Maldonado, S. B., & Buera, M. P. (2006). Water-dependent thermal transitions in quinoa embryos. *Thermochimica Acta, 448*, 117-122. https://doi.org/10.1016/j.tca.2006.06.016

Morales, A. J., Bajgain, P., Garver, Z., Maughan, P. J., & Udall, J. A. (2011). Physiological responses of *Chenopodium quinoa* to salt stress. *Int. J. Plant Physiol. Biochem., 3*, 219-232.

Ouerghi, Z., Zid, E., Hajji, M., & Soltani, A. (1998). *Comportement physiologique du blé dur (Triticum durum L.) en milieu sale* (pp. 309-313). CIHEAM-Options Méditerranéennes.

Pulvento, C., Riccardi, M., Lavini, A., d'Andria, R., Iafelice, G., & Marconi, E. (2010). Field trial evaluation of two *Chenopodium quinoa* genotypes grown under rain-fed conditions in a typical Mediterranean environment in South Italy. *J. Agr. Crop Sci., 196*, 407-411. https://doi.org/10.1111/j.1439-037X.2010.00431.x

Pulvento, C., Riccardi, M., Lavini, A., Lafelice, G., & Andrea, R. (2012). Yield and quality characteristics of quinoa grown in open field under different saline and unsaline irrigation regimes. *J. Agron. Crop Sci., 198*, 254-263. https://doi.org/10.1111/j.1439-037X.2012.00509.x

Razzaghi, F., Ahmadi, S. H., Adolf, V. I., Jensen, C. R., Jacobsen, S. E., & Andersen, M. N. (2011a). Water relations and transpiration of quinoa (*Chenopodium quinoa* Willd.) under salinity and soil drying. *J. Agr. Crop Sci., 197*, 348-360. https://doi.org/10.1111/j.1439-037X.2011.00473.x

Razzaghi, F., Ahmadi, S. H., Jacobsen, S. E., Jensen, C. R., & Andersen, M. N. (2011b). Effects of salinity and soil-drying on radiation use efficiency, water productivity and yield of quinoa (*Chenopodium quinoa* Willd.). *J. Agr. Crop Sci., 198*, 173-184. https://doi.org/10.1111/j.1439-037X.2011.00496.x

Razzaghi, F., Plauborg, F., Jacobsen, S.-E., Jensen, C. R., & Andersen, M. N. (2012). Effect of nitrogen and water availability of three soil types on yield, radiation use efficiency and evapotranspiration in field-grown quinoa. *Agric. Water Manag., 109*, 20-29. https://doi.org/10.1016/j.agwat.2012.02.002

Ruiz-Carrasco, K., Antognoni, F., Coulibaly, A. K., Lizardi, S., Covarrubias, A., Martínez, E. A., … Zurita-Silva, A. (2011). Variation in salinity tolerance of four lowland genotypes of quinoa (*Chenopodium quinoa* Willd.) as assessed by growth, physiological traits, and sodium transporter gene expression. *Plant Phys. Biochem., 49*, 1333-1341. https://doi.org/10.1016/j.plaphy.2011.08.005

Talebnejad, R., & Sepaskhah, A. R. (2015). Effect of different saline groundwater depths and irrigation water salinities on yield and water use of quinoa in lysimeter. *Agric. Water. Manag., 148*, 177-188. https://doi.org/10.1016/j.agwat.2014.10.005

Wilson, C., Read, J. J., & Abo, K. E. (2002). Effect of mixed-salt salinity on growth and ion relations of a quinoa and a wheat variety. *J. Plant Nutr., 25*(12), 2689-2704. https://doi.org/10.1081/PLN-120015532

Yeo, A. R. (1983). Salinity resistance: Physiologies and prices. *Physiol. Plant, 58*, 214-222. https://doi.org/10.1111/j.1399-3054.1983.tb04172.x

Zhu, J. K. (2002). Salt and drought stress signal transduction in plants. *Annu. Rev. Plant Biol., 53*(1), 247-273. https://doi.org/10.1146/annurev.arplant.53.091401.143329

Zhu, J. K. (2003). Regulation of ion homeostasis under salt stress. *Curr. Opt. Plant Biol., 6*, 441-445. https://doi.org/10.1016/S1369-5266 (03)00085-2