Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2013.777944

52 (2014) 2208–2213
February

Taylor & Francis
Taylor & Francis Group

The combined effect of deficit irrigation by treated wastewater and organic amendment on quinoa (*Chenopodium quinoa* Willd.) productivity

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Received 23 December 2012; Accepted 13 February 2013

ABSTRACT

One of the most important factors that limits crop production is the availability of water. Deficit irrigation is the most important irrigation strategy to increase water use efficiency and crop water productivity. Organic amendment combined with deficit irrigation can be practical solution to compensate the negative effect of water deficit through the improvement of soil water-holding capacity. This research was conducted in the south of Morocco (IAV-CHA, Agadir) between October 2011 and January 2012. The mean objective of this study was to evaluate the combined effect of organic matter and deficit irrigation with treated wastewater on quinoa (*Chenopodium quinoa* Willd.) productivity. Three organic matter levels (0, 5, and 10 t ha^{-1}) have been supplied as compost amendment combined with two deficit irrigation levels (50 and 100% of full irrigation). Statistical analysis revealed very highly significant difference only between deficit irrigation treatments for most measured parameters. However, significant difference was obtained between organic matter treatments in terms of grain yield. The highest grain yield (66.3 g plant^{-1}) has been recorded when quinoa was subjected to full irrigation and received 10 t ha^{-1} of compost; however, the lowest yields were obtained by treatments receiving 50% of full irrigation without organic matter supply. From the findings, it can be concluded that reducing irrigation requirement by half affected negatively quinoa growth and productivity and reduced grain yield by 36%, organic amendment improved significantly yield and biomass production better under deficit irrigation conditions.

Keywords: Yield; Irrigation; Compost; Water stress; Quinoa

1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) is a seed crop traditionally cultivated in the Andean region for several thousand years [1], quinoa has been introduced in Morocco for the first time in Khenifra region in 1999 within the project BAFI/BYU-IAV HASSAN II in which 14 lines were tested for adaptation goal [2]. Stikic et al. [3] reported that quinoa has a big agronomic and nutritional potential, even under rain-fed conditions, without fertilization, a seed yield as high

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Presented at the 6th International Conference on Water Resources in Mediterranean Basin (WATMED6), 10–12 October 2012, Sousse, Tunisia

as 1.72 t ha^{-1} was obtained and seed quality was remarkably good, with protein content ranging from 15.16 to 17.41%. There is no crop other than quinoa that resists the combination of adverse factors (drought, salinity, frost, and high temperature) [4]. Quinoa is generally less affected by frost than most other crop species [5]. It is salt-tolerant crop [6–8] that had its yield reduced by only 50% when saline water with 40 dS m^{-1} was applied compared to control with fresh water [7]. There are several resistance mechanisms to water stress for quinoa allowing to this plant to adapt to arid and semi-arid regions [4,9], potential yield of quinoa in optimal conditions varies according to climate, soil, sowing date, and vegetal material. Garcia et al. [10] recorded grain yield equal to 3.7 t ha^{-1} for quinoa under optimal conditions cultivated in lysimeters and 1.05 t ha^{-1} under rain-fed conditions, a grain yield of 2.3 t ha^{-1} was obtained under control conditions by Razzaghi et al. [7]. Geerts et al. [11] reported that maximal grain yield obtained by quinoa under full irrigation was equal to 2.04 t ha^{-1}, while under deficit irrigation, maximal obtained yield was equal to 2.01 t ha^{-1}, under rain-fed conditions quinoa recorded an average yield equal to 1.68 t ha^{-1}.

Adding organic matter, particularly compost, increases soil water-holding capacity under water deficit. In fact, supplying organic matter was effective in improving the plant growth [12]. Many studies were conducted on several crops in order to study the effect of organic amendment on the water-holding capacity of soils and especially under arid and semi-arid conditions indicated that organic matter input improved field capacity and soil water content at wilting point and increased soil hydraulic conductivity [12–14]. Organic matter incorporation in the soil has also a positive effect on crop productivity and yield [16–20].

The objectives of the present study were to determine: (i) how organic amendment improve quinoa productivity and growth under deficit irrigation, (ii) the combined effect of deficit irrigation and organic matter on stomatal conductance of quinoa.

2. Materials and methods

This research was conducted in the south of Morocco (Complex of Horticulture, Agadir) between October 2011 and January 2012. Quinoa (Cultivar: DO 708) was sown first in nursery, where it was grown during 20 days, quinoa plants were then transplanted in field. The nursery period was necessary to have homogeneity of plants in terms of initial plant height and to avoid heterogeneity conditions of the field and germination which may affect the experiment results. Soil type was loamy with pH equal to 8.13 and EC 0.27 dS m^{-1}. The soil was moderately rich in organic matter (1.6%), field capacity soil moisture (FC_{RH}) was 30%, and the permanent wilting point soil moisture (PWP_{RH}) was 15%. Organic amendment based on olive mill waste compost was incorporated in the soil before transplanting. Experimental units (18 m^2) were organized in a four completely randomized blocs, and in each bloc, the six treatments were randomized installed (Table 1). Inside each plot, there were five sowing lines, a distance of 50 cm between lines and 40 cm between plants has been adopted.

To calculate net irrigation requirement, four approaches related to soil, climate, crop, and irrigation system have been used according to Elattir [21]. Stomatal conductance was measured by Leaf porometer (model SC-1) at daily scale every hour from 9AM to 6PM plant growth and biomass production parameters were measured every 10 days. Final harvest was measured, when all plants were dried in the field, and harvested panicles were threshed and grains were extracted and weighted. Differences between response variables to deficit irrigation and organic amendment treatments were assessed with StatSoft STATISTICA 8.0.550 using three ways variance analysis. All statistical differences were significant at $\alpha = 0.05$ or lower. Tukey's HSD test was used to reveal homogeneous groups.

3. Results

3.1. Crop evapotranspiration

Fig. 1 shows the maximal crop evapotranspiration (ETm) that is equal to reference evapotranspiration (ETo) multiplied by the crop coefficient (Kc). The figure shows clearly the different crop stages that are: initial stage in which the evapotranspiration was stable, vegetative growth stage where the crop evapotranspiration increased, middle stage in which again crop evapotranspiration was stable and crop enters in

Table 1
Applied treatments (irrigation supply and organic amendment)

Treatment	Irrigation supply (% of full irrigation)	Organic matter (t ha^{-1})
T1	100	10
T2	100	5
T3	100	0
T4	50	10
T5	50	5
T6	50	0

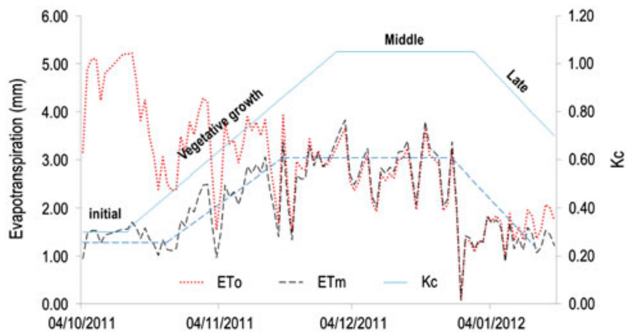

Fig. 1. Evapotranspiration and crop coefficient evolution during the growing period of quinoa.

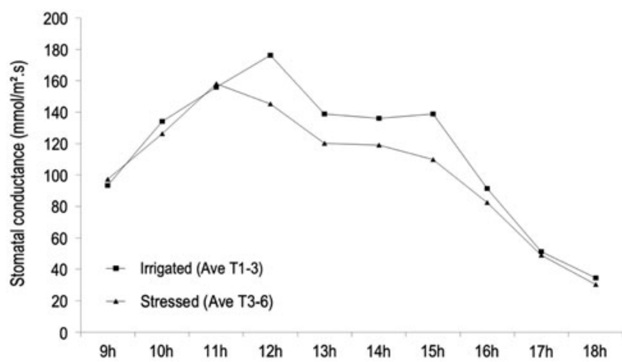

Fig. 2. Stomatal conductance evolution at daily scale of quinoa.

its grain filling phase, and finally, the late stage that is corresponding specially to the senescence stage.

3.2. Stomatal conductance (gs)

Response of stomatal conductance to deficit irrigation and organic amendment at daily scale is presented in Fig. 2. Statistical analysis carried out on stomatal conductance (gs) revealed highly significant difference ($p < 0.001$) between deficit irrigation treatments only during the period between 12 noon and 4PM. However, organic matter had no effect on this parameter. Stomatal conductance has been affected negatively when crop was subjected to deficit irrigation (50% of full irrigation). Highest stomatal conductance was measured at 12 noon where the photosynthetic activity of the crop was maximal. For irrigated plants, stomatal conductance during this period was equal to 176 mmol $m^{-2} s^{-1}$ on average. However, for stressed plants, it was equal to 145 mmol $m^{-2} s^{-1}$, before 11AM and after 4PM, the difference between irrigated and stressed treatment was smaller. At The end of the day stomatal conductance declined and reached 30 and 34 mmol $m^{-2} s^{-1}$ for stressed and fully irrigated treatments, respectively.

3.3. Plant height and mean stem diameter

According to statistical analysis, plant height of quinoa has been affected during the cropping period only by deficit irrigation ($p < 0.001$); however, organic matter has not affected quinoa height ($p = 0.49$). During the second half of the growing period, fully irrigated treatment showed the highest crop height (93 cm), with an increment of 10 cm compared with stressed treatments (Fig. 3(a)). For stem diameter, very highly significant difference ($p < 0.001$) was found between deficit and full irrigated treatments. From Fig. 3(b), we can conclude that inside each deficit irrigation treatment (100 or 50% of full irrigation) organic matter has improved slightly but not significantly stem diameter.

3.4. Leaf area and biomass production

According to Fig. 4, leaf area and other biomass production parameters (roots, stems, and leaves) showed significant difference mainly between deficit irrigation treatments for most of measurement points during the growing period. Within fully irrigated treatments, organic matter has improved leaf area and biomass production. Fully irrigated treatment that received 10 t ha^{-1} of compost (T1) showed always the

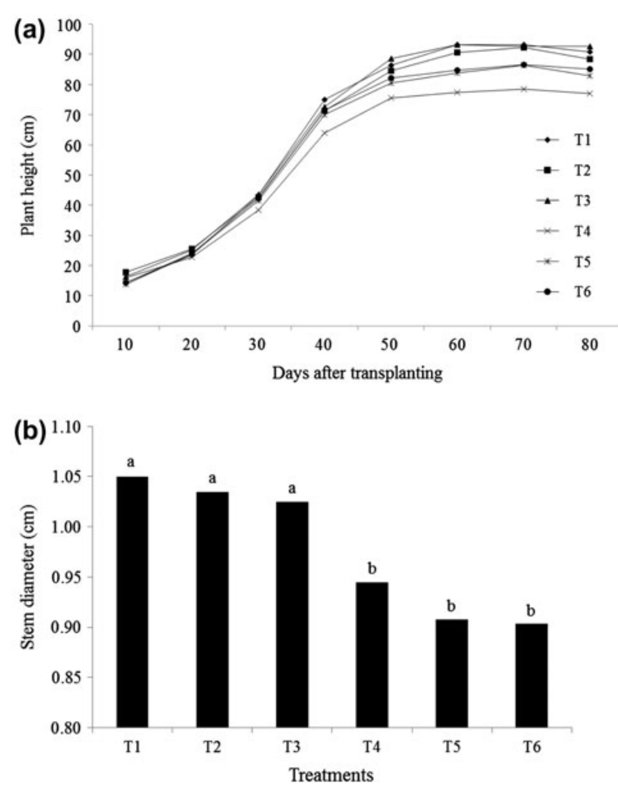

Fig. 3. Quinoa height (a) evolution during growing period and final mean stem diameter (b).

highest value of leaf area and biomass production followed by treatment received 5 t ha^{-1} (T2). Results presented in Fig. 4 indicated that organic matter has more effect in fully irrigated plots (T1–T3); however, for stressed plots (T4–T6), it is obvious that organic treatments were closes to each other for all measured parameters (leaf area and biomass production).

3.5. Quinoa yield

Table 2 reports the obtained result in terms of dry grain yield of quinoa. Statistical analysis revealed very highly significant difference ($p < 0.001$) between deficit irrigation treatments and significant difference ($p < 0.05$) between organic matter treatments. Highest yield (66.3 g $plant^{-1}$) was recorded by treatment fully irrigated and amended with 10 t ha^{-1} of compost (T1), while lowest yield (33.9 g $plant^{-1}$) was obtained by stressed treatment without organic amendment (T6). Results indicated that organic amendment of 10 and 5 t ha^{-1} increased grain yield of quinoa by 16 and 3%, respectively, for fully irrigated, and by 18 and 13%, respectively, for stressed treatments. Supplying full irrigation for quinoa increased dry grain yield by 25% compared with treatment subjected to deficit irrigation with 50% of full irrigation.

Table 2
Dry grain yield obtained for each treatment, (***) indicates that difference was very highly significant between deficit irrigation treatments and (*) indicates that difference was significant between organic matter treatments, a and b indicate statistically homogeneous groups

Treatments	Deficit irrigation*** (% of full irrigation)	Organic matter* (t ha^{-1})	Dry grain yield (g/plant)
T1	100	10	66.3 a
T2	100	5	59.0 a
T3	100	0	57.2 a
T4	50	10	39.8 b
T5	50	5	38.2 b
T6	50	0	33.9 b

4. Discussion

Presented results proved that stomatal conductance as is indicator of photosynthetic activity has

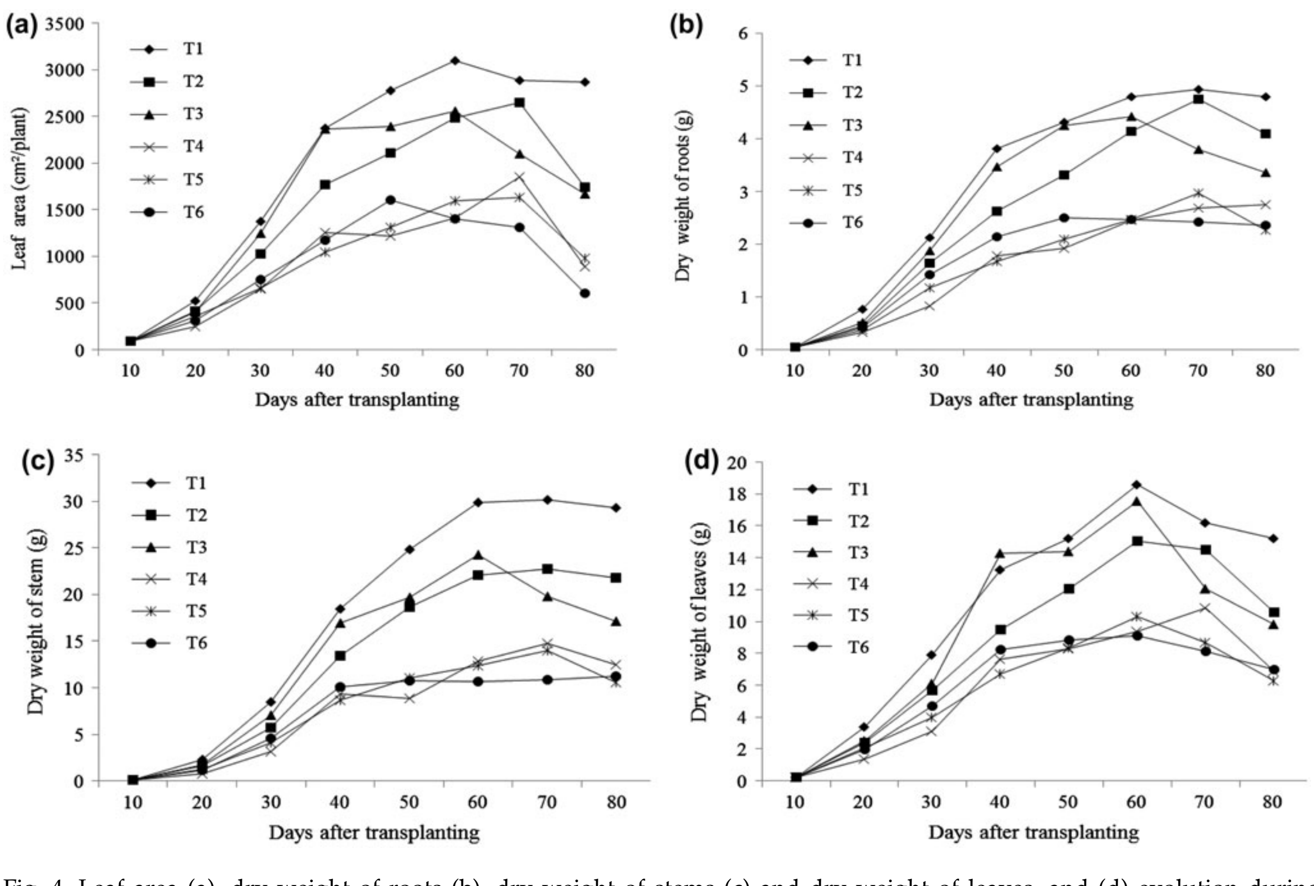

Fig. 4. Leaf area (a), dry weight of roots (b), dry weight of stems (c) and dry weight of leaves, and (d) evolution during growing period of quinoa.

been affected negatively by deficit irrigation factor. However, stomatal conductance has not varied with organic amendment supplies. It has been found that stomatal conductance was affected by water stress inducing stomatal closure and decreasing leaf water status [9,22]. Jacobsen et al. [23] explained that at mild soil water deficit chemical signals may be produced in roots and transported via the xylem to the shoot where they reduce leaf growth and stomatal conductance, resulting in a delay in plant water deficit. Abscisic acid (ABA) was one of those chemical signals playing a role for the regulation of stomata under drought in quinoa. From presented results, it can be concluded that well-planned deficit irrigation using only half of the water required for full irrigation allows the stabilization of quinoa yields between 1.7 and $2\,t\,ha^{-1}$. This is approximately the mean results reported by Geerts et al. [11] who obtained that deficit irrigation using 50% of full irrigation allowed stabilization of quinoa yield between 1.2 and $2\,t\,ha^{-1}$. Results presented in Table 2 indicated that maximal obtained yield was equal to $3.3\,t\,ha^{-1}$ applying transplanting density of 0.5×0.4 m. Garcia et al. [10] found that under optimal conditions quinoa yield was equal to $3.7\,t\,ha^{-1}$; however, under limited irrigation in field and in rain-fed conditions, yield was equal to 2.9 and $1.1\,t\,ha^{-1}$, respectively. Results indicated that dry weight of individual parts of plant was affected negatively by deficit irrigation confirming those obtained by Gonzàlez et al. [24] who reported that dry weight of the whole plant as well as of individual plant was higher in control than under drought.

Very few reports are available on the effect of organic amendments to soil on the total biomass of crop. In the present study, organic matter treatments have not affected growth parameters as plant height, stem diameter, leaf area, and biomass production, while it affected significantly dry grain yield. Comparing percentage of increasing in grain yield when supplying 10 or $5\,t\,ha^{-1}$ under fully irrigated and stressed treatments indicated that this percentage was higher under stressed treatment, and thus, organic matter influence on yield was more important under deficit irrigation conditions in which quinoa responded well to organic amendment. Consequently, combining deficit irrigation and organic matter can be the key to improve quinoa yield under water scarcity, since organic matter improve soil water holding capacity and so increase water availability for plant [14,15]. Very few studies conducted on quinoa evaluating organic amendment on yield are available, and nevertheless, other crops were tested regarding to organic amendment and showed a positive response to organic amendment. Roy et al. [25] reported that organic amendment to soil using three kinds of amendment: mulch, compost, and vermicompost improved significantly crop growth and yield of three tested crops: corn, bean, and gumbo where vermicompost treatment affected the biomass accumulation most favorably for all the tested plants, followed by the compost treatment. Results related to the effect of several doses of compost on yield presented in this paper are in agreement with those obtained by Smith et al. [26] where increasing the amount of compost in the pot experiment from 0 to 25 and to 50% (m/m) increased yield, number of seeds per pod and seeds per pot significantly for common bean and fresh biomass for Swiss chard. Olive mill waste compost effect on tomato has been evaluated by Altieri and Esposito [27] who reported that yield was improved significantly compared to control conditions when tomato was amended by olive mill waste compost.

5. Conclusion

Through this study, it was demonstrated that organic amendment can be the key to compensate the negative effect of deficit irrigation on quinoa productivity in dry regions. Yield response to compost amendment was higher under water deficit conditions than full irrigation. Stomatal conductance and growth parameters were affected by deficit irrigation treatments rather than by organic matter amendment.

Acknowledgments

This research was funded by the EU 7th Framework Program through the project ''Sustainable water use securing food production in dry areas of the Mediterranean region (SWUP-MED)'', We are also grateful to the technical staff of the salinity and plant nutrition laboratory in the IAV-CHA Institute, Agadir, Morocco.

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