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ONION CROP RESPONSE TO REGULATED DEFICIT IRRIGATION UNDER MULCHING IN DRY MEDITERRANEAN REGION

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ABSTRACT

Enhancing water productivity for sustainable crop production and water savings represents a major challenge for agricultural water management. Pot experiments under open field conditions were conducted for two years, 2016 and 2017, to assess the effects of regulated deficit irrigation under mulch on onion crop production, following a 2 × 3 factorial experiment with two soil cover systems (wheat straw mulch and no-mulch) and three irrigation levels (100%, 80%, and 60% of crop evapotranspiration), with six replications.The results indicated that onion plants were responsive to straw mulching. Bulb diameter, total yield, dry matter, and water productivity were significantly enhanced under mulch whatever the irrigation level used. The seasonal crop water requirements also considerably decreased (about 33%). The results also showed the sensitivity of onion to water stress. Yield, dry matter, and water productivity were higher under full irrigation compared to the deficit irrigation. However, when mulch was used, regulated deficit irrigation highly significantly improved water productivity and onion crop quality and quantity; and this approach could be a promising management practice to meet water shortage consequences in the dry Mediterranean region.

Keywords: bulb yield, bulb diameter, water productivity, clay loam soil

INTRODUCTION

Improving water productivity (WP) represents a major challenge for agricultural water management and consequently sustainable crop production. WP (also known as evapotranspiration water use efficiency) is the relationship between crop yield and crop evapotranspiration (ETc). WP is typically used to identify the environments or management strategies by which the yield per unit water can be maximized. This type of performance indicator is very useful under conditions of scarcity of water resources, as in the dry Mediterranean region. So, adaptation of economically sound and scientifically proven techniques is a feasible tool for improving WP.

Deficit irrigation (DI) with mulching could be one of the most desirable management practices to meet water scarcity and its consequences. By applying DI, the crop is exposed to a certain level of water stress but significant water savings could be attained (Kirda 2000; Fereres & Soriano 2007). Moreover, crop quality as the sucrose concentration of sugar beet, the protein content of wheat, the length and strength of cotton fibers, and so on could ameliorate well-managed DI (Kirda 2000). As a result of the reduction of soil evaporation, when the soil surface is covered with mulches, more water remains potentially available for crop, and consequently, irrigation requirements could be decreased. Moreover, using a sufficient mulching layer could control both weed growth and soil temperature fluctuations. Yield can also increase under mulching by improving soil physical properties and fertility (Khaledian et al. 2010; 2011). Mulch is composed of synthetic or biological materials such as plant residues, for example, a straw. Depending on the type of mulch and the fraction of the soil surface covered by mulch, the reduction in soil evaporation might be more or less considerable.

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Onion (*Allium cepa* L.) is one of the most important horticultural crops worldwide. Many studies have been carried out regarding its water requirements and the effects of DI on yield (Igbadun et al. 2012; Patel & Rajput 2013; Tsegaye et al. 2016). Onion crop was found to be sensitive to water deficit during the whole growing season, and, therefore, it is better to partition the available water for the whole growing season to maintain moderate stress (regulated deficit irrigation, RDI) rather than creating a stress during the critical stages of plant growth (Kadayifci et al. 2005; Patel & Rajput 2013). For instance, Tsegaye et al. (2016) found that DI given at 75% of ETc was economically recommended in their studied region, in southern Ethiopia. Patel and Rajput (2013) reportedthat with 40% DI throughout the growing season, WP can be significantly ameliorated with saving of 272-mm water, which may be used to irrigate additional 0.5 ha of cropped area. Nagaz et al. (2012) observed that applying 60% of crop evapotranspiration caused significant decreases in fresh yield, dry matter, bulbs per hectare, and bulb weight of onion, compared to those under both full irrigation (100% ETc) and RDI (80% ETc). Igbadun et al. (2012) determined the onion yield response under RDI and different mulch cover. They showed that the water consumption of onion crop was reduced by about 20% when an RDI of 50% ET_0 (reference evapotranspiration) was applied. Also, they reported that the proportional decrease in yield under the mulch condition was much lower than under the no-mulching condition. For different mulch cover, the proportional reduction in yield in the polyethylene materials was found to be 10% lower than the rice straw.

In dry areas of the Mediterranean region, water shortage is the most limiting factor for onion crop production, because of the lack of rainfall over the production period between April and August (Ragab & Prudhomme 2002; Turner 2004). So, the aim of research findings is an urgent need to determine water requirements for the onion crop in the production areas. The objective of the present work was to assess the effects of different levels of RDI with mulching on onion yield and WP. The results may contribute to introduce practical alternative to meet sustainable onion production, water shortage, and environmental protection in the dry Mediterranean region.

MATERIALS AND METHODS

Pot experiments under open field condition were carried out at the Deir Al-Hajar Agricultural Experiment Station, Damascus, Syria (33°20’ N, 36°26’ E, altitude 600 m), for two cultivation seasons: 2016 and 2017. The region is characterized by a dry Mediterranean type climate. No rainfall was recorded during both growing seasons. Some climatic data from the experimental station are given in Table 1. Soil contained, on an average, 27.8% of sand, 42.7% of silt, and 29.5% of clay, and was classified as a clay loam soil. Soil water content (SWC) at field capacity (FC) was 0.36 $m^3 \cdot m^{-3}$ and at permanent wilting point (PWP) was 0.18 $m^3 \cdot m^{-3}$. The cropped soil was characterized by about 1% of organic matter, pH of 8.0, EC of 0.6 $ds \cdot m^{-1}$, available P of 6 ppm, and soil nitrogen content of 60 kg $N \cdot ha^{-1}$.

Three small bulb sets of onion (*A. cepa* L., cv. ‘Selmouni’ red) were planted in pots at the beginning of April for both 2016 and 2017 seasons. The depth and diameter of each pot were 30 and 25 cm, respectively, containing 8 kg of natural soil. Two weeks after planting, onion crop was thinned to 2 $plants \cdot pot^{-1}$, giving about 400,000 onion $bulbs \cdot ha^{-1}$. The experiment was started on the planting day with SWC at field capacity, as measured by pot’s weight, for all tested pots.

Table 1. Climatic data of the experimental location during the 2016 and 2017 growing seasons

Season		T_{min} (°C)	T_{max} (°C)	$T_{average}$ (°C)	RH (%)	Precipitation (mm)
2016	April	11.6	29.2	21.2	67.0	0.0
	May	14.9	30.5	23.6	58.0	0.0
	June	18.7	36.6	30.6	69.0	0.0
	July	19.9	38.1	28.9	64.0	0.0
	Aug.	21.0	37.8	29.5	65.0	0.0
2017	April	9.7	26.2	19.2	63.1	0.0
	May	14.4	31.6	24.9	57.9	0.0
	June	17.3	35.8	28.4	56.3	0.0
	July	20.6	40.6	31.1	55.6	0.0
	Aug.	20.0	38.5	28.9	59.3	0.0

T_{min} – minimum temperature; T_{max} – maximum temperature; $T_{average}$ – average temperature; RH – relative air humidity

Experiments during both growing seasons were conducted in a 2 × 3 factorial design in a randomized complete block, with two systems of soil cover and three irrigation levels with six replications, making a total of 36 experimental pots. The two systems of soil cover composed of (i) no mulch and (ii) with mulch. Wheat straw was used as mulching material, which was prepared by cutting straw into 3- to 5-cm pieces. The weight of wheat straw mulch was 40 $g \cdot pot^{-1}$ (about 8 $Mg \cdot ha^{-1}$). The three various irrigation levels were 100ET, 80ET, and 60ET. The 100ET was a full irrigation treatment in which onion received 100% of the cumulative crop evapotranspiration (100% of ETc) by replenishing the root zone to the field capacity in each irrigation event. The 80ET and 60ET were RDI treatments in which irrigation was applied at the same frequency as in treatment 100ET but with water amounts equal to 80% and 60% of that applied in the full irrigation treatment (i.e., 80 and 60% of ETc, respectively). For the three watering treatments, irrigation was applied three times per week. The pots were weighed before and after each irrigation event. The water amounts were regulated by weight according to the following equation. The depleted water amount (ETc mm) between two successive irrigations was calculated as follows:

$$ETc = \frac{W_1 - W_2}{\rho_w \times A} \qquad K\,[1]$$

where W_1 (kg) is the weight of the pot after irrigation, W_2 (kg) is the weight of the pot before the next irrigation, ρ_w ($g \cdot cm^{-3}$) is the water density, and A (m^2) is the area of soil surface in the pot. The daily crop evapotranspiration ($mm \cdot day^{-1}$) was estimated by dividing the cumulative crop evapotranspiration from equation. 1 by the number of days between two successive irrigation events. The summation of the daily ETc represented the total crop water use during the growing season, that is, the seasonal crop evapotranspiration. Irrigation water amounts added to the mulched treatments were based on measurements of the 100ET treatment under mulch; while those added to the no-mulch treatments were based on the measurements of the treatment 100ET under no-mulch.

Full dose of potassium and phosphorous was added before planting. Nitrogen fertilizer was divided into two equal doses and added along with water through the early growth stage. Irrigation was terminated when 60% of the leaves top turned yellow as signs of maturity. After that, the onions were lifted to field cure for two weeks. The leaves were cut at about 2.0 cm above the bulb. The diameter and weight of matured onion bulbs were measured for each pot. The weight of matured onion bulbs was expressed in $Mg \cdot ha^{-1}$ according to the area of soil surface in the pot. Then, bulbs were dried at 50 °C to a constant weight to estimate the dry matter (DM) yield. WP ($kg \cdot m^{-3}$) was calculated by dividing the total yield by the total water quantity evapotranspired during the growing season. Multicentered bulbs were not observed at harvest.

With one qualitative factor (soil cover system) and one quantitative factor (irrigation level), the two-way analysis of variance (ANOVA) was conducted using the DSAASTAT add-in version 2011 (Onofri 2007).

A combined analysis of data over both the years was performed to identify soil cover system and irrigation level whose average effect over years is stable and high. Mean comparison was made for data after combined analysis at the 5% level of significance. Moreover, trend comparison, that is, regression analysis, was performed to examine the functional relationship between variable and the irrigation level that covers the whole range of tested levels. The estimated regression function, its determination coefficient, and its significance were presented. Data were presented and illustrated according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Bulb diameter

As the oval- to elongated-shape onion was tested herein, the diameter of bulb is a very important index for both growers and consumers for the appearance and marketing purposes. The analysis of variance indicated that the bulb diameter was significantly influenced by only the main effects of both studied factors (soil cover system and irrigation level) in both years, 2016 and 2017; and the combined analysis of data over years confirmed these effects (Table 2).

The mean value of bulb diameter under mulch (3.1 cm) was significantly higher than that without mulch (2.6 cm), with a significant increase of about 20% irrespective of the level of irrigation (Fig. 1a). As can be seen in Figure 1b, trend analysis indicated that the bulb diameter was related linearly with the irrigation levels (as percentage of ETc), with values of R^2 of 0.998 and 0.994 at the 1% level, under mulch and no-mulch, respectively. The practical parallel between both representative lines confirmed the findings of ANOVA about the lack of interaction between soil cover system and irrigation level. Irrespective of the system of soil cover used, the highest diameter was recorded at the 100% of ETc and the lowest value was recorded at the 60% of ETc (Fig. 1b), with a significant decrease of about 40%.

Table 2. Analysis of variance for measured variables as affected by year, soil cover system, and irrigation level (significance of *F*-test values)

Source of variance	*df*	BD	Yield	DM	WP
2016					
Soil cover system (SC)	1	**	**	**	**
Irrigation level (I)	2	**	**	**	**
SC × I	2	ns	ns	ns	ns
Error	25				
CV (%)		8.7	12.9	20.6	14.5
2017					
Soil cover system (SC)	1	**	**	**	**
Irrigation level (I)	2	**	**	**	**
SC × I	2	ns	ns	ns	ns
Error	25				
CV (%)		11.4	21.4	21.7	24.7
Combined analysis 2016-2017					
Soil cover systems (SC)	1	*	**	**	**
Irrigation level (I)	2	**	**	**	*
SC × I	2	ns	ns	ns	ns
Year × SC	1	ns	ns	ns	ns
Year × I	2	ns	ns	ns	ns
Year × SC × I	2	ns	ns	ns	ns
Pooled error	50				
CV (%)		9.8	17.2	21.0	19.7

*Significant at 5% level; **Significant at 1% level
ns, non-significant at 5% level; *df*– degree of freedom; BD – bulb diameter; Yield – total bulb yield; DM – bulb dry matter yield; WP – water productivity.
For each measured variable, the CV(%) was calculated based on the mean square for error from ANOVA as sqrt (Error mean square)/Grand mean×100 (Gomez & Gomez 1984)

Total bulb yield and dry matter

The ANOVA proved that the total bulb yield was significantly influenced by the main effects of both tested factors in both years of study at the 1% level. The combined analysis over years confirmed these effects. However, none of the three-factor or two-factor interactions were significant at the 5% level (Table 2).

Averaged over all irrigation levels, the mean values of 20.1 and 13.1 Mg·ha^{-1} were recorded with and without mulch, respectively, as shown in Figure 2a. This indicated that using mulch significantly increased the total bulb yield by 53.4% compared to the no-mulching condition.

As mentioned earlier, the effect of irrigation levels on the total bulb yield was highly significant. Data were averaged over both soil cover systems, because none of the interaction effects involving irrigation was significant. Irrespective of the soil cover system used, the highest value of total bulb yield was 23.7 Mg·ha^{-1} as recorded under full irrigation condition (at 100% of ETc) and 16.2 Mg·ha^{-1} as recorded at 80% of ETc, reaching the lowest value of 9.8 Mg·ha^{-1} under the 60% of ETc condition. However, for the purposes of presentation and discussion, data were presented for each system of soil cover separately as can be seen in Figure 2b. Trend analysis indicated that the relationship between the total bulb yield and irrigation level (as a percentage of ETc) was linear within the tested range of irrigation levels ($R^2 = 0.999$ under mulch and $R^2 = 0.988$ with no-mulch; $p<0.01$). Both representative straights were practically parallel, confirming the lack of interaction found by ANOVA. A significant linear increase in the total bulb yield was predicted with decreasing water deficit.

Similarly, the main effects of both soil cover system and irrigation level for DM yield of bulbs were significant during both years of study, with any interaction effects (Table 2).

Figure 3a shows that the mean value of DM yield under mulch condition (3.2 Mg·ha^{-1}) was significantly higher than that found with no-mulching (2.2 Mg·ha^{-1}). A considerable increase of 47.9% in DM yield could be obtained when mulch is used relative to no-mulching condition. As shown in Figure 3b, under both soil cover systems, full irrigation treatment surpassed those under deficit conditions.

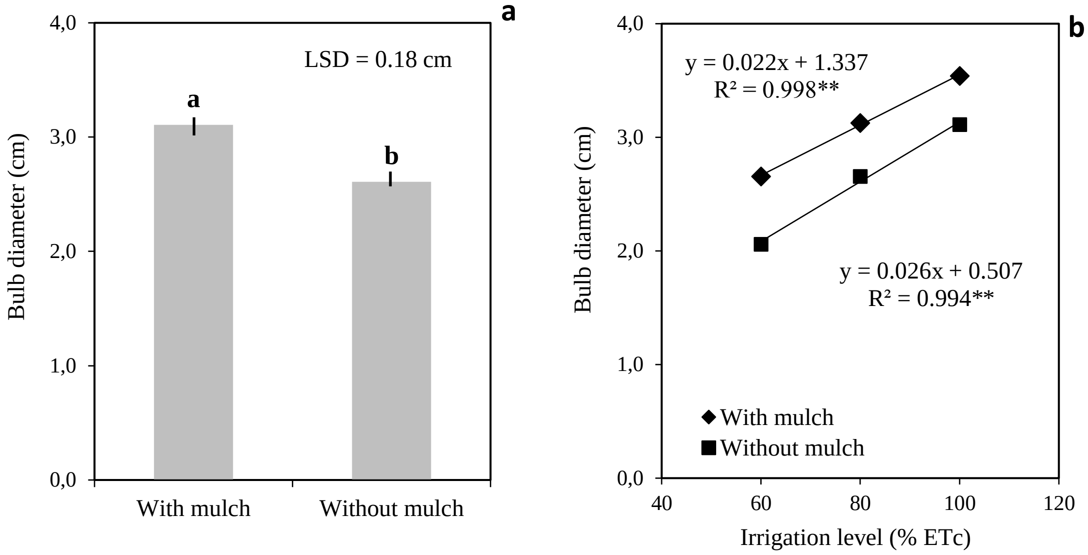

Fig. 1. Response of the bulb diameter to (a) soil cover system and (b) irrigation level. Means in the bar chart marked in different letters are significantly different at the 1% level. For line graph, a regression equation is fitted and coefficient of determination (R^2) is given under each soil cover system. **Significant at 1% level. Error bars represent the standard error of the mean as derived from ANOVA

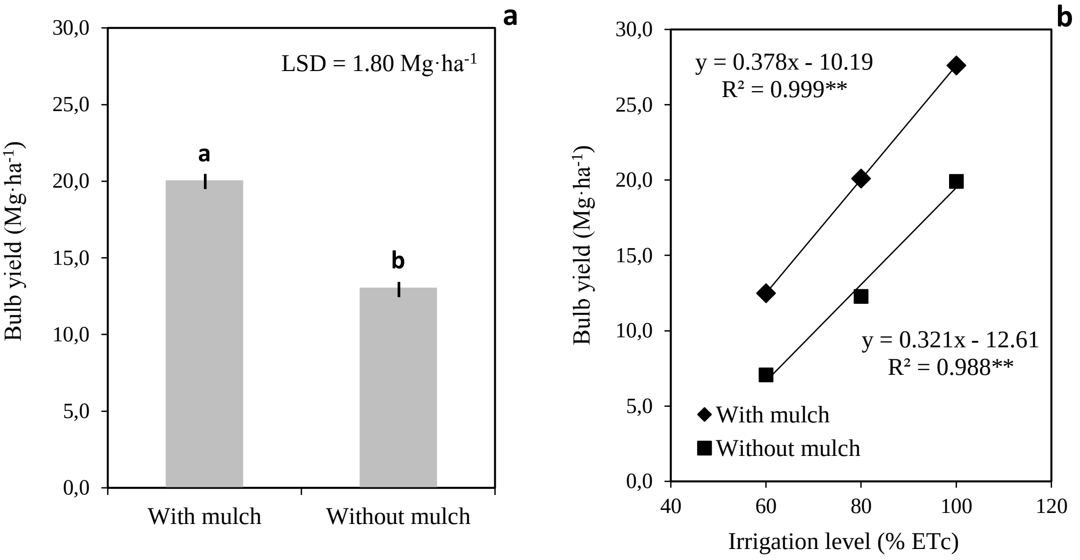

Fig. 2. Response of the total bulb yield to (a) soil cover system and (b) irrigation level. Further explanations as in Fig. 1

Regression analysis designated that the DM yield changed linearly with irrigation levels (as a percentage of ETc) with $R^2 = 0.993$ under mulch and $R^2 = 0.999$ without mulch ($p<0.01$). As detected by the ANOVA, both fitting lines were found practically parallel. DM yield was predicted to significantly increase with the decrease in the level of water deficit.

This is in close conformity with findings of Kadayifci et al. (2005), Nagaz et al. (2012), and Patel and Rajput (2013). For example, Nagaz et al. (2012) found that applying 40% of water deficit (i.e., irrigating with 60% of ETc) caused considerable decreases in yield, dry matter, bulb weight, and bulbs per hectare compared to those under either

100% ETc or RDI at 80% ETc. This confirmed that the onion crop was sensitive to water deficit during the total growing season.

Moreover, for the total bulb yield and DM yield, the linear relationships indicated that for a given value of yields, a water amount of about 20% of ETc would be saved when mulch was used compared to the no-mulching condition (Figs. 2b & 3b). For instance, without mulch, 100% of ETc (full irrigation) has to be applied to crop in order to obtain a total bulb yield of about 20 $Mg \cdot ha^{-1}$ and a DM yield of about 3 $Mg \cdot ha^{-1}$, whereas 80% of ETc could be sufficient to obtain the same target yields when mulch covers the soil surface. This is in agreement with the results of Igbadun et al. (2012) who determined the onion yield response under RDI and different mulch cover. They showed that the proportional decrease in yield under the mulch condition was much lower than the no-mulching condition. In fact, mulches reduce the soil evaporation, and, therefore, more water remains available for rooting system (Kirda 2000; Fereres & Soriano 2007; Igbadun et al. 2012). This may mitigate the severity of wetting–drying cycle after each irrigation event and yield could be enhanced. Khaledian et al. (2010, 2011) indicated that crop yield could also be increased because of the improvements in soil physical properties and fertility under mulching.

Crop water requirements and water productivity

As no rain precipitated during both growing seasons, large amounts of water were applied to meet crop water requirements under the dry conditions. During the 2016 growing season, cumulative crop evapotranspiration (ETc) calculated using applied equation was about 995, 800, and 610 mm with no mulch and 673, 555, and 427 mm with mulch for 100ET, 80ET, and 60ET, respectively. Respective values for the 2017 growing season were about 1010, 825, and 630 mm for 100ET, 80ET, and 60ET, respectively, when no mulch was used. However, they were about 669, 547, and 415 mm, for 100ET, 80ET, and 60ET, respectively, when mulch was used. It is very important to notice that about 33% of ETc was saved when mulch was used compared to no-mulching conditions, irrespective of the irrigation level tested. This result is in agreement with the findings of Igbadun et al. (2012) who showed that the water needs of onion crop reduced by about 20% with increase in irrigation deficit of 50% of reference evapotranspiration. As a result of the reduction in soil evaporation when mulches cover the soil surface, more water remains potentially available in the root zone and, consequently, irrigation requirements could be decreased (Kirda 2000; Fereres & Soriano 2007; Igbadun et al. 2012). This confirmed the important role of straw mulch in terms of significant decrease in crop water requirements, even under dry climatic conditions.

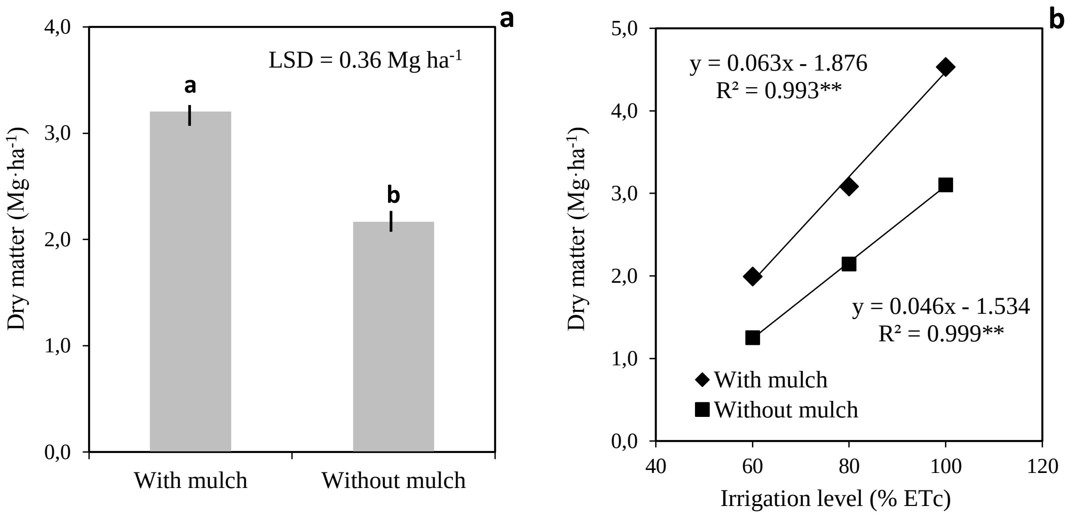

Fig. 3. Response of the dry matter yield to (a) soil cover system and (b) irrigation level. Further explanations as in Fig. 1

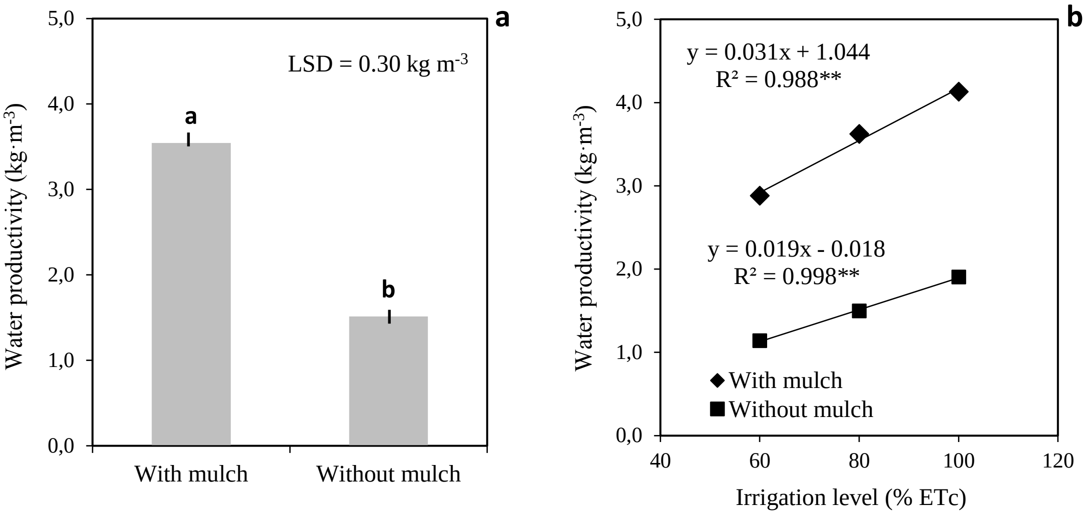

Fig. 4 Response of the water productivity to (a) soil cover system and (b) irrigation level. Further explanations as in Fig. 1

The ANOVA revealed that WP was highly significantly influenced by both soil cover system and irrigation level. Moreover, none of the two- or three-factor interactions were significant at the 5% level (Table 2).

The mean values of WP were 3.5 and 1.5 kg·m^{-3}under mulching and no-mulching conditions, respectively, as demonstrated in Figure 4a. This indicated that an enhancement in WP could be obtained under mulch with an increase of about 134% compared to the traditional practices with no mulch, irrespective of the selected level of irrigation.

Figure 4b illustrates the values of WP under different irrigation levels under soil cover. Regression analysis indicated that the relationship between WP and irrigation level (as percentage of ETc) was linear with the values of R^2 of 0.988 and 0.998 at the 1% level, under mulch and no-mulch, respectively. No interaction between both factors was found. With and without the application of soil cover, DI did not ameliorate the WP compared with the full irrigation. This finding was in disagreement with the results of Fereres & Soriano (2007), Patel & Rajput (2013), Tsegaye et al. (2016). For example, Patel and Rajput (2013) reportedthat with 40% DI, WP can be significantly ameliorated. This confirms that onion crop is very sensitive to the water deficit during the total growing season.

However, trend analysis confirmed that when mulch was used, WP was significantly greater than that without mulch even at the full irrigation (Fig. 4b). For instance, the value of WP under the 60ET and with mulched soil (2.88 kg·m^{-3}) was significantly higher than that without mulch (1.14 kg·m^{-3}), even higher than that under the condition of 100ET (1.90 kg·m^{-3}) as well. Herein, crop water requirement under 100ET without mulch was, on an average, about 1000 mm; and that under 60ET with mulch was about 420 mm, on an average. The water saving of about 580 mm (1000 – 420 = 580 mm) could be used to irrigate the area of more than 1 ha cropped with onion crop or others. This result is in agreement with Patel and Rajput (2013) who reportedthat with 40% DI throughout the growing season, a water saving of about 272 mm may be used to irrigate additional cropped area (half a hectare).

CONCLUSIONS

Onion yield was found to be responsive to straw mulching, which translates into increase in bulb diameter, total bulb yield, and dry matter. Also, water productivity increased considerably and the seasonal crop water requirements under mulch decreased obviously (water savings of about 33% of crop evapotranspiration). Yield and water productivity were significantly higher under full irrigation relative to deficit irrigation. However, they were also appreciably enhanced under regulated deficit irrigation when the straw mulching was used.

Adopting regulated deficit irrigation with straw mulch can effectively address water shortage and its consequences and sustain the crop production in the dry Mediterranean region.

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