Adv. Hort. Sci., 2020 34(1): 49-60 DOI: 10.13128/ahsc-8401

AHS
Advances in Horticultural Science

Improving water productivity and yield of onion crop by combining early planting and straw mulch under different irrigation levels in dry Mediterranean region

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Key words: *Allium cepa* L., irrigation water use efficiency, onion bulb yield.

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Citation:
MUBARAK I., 2020 - *Improving water productivity and yield of onion crop by combining early planting and straw mulch under different irrigation levels in dry Mediterranean region.* - Adv. Hort. Sci., 34(1): 49-60.

Data Availability Statement:
All relevant data are within the paper and its Supporting Information files.

Competing Interests:
The authors declare no competing interests.

Received for publication 25 March 2019
Accepted for publication 31 October 2019

Abstract: In response to the Sustainable Development Goals (SDGs) adopted by United Nations, combining using straw mulching, the proper crop planting date, and regulated deficit irrigation (RDI) is fundamental to adapt to climate change and to promote sustainable agriculture in the dry Mediterranean region. Two-year pot experiment under field conditions (2017 and 2018) was conducted in Damascus Countryside, Syria (altitude 600 m), to evaluate the onion crop response to early planting, irrigation level, and straw mulching. Treatments composed of three different planting dates with 28-day intervals (two early dates in February and March, and the traditional date in April), three irrigation levels (100, 80, and 60% of crop evapotranspiration, ETc), and two types of soil cover (with and without wheat straw mulch), with three replicates. Findings revealed that the seasonal ETc decreased from about 900 mm under current practice (planting in April without mulch) to only about 550 mm under both straw mulch and earliness in planting. Large bulb yield increases (more than double) were also obtained. Moreover, early planting using straw mulching significantly enhanced the onion crop response to RDI, even at 60% of ETc. Combining early planting in February, straw mulching, and full irrigation represents the best agricultural management.

1. Introduction

Onion (*Allium cepa* L.) is an important crop worldwide. The environmental conditions such as photoperiod and temperature mainly affected its growth, development, and bulb yield. The agronomic practices such as planting date and irrigation water availability have also an effect on onion crop production (Brewster, 2008; Khokhar, 2014; Mubarak and Hamdan, 2018 a). Onion crop thrives best when temperatures are cool during early development period and then warmer and sunny during maturity. Hence, planting date has a profound impact on onion crop growth and development. Early planting date tends to have a longer onion growing season before bulb initiation ensuing larger plants. However, large plants are more likely to become sensitive to the cold stimulus resulting in bolting (formation of seed stalk followed by flowering), which represents a highly unfavourable feature for onion bulb production. Large plants are also related with split bulbs. However, late-date-planted onions start forming bulbs before reaching satisfactory plant growth to support the final size of bulbs. This would produce small bulbs, and therefore, decreasing the bulb yield (Brewster, 2008; Rohini and Paramaguru, 2016). Thus, determining the proper onion crop planting date is central to adapt to the regional climate changes.

Onion crop has a shallow rooting system, and therefore, it is considered as a sensitive crop to soil water deficit than other deep-rooted crops. Water productivity (WP, also known as water use efficiency, WUE) is usually used to recognize the environments or management practices by which the yield per unit water can be optimized. In the dry regions where water resources are limited as in the dry Mediterranean region, improving water productivity and crop production represents also a main challenge for agricultural water management.

Mulch has been widely adopted because of its agro-pedo-ecological benefits. It constitutes of synthetic (plastic films) or natural (plant residues as wheat or rice straw) materials. Both materials reduce the loss of soil water through evaporation. However, unlike plastic films, straw mulch allows rain and irrigation water to penetrate and to reach the soil. This conserves soil water content, and thereby reducing irrigation water requirements, promoting rooting system development, and increasing crop growth, development and yield (Vavrina and Roka, 2000; Gimenez *et al.*, 2002; Mubarak and Hamdan, 2018 b). From eco-environmental point of view, the use of plastic mulch would not be justified at low crop prices and/or very high plastic films costs, especially it requires to be removed after use annually. The re-use of plastic films is not practical agronomically and technologically. This could increase the harmful environmental impacts from plastic components. For these reasons, straw mulching present an eco-environmentally sustainable choice. Unlike plastic films, straw mulch could incorporate into the soil ecosystem, where it is expected to biodegrade. Thus, straw mulching could be considered as a slow-acting organic fertilizer, improving soil fertility and soil physical properties, and consequently, crop yield (Khaledian *et al.*, 2010, 2011).

Deficit irrigation (DI) in combination with mulching could be considered as a key water-saving technique that would help in meeting both water scarcity and sustainable crop production (Fereres and Soriano, 2007; Chai *et al.*, 2016). The effects of deficit irrigation under mulching on onion yield have been documented (Vavrina and Roka, 2000; Igbadun *et al.*, 2012; Patel and Rajput, 2013; Tsegaye *et al.*, 2016; Mubarak and Hamdan, 2018 b). Several studies showed that it is better to fractionate the water stress during the cropping season (Regulated deficit irrigation, RDI) rather than applying a water stress during the critical stages of crop growth period (Kadayifci *et al.*, 2005; Patel and Rajput, 2013). For example, deficit irrigation given at 75% of crop evapotranspiration (ETc) was recommended for onion crop production (Tsegaye *et al.*, 2016).

In the dry Mediterranean area, onion bulb sets as directly planted in the soil is the common method employed to establish onion plantings in the field. Farmers plant onion bulb sets early in the spring and harvest in the summer. The production period between April and August is characterized by no rainfall (Ragab and Prudhomme, 2002; Turner, 2004). Moreover, the Mediterranean climate is extremely variable with hot dry summers, and cold wet to dry winters. The Middle East and North Africa are in particular dry areas, with only 1% of renewable water resources (Joffre and Rambal, 2001; Turner, 2004; Ceccarelli *et al.*, 2007). The increasing climatic change have intensified the vulnerability to drought (Giorgi and Lionello, 2008; Somot *et al.*, 2008; FAO 2011; Polade *et al.*, 2014). An increase by 1.25-2.5°C in temperature is predicted in winter, and the precipitation between October and March will decrease by 10-15 % in the southern Mediterranean countries (Ragab and Prudhomme, 2002).

As the onion crop production is already limited by the water availability and local climate, moving towards feasible tools (such as using regulated deficit irrigation under mulching) and agronomic practices (such as determining the proper crop planting date) adapted to the regional climate change is urgently needed for better water saving and cultivation period of the crop (FAO, 2011; Khokhar, 2014; Zinkernagel *et al.*, 2015).

In this context, and in response to the ambitious Sustainable Development Goals (SDGs) proposed by United Nations to adapt to climate change and to promote sustainable agriculture, the present study aimed to assess the interactive effects of various planting dates, different irrigation levels, and straw mulching on onion crop production. The outcomes may introduce appropriate agronomic alternatives to meet the ever increasing demand for onions and to save irrigation water in the dry Mediterranean area. Moreover, results may contribute to make regulated deficit irrigation with straw mulching familiar for most farmers, and to stimulate them to adopt these techniques in their fields.

2. Materials and Methods

Pot experiments were conducted under open field conditions at the Deir Al-Hajar Agricultural Experiment Station, Damascus Countryside, Syria (33°20′ N, 36°26′ E, altitude 600 m), for different planting dates during February to May in two consecutive years 2017 and 2018. The site is located within a dry Mediterranean area, in which the total annual rainfall is about 120 mm, and the annual reference evapotranspiration is about 2000 mm. Some climatic data for the studied site collected during the growing seasons were fairly close to those averaged over the last 16 years (from 2000 to 2016) as can be shown in Table 1. For this reason, testing different planting dates during two years seemed somewhat adequate.

The soil is classified as a clay loam (29.5% clay, 42.7% silt, and 27.8% sand). Both volumetric soil water contents at permanent wilting point (*PWP*) and field capacity (*FC*) are 0.18 and 0.36 m^3 m^{-3}, respectively. Some chemical and physical soil properties are: pH of 8.0; ECe of 0.34 ds m^{-1}; organic matter of 1.00%; available P of 5.7 ppm; NO_3^- of 28.3 ppm; NH_4^+ of 12.6 ppm.

Pots with dimensions of 25×30 cm and containing 8 kg of soil were used in the experiments. Three bulb sets of onion (*Allium cepa* L., c.v. Selmouni) were planted in each pot. The pots were set in an open field under natural climatic conditions. Plants were thinned after germination to two bulbs per pot, getting a plant density of about 400000 plants ha^{-1}.

Four different planting dates separated with 28 days were tested: PS1 (early February), PS2 (early March), PS3 (early April), and PS4 (early May). Unfortunately, onion bulb sets which were planted in May (PS4) in both studied years did not properly germinate, and therefore, they were ignored. Within a year and at each planting date, the experiment was laid out following a 2×3 factorial experiment arranged in a randomized complete block design (RCB design) with two modes of soil cover and three irrigation levels, replicated three times. The soil covering comprised of two distinct types. The first one was with mulching using 40 g of wheat straw per pot (about 8 t ha^{-1}); and the second one was with no mulching. The irrigation levels composed of IL100 (full irrigation, 100% ETc), in which plants received 100% of the crop evapotranspiration; and the root zone was replenished to field capacity. IL80 and IL60 treatments (regulated deficit irrigation) were irrigated at the same frequency as in IL100 but with water amounts equal to 80 and 60% of the ETc as calculated in IL100, respectively. In other words, the three watering treatments received at each irrigation event 1.0, 0.8 and 0.6 times the soil water depletion

Table 1 - Some climatic data for the experimental site during both studied years (2017 and 2018) and the 16 years average (from 2000 to 2016)

Variable	Year	Feb.	Mar.	Apr.	May	Jun.	Jul.
Minimum temperature (°C)	2017	4.0	6.2	9.7	14.4	17.2	20.6
	2018	5.7	7.9	10.0	15.6	18.2	19.8
	2000-2016 average	4.0	6.8	10.1	14.1	17.6	19.3
Maximum temperature (°C)	2017	14.7	18.7	26.2	31.6	35.7	40.6
	2018	18.8	24.3	27.2	31.5	34.6	36.9
	2000-2016 average	15.7	20.6	25.3	30.4	35.0	37.4
Mean temperature (°C)	2017	9.1	14.0	19.2	24.9	28.4	31.1
	2018	12.7	17.3	19.9	25.7	27.7	28.8
	2000-2016 average	10.6	15.0	18.1	23.6	27.7	29.4
Relative air humidity (%)	2017	69.3	74.4	63.1	57.9	56.3	56.0
	2018	68.8	65.0	54.8	51.5	59.6	55.6
	2000-2016 average	75.0	64.1	60.9	56.5	56.3	60.7
Precipitation (mm)	2017	11.6	42.6	0.0	0.0	0.0	0.0
	2018	30.3	1.0	14	9.9	0.0	0.0
	2000-2016 average	31.0	31.6	5.9	4.2	0.0	0.0

occurred in the full irrigation treatment (IL100), respectively. Irrigation water was added 3 times per week. Each experiment was started on the planting day with a wet soil at field capacity as measured by pot's weight. The pots were weighed before and after each irrigation event. The water amount depleted (mm) between two successive irrigation events (ETc) was regulated by weight and estimated using (Eq. 1) as:

$$ETc = (W_1 - W_2)/(P_w \times S) \qquad [1]$$

where ETc = the crop evapotranspiration between two irrigation events (mm); W_1 = the weight of the pot (kg) after irrigation (the soil water content in the pot was at the field capacity); W_2 = the weight of the pot (kg) just before the next irrigation event; ρ_w = the water density (g cm^{-3}); and S= the pot soil surface area (m^2). The daily crop evapotranspiration (mm day^{-1}) was estimated by dividing the ETc calculated using Eq. (1) by the number of days between two successive irrigations. The seasonal crop evapotranspiration was the summation of the daily ETc, which represented the total crop water requirements during a growing season. Irrigation water amounts, which were applied to the non mulching treatments, were based on the IL100 treatment under no-mulching conditions; whereas those applied to the straw mulching treatments were based on the IL100 treatment under mulching conditions.

For each planting date, phosphorous and potassium were applied as basal application at planting day; wherease, nitrogen fertilizer was splited into two equal applications, and added during early vegetative stage. Irrigation was stopped when almost 70% of leave-head dropped as signs of maturity. The onions were lifted to field cure. Then the leaves were cut leaving about 2.0 cm tops above the bulb. The length, diameter, and weight of both matured onion bulbs from each pot were measured. The sum of weights of both bulbs represent the bulb yield per pot (Y-pot), and was expressed as g pot^{-1}. Water productivity (WP, kg m^{-3}) and irrigation water use efficiency (IWUE, kg m^{-3}) were calculated using equations [2] and [3] (Mubarak *et al*., 2018). WP is the relationship between yield and seasonal evapotranspiration (ETc). Whereas, IWUE is the relationship between yield and the total amount of irrigation water applied (I, Liter pot^{-1}).

$$WP = Yield/ETc \qquad [2]$$

$$IWUE = Yield/I \qquad [3]$$

Within a year, a combined analysis of data over planting seasons was carried out to examine the interaction between planting season and the studied treatments (Gomez and Gomez, 1984). The analysis of variance (ANOVA) was conducted using the DSAA-STAT add-in version 2011 (Onofri, 2007). Mean comparison was made using the LSD test at the 1% level. Trend comparison (regression analysis) was also performed. Data was presented and illustrated according to the rules described by Gomez and Gomez (1984).

3. Results

As mentioned above, onion bulb sets planted in May did not properly germinate. This could be explained by the fact that onion is a vegetative overwintering stage in its life cycle, i.e., it grows best when temperatures are cool during early development period (Brewster, 2008). Therefore, it is not recommended to delay planting onion sets after April in the dry Mediterranean area.

Bulb shape indicators

The shape of onion bulbs was represented herein by two indicators: bulb length (BL) and diameter (BD). The ANOVA revealed that the main effects of all studied factors (planting date, soil cover system, and irrigation levels) highly significantly affected bulb shape indicators in both years (Table 2). Within a year, the data under each factor were pooled over the other factors as can be seen in Table 3. Results indicated that both indicators (BL and BD) found in 2017 were comparable with their homologues in 2018.

Early planted onion sets (PS1) produced the tallest onion bulbs (7.9 and 8.5 cm in 2017 and 2018, respectively) than the other planting dates, while the later planted sets (PS3) produced bulbs significantly shorter by 10-22% than those in PS1 and PS2, in both years. Moreover, onion sets grown under straw mulching produced bulbs considerably taller by about 14% in average than those grown under no-mulching conditions. With regard to irrigation levels, the higher value of BL was observed under full irrigation (IL100); then, bulb length decreased as the water application rate decreased. The mean value of BL reduced by about 8 and 25% in 2017, and by about 3 and 14% in 2018, when onion sets were planted in March (PS2) and April (PS3), respectively (Table 3).

Table 2 - Analysis of variance of the data of crop responses as affected by planting date, soil cover system, and irrigation level (significance of *Fisher* test)

Source of variance	df	BL	BD	Y-pot	WP	IWUE
			2017			
Planting date (PS)	2	***	***	***	***	***
Rep. within PS	6					
Soil cover system (SC)	1	***	***	***	***	***
PS × SC	2	***	NS	NS	***	***
Irrigation level (IL)	2	***	***	***	***	***
PS × IL	4	NS	NS	NS	NS	NS
SC × IL	2	NS	NS	NS	NS	NS
PS × SC × IL	4	NS	NS	NS	NS	NS
Pooled error	30					
Total	53					
CV (%)		5.88	6.12	9.14	9.07	9.26
			2018			
Planting date (PS)	2	***	***	***	***	***
Rep. within PS	6					
Soil cover system (SC)	1	***	***	***	***	***
PS × SC	2	NS	NS	NS	***	***
Irrigation level (IL)	2	***	***	***	***	***
PS × IL	4	NS	***	NS	NS	NS
SC × IL	2	NS	**	NS	NS	NS
PS × SC × IL	4	NS	NS	NS	NS	NS
Pooled error	30					
Total	53					
CV (%)		6.90	3.83	5.89	5.49	5.45

*** = significant at 1‰ level, ** = significant at 1% level, NS = non-significant at 1% level. df = degree of freedom, BL = Bulb length, BD = Bulb diameter, Y-pot = bulb yield per pot, WP = water productivity, IWUE = irrigation water use efficiency.

On the other hand, the planting date×soil cover system (PS×SC) interaction effect on bulb length was found to be also significant at the 1‰ level only in 2017 (Table 2). To examine the nature of this interaction, the BL data of planting dates were compared under both soil cover systems. The values of BL under straw mulching were 8.23, 7.78, and 7.03 cm, and under no-mulching condition were 7.62, 7.05, and 5.38 cm, for PS1, PS2, and PS3, respectively. The mean values of BL in PS1 and PS2 under no-mulching were smaller by 8-10% than those under straw mulching. While in the traditional planting date in April (PS3), BL under no-mulching was 31% smaller than that with straw mulching. This difference could explain the nature of PS×SC interaction.

The largest BD was produced from onion sets planted early in February (PS1) in both year: 4.7 and 4.0 cm in 2017 and 2018, respectively. It then significantly reduced as the planting date delayed. The mean values of BD from PS3 were shorter by 35% in 2017 and 23% in 2018 than those from PS1. Furthermore, using straw mulching led to a significant increase in BD by 17% compared with no-mulching conditions. Also, significant differences in BD were observed in relation to irrigation levels. The maximum values of BD of 4.5 cm in 2017 and 4.6 cm in 2018 were found under full irrigation condition (IL100). Then, they significantly decreased as the irrigation level decreased. The effect of decreasing water application rate by 40% of ETc (as in IL60 treatment) resulted in a decreased BD by about 48% relative to those in IL100, in both years (Table 3).

Only in 2018, both PS×IL and SC×IL interactions were highly significant (Table 2). To examine the nature of PS×IL interaction, the BD data of planting dates were compared under irrigation levels (data not shown). The decline in BD as planting date delayed was found to be more severe under full irrigation compared with water stress conditions. Also, to examine the nature of SC×IL interaction, the BD data of both soil cover systems were compared under irrigation levels (data not shown). The increase in BD as irrigation level increased was found to be more severe under straw mulching compared with no-mulching conditions. These differences could explain the nature of both interactions.

Table 3 - Mean comparisons of crop responses as influenced by planting date, soil cover system, and irrigation level for both studied years

Tested factor	BL (cm)	BD (cm)	Y-pot (g pot^{-1})	WP (kg m^{-3})	IWUE (kg m^{-3})
			2017		
Planting date					
PS1 (February)	7.9 a	4.7 a	119.74 a	4.60 a	5.71 a
PS2 (March)	7.4 b	3.7 b	110.52 b	4.09 b	4.26 b
PS3 (April)	6.2 c	3.0 c	83.79 c	2.82 c	2.87 c
LSD 0.01	0.4	0.2	8.77	0.32	0.36
Soil cover system					
with mulch	7.7 a	4.1 a	123.07 a	5.14 a	5.80 a
without mulch	6.7 b	3.5 b	86.30 b	2.53 b	2.76 b
LSD 0.01	0.3	0.2	7.16	0.26	0.30
Irrigation level					
IL100 (100% ETc)	7.9 a	4.5 a	141.77 a	4.39 a	4.76 a
IL80 (80% ETc)	7.3 b	3.9 b	105.11 b	3.95 b	4.39 b
IL60 (60% ETc)	6.3 c	3.1 c	67.11 c	3.18 c	3.70 c
LSD 0.01	0.4	0.2	8.77	0.32	0.36
			2018		
Planting date					
PS1 (February)	8.5 a	4.0 a	122.32 a	4.96 a	5.44 a
PS2 (March)	7.8 b	3.9 a	115.42 b	4.21 b	4.46 b
PS3 (April)	7.0 c	3.5 c	92.83 c	3.13 c	3.30 c
LSD 0.01	0.5	0.1	5.95	0.21	0. 22
Soil cover system					
with mulch	8.2 a	4.1 a	126.54 a	5.37 a	5.81 a
without mulch	7.3 b	3.5 b	93.83 b	2.83 b	2.99 b
LSD 0.01	0.4	0.1	4.86	0.17	0.18
Irrigation level					
IL100 (100% ETc)	8.2 a	4.6 a	148.65 a	4.52 a	4.86 a
IL80 (80% ETc)	8.0 a	3.8 b	110.53 b	4.17 b	4.48 b
IL60 (60% ETc)	7.2 c	3.1 c	71.39 c	3.60 c	3.87 c
LSD 0.01	0.5	0.1	5.96	0.21	0.22

* Means followed by the same letter within a year and column for each tested factor are not significantly different according to LSD at 1% level. BL = Bulb length, BD = Bulb diameter, Y-pot = bulb yield per pot, WP = water productivity, IWUE = irrigation water use efficiency).

Bulb yield per pot (Y-pot)

Analysis of variance shown in Table 2 indicated that the main effects of the three studied factors on Y-pot were significant at the 1‰ level. However, none of the three-factor or two-factor interactions were significant at the 1% level in both studied years. The data under each factor were averaged over all levels of the other factors for mean comparison purposes (Table 3). In both years, earliness in planting date resulted in an increase in the bulb yield. The mean yield of bulbs which were planted in February (PS1), were the highest with 119.7 and 122.3 g pot^{-1} in 2017 and 2018, respectively. Y-pot significantly decreased with delayed planting. It reduced considerably by 8 and 30% in 2017 and by 6 and 24% in 2018 when onion sets were planted in PS2 and PS3, respectively, compared with sets planted in PS1.

In addition, Y-pot was found to be increased significantly by 30% in 2017 and 26% in 2018 when straw mulching was used relative to no-mulching conditions (Table 3).

On the other hand, decreasing water application rate resulted in a significant decline in the bulb yield. The lowest mean values of Y-pot (67.1 g pot^{-1} in 2017 and 71.4 g pot^{-1} in 2018) were observed under sharp deficit irrigation when only 60% of ETc was applied to irrigate onion plants. Then, Y-pot was highly improved with increasing irrigation level. Y-pot increased by about 110 and 56% when onion plants were irrigated by 100 and 80% of ETc, respectively, compared with those irrigated by only 60% of ETc, in both years.

However, for presentation and discussion purposes, all experimental data of Y-pot under all studied treatments were demonstrated in figure 1a for 2017 and 1b for 2018. Trend analysis indicated that the relationships between Y-pot and irrigation level (as a percentage of ETc) for each planting date and under both soil cover systems were linear (equations not presented). As can be seen in figure 1, the rate of increasing yield with increasing irrigation water level was similar regardless of the planting date adopted under both soil cover systems. This confirmed the lack of interaction as found by ANOVA (Table 2). As shown also in figure 1, the maximum value of bulb yield was recorded in the treatment combining between planting in February under straw mulching and 100% of ETc (IL100) conditions. The yield of bulbs produced under such conditions could be attained about 185g pot^{-1} in both years (Fig. 1). Moreover, irrigating onion plants with only 60% of seasonal ETc (IL60) could produce bulb yield comparable with that under 80% of ETc (IL80), provided using straw mulching and planting onion sets as early as possible.

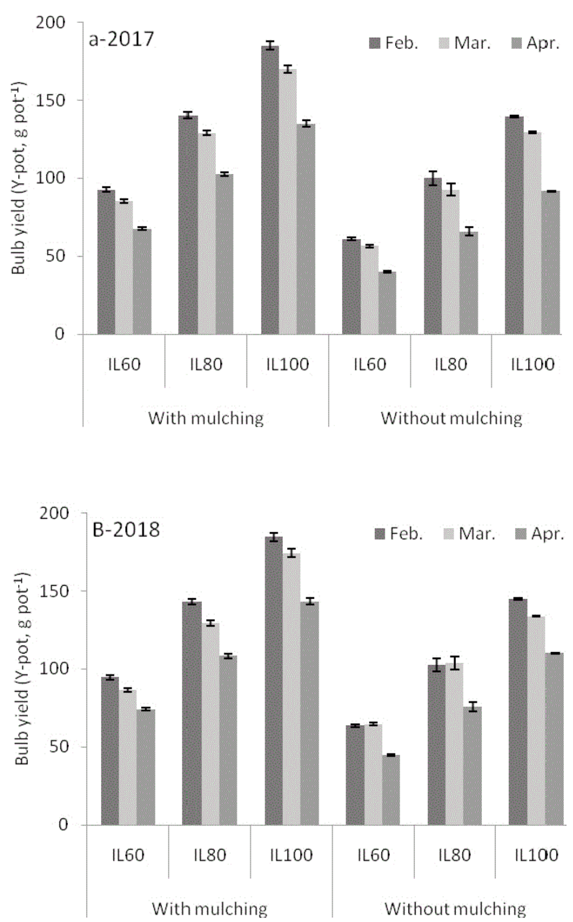

Fig. 1 - Response of onion bulb yield (Y-pot) in 2017 (a) and in 2018 (b) to planting date (February, March, and April), soil cover system (with and without mulching), and irrigation level (IL100, IL80, and IL60). Error bar represents one standard deviation.

Water use parameters

As mentioned above, irrigation treatments (IL100, IL80, and IL60) received at each irrigation event 100, 80 and 60% of the amount of soil water depleted under IL100 conditions, respectively. Irrigation water amounts and seasonal crop evapotranspiration (ETc) for the studied treatments are shown in Table 4 for both years. The seasonal ETc were close to the applied water amounts, because water amounts added to the pots were equal to the depleted water amounts, as regulated by weight. As can be seen, both irrigation water amounts and crop water consumption were greatly decreased when straw mulch was applied. For the three planting dates (PS1, PS2, and PS3), an average of 30% of water was saved when straw mulching was used compared with non-mulching conditions, regardless of the tested irrigation level. Moreover, early planting resulted in a noticeable decrease in both irrigation water amount and crop water use compared with the other planting dates (Table 4). For instance, onion crop planted in February (PS1) required irrigation amount 20-30% lesser than that planted in the traditional planting date (April, PS3). These results highlight the need for changing cultural practices and adopting early planting in order to conserve water resources.

The ANOVA detected that both crop water productivity (WP) and irrigation water use efficiency (IWUE) were significantly influenced by the main effects of planting date, soil cover system, and irrigation level at the 1‰ level, within both years. The interaction between planting date and soil cover system (PS×SC interaction) was also significant at the 1‰ level (Table 2). It is worth to examine the nature of this interaction. Figure 2 illustrates the data of both WP and IWUE under different planting dates (as averaged over all irrigation levels)under each system of soil covering, for both years. Regression analysis indicated that the relationship between both traits (WP and IWUE) and planting date were linear with significant values of R^2 at the 1% level, under both straw mulching and no-mulching conditions. For each trait, both representative straights were not parallel, but did not intersect over the studied period. The slope of straight is about two times greater under straw mulching than that without mulching. This indicates that the enhancements in both WP and IWUE due to the earliness in planting date, could be dou-

Table 4 - Irrigation water amount (without rainfall) and crop evapotranspiration (ETc) as influenced by planting date (PS1, PS2, and PS3), soil cover system, and irrigation level, for both studied years

Parameters	Soil cover	Irrigation level	PS1 (Feb.)	PS2 (Mar.)	PS3 (Apr.)
			2017		
Irrigation water amount (mm)	Without mulch	IL100	705.3	798.8	899.6
		IL80	561.0	649.9	734.2
		IL60	416.7	502.6	570.8
	With mulch	IL100	458.4	561.4	636.0
		IL80	363.9	461.3	524.9
		IL60	269.4	361.2	413.8
Crop evapotranspirationETc	Without mulch	IL100	800.2	819.1	909.2
		IL80	664.5	671.8	745.7
		IL60	525.4	528.1	586.2
	With mulch	IL100	552.5	578.0	641.5
		IL80	459.9	479.8	532.5
		IL60	367.5	387.3	429.9
			2018		
Irrigation water amount (mm)	Without mulch	IL100	706.5	809.6	886.8
		IL80	572.3	655.8	718.3
		IL60	431.0	493.9	540.9
	With mulch	IL100	494.6	566.7	620.8
		IL80	400.6	459.0	502.8
		IL60	301.7	345.7	378.7
Crop evapotranspirationETc	Without mulch	IL100	760.3	848.1	924.3
		IL80	615.8	687.0	748.7
		IL60	463.8	517.3	563.8
	With mulch	IL100	548.4	605.2	658.3
		IL80	444.2	490.2	533.2
		IL60	334.5	369.2	401.5

bled if straw mulching is used. This could explain the existence of the interaction between planting date and soil cover system.

The obtained data of both WP and IWUE under all tested treatments were shown in figure 3a and 3b for WP, and in figure 4a and 4b for IWUE, in 2017 and 2018, respectively. Also, the mean values under each factor were presented in Table 3 for mean comparison purposes. Both WP and IWUE as derived from the traditional planting date (PS3, in April) were the lowest: 2.82 and 3.13 kg m^{-3} for WP, and 2.87 and 3.30 kg m^{-3} for IWUE, in 2017 and 2018 respectively. Earliness in planting date resulted in a noticeable increase in both efficiencies. For instance, when onion sets were planted early in February (PS1), WP and IWUE were significantly augmented by 63 and 99% in 2017, and by 59 and 65% in 2018, respective-

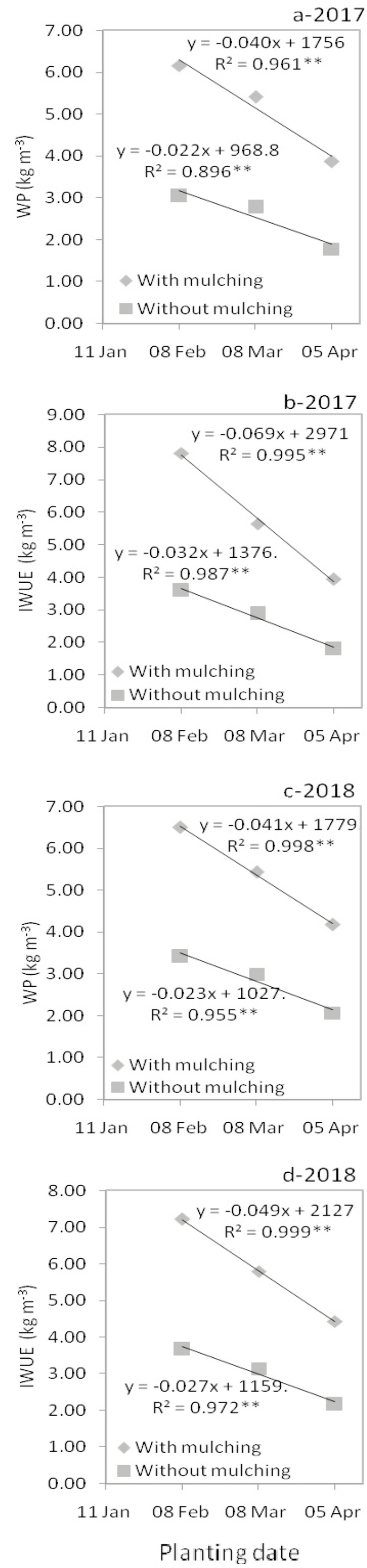

Fig. 2 - For both years, responses of both (a and c) crop water productivity, WP, and (b and d) irrigation water use efficiency, IWUE, to planting dates under both soil cover systems. Regression equations are fitted and coefficient of determination (R2) is given under each system of soil cover. ** = significant at 1% level.

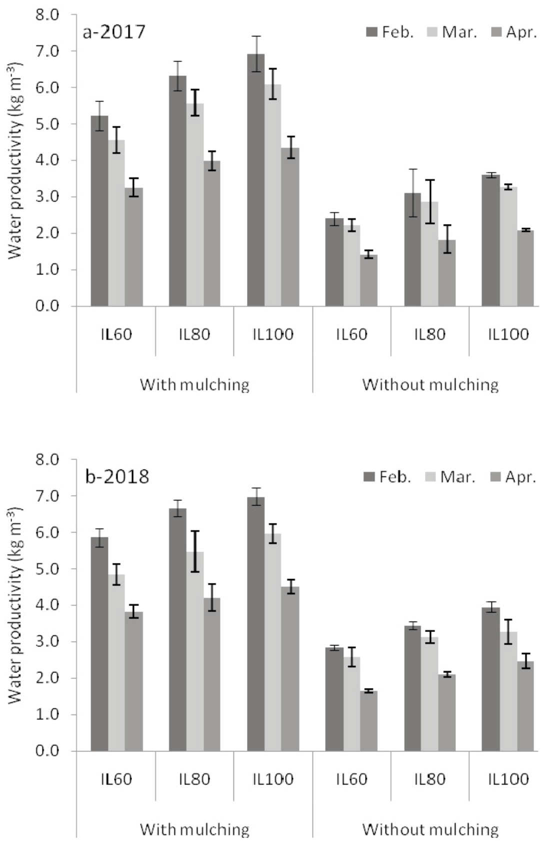

Fig. 3 - Response of water productivity (WP) in 2017 (a) and in 2018 (b) to planting date (February, March, and April), soil cover system (with and without mulching), and irrigation level (IL100, IL80, and IL60). Error bar represents one standard deviation.

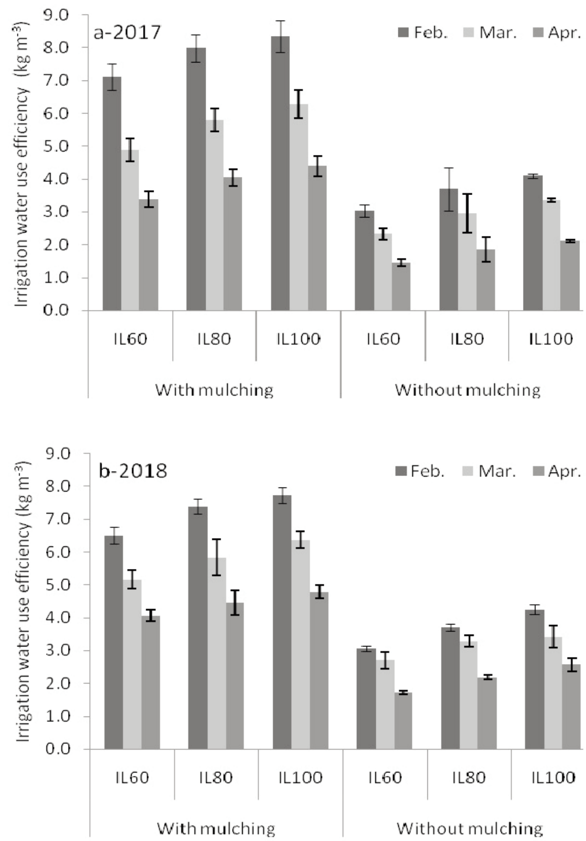

Fig. 4 - Response of irrigation water use efficiency (IWUE) in 2017 (a) and in 2018 (b) to planting date (February, March, and April), soil cover system (with and without mulching), and irrigation level (IL100, IL80, and IL60). Error bar represents one standard deviation.

ly. Furthermore, both WP and IWUE were found to be enhanced considerably when straw mulching was used: they were two times more than those under no-mulching conditions regardless of the planting dates or irrigation levels chosen. In addition, increasing water application rate resulted in an efficient use of water. The maximum values of both WP and IWUE (4.39 and 4.76 kg m^{-3} in 2017, and 4.52 and 4.86 kg m^{-3} in 2018, respectively) were recorded under full irrigation treatment. They then declined dramatically with decreasing irrigation level.

Trend analysis revealed that both WP and IWUE were linearly related to the irrigation level (as % of ETc) under both soil cover systems, regardless of the planting date considered, as shown in Figures 3 and 4 (mathematical equations not presented). Such developed linear functions could be invested for predicting the targeted values of WP and IWUE under similar climatic conditions in the dry Mediterranean area. For instance, the best agricultural management suggested to have maximum values of both traits (WP and IWUE) is to plant onion sets in mulched soil in February under full irrigation conditions. The values of WP and IWUE produced under such conditions could reach in average 6.95 and 8.05 kg m^{-3} (Figs. 3 and 4).

4. Discussion and Conclusions

As the tested onion variety is an oval- to elongated-shape onion, the larger the bulb size (both length and diameter), the better the bulb shape for appearance and marketing purposes. The onion bulb size was found to be increased when onion sets were planted early under straw mulching and 100% of ETc conditions. This could be related to the soil water availability. Under water stress, the soil is drier and relatively more compacted. Its mechanical resistance may limit the growth of the bulb and cause it to grow longitudinally. Moreover, straw mulching can reduce the soil evaporation and conserves soil humidity (Kirda, 2000; Fereres and Soriano, 2007; Igbadun *et al.*, 2012), and consequently, may encourage developing onion bulbs to grow in both length and diameter directions. Thus, the recommended agricultural management to produce better shape of onion bulbs for consumers, is to plant onion sets in February under straw mulching and full irrigation level conditions. Similar results about the role of straw mulching in enhancing the bulb shape indicator were reported by Mubarak and Hamdan (2018 b).

The bulb yield, and both WP and IWUE were also found to be maximized when onion sets were planted early, under straw mulching and full irrigation. These results could be explained by the fact that the early planting partially covers the late winter time in which onion plants grow well and there would be relatively plenty of water available, compared with the rest of the year from spring to the end of summer. Onion sets planted early also had enough time to benefit from cool period during the vegetative stage, which improved photosynthesis, and therefore production, compared with the actual practice followed by farmers (planting in April). This finding is in agreement with similar results obtained by Hamma (2013) and Rohini and Paramaguru (2016). Also, both irrigation water amount and crop water consumption were found to be greatly decreased, saving about of 30% of water when straw mulch was used compared with no-mulch conditions, irrespective of irrigation level. Under current practices of planting in April without mulching, farmers are not in favor of fully irrigating their crops even if the yield is reduced, due to the huge irrigation water needs (about 900 mm). Thus, using straw mulch could regulate such case. Our research results indicated that onion plants planted in February and grown under straw mulch could be fully irrigated with only 550 mm. The favorable impact of mulching was preveiously reported (Vavrina and Roka, 2000; Igbadun *et al.*, 2012; Hamma, 2013; Tsegaye *et al.*, 2016; Mubarak and Hamdan, 2018 b). In fact, mulching decreases evaporation from soil surface, remaining more water available for plants (Kirda, 2000; Fereres and Soriano, 2007; Igbadun *et al.*, 2012). This could also moderate the severity of wetting-drying cycle between irrigations, and therefore, yield could be improved (Vavrina and Roka, 2000; Gimenez *et al.*, 2002; Mubarak and Hamdan, 2018 b). Moreover, Khaledian *et al.* (2010 and 2011) showed that increasing in crop yield could be also attained under straw mulching due to the enhancements in both soil fertility and soil physical properties.

Results indicated that the tested onion variety was very sensitive to regulated deficit irrigation. Many reports cited similar results that onion yield was optimized under full irrigation rather than under regulated deficit irrigation (Bekele and Tilahun, 2007; Kumar *et al.*, 2007; Nagaz *et al.*, 2012; Igbadun *et al.*, 2012). For example, Nagaz *et al.* (2012) observed that irrigating onion crop with 60% of ETc resulted in considerable reduction in bulb yield, dry matter, and bulbs per hectare, compared with those irrigated by 100% or 80% of ETc. However, an important finding of our experiments is that the onion crop response to regulated deficit irrigation was found to be significantly enhanced when straw mulching is used. For example, irrigating with only 60% of ETc using straw mulching resulted in WP and IWUE much higher even than those irrigated by 100% of ETc without mulching (Figs. 3 and 4). The irrigation water saving in such treatment (deficit irrigation using straw mulching) could be used to irrigate additional cropped area. Patel and Rajput (2013) reported similar outcome that with 40% deficit irrigation throughout the growing period, a water saving obtained could be utilized to irrigate additional ½ ha.

To conclude, onion crop was found to be responsive to early planting and straw mulching, so that both onion bulb size and yield were significantly enhanced, compared with those obtained under the traditional agricultural practices (planting in April without mulching). Both crop water productivity and irrigation water use efficiency were also considerably increased; and the seasonal crop water requirements obviously decreased. Our research results suggest that the best agricultural management is to plant onion sets in mulched soil in February under full irrigation conditions. Moreover, early planting date and straw mulching improved the response of onion crop to the regulated deficit irrigation. This could be an appropriate agronomic alternative to meet the ever increasing demand for onions and to save irrigation water. Onion bulb responses were predicted to be increased linearly with the increment in water application rate and with the earliness of planting date, with an obvious better preference under straw mulching. Both experimental data and the developed equations could be used for predicting onion crop responses under similar agro-pedo-climatic context without carrying out any additional experiments. Moreover, they could be used as a tool for rational management of limited irrigation water.

Acknowledgements

The author would like to thank the Atomic Energy Commission of Syria (AECS) for encouragement and financial support.

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