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Onion crop response to different irrigation and N-fertilizer levels in dry Mediterranean region

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Abstract: Due to the water scarcity in dry Mediterranean condition, determination of water and nitrogen (N) fertilizer needs is a major challenge for crop production and environment protection. Pot experiments under open field conditions were conducted for two consecutive years (2016 and 2017) to assess the effects of various levels of N-fertilizer and irrigation on onion crop, following a 4×3 factorial experiment arranged in a randomized block design with four N-fertilizer rates (0, 40, 80, and 120 kg N ha^{-1}), and three irrigation levels (100, 80, and 60% of the seasonal water use), with three replications. Results indicated that the initial soil N-content (about 60 kg N ha^{-1}) was sufficient to meet crop nitrogen requirements. However, results indicated that onion crop was sensitive to water stress, so that the highest total bulb yield (BY, 19.1 t ha^{-1}), dry matter in bulbs (DM, 2.97 t ha^{-1}), and water productivity (WP, 1.9 kg m^{-3}) were found under full irrigation compared to the deficit conditions. BY, DM, and WP were predicted to be increased linearly with increasing levels of irrigation. The developed equations could be used for predicting onion crop yields under similar agro-pedo-climatic context, and as a tool for rational management of limited irrigation water.

1. Introduction

Onion (*Allium cepa* L.) is one of the most important horticultural crops worldwide. Many studies have been carried out regarding the water and nitrogen fertilizer requirements of onion crop and the effects of deficit irrigation on yield and yield components (Abdissa *et al.*, 2011; Igbadun *et al.*, 2012; Patel and Rajput, 2013; Tsegaye *et al.*, 2016). A nitrogen fertilizer level of less than 100 kg ha^{-1} was found to be sufficient for onion crop production as in Abdissa *et al.* (2011) and Tsegaye *et al.* (2016). Russo (2008) reported that nitrogen fertilizer had no significant effect on onion yield. Moreover, the onion crop was found to be more moderately responsive to water deficit during the total growing season; and it is better to partition the water stress throughout the growing season (Regulated deficit irrigation, RDI) rather than creating a stress during the critical stages of crop growth (Kirda, 2000; Kadayifci *et al.*, 2005; Patel and Rajput, 2013). The deficit irrigation given at different levels (up to 40%) was found to be economically recommended. This wide range in allowable deficit levels could be due to the various agro-pedo-climatic context of their studied regions. In other word, onion grown in different soil and crop management factors responded differently to the application of both deficit irrigation and N-fertilizer. Therefore, there is a continuous need to select both optimum N-fertilizer rate and irrigation level for onion crop in ever changing agro-pedo-climatic conditions.

In dry areas of the Mediterranean region, scarcity of water is the most limiting factor for onion crop production, due to the lack of rainfall over the production period between April and August (Ragab and Prudhomme, 2002; Turner, 2004). The onion crop is grown in arid and semi-arid area in that region, with many cultivars. In the eastern Mediterranean, as in Syria, the oval- to elongated-shape onion, referred to as 'Selmouni red', is the famous variety used for its long-day storage capacity. Growers have targeted the larger bulb size and the higher marketable yield. They imagined the greater yields would require increased N fertilizer and water amount. High nitrogen fertilizer and irrigation water amounts may allow nitrate and other components to be most likely deeply percolated. So, research findings are an urgent need to determine water and N-fertilizer requirements for the onion crop in the production areas. In this context, the study reported herein has been designed to predict onion crop response to various levels of regulated deficit irrigation and N-fertilizer rates in dry Mediterranean areas. Results may contribute to introduce practical alternatives that would sustain onion productivity while using less water and fertilizer in the context of water scarcity and environmental protection.

2. Materials and Methods

Pot experiments under open field conditions were carried out at the Deir Al-Hajar Agricultural Experiment Station, Damascus, Syria (33°20′ N, 36°26′ E, altitude 600 m), for two consecutive growing seasons 2016 and 2017. Table 1 shows some climatic data for the studied site during the course of these experiments. No rainfall was recorded during both growing seasons. The chemical and physical soil properties are: pH 8.0; ECe 0.58 ds m^{-1}; organic matter 1.19%; available P 6 ppm; total N 0.06%; NO_3^- 51.8 ppm; NH_4^+ 39.2 ppm. Particle-size distribution analysis showed that the soil contains on average 27.8% sand, 42.7% silt and 29.5% clay, and therefore classified as a clay loam. Average volumetric soil water contents at field capacity (*FC*) and permanent wilting point (*PWP*) are 0.36 and 0.18 m^3 m^{-3}, respectively.

Table 1 - Some climatic data of the experimental site during both growing seasons

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

T_{min}= minimum temperature, T_{max}= maximum temperature, $T_{average}$= average temperature, RH= relative air humidity.

Each pot was of diameter and depth of 25×30 cm, and contained 8 kg of natural soil from the field. Three small bulb sets (also called as bulbils or bulblets) of onion (*Allium cepa* L. 'Selmouni red') were grown in each pot. After germination, plants were thinned to two bulb sets per pot, making a plant density of about 400000 plants ha^{-1}. The pots were set outdoors under natural climatic conditions. The experiment was started on the planting day (March 31st and April 2nd for the 2016 and 2017 seasons, respectively) with the soil water content (SWC) of all pots at field capacity (measured by pot's weight).

The experiment was laid out following a 4×3 factorial experiment arranged in a randomized complete block design (RCB design) with four N-fertilizer rates (N0, N40, N80, and N120), and three irrigation levels (FI, DI80, and DI60), with three replications, making a total of 36 pots. The N-fertilizer rates composed of N0, N40, N80, and N120 with 0, 40, 80, and 120 kg N ha^{-1} added to the soil, respectively. The three distinct irrigation treatments were: FI treatment (full irrigation) in which plants received 100% of accumulated crop evapotranspiration (100% of ETc) and the root zone was replenished to field capacity; DI80 and DI60 treatments (regulated deficit irrigation) were irrigated at the same frequency as FI treatment but with water amounts equal to 80 and 60% of the accumulated ETc, respectively. In other words, the three watering treatments received at each irrigation event 1.0, 0.8 and 0.6 times the amount of soil water depleted under FI conditions, respectively. Irrigation was applied 3 times per week. The pots were weighed before and after each irrigation event. The water amounts were regulated by weight (Eq. 1). The depleted water amount (crop evapotranspiration, ETc) (mm) between two successive irrigations was calculated as:

$$ETc = \frac{W_1 - W_2}{\rho_w \times S} \quad [1]$$

where W_1 was the weight of the pot (kg) after irrigation; W_2 was the weight of the pot (kg) just before the next irrigation; ρ_w is the water density (g cm^{-3}); and S is the soil surface area in the pot (m^2). The daily crop evapotranspiration (mm day^{-1}) was estimated by dividing the crop evapotranspiration estimated from Eq. (1) by the number of days between two successive irrigation events. The seasonal crop evapotranspiration, i.e., the total crop water use during the growing season, was the summation of the daily ETc.

Full doses of phosphorous and potassium were applied as basal dose at the time of planting. Nitrogen was divided into two equal doses (according to the studied N-fertilizer rate) and applied with the irrigation water during early vegetative growth stage. Irrigation was stopped at the end of July when over 50% dropping of leaf-tops was observed as signs of maturity. The onions were lifted to field cure about two weeks after (up to mid-August). After the leaves were completely dried, they were cut leaving about 2.0 cm above the bulb. The length, diameter, and weight of both matured onion bulbs from each pot were measured. The total bulb yield (BY, t ha^{-1}) was estimated. The dry matter in bulbs (DM, t ha^{-1}) was also estimated by drying bulbs at 50°C to a constant weight. Water productivity (WP, kg m^{-3}) was computed by dividing the total bulb yield by the seasonal evapotranspiration. Bulb shape index (Sh I) was also calculated as the relationship between bulb length and diameter. No Multi-centred bulbs were observed at harvest even under deficit irrigation.

With two factors (N-fertilizer rate and 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 years was performed to verify if N-fertilizer rate and irrigation level may have a significant and stable effect over year. Mean comparison was made only for data after combined analysis using Duncan's Multiple Range test (DMRT) at the 1% level of significance. Trend analysis (regression analysis) was also used to examine the relationship between measured variables and the quantitative factors showing a significant effect. The trend analysis was done based on the method of orthogonal polynominals as described by Gomez and Gomez (1984).

3. Results and Discussion

The effects of years, N-fertilizer rates, and irrigation levels on the measured variables of onion crop (BY, DM, WP, and Sh I) were summarized in Table 2. Since no significant interaction year × treatments was observed, data are shown as the averages of the two years (Table 3 and Figs. 1-3).

Table 2 - Analysis of variance of the combined data of measured variables as affected by years, N-fertilizer rates, and irrigation levels (F-test values)

Source of variation	*df*	BY	DM	WP	Sh I
Year (Y)	1	*b*	*b*	*b*	*b*
Reps. within year	4				
Irrigation level (I)	2	213.4 **	75.44 **	41.35 *	12.30 NS
N-fertilizer rate (N)	3	<1	<1	<1	1.90 NS
Y x N	3	2.20 NS	1.24 NS	1.65 NS	1.30 NS
Y x I	2	<1	<1	1.03 NS	<1
N x I	6	<1	1.82 NS	<1	<1
Y x N x I	6	2.89 NS	1.47 NS	2.58 NS	2.61 NS
Residual (Pooled error)	44				
Total	71				
CV (%)		18.6	22.8	18.9	14.9

* = significant at 5% level, ** = significant at 1% level, NS = non-significant at 5% level.
b = the degree of freedom of Reps. within year is not adequate for valid test of significance (Gomez and Gomez, 1984).
df = degree of freedom, BY = total bulb yield, DM = dry matter in bulbs, WP = crop water productivity, and Sh I= shape index.

Total bulb yield

The combined analysis of data over years indicated that only the main effect of irrigation was significant, and highly influenced BY (p<0.01) (Table 2 and 3).

No significant change in BY was recorded with the addition of N fertilizer (Table 3), indicating that the initial soil nitrogen content (about 60 kg N ha^{-1}) was sufficient to meet the crop nitrogen requirements, and no extra N-application was needed. This is in agreement with the results of Abdissa *et al.* (2011) who found that a rate of 69 kg N ha^{-1} was sufficient for onion crop production. Tsegaye *et al.* (2016) reported that a N level of 100 kg ha^{-1} was economically recommended for onion in southern Ethiopia. According to Russo (2008), nitrogen fertilizer did not affect onion yield.

The effect of irrigation level resulted in the highest BY (19.1 t ha^{-1}) in FI treatment, while under DI80 conditions, total bulb yield decreased by 36.4%, reaching 63.0% of decrease (7.1 t ha^{-1}) under DI60 conditions (Table 3). Similar results were also obtained by Kumar *et al.* (2007) and Bekele and Tilahun (2007). Trend analysis indicated that the relationship between total bulb yield and irrigation level

Table 3 - Effect of N-fertilization rate and irrigation level on total bulb yield (BY), dry matter in bulbs (DM), crop water productivity (WP), and shape index (Sh I) in onion 'Selmouni red' (data are the averages of the two years of experimentation)

Studied factor	BY (t ha^{-1})	DM (t ha^{-1})	WP (kg m^{-3})	SH I (cm cm^{-1})
N-fertilization rate				
N0 (0 kg N ha^{-1})	13.47 a	2.26 a	1.59 a	1.78 a
N40 (40 kg N ha^{-1})	12.26 a	2.14 a	1.47 a	1.86 a
N80 (80 kg N ha^{-1})	12.73 a	2.06 a	1.52 a	1.86 a
N120 (120 kg N ha^{-1})	12.61 a	2.08 a	1.47 a	1.65 a
Irrigation level				
Full irrigation (100% ETc)	19.08 a	2.97 a	1.90 a	1.72 a
Deficit irrigation at 80%of ETc	12.14 b	2.16 b	1.50 b	1.67 a
Deficit irrigation at 60%of ETc	7.08 c	1.27 c	1.14 c	1.98 a

In each column and for each studied factor, means followed by different letters are significantly different according to the DMR test.

was linear within the range of irrigation levels tested (R^2=0.991 with p<0.01) (Fig. 1). A significant linear decrease in the total bulb yield was predicted with increasing water deficit. In other word, BY increased with increasing irrigation level (Fig. 1). This is in agreement with other published findings (Kadayifci *et al.*, 2005; Kumar *et al.*, 2007; Bekele and Tilahun, 2007; Nagaz *et al.*, 2012). For instance, Nagaz *et al.* (2012) observed that applying 60% of crop evapotranspiration (ETc) caused significant decreases in fresh yield, dry matter, bulbs per hectare and bulb weight, compared to full irrigation (100% ETc). This result confirmed the sensitivity of the onion crop to water deficit during the total growing season. On the contrary, other studies showed that onion crop is responsive to deficit conditions as compared with full irrigation. For example, Tsegaye *et al.* (2016) and Igbadun *et al.* (2012) found that deficit irrigation given at 75% of ETc was economically recommended. Also, Nagaz *et al.* (2012) found no significant differences between regulated deficit irrigation at 80% ETc and full irrigation (100% ETc). These differences in onion crop response to deficit irrigation levels could be due to the various agro-pedo-climatic conditions.

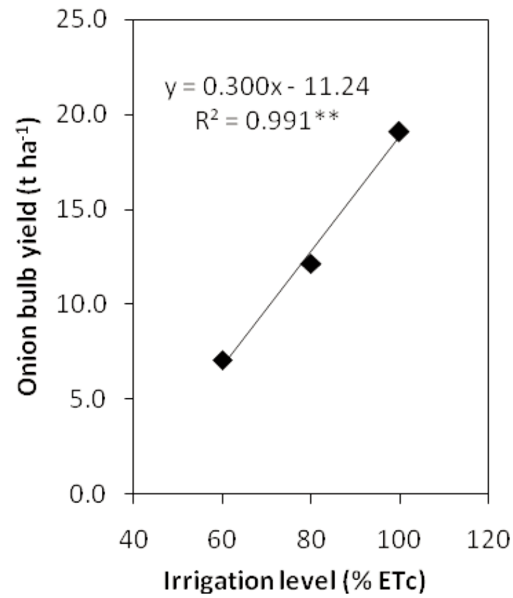

Fig. 1 - Response of onion total bulb yield (BY) to irrigation levels. A regression equation is fitted and coefficient of determination (R^2) is given. ** = significant at 1% level. Each experimental point represents the data of BY averaged over both years and all levels of N-fertilizer, at the specific irrigation level.

Dry matter yield in onion bulbs (DM)

Also DM was found to be highly affected only by the main effects of irrigation levels (Table 2 and 3). The mean values of DM were 2.97, 2.16, and 1.27 t ha^{-1} under FI, DI80 and DI60, respectively. That is to say, significant decreases of 27.2 and 57.1% in DM could be attained when onion crop was under DI80, and DI60, respectively, compared with FI (p<0.01) (Table 3). Trend analysis designated that the response of DM to various irrigation levels followed a linear relationship (R^2=0.999 with p<0.01). Dry matter yield increased with increasing levels of irrigation as can be seen in figure 2. Thus, dry matter yield could be maximized whatever the N-fertilizer rate used in this study, when full irrigation was applied. Several studied reported similar results, showing that dry matter yield was maximized under full irrigation rather than under deficit conditions (e.g., Nagaz *et al.*, 2012).

Concerning fertilizer rates, as mentioned above, ANOVA did not detecte any significant change in DM yield with the addition of nitrogen fertilizer (Table 3). This is in agreement with the findings of Russo

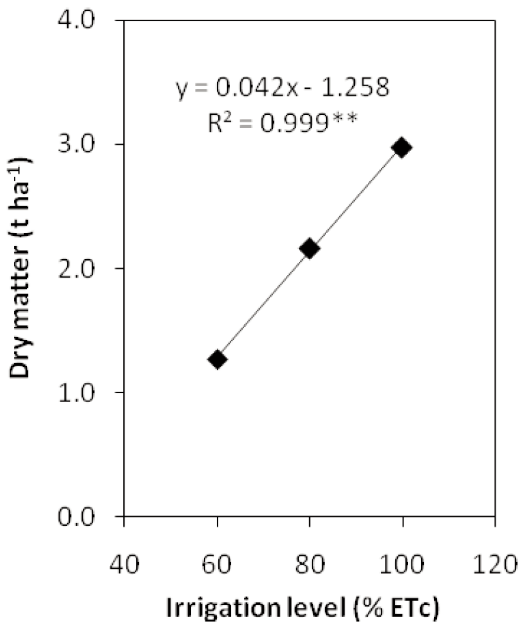

Fig. 2 - Response of onion dry matter yield in bulbs (DM) to irrigation levels. A regression equation is fitted and coefficient of determination (R^2) is given. ** = significant at 1% level. Each experimental point represents the data of DM averaged over both years and all levels of N-fertilizer, at the specific irrigation level.

(2008). This result newly indicated that the initial soil nitrogen content was sufficient to meet the N-fertilizer needs of onion crop.

Irrigation water applied and water productivity

With no rainfall received during both growing seasons (Table 1), large water amounts were applied to meet the high crop water demand. The irrigation water applied to FI, DI80, and DI60 were, 1014, 822, and 634 in the 1st season, and 1039, 849, and 566 mm in the 2nd one, respectively. Seasonal crop evapotranspiration (ETc), as calculated using Eq. (1), during the 2016 season was 993, 803, and 615 mm, and during the 2017 season was 1013, 823, and 630 mm, for FI, DI80, and DI60, respectively. As it can be seen, the seasonal ETc values were very close to the irrigation water amounts even in DI80 and DI60 treatments. Therefore, WP can be considered also a good estimate of irrigation water use efficiency (IWUE).

The combined analysis over years detected that WP was highly significantly influenced by the irrigation levels. It was unchanged with the addition of N fertilizer (Table 2 and 3). The mean value of WP under FI (1.90 kg m^{-3}) was significantly higher than both deficit irrigation levels, i.e., DI80 (1.50 kg m^{-3}) and DI60 (1.14 kg m^{-3}) (Table 3). Trend analysis indicated that the relationship between WP and irrigation level was linear with values of R^2 of 0.998 at the 1% level (Fig. 3). Results indicated that WP was not ameliorated under deficit irrigation. This could be due to high onion crop sensitiveness to the water deficit during the total growing season. Thus, the water savings under deficit irrigation could not balance the huge decrease in the total bulb yield under the dry conditions. This result is in agreement with similar results obtained by Kadayifci *et al.* (2005), who found that high water use efficiencies were observed with increasing levels of irrigation. Contrariwise, this result was in disagreement with the findings of other researchers (Fereres and Soriano, 2007; Kumar *et al.*, 2007; Bekele and Tilahun, 2007; Patel and Rajput, 2013; Tsegaye *et al.*, 2016). For example, Patel and Rajput (2013) reported that with 40% deficit irrigation throughout the growing season, water productivity can be significantly improved with 272-mm water saving which may be used to irrigate additional cropped area (half a hectare). Kumar *et al.* (2007) found that irrigation water use efficiency and water productivity both were highest under 80% of ETc and then declined with the increase in irrigation with microsprinkler irrigation system. Igbadun *et al.* (2012) showed that higher water productivity in terms of water supplied could be obtained by irrigating onion crop at 50 and 75% of ETc. These different results could be due to

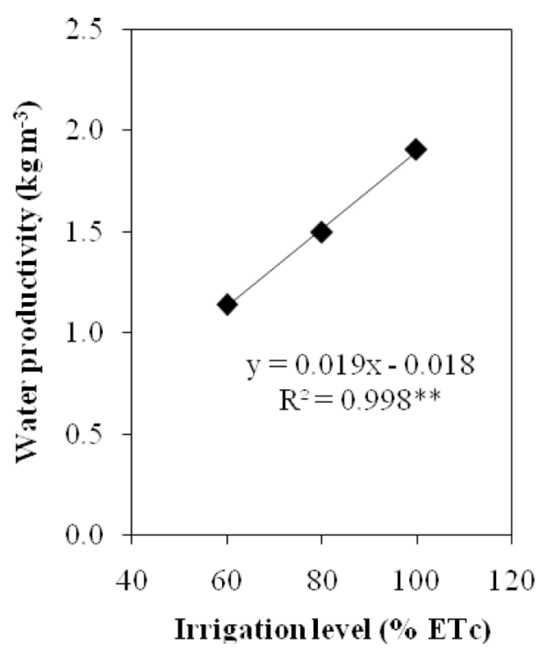

Fig. 3 - Response of onion crop water productivity (WP) to irrigation levels. A regression equation is fitted and coefficient of determination (R^2) is given. ** = significant at 1% level. Each experimental point represents the data of WP averaged over both years and all levels of N-fertilizer, at the specific irrigation level.

the differences in tested onion cultivars, soil type, and climatic conditions. They indicated that onion crop produced in different agricultural managements responded differently to water stress.

Bulb shape index

No significant effects of both tested factors were observed on this variable (Table 2 and 3). As above mentioned, the oval- to elongated-shape onion, referred to as 'Selmouni red', was tested. Its shape index generally varies from 1.5 to 3.0, according to several environmental conditions including planting dates, plant density, planting depth, and soil water availability. The lower the shape index, the better the bulb shape for marketing purposes (appearance and ease of packaging). The mean values of Sh I, found in this study, were 1.72, 1.67, and 1.98 under FI, DI80, and DI60, respectively (Table 3). The average Sh I under severe water stress (DI60) was 14.7% larger than that under non-water stress conditions (FI). In other word, sharp deficit irrigation tended to increase the bulb length, although this increase not significant, compared to its diameter. Thus, the recommended agricultural management to produce better shape index of onion bulbs, is to irrigate onion plants using irrigation level of 100 or 80% of ETc.

4. Conclusions

The following conclusions can be drawn from the results obtained in onion subjected to different N-fertlizer rates and irrigation levels in the studied agro-pedo-climatic context:

No additional N application over the initial soil N content (about 60 kg N ha^{-1}) was found to be required for the tested onion cultivar.

The highest total bulb yield, dry matter, and water productivity were recorded under full irrigation compared to the deficit conditions, indicating that onion crop was sensitive to water stress.

Total bulb yield, dry matter, and water productivity were predicted to be increased linearly with the increment in irrigation water amount. The developed equations could be useful for predicting onion crop yields under similar agro-pedo-climatic context and for rational management of limited irrigation water.

With huge crop water requirements, further studies should focus on how to improve the regulated deficit irrigation practices in order to address water shortage and sustainable crop production in dry areas of the Mediterranean region.

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