Investigation of the Response of onion (*Allium Cepa* L.) to continuous deficit irrigation as smart approaches to crop irrigation under Mediterranean conditions

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Abstract. Water is a crucial resource for food production and its scarcity associated with frequent droughts has increased the need for a more efficient use of it along with new irrigation management technologies. This study addressed onion crop responses to continuous deficit irrigation with triggering thresholds of readily available water content. The experiment was conducted on an experimental plot in open field in Morocco. Three water regimes were applied T1 control (100%), T2 (75%) and T3 (50%) of crop evapotranspiration ET_c combined with two triggering thresholds (10% and 5%). This is a complete random block device with four repetitions. The measurements concerned the monitoring of vegetative, Eco physiological and yield parameters. The results obtained show that: (i) 100% ET_c irrigation at a threshold of 5% of RAW recorded the maximum bulb diameter and weight, thus achieving the best marketable bulb yields. However, in terms of yields, this treatment is not significantly different from the other irrigation regimes with the exception of the irrigated treatment at 50% daily ET_c and at a threshold of 10% RAW. The latter recorded the lowest values in terms of production parameters. (ii) For the eco-physiological parameters, significant effects of irrigation dose were observed for proline content, stomatal conductance and leaf temperature, and the effect of the triggering threshold was clearly observed for the moisture content of the leaves. (iii) Water restrictions have minimized the rate of premature run and population density of Thrips tabaci in the onion. (iv) Finally, the best agronomic efficiencies in the use of irrigation water were recorded in treatments with a water restriction of 50%.

Key word: Continuous deficit irrigation, onion, Crop coefficient, available water content

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Introduction

Decrease in water resources has become a worldwide problem and there may be insufficient water for food production by 2025 (Girona et al., 2010), especially in Mediterranean region which is a climate change "hot spot" (Abouabdillah et al., 2010). As a consequence, saving water in irrigation is the most critical issue to be considered (Ayas., 2019). Irrigation water is considered as a crucial element for crop production (Howell, 2001; Steduto et al., 2012; Abdelkhalik et al., 2019). In Morocco, about 75% of water is allocated to agriculture (Abdelkhalik et al., 2019). Therefore, agriculture is a key sector in the Moroccan economy, as it represents approximately 15% of the Gross Domestic Product (Brouzyne et al., 2018). It should be pointed out that 43 % of Moroccan population makes a living from agricultural activity (Bzioui, 2004). Actually, major challenges exist in maximizing water use efficiency (WUE) and increasing crop productivity per unit of water applied. Within this context, deficit irrigation (DI) is used as a practice that provides water below optimal crop water requirements leading to increased WUE (Pereira et al., 2002; Costa et al., 2007; Fereres and Soriano, 2007; Capra et al., 2008; Evans and Sadler, 2008; Sharma et al., 2014 ; Chai et al., 2016). However, DI can save a significant amount of irrigation water with the risk of reducing the yield of some crops. Generally, a distinction is made between two types of deficit irrigation that can be applied: Sustainable Deficit Irrigation (SDI) which means the application of continuous water restriction throughout the entire crop cycle (Goldhamer et al., 2006), or a water stress during particular crop developmental periods (RDI: Regulated Deficit Irrigation) (English et al., 1990; Chalmers et al., 1981; Hueso and Cuevas, 2004). Among vegetable crops, onion is one of the main foods widely used around the world. According to the most recent data of the United Nations Food and Agriculture Organization (FAO), worldwide onion production was approximately 96.7 million tons from 5.03 million hectares (FAO, 2018). Average world yields increased from 18.4 t/ha in 2004 to 19.2 t/ha in 2018. The leading onion producing countries are China, India and the United States of America accounting for 20% of the world production (FAO, 2018). Based on FAO data, Morocco produces 954801 tons of onions annually, which is approximately 1% of the world's onion production. This study was carried out in the Fes-Meknes region of Morocco. This region is the country's leading onion producer, accounting 54 % of the total production. Water requirements for onion varies depending on location and irrigation system (López-Urrea, 2009). The maximum root penetration of onion is 76 cm, but most of it is in the first 18 cm of soil limiting the amount of soil water available for roots (Hanci and Cebeci, 2014). As a result, rainfall is insufficient to sustain its production, making irrigation crucial. Some previous experiments on onion field grown in different climates were studied. Deficit irrigation (50 % ETc) saved 50 % of irrigation water with a 25 % reduction in bulb yield while at 75 % of ETc, the reduction in bulb yield is not significant in comparison with the control (Igbadun et al., 2012). Deficit irrigation increased the water use efficiency of the onion (Santa Olalla et al., 2004; Singh et al., 2017; Igbadun et al., 2012). In addition to water savings, deficit irrigation may also have positive effects on fruit quality (Sharma et al., 2014). Therefore, the objectives of this study were to determine optimal irrigation parameters for yield optimization and increased water use efficiency, as well as to study the combined effect of deficit irrigation and irrigation frequencies on the onion crop.

1 Materials and methods

1.1 Experimental site and climatic conditions

The field experiment was conducted during the growing season of 2018 from April to august at the National School of Agriculture of Meknes, situated in Fès-Meknès region, Morocco(Fig. 1). Its geographical coordinates are: latitude 33°50’36’’ N, longitude 5°28’39’’ W and its altitude is 546 m above sea level. The soil texture at the site is loamy-clayey. The volumetric water content for the first 0.3 m was 38 % at field capacity and 21.3 % at wilting point. Soil characteristics are detailed in Table 1.

The climate of the study area is Mediterranean with an average annual rainfall of approximately 450 mm. Maximum and minimum temperature values at the experimental site during the experiment were 40°C and 4°C, respectively (Fig. 2a). The highest and lowest relative humidity values were found as 100% and 16%, respectively. As shown in Fig. 2(b), daily reference evapotranspiration, values vary between 0.5 and 7mm.Rainfall during the irrigation season was 55 mm, which was taken inconsideration in the irrigation water allocation for each treatment.

Table 1.Soilphysico-chemical characterization at the experimental site.

Parameters (unit)	Soil property
Clay (%)	37.3
Silt (%)	56.5
Sand (%)	16.2
Electrical conductivity (dS m-1)	0.102
pH	8.41
Total limestone (mg kg-1)	24.4
Organic matter (%)	2.78
Mineral nitrogen (mg kg-1)	25.9
Olsen P2O5 (mg kg-1)	9.0
Extractable K2O (mg kg-1)	317.0

Fig. 1.Geographic location of the experimental site (prepared using ArcGIS software 10.3).

Fig. 2.Daily Average (a) temperature (°C) (b) reference evapotranspiration (ET0) during the growing season

1.2 Crop Management

The onion plant (*Allium cepa* L.) was transplanted on April 29, 2018 at a spacing of 0.1 m by 0.8 m at a depth of 1 cm. After transplanting, all treatments were fully irrigated to restore the soil moisture content to the field's capacity. The type and rate of application was based on the results of the soil analysis. Fertilizer units applied during the crop cycle were 73 kg/ha N, 44 kg/ha P2O5 and 60 kg/ha K2O. The crop was harvested 99 days after transplanting, when the bulb onions were mature. Mature bulb onions were hand pulled from the ground and sun-dried for one month and then stored in silos before measuring yield and quality parameters.

1.3 Irrigation treatments and experimental design

The plot is provided with a drip irrigation system. Each planting line has a single polyethylene drip line, with self-regulating drippers, uniformly spaced 40 cm apart on the drip line and delivering 1.6 l/hour. Crop evapotranspiration (ETc) was calculated using the following formula(Allen at al., 1998) : $ETc\ (mm) = (ET0 \times Kc) - \text{effective rainfall}$. ET0 is the reference daily evapotranspiration calculated by the modified Penman-Montheith formula based on climatic parameters collected continuously from a weather station located approximately 30

m from the experimental site. The Kc used in this study is that published by López-Urrea (2009)(Table 2). Effective rainfall is the fraction of precipitation that directly meets the crop water requirements, it corresponds to 80 % of total rainfall, taking in consideration the amount of rain lost through surface runoff, deep percolation or evaporation (El Jaouhari et al., 2018). In this experiment there were six treatments combining three doses of irrigation (100%, 75% and 50% of daily ETc) and two thresholds of the Readily available water RAW (10% and 5%). On the one hand, a threshold of 10 % with 100 % (T1), 75 % (T2) and 50 % (T3) of ETc, on the other hand a threshold of 5 % with 100 % (T4), 75 % (T5) and 50 % (T6) of ETc throughout the cycle.

In order to determine the water amount to be applied for each irrigation, it was necessary to calculate the Readily Available Water (RAW) equivalent to the Net Maximal Amount of irrigation, which corresponds to the amount of water that a soil can hold in the effective root depth, and which is calculated by using the formula below:

$$RAW = f \times (Fc - PWP) \times Rd \times PHS$$

With

f: Irrigation triggering threshold (5%) and 10% in this study

Fcc: Humidity at field capacity

Hpfp: Humidity at permanent wilting point

Rd: effective root depth

PHS: Percentage of humidified soil using the installed drip irrigation system

All the key parameters of the RAW were calculated at the beginning of the experiment. The factor f is an important indicator for judging the work quality in irrigation management. The values of f chosen for this test were 5% and 10%.

The basic meaning of f = 5% or 10% is that irrigation is triggered when 5% or 10% of the available soil water storage is consumed.

A randomized complete block design was used with four block replicates. Each replicated block contained all six treatments. Each elementary plot consisted of six planting line of 20 m long each.

Table 2. Proposed Kc model for onion growing by López-Urrea (2009).

Stage	Kc	Duration
1 leaf	0.70	52
2 leaf	0.80	
3 to 4 leaf	0.90	62
Bulb growth	1.05	30
Bulb thickening	1.20	
Ripening	0.7	24

1.4 Data analysis

Statistical analysis methods were used to analyze the data obtained from the experiment for the effect of water stress and irrigation frequency on yield and quality components of onions. Analysis tools used comprised Analysis of Variance (ANOVA) and Student-Newman-Keuls

(SNK) multiple comparison test using SPSS software (version 20). Treatments effects were considered significant at $P < 0.05$.

1.5 Plant measurements

1.5.1 Growth parameters

For growth monitoring, observations and measurements included leaf number and plant height. They were carried out every 15 days during the trial period on 48 selected randomly (8 plants per treatment). Plant height (cm) was measured using a double decameter.

The Relative Growth Rate (RGR in $\text{cm.cm}^{-1}.\text{j}^{-1}$) is an indicator of plant growth and was calculated in relation to plant height measurements according to the following equation (James and Richards, 2006) :

$$\text{RGR (cm.cm}^{-1}.\text{day}^{-1}) = \frac{\text{Ln (Height)}_{t2} - \text{Ln (Height)}_{t1}}{t2 - t1}$$

Where : (Height) t_1 = plant height measured at time t_1 ; (Height) t_2 = plant height measured at time t_2 ; $t_2 - t_1$ = the number of days between (Height) t_1 and (Height) t_2 .

1.5.2 Eco-physiological parameters

In this study, the relative chlorophyll content was non-destructively measured with the use of chlorophyll content meter model CCM-200 (Opti-Sciences, Inc., Hudson, NH). Three measurements were taken every 20 days on a random sample of 24 plants per treatment. The stomatal conductance was measured on mature leaves using a porometer (Leaf Porometer Decagon Devices, INC). Three leaf temperature measurements were taken using an infrared thermometer on two plants per experimental unit.

The leaf relative water content (LRWC ; %) was determined in fresh leaf discs. The discs were weighed (FW), and immediately floated on water to saturate them with for 6h in darkness. The adhering water of the discs was blotted, and turgor weight (TW) was recorded. After dehydration at 70°C for 48h, the dry weight (DW) of the disc was noted. LRWC was calculated using the equation developed by Turner (1981) :

$$\text{LRWC (\%)} = \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \times 100$$

Proline was extracted from a sample of 100 mg fresh leaves and roots crushed for each treatment in 10 ml of 3% aqueous sulpho-salicylic acid and estimated using the ninhydrin reagent according to the method described by Bates et al. (1973). The absorbance of fraction was read at a wavelength of 520 nm. Concentration of proline (expressed as $\mu\text{mol g}^{-1}$ of fresh weight) was determined by referring to a calibration curve prepared from a standard range of proline based on the following concentrations: 5, 10, 15, 20 and 25 $\mu\text{g/ml}$ proline per tube.

1.5.3 Fruit yield, quality and water use efficiency

The average bulb weight per treatment was determined for two plants from each experimental unit were randomly picked. The marketable bulb yield (MBY) per treatment was calculated using the bulb weight and the number of plants per line. The equatorial diameter (mm) of

onion bulbs were measured using a digital caliper as one of the parameters of crop quality (Rop, 2007).

Water use efficiency (WUE) is the ratio between the fruit yield (kg.ha⁻¹) obtained and the amount of water applied (m3) (Bouaziz et al., 2002). The WUE was calculated as follows:

$$\text{WUE (kg/m}^3\text{)} = \frac{\text{Yield (kg/ha)}}{\text{total of water received (mm)}}$$

2 Results and discussion

2.1 Growth parameters

The evolution of the growth parameters (Leaf number, plant height, root mass and volume) is presented in Fig. 3. During the experiment, the six applied irrigation regimes did not show any significant effect. Fig. 3 (a) indicated that the highest average number of leaves per plant (8.29 leaves) was recorded within T2, while T6 recorded the lowest leaves number (7.54 leaves). These results are in accordance with Enchalew et al. (2016), who reported that the highest onion leaves number was found in the treatment receiving 90% ETc and up to 20% water restriction was tolerable to obtain at least seven leaves per plant. Karim (1981) worked on the effect of irrigation frequencies on the onion crop and reported that as soil water supply increased, plant growth parameters increased. Fig.3 (b) shows that plant growth was influenced with the amount of water applied between the treatment. The evolution of onion plant height followed the same pattern, with the exception of the T6 treatment where the decrease in height started as early as the 68th day after transplanting. The average height of plants varies most of the time between 39 and 48 cm. Our results do not match with those of Bagali (2010) who noted that the plant height show a significant effect of irrigation frequency as the highest heights were observed at 100% of ETc. In the same study by Enchalew et al. (2016), the highest and lowest plant heights were obtained within the treatments receiving 90% and 50% ETc, respectively. However, another study, published by Kanton et al. (2003), who examined the effect of irrigation frequency on onion crop, indicates that as irrigation intervals increased, plant height decreased significantly. The effect of SDI and irrigation frequencies on relative growth rate (RGR) are shown in Fig. 3(c). The RGR peaks are reached between days 68 and 82 after transplanting for the T1 treatment, and between days 56 and 68 after transplanting for the rest of treatments. However, significant difference was found between T1 and the others treatments. The highest RGR was recorded by T1 during the 14–26 day interval after transplanting. Our results showed that the highest relative growth rate is obtained in the non stressed treatment, which is consistent with the results of Galmes et al. (2005). It was found by Hegde (1986) that irrigation had no significant effect on onion RGR except between 21 and 35 days after transplanting.

Fig. 3.Plant growth (a) number of leaves per plant, (b) plant height, (c) evolution of the relative growth rate after transplanting

2.2 Eco-physiological parameters

The relative chlorophyll content was unaffected significantly by the irrigation doses and frequencies. Indeed, T4 treatment had the highest value and the lowest was recorded by T3, T5 and T6 treatments (Fig. 3A). Pirzad et al. (2011) concluded that a water stress (excessive or deficit water) decreases significantly leaf chlorophyll concentrations (chlorophyll-a, chlorophyll-b and total chlorophyll). It was found that water deficit can destroy or prevent the production of chlorophyll (Montagu and Woo, 1999). For the stomatal conductance, significant effect of SDI treatments (T3 and T6) was observed (Fig. 3B). The results of this study are not in accordance with those obtained by Cornic and Briantais (1991), who noted that the stomatal conductance increases for treatments receiving more water. In this experiment, it may be due to the fact that T1, T2, T4 and T5 treatments plants were not stressed during the measurement. A significant difference was discerned between the treatments under SDI for leaf temperature (Fig. 3C). The lowest values were 27.75 and 27.25 °C recorded in the T1 and T4 treatments, respectively. According to Hsiao (1973), the increase in leaf temperature depends strongly on environmental factors.

Fig.4.Eco-physiological parameters (A) relative chlorophyll content, (B) stomatal conductance, (B) leaf temperature under different irrigation treatments. Different letters indicate significant differences according to the SNK test at $p < 0.05$. The error bars show the standard deviation of measurements between replications.

Deficit irrigation at 50 % of ETc had significant effect on proline content (Fig. 5). Proline value increased significantly under drought stress regardless of frequency. The highest concentration of proline was found in plants that were under maximum stress (50% of the ETc throughout the cycle) within the T3 and T6 treatments, in comparison with other treatments. Plants generally accumulate free proline in response to many environmental stresses (Hare and Cress, 1997). The results obtained in this study are considered similar to those obtained by Pirzad et al. (2011) and those found by Delauney and Verma (1993), in which maintaining high-water levels prevents the accumulation of osmotic elements, such as proline and total soluble sugars.

Fig. 5.Effect of different irrigation treatments on proline content. Different letters indicate significant differences according to the SNK test at $p < 0.05$. The error bars show the standard deviation of measurements between replications.

The results of variance analysis highlighted the presence of significant effect of the irrigation frequency factor on the leaf relative water content during the experiment, the irrigation regime did not have an effect on this parameter. The LRWC values for T1, T2, T3, T4, T5 and T6 were 92.74, 93.98, 91.65, 95.47, 95.31 and 95.66 %, respectively. Treatments with 5 % threshold (T4, T5 and T6) had the highest LRWC values (Fig. 6). It appears that LRWC increases with decreasing the threshold of the RAW. Surendar et al. (2013) reported that a reduction of net photosynthesis when the LRWC was reduced.

Fig. 6. Effect of different irrigation treatments on leaf relative water content (LRWC) of onion plants. Different letters indicate significant differences according to the SNK test at $p < 0.05$. The error bars show the standard deviation of measurements between replications.

2.3 Fruit yield, quality and water use efficiency

In the present study, no significant differences were observed between the six treatments concerning the marketable bulb yield (MBY) (Table 3). The T4 treatment reached the highest MBY (36.9 t/ha), followed by the T2 treatment (34.9 t/ha). It should be noted that in our study, as a result of experimental constraints, we planted at a density of 134,663 plants/ha, whereas the known planting density in the region varies between 200,000 and 250,000 plants/ha. This is in agreement with the findings of Santa Ollala et al. (2004), who did not

obtain in their experiment a significant difference in dry matter yied between treatments that were water restricted at different levels and those that received 100 % of their water requirements. Other studies (Hegde, 1986; Al-Jamal et al., 2000) showed that onions can reach maturity with different levels of water restriction. According to Pelter et al. (2004), water stress can reduce the yield of yellow onion and that the greatest reduction could be observed when irrigation is withheld at the 5-leaf, 7-leaf stage. The highest onion yields have been recorded among low RAW thresholds (Mermoud et al., 2005). Irrigation at 100 % of the field capacity every 2 days recorded the maximum yield (Mbagwu et al. (1985). Statistical analysis showed a highly significant effect of the interaction between dose and frequency on bulb weight (Table 3). Bulb weight varied significantly between the T4 and the rest of treatments. Irrigation at 100 % ETc with 5 % RAW threshold produced the maximum bulb weight. These results are in line with Al-Moshileh (2007), which indicates that a high application of soil moisture leads to significant photosynthesis. Onion bulb diameter was found not being significantly influenced by the irrigation treatments applied. The largest diameter (70 mm) was from T4 which received maximum amount of water with 5 % RAW threshold while T5 treatment gave the smallest diameter (Table 3). Santa Ollala et al. (2004) found the similar results, considering that the increase in bulb was attributed to the enhancement in the water quantity applied. The highest onion bulb diameter was recorded by the irrigation at 100 % ETc (Enchalew et al., 2016). The reduction of 50 % ETc in irrigation water amount had a significant increase in the WUE, reaching 0.83 kg/m3 and 0.93 kg/m3 for T3 and T6, respectively (Table 3). The lowest WUE was 0.52 kg/m3 obtained with the irrigation level equivalent to 100 % ETc and 10 % RAW threshold. The maximum WUE for onion was obtained in treatment with 50 % restriction in irrigation water quantity compared to control (Shock et al., 2000; Kebede, 2003). This result is supported by the results of Singh et al. (2017). With deficit irrigation, the reduction in yield is compensated by increased production from the additional irrigated area with the water saved (Ali et al., 2007).

Table 3. Effect of the irrigation dose and frequency on marketable bulb yield (MBY), bulb weight (BW), bulb diameter (BD) and water use efficiency (WUE). Mean values followed by different letters in each column indicate significant differences at $P \leq 0.05$ according to the SNK test.

Treatment	MBY (t/ha)	BW(g)	BD(mm)	IWUE (kg/m ³)
T1	34.2 a	292.1 a	65.6 a	0.52 a
T2	34.9 a	286.1 a	67.5 a	0.71 a
T3	27.0 a	318.9 a	60.6 a	0.83 b
T4	36.9 a	381.1 b	70.0 a	0.57 a
T5	28.2 a	302.3 a	60.1 a	0.58 a
T6	30.1 a	300.0 a	64.6 a	0.94 b

3 Conclusion

In this study, the effect of sustainable deficiency irrigation and irrigation frequencies are being tested on the growth, yield and quality of the onion crop. Our results showed no significant effect on growth parameters and relative chlorophyll content. The sustainable

water restriction to 75% of the crop water requirement increased proline content and water use efficiency compared to the 100% ETc control irrigated treatment throughout the cycle.. However, this treatment recorded the highest marketable bulb yield with a RAW threshold of 10%. Severe deficit irrigation at 50% of the water requirement could significantly influence stomatal conductance and leaf temperature, and also recorded the lowest values in terms of yield and quality parameters. Concerning the eco-physiological parameters; total chlorophyll, no significant difference was generated except for the leaf relative water content, which was significantly affected by the irrigation frequency. According to this study, it is advisable to apply 100 % of water requirements with a triggering threshold of the readily available water content of 5%, if water is not a limiting factor. But, if water is rare, it could be better to apply 75 % of water requirements, saving 25% of irrigation water without having a significant effect on production and quality.

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