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RESPONSE OF ONION PRODUCTIVITY TO DEFICIT IRRIGATION IN CALCAREOUS SOIL

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ABSTRACT

Field experiments were conducted at Nubaria Agriculture Research Station (30º 54´ N, 29° 57´ E, and 25 m above sea level) Egypt on onion (*Allium cepa* L.) grown in calcareous soil under drip irrigation system during 2015/16 and 2016/17.The study was aim to evaluate the effect of deficit irrigation treatments on amounts of applied irrigation water, onion yield and its components, bulb quality and to develop local onion crop coefficient (Kc).The field experiments were laid out in a strip plot design with four replicates. Four irrigation treatments (120, 100, 80 and 60 % ETo)were applied. Results indicated that, the distribution uniformity values were 87.95 and 91.35 % for the two tests conducted in the beginning of 2015/16 and 2016/17 growing seasons respectively. Average amounts of applied irrigation water for the 120, 100, 80 and 60 % ETo treatments were 5760, 4819, 3855 and 2891m^{3}ha^{-1}, respectively. The two-year average total yield values were 44.46, 40.17, 36.56 and 35.24 tons ha^{-1} for the same respective treatments. Average highest onion yield of 44.46 tons ha^{-1} was obtained from irrigation with 120% ETo. The total soluble solids (TSS) of onion bulb increased with increasing deficit irrigation. Average TSS values were 7.89, 8.81, 9.75 and 10.21 % for the 120, 100, 80 and 60 % ETo irrigation treatments respectively. Results also showed that, average highest water use efficiency and water productivity values of 14.72 kg/m^3 and 12.20 respectively were obtained under irrigation with 80% ETo. The Kc values for the 120% ETo irrigation treatments were 0.54-0.88, 1.0-1.05, 0.95, and 0.62 for initial, development, mid- and late-season growth stages, respectively. From the obtained results, it could be concluded that, in case of water shortage, irrigating onion in calcareous soil under drip irrigation with amount of water equals to 100% ETo will save 17% of the irrigation water and reduce the yield by 8% compared to 120% ETo.

(Key words: Drip irrigation, calcareous soil, onion yield and quality, crop coefficient, water use efficiency;, water productivity)

INTRODUCTION

Egypt is facing severe shortage in water resources, where the demand for water is increasing due to growing population, competition between different sectors, and the horizontal expansion in irrigated agriculture. Hence, attempts are required to increase the water use efficiency of the cultivated crops. Demand management in on-farm irrigation level would be a focus point to reduce the aggregated demand of water to match with available future supplies, thereby reducing the extent of water stress that the country faces now (Allam, 2007).Water availability to the agricultural sector is becoming a major constraint to agricultural production, which is the largest consumer of water resources in Egypt (Allam, 2007 and Wagd, 2008). Egypt water policy mainly depends on the expansion of modern irrigation techniques in the newly reclaimed lands of desert and the improvement in irrigation practices in old lands of the Nile Delta and Valley (Anonymous, 2002).The application of modern irrigation techniques, such as drip, bubbler, and sprinkler to increase irrigation efficiency is one of the measures utilized for competent use of water (Anonymous, 2002).

Onion (*Allium cepa* L.) is a very important vegetable crop worldwide. In arid and semi-arid regions, onion production is entirely dependent on irrigation (Halvorson *et al.,* 2008 and Mohammadi *et al.,* 2010). The annual world production of onion is 46.7 million tons resulted from 2.7 million hectares (Anonymous, 2011). In Egypt, onion represents an exporting commodity beside its use as food and medical product. Egypt is in the fifth place among the ten countries in the world in terms of cultivated

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area, and is ranked ninth in terms of productivity (Anonymous, 2002). The onion crop ranked second after tomato in terms of total annual production in Egypt, where 2.22 million tons were produced in 2015, compared to 2.00 million tons were produced in 2013, and the cultivated area of onion in Egypt is about 8% of the total cultivated area in the world (Anonymous, 2017). Onions have different water requirements according to its developmental stage, where the development of early good canopy is crucial to ensure good production (Ortolá and Knox, 2015). To produce high yields of onions, repeated irrigation is required to maintain soil moisture (Al-Jammal *et al.,* 2001). The most sensitive growth stage in onion crop is bulb initiation stage, identified 20-30 days after transplanting, where onion plants are sensitive to water stress (Ghodke *et al.,* 2018).

Drip irrigation is considered a highly efficient system of supplying water and fertilizer uniformly to the cultivated crops.Moreover, supply precise amounts of water directly into the vicinity of root zone at right time, matching with the consumptive water demand of plant for optimum growth, improved yield and quality of product with substantial water saving (Kumar *et al.,* 2005;Thangaselvabai *et al.,* 2009 and Abd El-Wahed and Ali, 2013).Drip irrigation can save 39-62% of water over flood irrigation, then more area can be brought under irrigation with better yield and quality which may compensate the cost of drip installation (Barker *et al.,*2003). Improving the productivity of water use in horticulture is an important part of the overall framework for managing water demand, thereby increasing the ability of agencies and other interested parties to transfer water (Kijne *et al.,* 2003).There is an increasing interest in a practice, in which water supply is reduced below the maximum level and marginal stress is allowed with minimum impact on crops, thus increasing water productivity and water use efficiency (Mekonen, 2011 and Dirirsa *et al.,* 2017). Deficit irrigation is a water saving technology that is relatively inexpensive and easy to implement (Tilahun *et al.,* 2004 and Temesgen *et al.,* 2018). Under water shortage conditions and drought in arid and semi-arid areas, deficit irrigation can lead to greater water use efficiency by maximizing yield unit^{-1} of water used (Temesgen *et al.,* 2018).Using irrigation scheduling and fertigation practices in new lands (sandy and calcareous soils) is considered one of the useful practices to improve irrigation and fertilizers use efficiency in Egypt (Taha, 2012). Moreover, management factors include irrigation scheduling decisions, which affect irrigation frequencies and durations, are also important (Taha, 2012).

The objectives of this study were to evaluate the effect of deficit irrigation treatments on applied irrigation water, water consumption, onion yield and its components, onion quality, water productivity, and to develop local onion crop coefficients (Kc) under the experimental conditions.

MATERIALS AND METHODS

Experimental site

Field experiments were conducted at Nubaria Agriculture Research Station (30º 54´ N, 29° 57´ E, and 25 m above sea level), Egypt during the years 2015/216 and 2016/17 growing seasons to evaluate the effect of different irrigation treatments, based on local ETo values, on the applied irrigation water to onion, water consumptive use, yield and its components, yield quality, water productivity, and to develop local onion crop coefficients (Kc) under the experimental conditions.

The experimental site represents the newly reclaimed calcareous soils at west Nile Delta region.The soil at the experimental site is calcareous sandy loam in texture with pH of 8.3 and total $CaCO_3$ of about 22%. Average monthly weather data at the experimental site for the period from 2011 to 2015 are presented in table 1. These values were used to calculate monthly reference evapotranspiration (ETo) using Penman-Montieth equation presented in the Basic Irrigation Scheduling (BISm) model as described by Snyder *et al.* (2004).

Table 1. Average (2011-2015) weather data*and the calculated reference evapotranspiration at the experimental site

Month	Srad (MJ m^{-2} day^{-1})	Tmax(ºC)	Tmin(ºC)	Ws(m s^{-1})	Td(ºC)	ETo(mm day^{-1})
December	9.66	16.86	8.10	3.16	5.39	2.40
January	10.46	15.68	6.33	3.32	3.51	2.50
February	12.25	17.86	6.85	3.89	3.30	3.30
Mach	16.42	20.65	8.50	3.51	3.96	4.20
April	19.44	24.60	10.79	3.52	5.18	5.40
May	22. 70	28.48	14.00	3.79	734	5.60

Srad: Solar radiation, Tmax: mean maximum temperature, Tmin: mean minimum temperature, Ws: mean wind speed,Td: mean dew point temperature,ETo: mean reference evapotranspiration.

*Sources of weather data: https://power.larc.nasa.gov/data-access-viewer/

Samples from the upper 60 cm soil surface were collected in 15 cm depth to determine the main soil physical (particle size analysis, and bulk density), chemical properties (pH, ECe, soluble cations and anions), and soil-moisture constants (field capacity, wilting point, and available water). Chemical and physical soil analyses were conducted by the standard methods as described by Tan (1996).Furthermore, soil samples were also analyzed for available macro nutrients.Total N and the available macronutrient values of P and K were 0.28%, 11.60 ppm, and 332.50 ppm respectively. Accordingly, the soil was characterized by low fertility and insufficient available water for plant growth as described by Page *et al*. (1982). EC of the irrigation water was 1.80dS/m and pH value was 7.42.Chemical and physical analyses of the soil at the experimental field are shown in table 2.

Experimental design and tested treatments

The field experiments were laid out in a strip plot design with four replications. Four irrigation treatments were tested as follows:

I1: Irrigation with amounts of water equal to 120% ETo.

I2: Irrigation with amounts of water equal to 100% ETo.

I3: Irrigation with amounts of water equal to 80% ETo.

I4: Irrigation with amounts of water equal to 60% ETo.

Table 2. Main physical and chemical properties of the soil at the experimental site

Soil properties	Soil depth (cm)			
	0-15	15-30	30-45	40- 60
Particle size distribution:				
Sand %	49.00	47.80	46.76	46.25
Silt%	18.40	17.70	16.90	16.99
Clay %	32.60	34.50	36.34	36.76
Texture class*	Sandy, Clay, Loam			
Bulk density, g cm-3	1.27	1.26	1.24	1.23
Field capacity, % w/w	19.25	19.23	19.15	19.00
Permanent wilting point, % w/w	6.50	5.95	5.49	5.45
Available water, %	12.75	13.28	13.66	13.40
ECe, dS/m	1.52	1.85	1.75	2.05
pH (1:2.5 soil: water)	5.25	8.19	8.15	8.10
OM, %	0.55	0.39	0.45	0.35
$CaCO_3$, %	30.10	31.00	27.10	24.30
N, mg kg^{-1}	30.10	32.30	24.26	25.34
P, mg kg^{-1}	13.30	10.65	12.12	11.52
Available K, $mgkg^{-1}$	385.50	320.50	325.50	298.50

* According to (USDA, 2014).

Onion seeds were sown in the nursery on 20/9/2014 in the first season, and on 22/9/2015 in the second season, using 12 kg seeds ha^{-1}. Onion seeds (Giza 20 cultivar)were planted in an area of 10 X 10 m^2as nursery. The experimental plot size was 34 m long and 32 m wide with total area of 1088 m^2. The seedlings were transplanted to the permanent field on December 15th and December 17th in 2015/16 and 2016/17 seasons, respectively. In the permanent field, onion seedlings were planted at density of 140 plants/m^2under surface drip irrigation system.

The irrigation treatments started in the third week of January in both seasons. The surface drip system included irrigation pump (60 hp) with100 m^3 hr^{1} discharge rate, connected to sand and screen filters and differential pressure tank fertilizer injector. The conveying pipeline system consists of a 160 mm PVC main line connected to 110 mm PVC sub-main line and 50.8 mm PVC sub-sub-main line. The drip lateral lines of 16 mm diameter are connected to the sub-main line. Each lateral line is 34 m long and spaced at 0.60 to 1.20 m on the sub-main and is equipped with build-in emitters of 3.8 L h^{-1} discharge rate spaced at 0.30 m on the lateral lines. Each lateral has 16 mm PE valve to control the application of irrigation water and mineral fertilizers used. There were two drip lines $plant^{-1}$ row.

Fertilizers were applied through irrigation water (fertigation) in 80% of irrigation time according to the findings of Taha (2012). All major fertilizers were added in equal doses (2 doses week^{-1}). The fertigation started after 25 days from transplanting onion in both growing seasons. Nitrogen fertilizer (ammonium nitrate, 33.5% N) was added in the rate of 214 kg N ha^{-1}. Potassium sulfate was added in the rate of 114 kg K_2O ha^{-1}, and phosphorus was added in the rate of 246 kg ha^{-1} as phosphoric acid (60% P_2O_5), where application started 25 days after transplanting. Micro-nutrients (11.9 kg of $FeSO_4$, $MnSO_4$, $ZnSO_4$, and 8.14 kg $CuSO_4$ ha^{-1}) were added as foliar spray. All other practices for onion production in calcareous soil were followed. Onion plants were harvested on the 25th of May in 2016 and 2017.

Irrigation water measurements and crop-water relations

Distribution uniformity (DU)

The water distribution uniformity (DU) parameters were measured in the field and calculated by the equation developed by Keller and Bliesner (1990) as follows:

$$DU = \frac{Qn}{Qa} x\ 100$$

where:

DU = Field distribution uniformity (%)

Qn = average flow rates collected from emitters at the lowest quarter of the drip line

Qa = average flow rates collected from all tested emitters

Water consumptive use (WCU)

Crop water use was estimated by the method of soil moisture depletion according to Majumdar (2002) as follows:

$$WCU = \sum_{i=1}^{i=4} (Q2 - Q1)/100 * Bd * D$$

where:

WCU = water consumptive use or crop evapotranspiration, ETc (mm)

i = number of soil layers

θ2 = soil moisture content after irrigation, (%, by mass)

θ1 = soil moisture content just before irrigation, (%, by mass)

Bd = soil bulk density, (g/cm^3)

d = depth of soil layer, (mm)

Applied irrigation water

The amounts of applied irrigation water were calculated according to the equation given by Vermeiren and Jopling (1984) as follows:

$$AIW = \frac{ETo\ X\ 1}{EA\ (1\text{-}LR)}$$

where:

AIW = depth of applied irrigation water (mm)

ETo = reference evapotranspiration (mm day $^{-1}$) calculated using BISm model

I = irrigation intervals (days)

Ea = irrigation application efficiency of the drip irrigation system (Ea = 87.95 and 91.35% for the first and second seasons, respectively)

LR = Leaching requirements (was not considered in this study to avoid the effect on the tested deficit irrigation treatments)

Crop coefficient (Kc)

The local crop coefficient values for onion crop were calculated under the 120% ETo treatment according to Allen *et al.* (1998) as follows:

$$Kc = \frac{ETc}{ETo}$$

Where,

ETc is crop evapotranspiration H" water consumptive use (WCU)

Water use efficiency (WUE)

Water use efficiency is calculated according to Stanhill (1986) as:

$$WUE = \frac{\text{Onion yield, Y (kg ha}^{-1}\text{)}}{\text{Consumed irrigation water, WCU (m}^3\text{ ha}^{-1}\text{)}}$$

Where,

Y = onion yield (kg ha^{-1}).

WCU =Water consumed by the crop during the growing season (m^3 ha^{-1})

Crop water productivity (WP)

Crop water productivity is calculated according to Zhang (2003) as follows:

$$WP = \frac{\text{Onion yield, Y (kg ha}^{-1}\text{)}}{\text{Applied irrigation water, AW (m}^3\text{ ha}^{-1}\text{)}}$$

Yield and yield components

A. Growth characters

After 133 days from transplanting, 20 plants were randomly selected from each plot to measure:

1.Plant height (cm) : Its value was recorded from the point of the green leaves emergence (the sheaths area) up to the top of the longest leaf.

2.Number of green leaves plant^{-1}: Its values were recorded by counting the visible leaves.

B.Chlorophyll in leaves: It was measured according to Barnes *et al.* (1992)

C.Bulb yield characters:

1.Total yield (ton ha^{-1}): total yield of each plot in the two seasons were recorded

2. Marketable yield (ton ha^{-1}): yield of bulbs free from double, damage, and bolters from each plot were recorded.

3.Average bulb weight (**g**): calculated from total weight of single bulbs and the total number plot^{-1}.

D.Bulb quality traits:

1. Percentage of single bulbs: It was determined by dividing the number of single bulbs by the total number of bulbs plot^{-1} then multiplied by100.
2. Percentage of double bulbs: The number of the double bulbs divided by total numbers of bulbs then multiplied by100.

3. Percentage of bolters: The number of bolters was divided by the total number of bulbs plot^{-1} then multiplied by100.
4. Total soluble salts (TSS): It was measured in extracted juice, by squeezing a cross section of flesh at the top the largest bulb diameter, using a sand hard refractometer after 200 days from harvest.
5. Storage ability: It was expressed by calculating the sprouted bulb ratio. This parameter measures the effect of the rest and dormancy periods, under normal storage conditions.
6. The increasing of the rest and dormancy periods; i.e., the low sprouting percentage; means increasing marketable bulbs. The bulbs were kept under normal storage conditions for 200 days after harvest, then the number of sprouted single bulbs were counted to estimate this parameter.

Statistical analysis:

Data were statistically analyzed according to analysis of variance (ANOVA) as reported by Gomez and Gomez (1984). Means of the treatments were compared using Least Significant Difference (LSD) at 5% level of significance as developed by Waller and Duncan (1969).

RESULTS AND DISCUSSION

Distribution uniformity

The calculated water distribution uniformity (DU) values of the two tests conducted at the beginning of the 1st and 2ndgrowing seasons were 87.95 and 91.35%, respectively. The obtained results showed a little increase in DU values in the second season, as compared to the first season due to injecting the drip irrigation system with phosphoric acid to flush the drip lateral lines. This trend of results was close to that obtained by El-Tomy (2008) and Taha (2012, 2013 and 2018), who stated that the distribution uniformity values for lateral lengths of 20, 24 and 40 m were 97, 93 and 92 %, respectively.

Applied irrigation water, saved water, and water consumption

Data regarding the effect of tested treatments on the depths of applied irrigation water and saved water during the 2015/16 and 2016/17 seasons are presented in table 3. Results indicated that the depths of applied water were 589.1, 490.9, 392.7, and 294.5 mm during 2015/16 season and were 562.9, 472.9, 378.3, and 283.7 mm during 2016/17 season for the 120, 100, 80, and 60% ETo treatments, respectively. The percentage of saved water were 17, 33, and 50% for the 100, 80, and 60% ETo, respectively as compared with the 120% ETo treatment. The results indicated, in general, that increasing water availability to the plants increased water consumption. The highest values of seasonal water consumptive use were 4595 and 4430 m^3 ha^{-1} under irrigation with 120% ETo treatment in the first and second growing seasons, respectively. Whereas, the lowest values of seasonal water consumptive use were 2431 and 2360 m^3 ha^{-1} obtained under irrigation with 60% ETo in the first and second seasons, respectively. This trend of results was close to that obtained by Teferi (2015) who found that the drip irrigation method saved 29.4 % and 43.5% water, and gives 32.8 % and 19.4 % more yields under 1.0 ETc and 0.8 ETc water application respectively.

Onion yield and its components

The effect of irrigation treatments on plant height (cm), number of leaves plant^{-1} and chlorophyll in leaves is shown in table 4. The results indicated that plant height increased with increasing quantities of water in both the seasons. The values of plant height were 74.10, 71.80, 69.75 and 67.45 cm in the first season and 76.50, 73.10, 69.54 and 67.20 cm in the second season for the 120,100, 80, and 60% ETo treatments, respectively. Results indicated that, plant height for the 120% ETo treatment was significantly higher than that of 60% ETo, while there was no significant difference among the 100, 80, and 60% ETo treatments. The same trend was recorded for number of leaves plant^{-1} trait. Increasing applied water increased number of leaves plant^{-1}. The 2-years average number of leaves plant^{-1} decreased with increasing deficit irrigation to be 7.50, 6.79, 6.63 and 5.28% under 120, 100, 80 and 60% ETo treatments, respectively which could be attributed to the negative effect of water stress on onion plants compared to application of 120% ETo irrigation treatment. Moreover, under 120% ETo the crop was able to develop sufficient biomass and root system leading due to increasing both plant height and number of leaves plant^{-1}. These results agreed with that reported by Khan *et al.* (2005), and byPejiæ *et al.* (2011), who found that yield components and morphological characteristics of onion bulbs were affected by irrigation treatments.

The results in table 4 showed also that increasing the applied irrigation water significantly increased the chlorophyll in onion leaves. The values were 36.15, 34.95, 30.80 and 27.91 in the first season and 36.40, 35.13, 31.10 and 28.10 in the second season under 120, 100, 80, 60% ETo irrigation treatments, respectively.

It can be noticed from table 4 that, all the studied characters slightly increased in the second growing season compared to the first growing season under all irrigation treatments. This result could be due to the increase in the distribution uniformity of the drip system in the second growing season with direct effect on more efficient water and fertilizer distribution in the field.

The results in table 5 indicated that irrigation treatments had significant effect on bulb weight (g), total and marketable yields in the two growing seasons. The results also showed that the highest bulb weight, and total and marketable yields were produced from irrigation with 120 % ETo compared to other treatments. Meanwhile, the lowest values were recorded under 60% ETo treatment . It is showed that average total onion yield was reduced under the 100%, 80% and 60% ETo treatments as compared to the 120% ETo by 8, 16 and 20%, respectively. The reduction in the yield could be attributed to shortage of water needed for the suitable growth of onion, while under the 120% ETo the crop was able to develop sufficient biomass and root system leading to achieving the highest yield. The obtained results were similar to those of Kandil and El-Feky (2006), who indicated that adequate irrigation provided at the early crop growth stages can realize high yields in calcareous soil. They also found that increased amount of irrigation water increased onion bulb yield, bulb weight, total and marketable yields under drip irrigation system. The results indicated also that there was significant difference between total marketable yields obtained from the 120% ETo treatment and the other treatments in the 1st season, while the marketable yields of the 120 and 100% ETo treatments were significantly different than the yields of 80% and 60% ETo treatments in the2nd season. From the obtained results, it could be concluded that irrigating onion with amount of water equal to 120% ETo irrigation water increased average marketable yield by 7.6, 18 and 21% as compared to the 100, 80 and 60% ETo treatments. It is recommended to meet the requirements of full irrigation allowing the crop to develop sufficient biomass and root system leading to increase in marketable yield under deficit irrigation. Similar results were obtained by Anonymous (2001) and Daniel *et al*.(2018), they reported that application of higher irrigation depths promoted higher production of bulbs in weight and classes diameter 60 to 90 mm. Similarly, Smith (2011) stated that the application of 80% of full irrigation water reduced bulb yields by about 10%.It can be also noticed that a slight increase in the values of all the studied characters occurred in the second growing season compared to the first season due to the increase in the distribution uniformity of the drip system with direct effect on more efficient water and fertilizer distribution in the field.

Effect of irrigation treatments on ratio of single, double bulbs and ratio of bolter

Table 6 showed the effect of irrigation treatments on ratio of single bulbs, ratio of double bulb and ratio of bolters. The results indicated that there was in significant difference between treatments on these ratios in the two seasons. On the other hand, the ratio of single bulb reached the highest values, namely 95.28, 95.26, 95.50 and 95.26% in the first season and 87.50, 87.72, 88.96 and 87.72% in the second season with 120, 100, 80 and 60% ETo, respectively. In addition, the ratio of double bulb and ratio of bolters together were 4.74, 4.50 and 4.44% in the first season and 13.74, 11.04 and 12.28 % in the second season under 120, 100, 80 and 60% ETo, respectively. This result due to temperature fluctuations during the latter part of the growing season (March and April), were believed to influence double bulbs formation, which lowered their marketable appeal. This result affirmed by Hannaalla *et al.* (1991) and Boyhan *et al.*, (2001), who reported that this trait is genetic character and not easily affected by fertilizer rates. In general, cool temperatures during the latter part of the growing season (March and April), when plants are relatively large, can result in a high percentage of seed stems (bolters), ultimately affecting their consumable appeal as indicated by Boyhan *et al*. (2001) and Khokhar *et al*. (2002). This result is supported by the finding of Clinton *et al*.(2007), who reported that drip irrigation could be more conducive to produce single-centered onions, because the irrigation interruptions necessary for cultivation and fertilization. Furthermore, onion single centeredness was reduced by short-duration water stress. Choice of irrigation system and cultivar are important factors in producing single-centered bulbs.

Effect of irrigation treatments on sprouting ratio and total soluble salts

The results in tables 7 showed the effect of irrigation treatments on sprouting ratio (%) and total soluble salts (TSS, %).The sprouting ratio increased with the increasing applied water, its values were 0.89, 0.86, 0.77 and 0.72% in the first season and 0.89, 0.87, 0.78 and 0.72% in the second season under 120, 100. 80 and 60% ETo of irrigation treatments, respectively. Kumar *et al.* (2006) indicated that the onion bulbs grown under low soil moisture regime resulted in higher loss in weight of bulbs. The soluble solids values increased with exposing onion plants to higher water stress, its values were 7.90, 8.81, 9.74 and 10.20% in the first season and 7.88, 8.82, 9.76 and 10.22% in the second season under 120, 100, 80, and 60% ETo of irrigation treatments, respectively, where these differences were statistically significant (Table 7). Rajput and Patel, (2006) indicated that the TSS value under surface drip irrigation was observed to be high, which may be attributed to better utilization of nutrients under frequent and controlled irrigation water application, as well as water replacement to the soil lower than 100% ETc causes the crop to use more energy in water absorption, thus not using it for bulb filling. These results were similar to what was obtained by Patel and Rajput (2013), Pejic *et al.*(2011), who reported that TSS content increased significantly with the decreasing soil moisture may be attributed to better utilization of nutrients under frequent and controlled irrigation water application under drip irrigation system.

Water use efficiency and water productivity

The results in table 8 showed that the highest water use efficiency values of 14.24 and 15.19 kg/m^3 for first and second season, respectively were obtained under the application of 60% ETo irrigation treatment. The lowest values of water use efficiency, i.e. 9.41 and 10.31 kg/m^3 for first and second season, respectively were obtained irrigation with 120%ETo.These results are in agreement with that of Enciso *et al.* (2015). They reported that the irrigation use efficiency of onion obtained under drip irrigation system ranged from 17.5 to 25.2 kg/m^3.Similarly, Walle (2014) found that net water use efficiency of 14.74 to 16 .75 kg/m^3 was obtained at full irrigation treatments under drip irrigation method. Gebremedhin (2015) found that higher irrigation water use efficiency of 7.1 kg/m^3 was obtained at 1.0 ETc under drip irrigation method. The results also showed that, crop water productivity values of 11.76 and 12.63 kg/m^3 were highest under the application of irrigation at 60% ETo than the other treatments in both the seasons. The values of water productivity in the second season were in a range of 3.38 to 5.51 kg/m^3, which decreased with the increase in irrigation depth or increase in irrigation water applied.

Crop coefficient (Kc):

The calculated Kc values for the optimum irrigation treatment, namely 120% ETo, are illustrated in Fig. 1. The Kc values for the 120% ETo irrigation treatments were 0.54-0.88, 1.0-1.05, 0.95, and 0.62 for crop initial, development, mid-season and late-season growth stages, respectively. The highest Kc value occurred after 90 days from transplanting, then declined rapidly from 0.95 to 0.62 during the late season stage after 135 days from transplanting. This may be due to the begin of the senescence of foliage, which is usually associated with less efficient stomatal conductance of leaf surfaces due to the effects of ageing (Allen *et al.,* 1998). Kc values of fully irrigated treatments ranged from 0.39 to 1.15.The values for the four growth stages (initial, crop development, midseason and late-season) were found to be 0.50, 0.76, 1.14 and 0.78, respectively.

Based on the results of the present study it could be concluded that the 2-year average total applied irrigation water for the 120, 100, 80, and 60% ETo treatments were 5760, 4819, 3855, 2891m^3 ha^{-1} respectively. There was a significant effect of the tested treatments on onion average bulb weight, total and marketable yields. The 2-years average total yield values were 44.46, 40.17, 36.56 and 35.24, tons ha^{-1} for the 120, 100, 80, and 60% ETo treatments, respectively. Soluble solids (TSS) increased with increasing deficit irrigation, the values were 7.90, 8.80, 9.74 and 10.20% in the first season and 7.88, 8.82, 9.76 and 10.22% in the second season under 120, 100, 80 and 60 % ETo of irrigation treatments, respectively. The Kc values for the 120% ETo irrigation treatments were 0.54-0.88, 1.0-1.05, 0.95, and 0.62 for initial crop development, mid-season and late-season growth stages, respectively. The measured Kc values in this paper can be used to manage irrigation scheduling for onion crop under similar conditions of agro-climatic zones in Egypt. In case of water shortage, irrigating onion in calcareous soil under drip irrigation with 100% ETo can be recommended, where 17% of the irrigation water could be saved, compared to 120% ETo without significant reduction in crop yield.

Table 3. Effect of tested treatments on the depths (mm) and amounts (m^3 ha^{-1}) of applied irrigation water, saved water and water consumption by onion during 2015/16 and 2016/17 growing seasons

Irrigation treatments	2015/16			2016/17		
	Applied water (mm) & (m^3 ha^{-1})	% saved	Water consumption (m^3 ha^{-1})	Applied water (mm) & (m^3 ha^{-1})	% saved	Water consumption (m^3 ha^{-1})
120% ETo	589.1 (5891)	—-	4595	562.9 (5629)	—-	4430
100% ETo	490.9 (4909)	17	3859	472.9 (4729)	17	3817
80% ETo	392.7 (3927)	33	3162	378.3 (3783)	33	3086
60% ETo	294.5 (2945)	50	2431	283.7 (2837)	50	2360

Table 4. Effect of irrigation treatments on average plant height, number of leaves $plant^{-1}$ and chlorophyll contents in leaves $plant^{-1}$

Irrigation treatments	Plant height (cm)		No. of leaves $plant^{-1}$		Chlorophyll in leaves $plant^{-1}$	
	2015/16	2017	2016	2017	2016	2017
120 % ETo	74.10	76.50	7.35	7.65	36.15	36.40
100% ETo	71.80	73.10	6.72	6.85	34.95	35.13
80 % ETo	69.75	69.54	6.61	6.65	30.80	31.10
60% ETo	67.45	67.22	5.25	5.3	27.91	28.10
LSD 0.05	4.77	4.09	1.65	1.48	2.29	1.98

Table 5. Effect of irrigation treatments on average bulb weight (g), total yield, reduction %, and marketable yield

Irrigation treatments	Average bulb weight (g)		Total yield (tons ha^{-1})				Marketable yield (tons ha^{-1})	
	2015/16	2016/17	2016	reduction %	2017	reduction %	2016	2017
120 % ETo	81.00	122.00	44.40	---	48.84	---	43.25	45.66
100% ETo	75.80	111.80	41.15	7	44.64	9	39.20	41.13
80 % ETo	69.80	103.60	37.75	15	40.39	17	35.82	37.30
60% ETo	68.20	101.00	36.22	18	37.85	23	34.64	35.84
LSD 0.05	6.81	9.35	3.80	---	2.95	---	3.12	5.33

Table 6. The effect of irrigation treatments on the ratio of single bulb, ratio of double bulb and ratio of bolters

Irrigation treatments	Ratio of single bulb (%)		Ratio of double bulb (%)		Ratio of bolters (%)	
	2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
120 % ETo	95.28 a	87.50	3.10 a	4.98 a	2.18 a	8.33 a
100% ETo	95.26 a	87.72 a	2.30 a	4.29	2.44 a	8.024
80 %ETo	95.50 a	88.96a	1.64 a	4.96 a	2.86 a	6.08a
60% ETo	95.26 a	87.72 a	1.50 a	5.26 a	2.94	8.49 a
LSD 0.05	-	-	0.53	-	-	0.49

Table 7. The effect of irrigation treatments on sprouting ratio and total soluble salts (TSS)

Irrigation treatments	Sprouting Ratio (%)		TSS (%)	
	2016	2017	2016	2017
120 % ETo	0.91 a	0.89 a	7.90 b	7.88 b
100% ETo	0.86 a	0.87 a	8.80 b	8.82 b
80 %ETo	0.77 ab	0.78 b	9.74 a	9.76 a
60% ETo	0.72 b	0.72 b	10.20 a	10.22 a
LSD 0.05	0.15	-	0.88	1.19

Table (8).Water use efficiency and water productivity of marketable onion as affected by different irrigation treatments in 2015/16 and 2016/17 growing seasons

Irrigation treatments	WUE (kg/m^3 consumed water)		WP (kg/m^3 applied water)	
	2015/16	2016/17	2015/16	2016/17
120% ETo	9.41	10.31	7.34	8.12
100% ETo	10.16	10.78	7.98	8.70
80% ETo	11.33	12.10	9.12	9.86
60% ETo	14.24	15.19	11.76	12.63

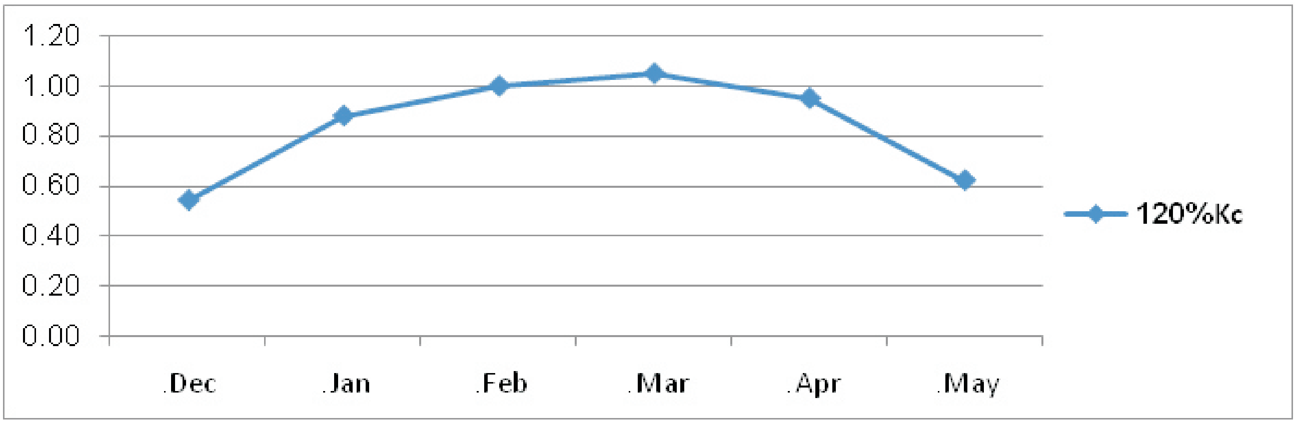

Fig. 1. Crop coefficient (Kc)curve for onion crop developed 120% ETo irrigation treatment

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