ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Water Requirements of Drip Irrigated Cumin and Their Effects on Growth, Yield and Some Physiological As Well As Biochemical Parameters.

Fahmy A.S. Hassan[a,c], and Esmat F. Ali* [b,c].

[a]Horticulture Department, Faculty of Agriculture, Tanta University, Tanta, Egypt
[b]Horticulture Department, Faculty of Agriculture, Assuit University, Egypt
[c]Current address: Biology Dep. Fac. of Science, Taif University, Saudi Arabia

ABSTRACT

The effect of different irrigation levels on growth, yield, oil content and chemical constituents of cumin plant were investigated. The amount of applied irrigation water was added as 20, 40, 60, 80 and 100 % of the potential evapotranspiration (ETP) values based on class-A pan. Plant growth as well as fruit and oil yields were negatively affected by deficit irrigation. Relative water content, membrane stability index and soil water content were maintained higher than those obtained by deficit irrigation. Irrigation water use efficiency (IWUE) was increased by reducing the irrigation level. Increasing the irrigation level from 20 to 100 % ETP gradually decreased the volatile oil percentage. GC-MS analysis of volatile oil revealed that the main components were cumin aldehyde, cumin alcohol, p-cymene, α-pinene and β-pinene. These components were slightly affected by deficit irrigation. Unlike carbohydrate percentages, chlorophyll content and N, P, K were increased with increasing irrigation level. Deficit irrigation increased fruit phenolic content as well as DPPH scavenging capacity. Applying 75 % ETP irrigation level was the optimum level and it can be recommended as a possible technique for saving water and maximizing the irrigation water use efficiency in cumin cultivation.

Keywords: cumin, phenolics, evapotranspiration, soil water content, membrane stability, oil.

INTRODUCTION

Cumin (*Cuminum cyminum,* L.) plant, Family (*Apiaceae*) is a short winter annual herb. It has been cultivated in the Mediterranean regions for a long time and also planted in different countries all over the world [1]. Because cumin fruits contain volatile oil (1-5 %), they are used as a spice for its distinctive aroma, [2] and have been used for treatment of toothache, dyspepsia, diarrhea, epilepsy and jaundice [3]. Because of the great importance of cumin as natural sources for producing volatile oil which has several uses for pharmaceutical and food industries [4], more investigations for improving the growth and productivity of this plant are still needed. Generally, irrigation is very important factor affecting the growth and yield of medicinal and aromatic plants. Because of the negative effects which occurred as a result of regular irrigation system, researchers have been working to find alternative methods for improving the irrigation techniques in order to obtain the efficient use of scarce water resources [5]. Water scarcity is a growing global problem that challenges sustainable development and expansion of cultivated area to meet increasing food requirements. In addition, water is characterized as such no alternative source can substitute it and it is not a commercial resource or commodity. Therefore, the great challenge for the coming decades will be the task of increasing the productivity of water unit [6].

Deficit irrigation is the most important factor restricting plant growth and productivity in the majority of agricultural fields of the world including cumin plant [7] even with its ability to absorb water in very low water potential. Therefore, irrigation scheduling is very essential to maximize crop yield and most efficient use of scarce water resources. There are several methods for estimating water requirements including potential evapotranspiration based on Class A Pan [8,9]. Vegetative growth and fruit yield of coriander were significantly improved when the highest evapotranspiration (ETP) was applied compared with lower levels [10,11]. Moreover, frequent irrigation has been found to be important to maximize the fruit yield and dry matter accumulation unlike carbohydrate content [12]. Water deficit based on evapotranspiration negatively affected the growth characters and yield components of some Apiaceae crops including cumin [12-14].

It has been reported that irrigation treatment had significant effects on growth, yield and volatile oil content of cumin [4, 15]. Reducing the amount of irrigation water applied has been found to increase the volatile oil percentage however the volatile oil yield was in an opposite manner [16, 17]. On the other hand, increasing both volatile oil percentage and yield with increasing irrigation water have been reported [11]. Water deficit also modified the essential oil chemo-type and changed its components and greatly influenced the biochemical composition of several medicinal and aromatic [9, 14, 17].

In plant production, instead of obtaining maximum yield from a unit area by full irrigation, water productivity can be optimized within the concept of deficit irrigation [18]. To the best of our knowledge, studies concerning the effects of the amount of water supply on the yield and oil content as well as its composition are very scarce on cumin plant especially when evapotranspiration potential was used as a tool to estimate the quantity of water applied. Of the few studies that have been carried out of cumin, most of them have been carried out on fruit yield and the information about the changes in water relation, membrane stability index and total phenolic content and fruits antioxidant activity is scarce. Therefore, it is very important to determine the optimum irrigation level of cumin plant in order to increase the productivity of water unit. So, the aim of this study was to estimate the optimum irrigation level based on class-A pan which maximizes the productivity as well as quality of cumin plant. Plant water relation, membrane stability index, soil water content and fruit phenolic content as well as antioxidant activity in relation to irrigation treatments were investigated.

MATERIALS AND METHODS

Plant material

In order to study water requirements and their effects on growth, yield and some physiological as well as biochemical parameters of drip irrigated cumin, five irrigation treatments based on class a pan were applied. The amount of irrigation water was 20, 40, 60, 80 and 100 % of evapotranspiration potential (ETP). The experiment was carried out at a private farm at Taif Governorate during 2013/2014 and 2014/2015 seasons. The physical properties of soil used were (sand, 84.25 %, silt 6.20 % and clay 9.55 %) and chemical

ISSN: 0975-8585

properties were (pH, 8.43, EC, 2.53 dsm^{-1}, OM, 0.13 %, Total $CaCO_3$, 0.94 %, Total N, P, K were 0.19, 0.042 and 0.087 %, respectively). The soil was prepared and divided into five blocks; each of them was 1.6 x 50 m and contained 3 rows and all treatments were randomly distributed in each one. The cumin fruits were sown on November 5st, 2013 in the first season and on November 8rd, 2014 in the second one. The distances between hills were 25 cm (74970 hills/ha). The treatments were arranged in a complete randomized block design with five replicates.

The efficiency parameters of drip irrigation system used were calculated and the emission uniformity was ranged between 96 % and 91 % based on the actual discharge rate of 3.6 Lh^{-1} along the drip lines.

At harvesting stage (before fruits were fully ripe but sufficiently hard and greenish yellow in color) 25 plants from each replicate in each season were randomly chosen to study the growth and yield parameters. The plants were harvested and left under shading for about one week then, hammered for fruit separation.

Growth characters and yield components

The following parameters were measured and recorded; plant height (cm), branch number/plant, plant fresh and dry weights (g), umbel number, weight of 1000 seeds, fruit yield/hill (g) and/ha (kg), volatile oil percentage and yield (ml/hill and L/ha).

Relative water content (RWC)

Leaves RWC were measured as mentioned by Weatherley [19] as following:

$$(W_{fresh} - W_{dry}) / (W_{turgid} - W_{dry}) \times 100,$$

where W_{fresh} is the sample fresh weight, W_{turgid} is the sample turgid weight after saturating with distilled water for 24 h at 4 °C, and W_{dry} is the oven-dry (70 °C for 48 h) weight of the sample. Samples were taken at Dec. 1st, Jan. 1st, Feb. 1st and Feb. 15th in both seasons.

Soil water relationships

Class A pan evaporation method was used to obtain potential evapotranspiration and crop coefficient potential evapotranspiration (ETP) and crop values by the method of Doorenbos and Pruitt [20] and the values were presented in Table (1).

$$ETP = E\ pan \times K\ pan$$

E pan = Pan evaporation (mm/day)
K pan = Pan coefficient - K pan values depend on the relative humidity wind speed and the site condition, the K pan value of 0.75 was used for the experimental site.

Amount of applied irrigation water (AIW)

The quantity of irrigation water was measured by flow water and calculated by the method of Vermelien and Goopling [21] and presented in Table (2) using the following equation:

$$AIW = \frac{ETP \times Kr \times I\ interval}{Ea} + LR$$

Where:

AIW: Applied irrigation water depth
ETP: Potential evapotranspiration (mm/day) values obtained by class A pan evaporation method.
Kr: Reduction factor that depends on ground cover. It varied from 0.7 at the beginning of the growing season to 0.1 for the rest of the season

Ea: Irrigation efficiency values measured at the site = $K_1 \times K_2$ = 0.85

where:
K_1: Emitter uniformity coefficient = 0.91 for the drip system at the site.
K_2: Drip irrigation system efficiency = 0.96.
I interval: Irrigation intervals = 3 days at the site
LR: Leaching requirements (no additional water for leaching was added during growing seasons due to the low EC values irrigation water and soil profile).

Soil water content measurement

Soil water content was measured before and after each irrigation event. Soil samples were taken during December and January (20 irrigations) in both seasons. The samples were taken from the soil under the drippers at depth of 0–30 and 30–60 cm. Soil water was recorded as oven dry basis according to Marshall et al. [22] and the available water was measured by the following equation:

$$De = \theta_v \times D / 100$$

Since:

De is equivalent water depth (mm), θ_v is the volumetric water content (%), and D is the soil depth (mm).

Table 1: E pan* and ETP* in (cm/month) during 2013/2014 and 2014/2015 seasons.

Month	E pan		ETP	
	2013/2014	2014/2015	2013/2014	2014/2015
Nov.	9.87	10.68	7.40	8.01
Dec.	6.76	6.84	5.07	5.13
Jan.	6.98	4.48	5.24	3.36
Feb.	7.82	5.61	5.87	4.21
Total	31.43	27.61	23.57	20.71
m^3/ha	2357.1	2070.6	1767.8	1552.9

E pan* means Pan evaporation; ETP* means evapotranspiration potential

Table 2: Amount of applied irrigation water (AIW) as affected by irrigation treatments based on evapotranspiration potential ETP (%) during 2013/2014 and 2014/2015 seasons.

ETP* (%)	20	40	60	80	100	20	40	60	80	100
Month	2013/2014					2014/2015				
Nov.	1.96	3.92	5.88	7.84	9.80	2.12	4.24	6.36	8.48	10.60
Dec.	1.34	2.68	4.03	5.37	6.71	1.36	2.72	4.07	5.43	6.79
Jan.	1.39	2.77	4.16	5.54	6.93	0.89	1.78	2.67	3.56	4.45
Feb.	1.55	3.11	4.66	6.21	7.76	1.11	2.23	3.34	4.46	5.57
Total	6.24	12.48	18.72	24.96	31.20	5.48	10.96	16.44	21.93	27.41
m^3/ha	467.9	935.6	1403.5	1871.2	2339.1	411.0	821.8	1232.8	1643.9	2054.7

***ETP means evapotranspiration potential.**

Irrigation water use efficiency (IWUE)

Irrigation water use efficiency IWUE, i.e. yield/unit of applied water was determined according to Howell et al. [23]. IWUE (Kgm^{-3}) =Yield (Kg/ha)/Total applied water (m^3/ha).

Volatile oil determination

The volatile oil percentages were determined by a water distillation method described in British Pharmacopea [24], using the following equation: Volatile oil percentage = oil volume in the graduated tube/fresh weight of sample x 100. Then, the oil yield (hill and ha) were calculated.

Volatile oil composition

Analysis of the oil was carried out using GC-MS. Varian GC CP-3800 and MS Saturn 2200 equipped with a Factor Four capillary column (VF-5 ms 30 X 0.25 mm ID and film thickness 0.25 µm). The chromatograph was fitted with a DB-5-Ms 30 m × 0.250 mm × 05µm film thickness fused silica capillary column. Helium was used as the carrier gas with a flow rate of 1.7 mL/min. Initial temperature 50 °C was held for 5 min, then programmed to rise (first from, 30 °C /min to 120 °C for 2 min and second, 20 °C/min to 170 °C for 2 min. The interface temperature was 230 °C, injector temperature was 190 °C, the final temperature was 170 °C for 3 min and the run time was 57.33 min. Det-gain 1.80 KV. Percentages of peak area were calculated with a Hewlett-Packard 3396 integrator. The volatile oil components were identified by comparing their retention times and mass spectrum with those of standards, NIST library of the GC-MS system.

Chlorophyll, carbohydrates and nutrients analysis

Leaf fresh samples were randomly taken from the middle part of plant for chlorophyll determination. Chlorophyll content was determined according to Sadasivam and Manickam [25] by using spectrophotometer (type GBC, UV/VIS 916) and calculated as (mgg^{-1} FW).

The wet digestion procedure for leaves dried sample (0.5 g) was performed to determine nutrient content. Samples were taken for determination of N, P, K and total carbohydrates percentages. Nitrogen was determined in the digestion using the micro-Kjeldahl method [26]. Phosphorus was spectrophotometrically determined and potassium was determined by flame photometer as described by A.O.A.C. [27]. Total carbohydrate percentages were determined in dried leaves in an electric oven at 70 °C for 24 hours. Then, the fine powder was used to determine total carbohydrate percentages according to Herbert et al. [28].

Total phenolic and DPPH radical scavenging

Samples of 1 g powder from dry fruits were stirred with 10 ml of 80 % acetone for 30 min. The acetone extracts were taken for determination of total phenolic amounts using Folin–Ciocalteu reagent according to Dewanto et al. [29] by measuring the absorbance at 760nm. Total phenolic contents were expressed as mg of gallic acid equivalents per gram of dry weight (mg GAE g^{-1} DW), through a calibration curve with gallic acid.

The acetone extracts were also used for radical-scavenging activity determination as described by Hanato et al. [30] by using DPPH methanolic solution and measuring the absorbance at 517 nm. BHA (butylated hydroxyanisole) was used as positive reference while methanol was used as negative reference. The activity of DPPH radical-scavenging was expressed as the inhibition percentage (I %) and was calculated according to the following equation:

$$I (\%) = 100 \times (A_{blank} - A_{sample}) / A_{blank}$$

where:

A_{blank} is the absorbance of the control at 30 min reaction (containing all reagents except the test compound), and A_{sample} is the absorbance of the sample at 30 min. The concentration of the extract generating 50 % inhibition was considered as antiradical activity (IC_{50}).

Membrane stability index (MSI)

Leaf samples from each treatment were taken at Dec. 1st, Jan. 1st, Feb. 1st and Feb. 15th in both seasons for determining ions leakage by using the method of Sairam et al. [31]. Two leaf samples (0.2 g) were taken and placed in 20 ml of double distilled water in two different 50 ml flasks. The first one was kept at 40 °C for 30 min while the second one was kept at 100 °C in boiling water bath for 15 min. The electric conductivity of the first (C_1) and second (C_2) samples were measured with a conductivity meter. The leakage of ions was expressed as the membrane stability index according to the following formula, MSI = $[1- (C_1/C_2)] \times 100$.

Statistical analysis

Data obtained from two experiments (2013/2014 and 2014/2015 seasons) were pooled and combined analysis was occurred for both of them together and the analysis of variance (ANOVA) was performed using MSTAT program, USA. Means were separated using Duncan's multiple range test at a significance level of 0.05 (*n=10*).

RESULTS

Vegetative growth characters

Plant height, number of branches as well as fresh and dry weights of cumin plant were increased with increasing water irrigation level and reached their maximum values when the highest level (100 % ETP) was used (Table 3). Although this treatment recorded the highest values, there were no significant differences when compared with 100 % ETP treatment. In addition, the statistical analysis of results showed that the differences between 80 and 60 % ETP were insignificant in most cases. On the other hand, the lowest irrigation level 20 % ETP gave the lowest vegetative growth values in this respect.

Table 3: Response of vegetative growth characters of cumin plant to different irrigation treatments based on evapotranspiration potential ETP (%).

Treatments ETP* (%)	Plant height (cm)	Number of branches	Plant fresh weight (g)	Plant dry weight (g)
20	14.13c	8.58b	4.83c	2.24c
40	15.42c	8.77b	4.94bc	2.33bc
60	17.05b	9.06ab	5.50b	2.61b
80	18.34ab	9.58a	5.90ab	2.76b
100	19.77a	9.91a	6.48a	3.22a

- *ETP means evapotranspiration potential.

- The results of two experiments (2013/2014 and 2014/2015 seasons) were pooled and combined analysis was occurred for both of them together. Means followed by different letters were significantly different according to Duncan multiple range test at 0.05 level (*n=10*).

Fruit yield components

Data presented in Table (4) clearly indicate that the fruit yield components significantly enhanced by increasing the level of water applied. The number of umbels, fruit yield of both hill and ha and 1000-fruits weight were gradually increased with increasing ETP level from 20 to 100 % however the differences among the three higher levels (60, 80 and 100 % ETP) were insignificant. Our results obtained here showed that the irrigation water use efficiency (IWUE) was significantly reduced with increasing the irrigation level. The best IWUE was recorded by using the lowest irrigation level (Table 4).

Volatile oil content

The volatile oil percentage of cumin fruits were decreased with increasing the amount of water applied. The highest volatile oil percentage was obtained by applying 20 or 40 % ETP treatments since the differences between them were insignificant (Table 4). An opposite trend was observed concerning oil yield since increasing the irrigation level from 20 to 100 % ETP led to an increase in oil yield. However, there were no significant differences among 60, 80 and 100 % ETP treatments in this respect.

Table 4: Response of fruit yield components and oil content of cumin plant to different irrigation treatments based on evapotranspiration potential ETP (%).

Treatments ETP* (%)	Umbel number /plant	Fruit yield g/hill	Fruit yield kg/ha	1000 fruit weight (g)	IWUE* (Kgm^{-3})	Volatile oil (%)	Oil yield (ml/hill)	Oil yield (L/ha)
20	12.12c	7.80c	584.41c	2.76b	1.34a	3.22a	0.25b	18.83b
40	12.56c	8.11c	607.97c	2.84b	0.70b	3.12a	0.25b	18.93b
60	13.51ab	9.19ab	688.65ab	2.93a	0.53c	2.91b	0.27a	20.03a
80	14.17a	9.82a	736.37a	3.05a	0.42d	2.87b	0.28a	21.16a
100	14.90a	9.94a	744.82a	3.15a	0.34e	2.82b	0.28a	21.03a

- *ETP means evapotranspiration potential.
- The results of two experiments (2013/2014 and 2014/2015 seasons) were pooled and combined analysis was occurred for both of them together. Means followed by different letters were significantly different according to Duncan multiple range test at 0.05 level (*n=10*).

Volatile oil composition

The results showed that the main components of volatile oil were cumin alcohol and cumin aldehyde since these two components recorded about 70 % from oil content (Table 5). Some components were identified also in volatile oil but recorded lower percentages such as α- pinene, β-pinene, p-cymene, β-phellandrene, α-terpineol and citral. The total percentage of identified components was ranged from 90.60 to 94.91 % according to the treatment. Generally, slight changes among treatments were recorded in this respect. Otherwise, the percentages of main components were slightly increased with increasing the irrigation level from 20 to 60 % ETP and decreased thereafter. The highest values of identified components were recorded by 60 % ETP treatment.

Table 5: Volatile oil composition of cumin fruits as affected by different irrigation treatments based on evapotranspiration potential ETP (%)

Components	ETP* %				
	20	40	60	80	100
α- Pinene	7.53	7.42	7.11	7.41	7.67
β- Pinene	4.98	4.77	4.37	4.58	4.22
β-Phellandrene	0.18	0.17	0.15	0.10	0.08
p- Cymene	9.76	9.85	10.25	9.72	9.64
α – Terpineol	0.13	0.17	0.19	0.19	0.17
Citral	0.58	0.53	0.59	0.62	0.56
Cumin alcohol	33.52	34.82	34.97	33.61	32.14
Cumin aldehyde	36.35	36.89	37.28	37.09	36.12
Total identified	93.03	94.62	94.91	93.32	90.60

*** ETP means evapotranspiration potential.**

Chlorophyll, carbohydrates and nutrients

The chemical analysis of cumin herb presented in Table (6) clearly show that total chlorophyll content of leaves were increased with increasing the irrigation level, however, there were no significant differences between 80 and 100 % ETP in this concern. The highest chlorophyll content (1.24 and 1.23 mgg^{-1} FW) was recorded by applying 80 and 100 % ETP treatments, respectively. The same trend was observed concerning N, P and K percentages However, the differences among the three higher levels were insignificant according to the statistical analysis of results. Concerning carbohydrate percentage in cumin herb, our results recorded an opposite trend was observed since it gradually decreased with increasing the amount of irrigation water applied. The treatment of 20 % ETP resulted in the highest carbohydrate percentage with a significant difference compared with other treatments (Table 6).

Relative water content (RWC)

RWC was decreased with the progressive development in all water levels applied however plants irrigated with higher levels maintained RWC at higher values (Fig. 1A). The highest RWC was obtained by 100 % ETP while, 20 % ETP recorded the lowest values in this respect.

Table 6: Chlorophyll, carbohydrates and nutrients of cumin herb as affected by different irrigation treatments based on evapotranspiration potential ETP (%).

Treatments ETP* (%)	Chlorophyll content (mgg^{-1})	Carbohydrates (%)	N (%)	P (%)	K (%)
20	0.97d	16.17a	2.52b	0.28c	1.85bc
40	1.02c	15.45b	2.54b	0.30b	2.03b
60	1.16b	14.31c	2.57a	0.36a	2.10ab
80	1.24a	13.34d	2.62a	0.35a	2.16a
100	1.23a	12.39e	2.60a	0.35a	2.13a

- *ETP means evapotranspiration potential.
- The results of two experiments (2013/2014 and 2014/2015 seasons) were pooled and combined analysis was occurred for both of them together. Means followed by different letters were significantly different according to Duncan multiple range test at 0.05 level (*n=10*).

Membrane stability index (MSI)

Data presented in Fig. (1B) showed that MSI was increased in plants irrigated with higher levels compared with those obtained lower water levels. The above mentioned trend was recorded at all plant growth stages. Although MSI was decreased with plant development, higher water levels reduced this reduction.

Phenolic content and DPPH scavenging capacity

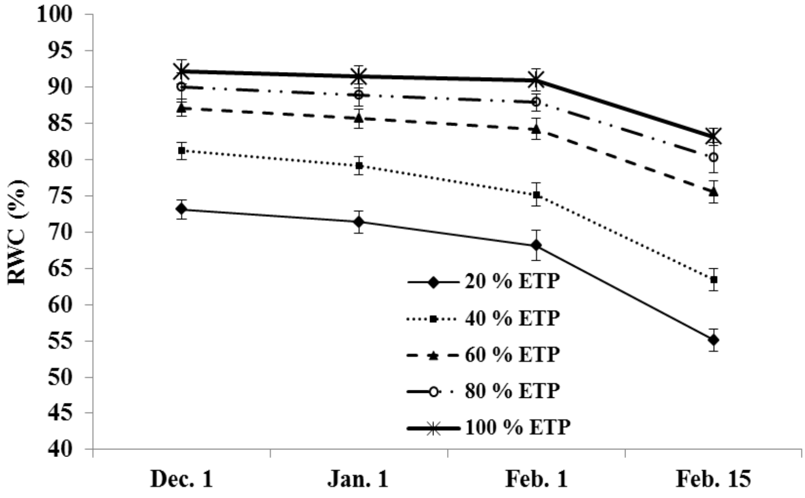
The total phenolic content in cumin fruits in relation to different irrigation levels was illustrated in Table (7). Decreasing the irrigation levels increased total phenolic content and the lowest values in this concern were obtained by 80 or 100 % ETP. In 100 % ETP treatment the phenolic content was 17.11 mg GAE g^{-1} DW however a significant increase in phenolic content occurred about 31.09, 27.18 and 48.21 % for 20, 40 and 60 % ETP, respectively in relation to 100 %. Results also showed that deficit irrigation had the capacity to scavenge DPPH free radicals (Table 7). Compared with 100 % ETP, treatments of 20, 40 and 60 % ETP significantly increased DPPH scavenging activity by 66.78, 54.94 and 24.89 %, respectively.

Table 7: Total phenolic content and DPPH radical scavenging capacity of cumin fruit extracts in relation to different irrigation treatments based on evapotranspiration potential ETP (%).

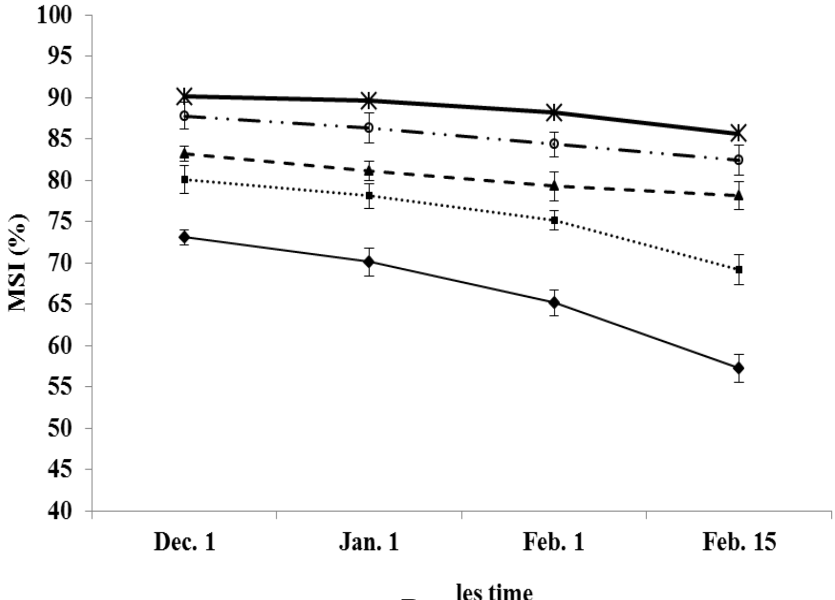
	ETP* (%)				
	20	40	60	80	100
Phenolic content (mg GAE g^{-1} DW)	22.43b	21.76b	25.36a	17.25c	17.11c
DPPH IC50 (µg/mL)	6.82e	9.25d	15.42c	19.76b	20.53a

- *ETP means evapotranspiration potential.
- The results of two experiments (2013/2014 and 2014/2015 seasons) were pooled and combined analysis was occurred for both of them together. Means followed by different letters were significantly different according to Duncan multiple range test at 0.05 level (*n=10*).

ISSN: 0975-8585



A



B

Figure 1: Relative water content (A) and membrane stability index (B) in relation to different amount of water applied based on evapotranspiration potential (ETP). Data are average of two experiments (2013/2014 and 2014/2015 seasons). Each point represents mean ±SE (*n=10*).

Soil water content

Soil water content determined after and before irrigation as average of two seasons at 0 -60 cm soil depth was presented in Fig. (2 A and B). Higher irrigation levels retained soil water content at higher values closer to field capacity after irrigation compared with deficit irrigation treatments. The soil water content after irrigation (average of 20 irrigations) for 20 % ETP was 20.27, 30.01, 35.17 and 38.56 % lower than 40, 60, 80 and 100 % ETP, respectively (Fig. 2 A). Soil water content before irrigation showed similar trend however the values were lower (Fig. 2 B). Compared with 100 % ETP, treatments of 20, 40, 60 and 80 % ETP reduced soil water content by 38.78, 50.95, 61.10 and 69.15, respectively.

Regression equations and correlation coefficients

The regression equations and correlation coefficients of certain characters were presented in Table (8). Fruit yield/ha was positively and strongly correlated with all yield components and chemical analysis examined (coefficient of determinations ranged from 0.86 to 0.99). The correlation was varied from 0.0 to ± 1. The larger the coefficient the stronger is the correlation. The same trend of correlation was observed between oil yield/ha and the same characters previously mentioned. Coefficient of determinations ranged from 0.77 to 0.97.

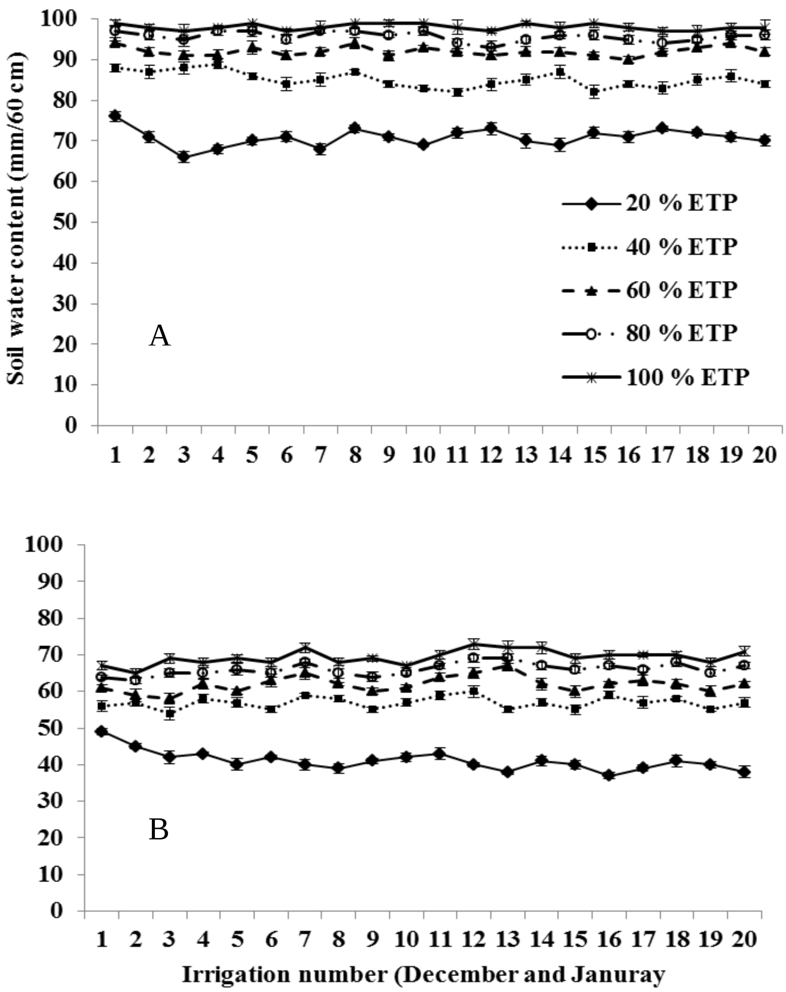


Figure 2: Soil water content, A: after irrigation and B: before irrigation in relation to different amount of water applied based on evapotranspiration potential (ETP). Data are average of two experiments (2013/2014 and 2014/2015 seasons). Samples were taken for twenty irrigations during December and January. Each point represents mean ±SE (*n=10*).

Table 8. Regression equations and correlation coefficients between fruit (Y) as well as oil yields (Y) and selected parameters (X) as a mean of two seasons

	Variables	Regression equation	R^2		Variables	Regression equation	R^2
Fruit yield/ha	Umble number/plant	y=16.495x +62.091	R^2= 0.9377**	Oil yield/ha	Umbel number/plant	y = .0956x - 20.72	R^2 = 0.9367**
	Fruit yield/hill.	y=1.9507x +0.4445	R^2= 0.9998**		Fruit yield/ hill	y = .7503x - 11.283	R^2 = 0.7717**
	Oil yield /ha	y=0.1141x -16.349	R^2= 0.8623**		Oil yield /hill	y = 2.661x - 6.1433	R^2 = 0.9261**
	Carbohydrate (%)	y=0.2301x -29.985	R^2= 0.9258**		Carbohydrate (%)	y=1.9269x +3.5851	R^2= 0.9792**

ISSN: 0975-8585

DISCUSSION

Our results obtained from this experiment showed that the amount of irrigation water significantly influenced the growth and yield of cumin plants. Supplying cumin plants with the optimum water requirements is very important factor to maximize the yield and quality. This was very clear from our results since the best growth and yield characters were obtained by applying 60 or 80 % ETP treatments. However, more excessive water did not add any significant increment in this respect while applying lower levels of water reduced the same parameters (Table 3 and 4). It has been reported that the decrease in turgor is one of the first signs of water shortage which causes a decrease in both growth and cell development, especially in the stem and leaves [32]. The growth of cells is the most important process that is affected by water deficit and the decrease in the growth of cells leads to decrease the plant height and consequently plant fresh and dry weights. Growth reduction as a result of water deficit has been widely reported [11,12, 17]. On the other hand, more water levels gave a chance for more luxuriant use of soil moisture, which ultimately resulted in greater fresh weight and increase of transpiration [20]. The higher physiological activity and better growth of plants with frequent irrigation might enhanced the supply of photosynthates from source to sink, consequently increasing the production of yield attributes with more frequent irrigation [9]. Negative effects on growth and yield characters were obvious when excessive or lower irrigation water was applied [4, 13, 15].

Lower WUE was associated with higher amount of irrigation water however the lowest irrigation level resulted in the highest WUE. These results may be due to the effects of different irrigation levels on fruit yield since the lowest fruit yield was obtained by the lowest irrigation level. Another explanation for this has been reported by Kamkar et al. [33] who mentioned that the lower WUE obtained by the higher irrigation level may be due to a greater loss of water by ET than the corresponding increase in fruit yield. Otherwise, Zhang et al. [34] reported that WUE values were higher under deficit than adequate irrigation, especially when irrigation is applied to critical stages of plant development. Similar trend has been observed on coriander [9].

Soil water content was influenced by amount of irrigation of water applied and this is because of the higher amount of water per irrigation in higher levels than deficit irrigation. Decreasing soil water content during cumin growth stages may not only negatively affect the plant growth but also fruit yield. Consequently, we observed reduction in both growth and yield as a result of deficit irrigation. Similar trend has been previously reported [14]. Because of RWC refers to the amount of water in the plant organs and their ability to keep the water, it is likely that the positive effects of optimum water level on fresh weight may be due to the higher values of RWC obtained when plants were treated with that level. That is, plants under deficit irrigation could not uptake or maintain water properly; meanwhile plants irrigated with the optimum water amount were in suitable conditions for uptaking and maintaining water. Therefore, MSI was maintained by higher irrigation levels unlike deficit irrigation which resulted in lower membrane stability (Fig. 1 B). Deficit irrigation improved total phenolic content in cumin fruits (Table 7) and hence the drought tolerance of cumin plant was suggested [35]. Increasing phenolic compound biosynthesis in relation to oxidative stress has been previously reported [14, 36]. On the other hand Neffati et al. [37] recorded a decrease in total phenolic under oxidative stress on coriander. It is well known that phenolics have great antioxidant activity hence; our data presented in Table (7) showed that deficit irrigation had higher capacity to scavenge DPPH free radicals compared with higher irrigation levels. These results support the previous of Neffati et al. [37] who reported that there was a significant correlation between total phenolic and antioxidant activity.

Increasing the irrigation levels resulted in a significant decrease in volatile oil percentage. On the other hand, volatile oil yield showed an opposite trend (Table 4). These results may be due to the effects of lower or higher irrigation levels than the optimum level in reducing the metabolic process rate for secondary products which lead to biosynthesis of volatile oil. It has been reported that water deficit is a primary factor in increasing oil percentage of medicinal plants and increasing irrigation times significantly decreased the cumin oil percentage [16]. Otherwise, the fruit yield reduction by deficit irrigation compared to the optimum may explain the changes in volatile oil yield under different irrigation levels since it depends on fruit yield and hence the volatile oil yield followed the same trend of fruit yield. Volatile oil accumulation under water deficit has been previously reported [4, 15, 35]. On the other hand, some Apiaceae crops showed an opposite trend of cumin concerning the volatile oil percentage [9, 11].

The main components of volatile oil were cumin aldehyde, cumin alcohol, p-cymene, α-pinene and β-pinene (Table 5). Various studies have been indicated that the previous components were intended as the main components of cumin volatile oil [38, 39]. The irrigation level treatments applied in our experiment slightly affected the chemical composition of volatile oil and since irrigation treatments affected volatile oil percentage, it may also affect the oil composition of cumin. Bettaieb et al. [14] revealed that water deficit was found to stimulate the essential oil production, especially terpenic hydrocarbons biosynthesis and significantly influence the secondary metabolites production. Similar results have been reported on some Apiaceae volatile oil fruits [9, 13, 17].

Increasing irrigation level had a positive effect on nutrient elements of cumin plant. As a result of vegetative growth promotion under higher levels of irrigation, the absorption of nutrient elements might be increased. The metabolic processes may also be promoted. However, water deficit reduced photosynthesis rate and lead to more loss in photosynthesis area in the plant [32] there, we recorded a decrease in chlorophyll content under water deficit (Table 6). The reduced yield obtained at low irrigation level may be resulted from deficiency of nutrients rather than of water, and that high irrigation frequency could compensate for nutrient deficiency [40]. On the other hand, increasing the irrigation level significantly decreased the total carbohydrate percentages. Under water deficit the increase of stomatal closure and decrease in carbon dioxide may occurred and hence accumulation of carbohydrates in leaves was recorded [41]. These results are in harmony with the findings of Hassan et al. [9, 17] who reported that the carbohydrate percentage was increased as a result of deficit irrigation. Finally, from the results of our experiment it could be concluded that applying 60 % ETP irrigation level was the optimum irrigation level which maintained RWC, MSI and soil water content and therefore resulted in increasing the fruit as well as oil yields of cumin plant. In addition, it also increased fruit phenolic content as well as antioxidant activity (higher capacity to scavenge DPPH free radicals than higher water levels) therefore, it can be recommended under our experimental conditions as a possible technique for saving water and maximizing the irrigation water use efficiency.

REFERENCES

[1] Thippeswamy, N.B., Naidu, K.A. Antioxidant potency of cumin varieties - cumin, black cumin and bitter cumin-on antioxidant systems. Eur. Food Res. Technol. 2005; 220: 472-476.

[2] Daniel Z, Maria H. Domestication of Plants in the Old World, vol. 531., third ed. University Press, Oxford, 2000; p. 206.

[3] Nostro A, Cellini L, Di Bartolomeo S, Di Campli E, Grande R, Cannatelli MA. Antibacterial effect of plant extracts against *Helicobacter pylori*. Phytother. Res. 2005; 19: 198-202.

[4] Sabzevar TS, Ghavidel RA. Effects of planting date and irrigation date on qualitative and quantitative characteristics of cumin (*Cuminum cyminum* L.). World Appl. Sci. J. 2011; 15 (6): 849-852.

[5] Al-Kayssi AW, Shihab RM, Mustafa SH, Impact of soil water stress on Nigellone oil content of black cumin seeds grown in calcareous-gypsifereous soils. Agric. Water Manag. 2011;100: 46-57

[6] Abdin AE, Salem S. Strategic plans for sugar cane cultivation in Upper Egypt towards the implementation of rational water use. Egyp. J. Agric. Econ. 2009; 19 (1): 308-333.

[7] Abedi T, Pakniyat H. Antioxidant enzyme changes in response to drought stress in ten cultivars of oilseed rape (*Brassica napus* L.). Czech J. Genet. Plant Breed. 2010; 46 (1): 27-34.

[8] Ruhi B, Osman K, Koksal A, Dursun B. The effects of drip irrigation on flowering and flower quality of glasshouse gladiolus plant. Agric. Water Manag. 2006; 81: 132-144.

[9] Hassan FAS, Ali EF. Impact of different water regimes based on class-A pan on growth, yield and oil content of *Coriandrum sativum* L. plant. Journal of the Saudi Society of Agricultural Sciences. 2014; 13(2):155–161.

[10] Sharma RN, Prasad R. Nitrogen and irrigation requirements of fennel. Ind. J. Agron. 1990; 35(4): 449-451.

[11] Osman AM, El-Fiky YS. Effect of applied irrigation water amounts and plant densities on coriander (*Coriandrum sativum*, L.) production in sandy soils. Ann. Conf. Egy. Soc. Agric. Eng. 2005; 22(4): 758-770.

[12] Kumar A, Singh R, Chhillar RK. Influence of omitting irrigation and nitrogen levels on growth, yield and water use efficiency of coriander (*Coriandrum sativum* L.). Acta Agron. Hung. 2008; 56(1): 69-74.

[13] Laribi B, Bettaieb I, Kouki K, Sahli A, Mougou A, Marzouk B. Water deficit effects on caraway (*Carum carvi* L.) growth, essential oil and fatty acid composition. Ind. Crop Prod. 2009; 31: 34-42.

[14] Bettaieb IB, Jabri-Karoui I, Hamrouni-Sellami I, Bourgou S, Limam F, Marzouk B, Effect of drought on the biochemical composition and antioxidant activities of cumin (*Cuminum cyminum* L.) seeds. Indust. Crop. Prod. 2012; 36: 238–245.

[15] Nejad AR. Productivity of Cumin (*Cuminum cyminum* L.) As Affected by Irrigation Levels and Row Spacing. Aust. J. Basic Appl. Sci. 2011; 5(3): 151-157.

[16] Ahmadian A, Tavassoli A, Amiri E. The interaction effect of water stress and manure on yield components, essential oil and chemical compositions of cumin (*Cuminum cyminum*). Afric. J. Agric. Res. 2011; 6(10): 2309-2315.

[17] Hassan FAS, Ali EF, Mahfouz SA. Comparison between different fertilization sources, irrigation frequency and their combinations on the growth and yield of coriander plant. Aust. J. Basic Appl. Sci. 2012; 6(3): 600-615.

[18] Istanbulluoglu A, Arslan B, Gocmen E, Gezer E, Pasa C. Effects of deficit irrigation regimes on the yield and growth of oilseed rape (*Brassica napus* L.). Biosyst. Eng. 2010; 105: 388-394.

[19] Weatherley PE. Studies in the water relations of the cotton plant.1.The field measurements of water deficit in leaves. New phytology 1950; 49:8.

[20] Doorenbhos J, Pruitt WO. Crop water requirement. Irrigation and drainage paper No. 24, 1984; FAO. Rome, Italy.

[21] Vermelien L, Goopling GA, Localized irrigation. FAO irrigation and drainage paper No. 36, 1984; Rome, Italy.

[22] Marshall TJ, Holmes JW, Rose CW. Soil Physics. Press Syndicate of the University of Cambridge, New York. 1996.

[23] Howell TA, Cunca RH, Solomon KH. Crop yield response. In: Hoffman G.J., *et al* (eds) Management of farm irrigation systems. ASAE Mongo, Chap. 4, St. Joseph, MI. 1990; p. 93-116.

[24] British Pharmacopea Determination of volatile oil in drugs. Published by Pharmaceutical Press. London. W.C.I. 1963.

[25] Sadasivam S, Manickam A. Biochemical Methods for Agricultural Sciences. 1992; p. 181-185. Wiley Eastern limited, New Delhi.

[26] Black CA, Evans DD, Ensminger LE. *Methods of soil analysis*. Agronomy J. Amer. Soc. Agron. Inc. Publ., Madison, Wisconsin, U.S.A. 1965.

[27] A.O.A.C. Official Methods of Analysis. Official method of analysis 16th Ed., Association of Official Analytical Chemists International, Arlington Virginia, USA. 1995.

[28] Herbert D, Phipps .J, Strange RE. Determination of total carbohydrates. Methods in Microbiology. 1971; 5(8) p. 290-344.

[29] Dewanto V, Wu X, Adom K, Liu R, Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. J. Agric. Food Chem. 2002; 50: 3010-3014.

[30] Hanato T, Kagawa H, Yasuhara T, Okuda T. Two new flavonoids and other constituents in licorice root: their relative astringency and radical scavenging effects. Chem. Pharm. Bull. 1998; 36: 2090-2097.

[31] Sairam RK, Deshmukh PS, Shukla DS. Tolerance to drought and temperature stress in relation to increased antioxidant enzyme activity in wheat. J. Agron. Crop Sci. 1997; 178: 171-177.

[32] Taiz L, Zeiger E. Plant Physiology, Third Ed. Sinauer Associates, Inc. Chapter., 2002;10:33-46.

[33] Kamkar B, Daneshmandb AR, Ghooshchic F, Shiraniradd AH, Safahani AR. The effects of irrigation regimes and nitrogen rates on some agronomic traits of canola under a semiarid environment. Agric. Water Manag. 2011; 98: 1005-1012.

[34] Zhang YQ, Kendy E, Yu Q, Liu CM, Shen YJ, Sun HY. Effect of soil water deficit on evapotranspiration, crop yield, and water use efficiency in the North China Plain. Agric. Water Manag. 2004; 64: 107-122.

[35] Bettaieb I, Knioua S, Hamrouni I, Limam F, Marzouk B. Water-deficit impact on fatty acid and essential oil composition and antioxidant activities of cumin (*Cuminum cyminum* L.) aerial parts. J. Agric. Food. Chem. 2011; 59: 328-334.

[36] Navarro JM, Flores P, Garrido C, Martinez V. Changes in the contents of antioxidant compounds in pepper fruits at ripening stages, as affected by salinity. Food Chem. 2006; 96: 66-73.

[37] Neffati M, Sriti J, Hamdaoui G, Kchouk ME, Marzouk B. Salinity impact on fruit yield, essential oil composition and antioxidant activities of *Coriandrum sativum* fruit extracts. Food Chem. 2010; 124: 221-225.

[38] El-Sawi S, Mohamed MA. Cumin herb as a new source of essential oils and its response to foliar spray with some micro - elements. Food chemistry. 2002; 77(1): 75-80.

[39] Iacobellis NS, Takayanagi T, Kitajmi J, Antibacterial activity of *Cuminum cyminum* L. and *Carum carvi* L. essential oils. J. Agric Food Chem. 2005; 53(1): 57-61.

ISSN: 0975-8585

[40] Silber A, Xu G, Wallach R. High irrigation frequency: the effect on plant growth and on uptake of water and nutrients. Acta Hort2003; 627: 89-96.
[41] Pelleschi S, Rocher JP, Prioul JL. Effect of water restriction on carbohydrate metabolism and photosynthesis in mature maize leaves. Plant Cell Environ. 1997; 20: 493-503.