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Effect of Deficit Irrigation Technique on Black Cumin (*Nigella sativa* L.*)* Water Use Efficiency

T. Yaghi[1]*, A. Arslan[2], and H. Saeed[3]

ABSTRACT

To increase the agricultural profit, an experiment was conducted at the Scientific Agricultural Research Center (SARC) at Salamiyah, Syria. The experiment aimed to estimate the optimum irrigation level that maximizes productivity as well as the black cumin's quality local quality standards under experimental conditions. The irrigation treatments were 25, 50, 75 and 100% of the Potential Evapotranspiration (ET_P) based on Class-A pan evaporation. The treatments were denoted as B, C, D and E, respectively. The no-irrigation treatment (A) was considered as control. Irrigation water was applied by a drip system. The A-E treatments were designed and implemented using complete randomized block design (CRBD) with four replications. The actual Evapotranspiration (ET_a) was calculated after calibration of soil using SPAW software. Furthermore, crop yield, Irrigation Water Use Efficiency (IWUE), yield response factor (k_y) and some parameters (period of growth stage, date of flowering…etc.) were studied during 2018-2019 successive growth seasons. Results showed that irrigation could be scheduled using some equations and Class-A pan evaporation. Moreover, the vegetative growth parameters flourished virtually and significantly by comparing higher and lower irrigation levels. However, Irrigation Water Use Efficiency (IWUE) values increased by reducing the applied irrigation water. Treatment B recorded the highest IWUE value (2.4 kg ha^{-1} mm^{-1}), but key values remained less than 1.0, indicating that the plant tolerates drought. Furthermore, treatment C scored the top-seed (130.6%) concerning the profit/total costs ratio. Finally, based on the results, we recommend that irrigation should not be more than 75% and not less than 25% of the ET_P.

Keywords: Class-A pan evaporation, Potential evapotranspiration, Yield response factor (k_y).

INTRODUCTION

Since spreading the Sustainable Development (SD) concept all over the world, many agricultural researchers have called for achieving the highest productivity of the least water unit declaring the following motto: "more crop per drop" (Molden *et al*., 2010). Salamiyah is a rural district located in the Al-Harron river sub-basin at the Orontes Basin, Syria, and has a semi-arid climate with limited annual precipitation ranging from 150 to 420 mm (Yaghi *et al*., 2016). Due to insufficient water resources, dry farming is practiced in most of the aforementioned areas. Therefore, efficient use of scarce water resources for sustainable agricultural water management in Salamiyah is a serious challenge. So, there is an increasing need to replace crops with high irrigation requirement (cotton, maize and alfalfa) with the low irrigation requirement; therefore, high economic return crops such as black cumin, chamomile, and thyme have become popular (Serman *et al*., 2021; Mauget *et al*., 2022).

Black cumin (*Nigella sativa,* L.) has been used as traditional natural medicine for

[1] General Commission for Scientific Agricultural Research (GCSAR), Syria.
[2] Department of Natural Resources and Environmental Science, University of Nevada, Reno, NV 89512, USA.
[3] Scientific Agricultural Research Center (SARC), Salamiyah, Hama, Syria.
* Corresponding author; e-mail: tammam.yaghi@gmail.com

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centuries. The crude oil and Thymoquinone (TQ) extracted from its seeds and oil are effective against many diseases like cancer, cardiovascular complications, diabetes, asthma, kidney disease, etc. It is effective against cancer in the blood system, lung, kidney, liver, prostate, breast, cervix, skin, with much safety (Khan *et al*., 2011). Identifying critical growth stages for water of a particular cultivar under local conditions of climate and soil fertility allows irrigation scheduling to maximize crop yield and increase the Water Use Efficiency (WUE) in areas with scarce water resources (Mahal and Sidhu, 2006; Kumar *et al*., 2019). There are different methods to estimate the irrigation requirements. One of them is by using potential evapotranspiration based on Class-A Pan (Allen *et al*., 1998; Ruhi *et al*., 2006). Prolonging the irrigation intervals reduces the growth and yield of various medicinal and aromatic plants (Hassan and Ali, 2014).

The increase in irrigation water increased the number of primary, secondary and tertiary branches, number of capsules per plant, capsule length, diameter of capsule, number of seeds per capsule, fresh and dry seed yield per plant, 1,000-seed weight, and seed yield of black cumin (Karim *et al*., 2017).

On the contrary, Elsafi (2003) found that the black cumin yield increased by prolonging the irrigation intervals and water stress applications, while the lower WUE was associated with a higher amount of irrigation water (Bondok and El-Sharkawy, 2014). Deficit Irrigation (DI) is one of the water management practices for increasing WUE. Ghamarnia *et al.* (2010) have shown that black cumin tolerates drought. They have found that irrigation at the rate of 50% of (crop Evapotranspiration, ET) achieved high crop productivity in Iran. Likewise, for the cumin crop, Bondok and El-Sharkawy (2014) have proved that as water decreased from 1.0 to 0.8 and 0.6 of ET_c, the cumin yield decreased by (14.05 and 14.25%) and by (25.6 and 26.89%) in two seasons, respectively. In the same study, WUE increased by (5.26% and 19.30%) and by (10.17% and 16.9%) compared with the full irrigation treatment, respectively.

Due to the consumptive needs of the rapidly increasing world population, black cumin has a quite large market, which is about $60 billion (Kumar, 2009). Furthermore, because of the great importance of black cumin (*Nigella sativa* L.) plants as natural sources for producing fixed and volatile oils, more investigations for improving the growth and productivity of this plant are still needed (Ghamarnia *et al*., 2014). In this context, there are some investigations in the field of sustainable irrigation in Syria concerning the application of virtual water concept and alternative crops. These include replacement of crops of low economic return (such as alfalfa, wheat, and cotton) with crops of high economical return (like garlic, grapes and medical plants: black cumin, thyme...etc.) to cope with water shortage, irregular demographic issues (localizing people according to safer areas because of the Syrian war), and high costs of farming (Mourad, 2012).

On the grounds of the previous scientific reports, it will be beneficial to determine the optimum irrigation level of black cumin plant to increase its productivity per unit of applied water. Therefore, the goal of this study was to estimate the optimum irrigation level, which maximizes the productivity as well as the crop quality under experimental conditions.

MATERIALS AND METHODS

The experiment was carried out at SARC at Salamiyah district (35° 00’ N, 37 02’ E and 480.8 m altitude), Hama Governorate, Syria. It forms about 37.1% of available arable land of Hama governorate; the average annual precipitation throughout the growing season (Feb-Jun, 2018-2019) was only 143 mm, while the total evaporation during that period was about 645.7 mm. Therefore, irrigation is essential for optimal crop yield and good quality. In this region,

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the largest percentage of water consumption in agriculture is supplied by groundwater, which are decreasing rapidly, and groundwater quality is deteriorating. Since the experimental area is far from the sea and close to Syrian Badia, it has a semi-arid climate. The physical and chemical properties of the soil are presented in Tables 1 and 2. Available soil water holding capacity was 109 mm at 0-60 cm depth. Furthermore, hand Beerkan infiltration methods have been used and their results in the same type of soil were compared with SPAW software results by Saxton and Willey (2006), similar data were reported by (Mubarak *et al*., 2009; Angulo-Jaramillo *et al*., 2019).

Thus, for accurate selection of the irrigation time, Management Allowable Depletion (MAD) value of about 65% was used, based on some previous researches that indicated that this crop could tolerate water shortage (Ghamarnia *et al*., 2010; Ghamarnia and Jalili , 2013).

Daily climate data were collected from Feb. 10 until Jun 29 during 2018-2019 growing seasons. Furthermore, ET_0 was calculated by using two programs (ET0 Calculator and New_LocClim software), and monthly values are shown in Table 3.

Experimental Treatments, Planting, Cultural Practices and Design of Drip Irrigation System

The study was carried out using Complete Randomized Block Design (CRBD) with four replications. Experimental treatments were A (without irrigation), B (25% of ET_P), C (50%), D (75%), and E (100%). The experimental area consisted of 20 plots. The area of each plot was 5 m^2 (2.5*2 m), and the total area was 157.3 m^2 (14.3×11 m). In order to prevent the interaction between irrigation treatments, 1 m space was left between the plots. Besides, two rows in each plot were left out of the assessment due to the edge's effect, and the remaining area formed the harvest plots, as shown in Figure 1.

Figure 1 shows that there are 4 drip lines for 5 cultivation lines in each plot. Each line was equipped with external drippers, except treatment A. The distance between two lines was 0.5 m. Based on technical advice received from soil lab staff, K (Potassium oxide, K_2O) was not needed while the fertilizers of N (100 kg ha^{-1}) and P (Super phosphate, P_2O_5) (60 kg ha^{-1}) were needed. Half of the total nutrient amount (fertilizers) was given during soil preparation, and the rest was given with the fertigation technique

Table 1. Physical properties of the soil.

Soil depth (cm)	Bulk density (g cm^{-3})	Texture[a]	Field capacity (%v)	Wilting point (%v)	Water holding capacity		Clay (%)	Silt (%)	Sand (%)
					(%)	(mm)			
0-30	1.41	CL	38.1	25.7	12.4	52.45	42	20	38
30-60	1.29	SCL	39.9	25.3	14.6	56.5	45	42.3	12.7
60-90	1.24	SCL	42.1	28.8	13.3	49.47	49	43	8

[a] CL: Clay, SCL: Silty Clay.

Table 2. Chemical properties of the soil.[a]

Soil depth (cm)	pH (1:5)	EC (1:5) (dS m^{-1})	Avail-P (mg kg^{-1})	Avail-K (mg kg^{-1})	Mineral-N (mg kg^{-1})	$CaCO_3$ (%)	OM (%)
0-30	7.75	0.37	38.2	504	1.34	7.2	1.19
30-60	8.03	0.32	39.2	430	1.89	4.3	1.38
60-90	7.43	0.49	19.4	380	2.1	3.3	1.34

[a] 1:5: Saturated soil paste; P: Phosphorus; K: Potassium, N: Nitrogen.

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Table 3. Climate data records taken monthly for short and long-term periods.

Month	Solar ($h\ d^{-1}$)	Temp (°C) Max	Temp (°C) Min	Rainfall (mm)	Relative humidity (%)	Wind ($m\ s^{-1}$)	E_{pan} (mm)	ET_0 [a] (mm)
Feb	5.1	17	2.7	76	83	3.3	36.7	20.3
Long-term [b]	4.13	12	2.4	32.3	87	3.7	-	19.4
Mar	8.4	18.1	5.8	18.4	81	3.4	60.7	60.7
Long-term	5.59	16.7	3.9	56.7	89	3	-	62.7
Apr	8.7	26.3	10.4	45	77	4.2	108.9	89.9
Long-term	8.12	26.1	11.9	42.4	76	4.5	-	82.7
May	11.4	33.1	15.9	19.6	64	3.1	185.2	114.4
Long-term	11.1	33.6	15	22	58	4.3	-	112.6
Jun	12.2	33.2	17.7	1.4	53	2.2	190	114.9
Long-term	12.1	34.1	17.2	1.2	48	1.7	-	115.8
Total average				160.4			581.5	400.2

[a] FAO Penman-Monteith method, Feb. 10-28. . . Until Jun 29, using ET_0 Calculator software (2018-2019).
[b] Between the years 1970 and 2020 using New_LocClim software.

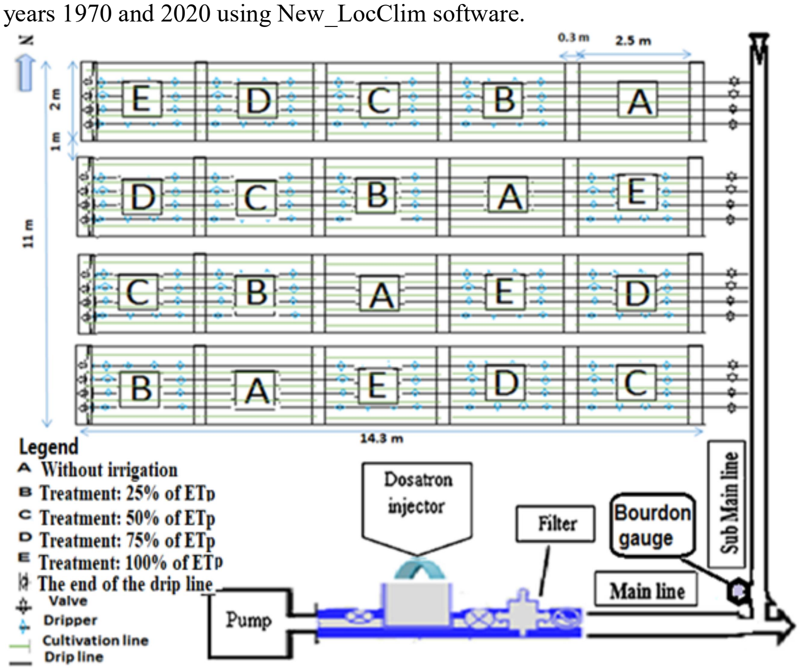

Figure 1. Layout of black cumin experiment and irrigation system at SARC, Hama, Syria.

as equal amounts during the irrigation period by dividing into the number of irrigations. The black cumin seeds were planted with a density of 4 kg ha^{-1}. Farming operations such as reseeding, weeding, and irrigation were done as required. Moreover, pesticides were not used during the two 2018-2019 growing seasons.

Irrigation Water, Eevapotranspiration, and Water-Yield Functions

Evapotranspiration was estimated from the water balance Equation (1):

$$ET= I+R\pm\Delta Sm-Dr \quad (1)$$

Where, ET is crop Evapotranspiration (mm), I is the amount of applied Irrigation water

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(mm), R is precipitation (mm), ΔSm is any change in Soil moisture content (mm) and Dr is Deep percolation water (mm), which was assumed to be zero. The method given by Allen *et al.* (1998) was chosen for calculating the amount of irrigation water:

$ET_P= K_p \times E_{pan}$ (Erteck, 2011) (2)

$ET_c= K_c \times ET_P$ (3)

Where, ET_P is Potential Evapotranspiration (mm), K_p is pan coefficient ranged 0.74-0.77 based on the principles given by Doorenbos and Pruitt (1977), E_{pan} is pan Evaporation (mm), ET_c is crop Evapotranspiration (mm) and K_c is crop coefficient. Four crop coefficients were picked up (0.52, 0.91, 1.27 and 0.77) for different black cumin growth stages (initial, development, mid-stage, and late), respectively, based on the scientific report of Ghamarnia *et al*. (2014).

The volume of irrigation water requirement for each treatment was calculated according to the squared area:

$I= ET_c \times Sd$ (4)

Where, Sd is irrigation water ratio (B= 25%; C= 50%; D= 75%; E= 100%).

$WUE= Y/(I+P_e)$ (Michael, 1978) (5)

$IWUE= (Y-Y_0)/IWU$ (6)

Where, I is Irrigation water amount (mm), P_e is effective rainfall (mm)= 0.6 P (Precipitation, mm) if P< 75%, P_e= 0.8 P if P> 75 mm. month^{-1}, Y is seed Yield obtained from the treatments (kg ha^{-1}), Y_0 is seed Yield obtained from treatment (A) (kg ha^{-1}), and IWU is Irrigation Water Use (mm).

The yield response factor (k_y) representing the decrease in black cumin seed yield, which may occur as a result of the decrease in the unit evapotranspiration was determined using Equations (2), (3), and (4) (Doorenbos and Kassam, 1986):

$(1-Y_a/Y_m)= k_y (1-ET_a/ET_m)$ (7)

Where, Y_a is actual seed Yield regarding the treatments (kg ha^{-1}), Y_m is maximum seed Yield (kg ha^{-1}), ET_a is actual seasonal Evapotranspiration (mm), and ET_m is maximum seasonal Evapotranspiration (mm).

The k_y values are crop specific and vary over the growing season according to growth stages of the report by Steduto *et al*. (2012): k_y< 1: Crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use.

The Reproductive and Vegetative Parameters

The collected data for this item were the plant height, number of branches per plant, dry matter, harvest index, number of the mature and dry follicles per plant, the follicle's diameter, number of the seeds per follicle, weight of the 1000 seeds, depth of the roots, yield of the seeds, and Water Use Efficiency (WUE). Furthermore, five plants were used to determine the dry weight per plant. The plants were dried and weighed using a sensitive balance. Harvest index was calculated as follow:

$HI= [Y/(Ps+Y)] \times 100$ (Ghamarina *et al*., 2010) (8)

Where, HI is Harvest Index (%), Y is an economical seed Yield (kg ha^{-1}), Ps is straw yield (kg ha^{-1}).

We had employed the univariate analysis of variance using a statistical package for social science (SPSS software) to analyze the collected data. The difference between treatment means was compared by Duncan's Multiple Range Test (DMRT) at 0.05 statistical significance level. Furthermore, an economical study was performed by determining the ratio between the profit and the total costs for each treatment.

RESULTS AND DISCUSSION

Impact of Water Stress on Black Cumin Growth

Black cumin Water Consumptive Use, ET_a

Daily black cumin water consumptive use values (actual water requirements) have differed according to the phenological phases (local quality standards compared to

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what area farmer does) and treatments. For example, in treatment B, the ETa value was 0.9 mm d^{-1} at initial stage and increased to 3.8 mm d^{-1} at mid-season stage, then, lowered to 3.33 mm d^{-1} again at the late and the harvest stage in the first season. The same thing in the second season but with simple differences because of the changes concerning climate and soil. Furthermore, the period of black cumin phenological phases has differed and recorded the best quality standard at the treatment B (23 days for initial phase, 42 days for development phase, 40 days for Mid-season phase and 25 days for late and harvest phase) compared to the rest of the other treatments (E, 140 days and A, 120 days) as shown in Figure 2.

The sum of black cumin water consumptive use values during two seasons were [488.4 (1) and 392.2 mm (2) at (E); 369.5 and 376.3 mm at (D); 290.4 and 300.6 mm at (C); 285.6 and 284.9 mm at (B); and 275.8 and 273.2 mm at (A)] as given in Table 4.These differences can be attributed to the impact of irrigation on roots depth and the corresponding ground canopy above that differed significantly between the treatments. It can be clarified through the water stress, which has led to a lack of absorption of nutrients in plant due to a lack of movement of nutrients in dry land, an inadequate water absorption and lack of extension and spread of roots (Beudez and Doussan, 2013).

That has been accompanied with a significant difference for the other studied plant attributes (plant height, branches number, dry matter and harvest

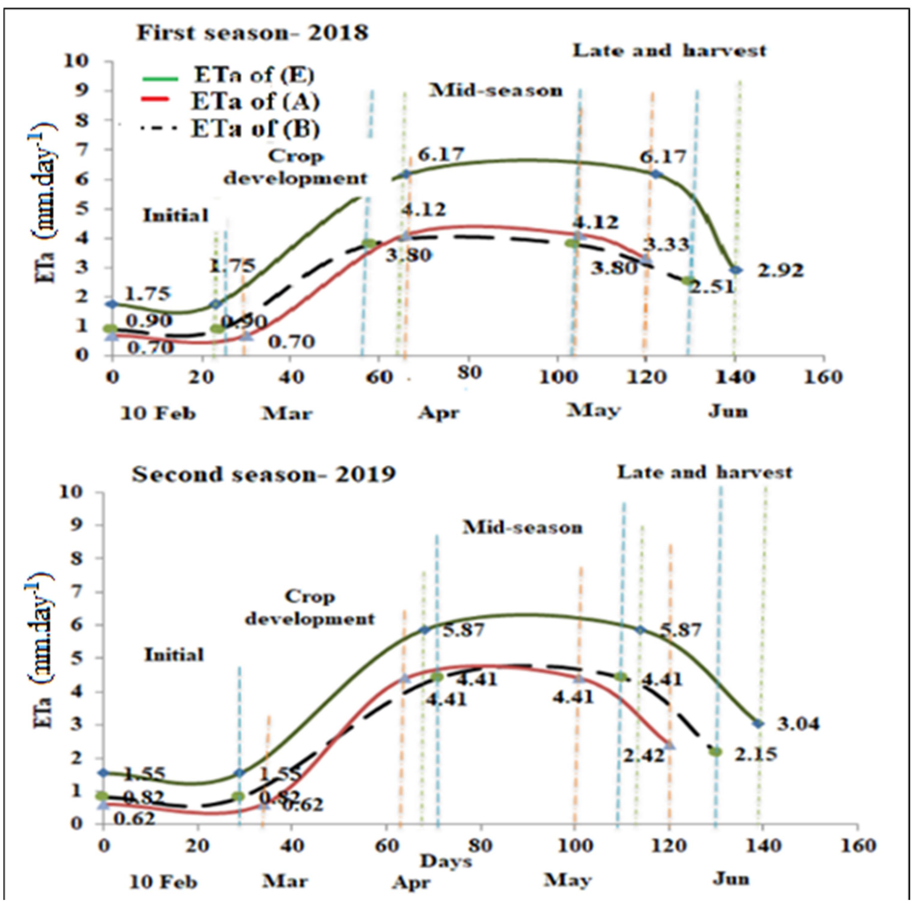

Figure 2. Black cumin water consumptive use (ET$_a$) at the optimal treatment (B) which achieves quality standards represented in phenological phases compared to the rest of the treatments during two seasons.

Table 4. Vegetative growth characters of black cumin as affected by different water regimes based on class-A pan during the two experimental seasons. [a]

ET_P (%)	Water consumptive use (mm)	Plant height (cm)	Branches number	Dry matter per plant (g)	Roots depth (cm)	Harvest Index (HI) (%)
First season-2018						
No irrigation (A)	275.8	10.32 d	6.50 e	0.57 e	8.30 d	33.95 d
25 (B)	285.6	27.92 c	11.30 d	1.31 d	18.03 b	48.50 c
50 (C)	290.4	28.20 c	18.73 c	1.75 c	19.43 b	53.00 b
75 (D)	369.5	33.90 ba	24.48 a	2.13 ba	17.23 c	56.25 a
100 (E)	488.4	38.35 a	23.00 ba	2.29 a	29.78 a	48.40 c
Second season-2019						
No irrigation (A)	273.2	13.38 e	8.90 d	0.93 d	7.90 d	36.05 dc
25 (B)	284.9	21.73 d	17.30 c	1.61 c	19.38 c	38.00 c
50 (C)	300.6	35.00 c	24.12 b	2.414 a	18.68 c	48.75 b
75 (D)	376.3	39.15 ba	32.58 a	2.57 a	21.13 ba	52.50 a
100 (E)	392.2	43.20 a	32.75 a	2.366 ba	31.98 a	49.10 b

[a] Means followed by different letter (s) within a parameter differed significantly by DMRT at $P \leq 5$ %.

index) at E and D compared to the rest of the other treatments as given in Table 4.

The gradual reduction in the dry weight under DI could be a result of a reduction in the chlorophyll content, and consequently, photosynthesis efficiency. This result was supported by Khalid (2006). Water is a very important factor, affects the growth of the black cumin plant when the water content of the plant decreases, its cells shrink and the cell walls relax which results in lower turgor pressure (Csonka, 1989). The principles that underlie the two processes are similar because leaf expansion depends mostly on cell expansion (Taiz and Zeiger, 2002). The larger the leaf area is the more the transpiration will be. Growth reduction because of DI has been widely reported (Karim *et al*., 2017; Mehriya *et al*., 2020). We cannot ignore the effect of precision irrigation like DI on the flowering stage that has shown multiplying of the follicles and seeds in each one as given in Table 5. These results are also in agreement with those of Haj Seyed Hadi *et al* (2012).

The results of the study indicated that DI treatments remarkably increased the yield, whereas the weight of one thousand seeds increased from A to E (A< B< C< D< E) as given in Table 6. Similar data were reported by Banon *et al* (2003).

On the other hand, the efficiency of sustainable irrigation does not agree with the aforementioned results. The maximum IWUE (2.4 and 2.28 kg ha^{-1} mm^{-1}) and (2.21 and 2.25 kg ha^{-1} mm^{-1}) were obtained by B and C treatments, respectively, while the lowest values in this respect (1.83 and 1.89 kg ha^{-1} mm^{-1}) were recorded for treatment (E) in both seasons, respectively. The lower WUE associated with a higher amount of irrigation water could be attributed to a greater loss of water by ET than the corresponding increase in seed yield (Al-Kayssi *et al*., 2011). These results are also in agreement with those of Senyigit and Arslan (2018), who concluded that the DI technique based on Class-A pan remarkably affects applied water and water use efficiency.

Relation between the Yield and Irrigation Water

Results have shown that there are linear relations between the amount of irrigation water and the yield (R^2 = 0.820), and between the evapotranspiration and the yield (R^2 = 0.804) at 0.05 significance level. Although the black cumin yield could be achieved even in the non-irrigated conditions, the equations have shown that

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Table 5. Black cumin seeds yield components as affected by different water regimes based on Class-A pan during the two experimental seasons. [a]

ET_P (%)	Diameter of follicle (cm)	Follicles per plant	Seeds per follicle	Empty follicles per plant	1000 seeds weight (g)	Seed yield (kg ha^{-1})	Irrigation Water Use Efficiency (IWUE) (kg ha^{-1} mm^{-1})
First season-2018							
No irrigation (A)	0.54 d	4.53 d	12.60 e	6.10 a	1.02 d	170.3 e	-
25 (B)	0.72 c	8.08 c	31.50 d	4.20 b	1.47 c	346.0 d	2.4 a
50 (C)	0.82 b	13.80 b	60.00 c	3.00 c	1.76 b	603.8 c	2.21 b
75 (D)	0.82 b	14.73 a	79.63 b	1.40 d	1.89 b	689.2 ba	1.99 c
100 (E)	1.01 a	14.30 a	81.45 a	1.20 d	2.18 a	725.5 a	1.83 dc
Second season-2019							
No irrigation (A)	0.59 e	5.13 d	16.70 d	5.50 a	1.30 d	207.8 e	-
25 (B)	0.82 d	8.03 c	41.05 c	2.40 b	2.40 c	341.8 d	2.28 a
50 (C)	0.97 c	14.50 b	66.35 b	1.20 c	2.42 c	634.0 c	2.25 a
75 (D)	1.27 b	16.13 a	87.98 a	0.82 d	2.91 a	696.9 ba	2.03 b
100 (E)	1.05 a	15.35 a	88.35 a	0.82 d	2.61 b	723.1 a	1.89 c

[a] Means followed by different letter (s) within a parameter differed significantly by DMRT at P ≤ 5 %.

when irrigation water and ET increased, yield also increased. These results were in agreement with those found by Yousuf et al (2018), Zapotoczny et al (2019) on black cumin and Oweis and Hachum (2012) on the grain crop. Knowing these relations between the yield and irrigation water will give us a real perspective about the significance of precision irrigation in agriculture compared to traditional one. A thing which would lead us to save more water (Molden et al., 2010).

The calculated values of yield response factor (k_y) confirmed that the DI technique was effective on black cumin. The k_y mean achieved about 0.43 in two seasons. Its highest values were obtained by the treatment (B) replicators recording (0.69, 0.72, 0.75 and 0.71). They gradually decreased to (0.17, 0.23, 0.21 and 0.14) in the treatment (D) as shown in Figure 3. Similar data were reported by Ozer *et al.* (2020).

Considering the scientific reports issued by FAO 36 (Steduto *et al*., 2012), we

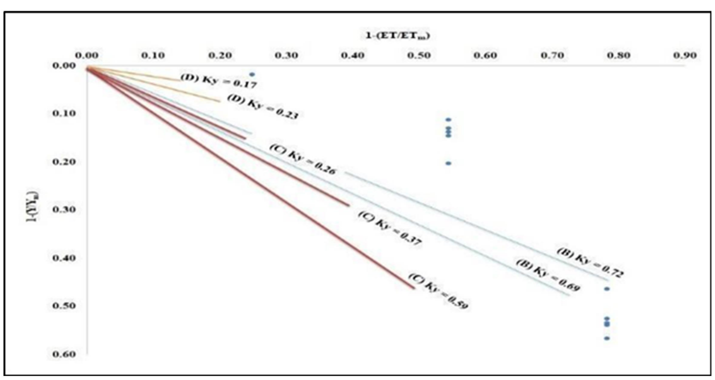

Figure 3. Average black cumin (k_y) values under (DI) technique during two seasons.

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Table 6. The economical study of the field trials of black cumin during 2018-2019 seasons. [a]

ET_p (%)	Yield (kg. ha^{-1})	Product value ($. ha^{-1})	Irrigation amount (mm. ha^{-1})	Irrigation costs ($. ha^{-1})	Uniform costs ($. ha^{-1})	Harvest costs ($. ha^{-1})	Total costs ($. ha^{-1})	Profit ($. ha^{-1})	Profit to total cost (%)
First season-2018									
No irrigation (A)	170.3 e	459.8 e	-	-	119.0	100.0	219	240.8 d	109.9
25 (B)	346.0 d	934.2 d	145.7	123.6	210.0	100.0	433.6	500.6 c	115.5
50 (C)	603.8 c	1630.3 c	273.0	231.5	345.0	130.4	706.9	923.4 b	130.6
75 (D)	689.2 ba	1860.8 b	346.2	293.5	390.0	148.9	832.4	1028.4 a	123.5
100 (E)	725.5 a	1958.8 a	395.6	335.5	410.0	156.7	902.2	1056.6 a	117.1
Second season-2019									
No irrigation (A)	207.8 e	602.5 d	-	-	180.5	110.0	290.5	312.0 d	107.4
25 (B)	341.8 d	991.1 c	150.0	144.0	210.3	115.0	469.4	521.8 c	111.2
50 (C)	634.0 c	1839.0 b	281.7	270.4	381.6	147.1	799.1	1039.9 b	130.1
75 (D)	696.9 ba	2012.0 a	343.9	330.2	415.3	161.7	907.2	1104.8 a	121.8
100 (E)	723.1 a	2097.0 a	381.0	365.8	431.9	167.8	965.5	1131.5 a	117.2

[a] Means followed by different letter (s) within a parameter differed significantly by DMRT at $P \leq 5$ %.

noticed that the crop yield response factor was less than one, which means that the crop can tolerate water shortage and is suitable to dry areas such as our study site. Consequently, we recommend that the deficit irrigation programs should be applied in the regions with limited water resources in order to increase the yield for black cumin plant, which is widely cultivated under rainfed (non-irrigated) conditions.

Black Cumin Economical Feasibility under the Impact of DI

Results of statistical analyses have indicated that the black cumin was successful economically and beneficial in dry environments, but the best profit will be achieved only after the application of deficit irrigation. The ratio (profit/total costs) value was higher at C and D than the rest of the treatments. Treatment C excelled all the treatments achieving 130.6 and 130.1% in both seasons, respectively, as given in Table 6. Therefore, we recommend not to fully irrigate the crop in this type of environments.

CONCLUSIONS

With growing water demand and increasing signs of water scarcity, there is an urgent need to achieve higher output per unit of water consumed. Fortunately, there is an extensive range to improve crop water productivity, particularly in areas where water shortage aggravates such as Syria. In the present study, effects of the deficit irrigation technique (DI) on water applied, crop quality standards and WUE were investigated. The results of the study indicated that DI treatments remarkably decreased the applied water in the order of B< C< D< E and simultaneously increased WUE in the order of B> C> D> E.

The B treatment has attained the highest WUE of 2.4 kg ha^{-1} mm^{-1}. The lowest WUE (1.85 kg ha^{-1} mm^{-1}) was at the treatment (E).

Reference evapotranspiration (ET_0) value was calculated based on class-A pan method (ET_0= ET_p), which was recorded as the maximum value during June. Water consumptive started to increase from the date of sowing in February till Midseason stage and reached maximum in May then again reduced in the last Maturity and harvest stage in June. The yield response factor (k_y) values decreased with increasing the irrigation water application. The average of (k_y) was 0.43 during both seasons. That certainly indicates that black cumin tolerates water shortage.

Concerning the water-yield functions, we recommend the 50% of ET_P treatment because there has not been a significant reduction in productivity compared to the savings in water consumption. Furthermore, the results of economical analyses have confirmed that there is a high economical return after the application of DI.

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اثر روش کم آبیاری بر کارایی مصرف آب زیره سیاه (*Nigella sativa* L.)

ت. یاغی، ع. ارسلان، و ح. سعید

چکیده

برای افزایش سود کشاورزی، آزمایشی در مرکز تحقیقات علمی کشاورزی (SARC) در Salamiyah درسوریه انجام شد. هدف این آزمایش برآورد مقدار آبیاری بهینه که بهره‌وری را به حداکثر می‌رساند و همچنین کیفیت زیره سیاه در شرایط آزمایشی بود. تیمارهای آبیاری ۲۵٪، ۵۰٪، ۷۵٪ و ۱۰۰٪ تبخیر و تعرق پتانسیل (ET_P) بر اساس تبخیر تشتک کلاس A بود. تیمارها به ترتیب B، C، D و E نشان داده شد. تیمار بدون آبیاری (A) به عنوان شاهد در نظر گرفته شد. آب آبیاری با سامانه قطره ای اعمال شد. تیمارهای A–E با استفاده از طرح بلوک‌های کامل تصادفی (CRBD) با چهار تکرار طراحی و اجرا شد. تبخیر و تعرق واقعی (ET_a) پس از کالیبراسیون خاک با استفاده از نرم افزار SPAW محاسبه شد. افزون بر این، عملکرد محصول، کارآیی مصرف آب آبیاری (IWUE)، ضریب پاسخ عملکرد (k_y) و برخی پارامترها (دوره رشد، تاریخ گل‌دهی و غیره) طی فصل‌های رشد سال‌های ۲۰۱۹–۲۰۱۸ تعیین شد. نتایج نشان داد که می توان برنامه آبیاری را با استفاده از برخی معادلات و تبخیر تشتک کلاس A انجام داد. نیز، در مقایسه سطوح آبیاری بالاتر و پایین‌تر، پارامترهای رشد رویشی به طور مجازی و قابل‌توجهی شکوفا شدند. با اینهمه، با کاهش آب آبیاری، مقادیر کارآیی مصرف آب آبیاری (IWUE) افزایش یافت. تیمار B بالاترین مقدار IWUE را ثبت کرد (۲.۴ کیلوگرم در هکتار برای هر میلی متر)، اما مقادیر کلیدی کمتر از ۱.۰ باقی ماند که نشان می‌دهد زیره سیاه خشکسالی را تحمل می‌کند. افزون بر این، در رابطه با نسبت سود به هزینه کل، تیمار C امتیاز برتر (۱۳۰.۶٪) را به‌دست آورد. در نتیجه، بر پایه نتایج، توصیه می‌کنیم که آبیاری بیش از ۷۵٪ و کمتر از ۲۵ ٪ ET_P نباشد.

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