Journal of Medicinal Plants Research Vol. 4(16), pp. 1612-1616, 18 August, 2010
Available online at http://www.academicjournals.org/JMPR
DOI: 10.5897/JMPR09.376
ISSN 1996-0875 ©2010 Academic Journals

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Full Length Research Paper

Yield and water use efficiency of *(Nigella sativa L.)* under different irrigation treatments in a semi arid region in the West of Iran

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Accepted 16 June, 2010

Black cumin (*Nigella sativa*) is a medicinal plant with economic influences, especially in medicine production. The present study investigates the effects of different drip tape and furrow irrigation treatments with normal and deficit irrigations on water use efficiency, various plant parameters and oil content of *N. sativa*. For this purpose, an experiment with three replications was conducted on a completely randomized block designed. The irrigation treatments consist of three modes of surface drip tape (SDT) irrigation with 50, 75 and 100% evapotranspiration (Et) as well as one mode of surface furrow (SF) irrigation with 100% (Et) requirement of the plant. The highest water use efficiency (1.39 kg/ha/mm) was obtained for drip tape 50% (Et) treatment while the lowest water use efficiency (0.492 kg/ha/mm) was obtained for furrow irrigation treatment 100%(Et). The results showed that seed yield and harvest index was significantly affected by different irrigation treatments ($P < 0.01$). Additionally, the number of follicles per plant and total yield were also affected by different water treatments ($P < 0.05$). The results showed, there were no significant effects on plant height, the number of seed per follicle, 1000 seed weight, the number of plants per m^2 and oil content, based on obtained results, this paper suggests that in different area with prevailing deficit water resources drip tape irrigation 50% (Et) has proven suitable to produce black cumin with high water use efficiency and significant oil content. The results showed that black cumin tolerates water deficiency.

Key words: *Nigella sativa*, drip tape irrigation, deficit irrigation, water use efficiency.

INTRODUCTION

The seed of *Nigella sativa* plant has been used since long to protect health and combat different diseases in countries especially in different parts of Middle East and Southeast Asia. In Southern parts of Asia, this plant has been known as Kalonji while its Arabic name is Habat-ul-Sauda. It is called black cumin in English (Nadkarni, 1976). This plant is widely grown in different parts of the A large number of medicinal and aromatic plants are locally adapted and considered as native to arid regions of the world (Bannayan et al., 2006 and Nadjafi, et al., 2006). Such regions grow a high portion of plants rich in secondary compounds. Black cumin (*N. sativa* L.) is an annual plant which is originally grown in arid and semi world especially in arid and semi-arid regions of Iran.

A large number of medicinal and aromatic plants are locally adapted and considered as native to arid regions of the world (Bannayan et al., 2006 and Nadjafi, et al., 2006). Such regions grow a high portion of plants rich in secondary compounds. Black cumin (*N. sativa* L.) is an annual plant which is originally grown in arid and semi arid regions (Patel et al., 1996; D' Antuno et al., 2002). It is reported that whole black cumin seeds or their extracts contain anti-abetic, antihistaminic, anti-hypertensive, anti-inflammatory, anti-microbial, antitumour, galactagogue and insect repellent compounds (Riaz et al., 1996; Siddiqui and Sharma, 1996; Worthen et al., 1998). Some studies shown that the black cumin is able to tolerate moderate levels of water stress (Mozzafari et al., 2000; Bannayan et al., 2008). Some researches have focused

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Table 1. The physical and chemical properties of soil.

Soil texture	Clay (%)	Silt (%)	Sand (%)	Zn (Meq/l)	Fe (Meq/l)	Mn (Meq/l)	C (%)	K (Meq/l)	P (Meq/l)	EC (µ mhos/cm)	pH
Silty clay	45	42.3	3.7	1.36	11.9	7.8	1.38	440	26	1.2	7.3

Table 2. The physical and chemical properties of water.

Physical properties of irrigation water		Chemical properties of water			
		Cations (meq/lit)		Anions (meq/lit)	
EC (µ ohs/cm)	1000	$Mg^{++}+Ca^{++}$	8.15	CO_3^{--}	0
pH	7.10	Na^+	1.08	HCO_3^-	6.15
TDS (mg/lit)	640	S.A.R	0.54	Cl^-	1.90
-	-	-	-	So_4^{--}	1.18

Table 3. Pan coefficient (Kp) in different months.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Coefficient	0.62	0.72	0.77	0.77	0.78	0.77	0.76	0.75	0.73	0.69	0.63	0.58

on response of black cumin to different irrigation intervals (Babai, 1995; Mozzafari et al., 2000) and irrigation scheduling based on developmental stage (Bannayan et al., 2008). Moreover, deficit irrigation is one way of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied where crop is exposed to a certain level of water stress either during a particular period or throughout the entire growing season (English and Raja, 1996). The aim of the present study is to investigate the yield, water use efficiency and oil content of (*N. sativa* L.) under different irrigation treatments in a semi arid region in the Kermanshah province, west Iran.

MATERIALS AND METHODS

The field experiments were performed in the Irrigation and Water Resources Engineering Research Field experimental station situated at 47° 9' N' and 34° 21' E, at the elevation of 1319 m in the Faculty of Agriculture, Razi University of Kermanshah west Iran during one year winter/autumn crop growing season (March - August, 2007). The experiment were conducted in complete randomized blocks design including different levels of irrigation water amount (50, 75 and 100%) with surface drip (SD), and surface furrow (SF) (with 100%) of evapotranspiration (Et) requirement. The physical and chemical properties of field soil like soil texture, pH, bulk density and electrical conductivity etc. are shown in Table 1. Irrigation water quality was C2S1 based on Wilcox diagram. Table 2 shows the physical and chemical properties of irrigation water used. 55 to 15 m field area was divided into three equal subplots to apply different irrigation treatments. Tape tubing with 10 cm emitter spacing was used in different drip irrigation treatments. The black cumin seeds were planted on 10 March 2007. The planting density was 4 kg/ha. The treatments were spaced by 2 m plots in order to minimize water movement among different treatments. Plot designed as 15 m long × 2.5 m wide (6 row per plot). The total concentration of fertilizer of N, P2O5 was 100, 100 and kg/ ha, respectively based on technical advice received from soil lab staff.

Evapotranspiration was estimated from the water balance equation below:

$$Et = I + R \pm \Delta S_m - D_r$$

Where, Et represents crop evapotranspiration (mm); I, is the amount of irrigation water applied (mm); R, is precipitation (mm), ΔS_m shows any change in soil moisture content (mm); and D_r is deep percolation water (mm). The amount of irrigation water applied to the highest irrigation water treatment was limited to the black cumin consumptive use demand. Consequently, percolation was assumed to be zero while the irrigation interval was 2 days.

In the calculation irrigation amount of water, the method given by Allen et al. (1998) was followed:

$$ETo = Kp\ Epan \quad \text{and} \quad ETc = Kc\ ETo$$

Where ETo is reference evapotranspiration (mm), pan coefficient, Kp (Table 3), Epan, pan evaporation (mm), ETc crop evapotranspiration (mm) and Kc is crop coefficient.

Three crop coefficients equal 0.34, 1.15 and 0.3 for different stages of initial, mid and end season of black cumin were used respectively. Crop evapotranspiration was calculated directly by multiplying pan evaporation by a crop pan coefficient as below:

ETc = Kcp Epan

The volume of Irrigation water requirement for each treatment was calculated by considering of area.

Irrigation water use efficiency (WUE) was estimated as the ratio of seed yield (kg/ha) and irrigation water applied (mm) based on below formula.

$$WUE = \frac{Seed.yield(kg/ha)}{Irrigation.water.applied(mm)}$$

Harvest index was calculated as follow:

$$HI = \frac{Y}{(Ps + Y)}$$

Where, HI is harvest index, Y is economical seed yield (kg/ha) and Ps is straw yield (kg/ha).

Final seed yield and yield components were measured from 1 m^2 of each plot. Characters were consist of biological yield, plant height, follicles per plant, seeds per follicle, 1000 seed weight, , harvest index, plant number per m^2 , total yield and finally oil percent. Seed oil of black cumin was extracted from seed samples per plot, finely ground under liquid nitrogen, by means of a Soxtech apparatus. Oil percentage value was determined according to standard method of oil analysis as suggested by Kufman, 1958.

Data were subjected to analysis of variance (ANOVA) using statistical analysis system, and following Duncan's multiple range tests and terms were considered significant at $P < 0.05$ and 0.01 by MSTAT-C software.

RESULTS AND DISCUSSION

Comparative water use efficiency in various treatment

Irrigation water uses during crop growing period for different treatments T1 (50% ET) SD, T2 (75% ET) SD, T3 (100% ET) SD and T4 (100% ET) SF, were 413.59, 620.38, 827.18 and finally 1461.5 mm, respectively. The result of total irrigation water use (mm), seed yield and water use efficiency (WUE) based on seed yield for all treatments and their Duncan test classes were given in (Table 4). The results of this experiment showed that maximum and minimum seed yield with (906.5 and 575.6 kg/ha) were achieved for treatments T3 and T1, respectively. The seed yield was affected significantly ($P < 0.01$) by water stress.

The results showed that the effects of different irrigation treatments on water use efficiency were significant ($P<0.01$) based on their Duncan test (Table 4). The highest and lowest water use efficiency (1.39 and 0.492 kg/ha/mm), were achieved for treatments T1 and T4, respectively.

Comparative crop yield in various water treatments

All measured plant parameters for different irrigation treatments are shown in Table (5). As results of this study demonstrated, water deficit had a negative effect on most of the morphological characteristics of black cumin. It was also observed that as the water stress increased, biologic yield, plant height, Follicles per plant, 1000 seeds weight, total yield of black cumin conversely decreased.

The results showed that water deficit stress significantly ($p < 0.01$) affected biological yield, the highest and lowest biological yield with 1356 and 827.40 kg/ha were obtained in treatments T4 and T1, respectively. No significant differences were found for the effects of water stress on plant height and the number of plant per m^2. The results showed that the effect of water stress on Follicles per plant was significant ($p < 0.05$). The highest and lowest Follicles with 24.24 and 17.52 per plant were achieved for treatments T3 and T1, respectively. There was no significant difference in the number of seed per Follicles were found for different treatments. The highest and lowest number of seeds per Follicles with 64.42 and 52.46 were achieved for treatments T3 and T1, respectively. Also, there was no significant difference in the number of 1000 seed weight among different treatments. The results were similar to those of (Bannayan et al., 2008) where no significant difference in the number of1000 seed weight was reported in different irrigation treatments for black cumin.

The results of experiment revealed that the effect of water stress on harvest index was significant ($p < 0.05$), with highest value (46.20) in T3 and lowest value (34.83) in T4. Finally, the results showed that the effect of water stress on total yield was significant ($p < 0.05$).

No significant differences in oil amounts (%) were observed for different drip tape irrigation treatments (Table 4). The highest and lowest oil amounts (%) were achieved in treatments T3 and T1 with 30.40 and 29.10%, respectively. The results were similar to those reported by Bannayan et al., 2006.

Linear correlation between yield and total water use

The total irrigation water use In different surface drip irrigation treatments were achieved 413.59, 620.38 and 827.18 mm and total seed yield for the treatments were 575.6, 697.2 and 906.5 kg/ha, respectively (table 5). The investigation of the obtained results also showed that there was a linear function between yield and total water use for different surface drip irrigation treatments as $y_a = 0.800TWU + 230.08$ (Musick and Dusek, 1994; Gowing et al., 2009) also reported the same linear relationship.

Table 4. The effect of irrigation treatments on seed yield and water use efficiency of black cumin.

Irrigation treatment	Irrigation water use (mm)	Seed yield (kg/ha)	Water use efficiency based on seed yield (kg/ha/mm)
T1(50% ET) SD	413.59	575.6 c	1.39 a
T2(75% ET) SD	620.38	697.2 b	1.123 b
T3(100% ET)SD	827.18	906.5 a	1.097 b
T4(100% ET)SF	1461.15	719.1 b	0.492 c

Different letters indicate significant differences at ($P < 0.01$) using Duncan's multiple range test. SD = surface drip (tape) irrigation. SF = surface furrow irrigation.

Table 5. The effect of irrigation treatments on some characteristics of black cumin.

Irrigation treatment	Biologic yield (kg/ha)	Plant height (cm)	Follicles per plant	Seeds per follicle	1000 seeds weight (gr)	Harvest index (%)	Plant per m^2	Total yield (kg/ha)	Oil (%)
T1(50% ET) SD	827.40 c	29.67b	17.52 b	52.46 a	2.333 a	41.08b	26.33a	1403b	29.10 a
T2(75% ET) SD	942.80 bc	35.2ab	19.28 b	59.92 a	2.357 a	42.54b	26a	1640b	29.63 a
T3(100% ET)SD	1056.50 b	38.53a	24.24 a	64.42 a	2.24 a	46.20 a	26.33a	1963a	30. 40 a
T4(100% ET)SF	1356 a	31.93ab	23.29 a	55.75 a	2.267 a	34.83c	25.33a	2075a	30.20 a

Different letters indicate significant differences at ($P < 0.01$) using Duncan's multiple range test.

Conclusion

According to the results obtained, the amount of water use in treatment T4 (100% ET) SF was 1.77 times more than treatment T3 (100% ET) SD, while seed yield production in treatment T3 was 187.40 kg/ha higher than treatment T4. Also, the water use efficiency T3 is higher by 0.61 (kg/ha/mm) compared to that of T4. These results showed that the surface drip tape (SD) irrigation treatment have resulted better yield and water use efficiency of black cumin compare to surface furrow irrigation (SF). In SD irrigation with treatment (100% Et), the seed yield was significantly higher compared to that of other treatments, hence the treatment can be proposed for area with enough water resources condition. However, in area with limited water resources, treatment T1 (50% ET) SD can be proposed, because it was clear that in this treatment compare to treatments T2 and T3, water use efficiency 0.27 and 0.29 (kg/ha/mm) was higher and the total water use about 25 and 50% was lower respectively. The treatment T1 (50% Et) SD can be suggested for areas with limited water resources. Additionally, the comparison of treatments T1 with T3 showed that by doubling the water use during crop planting period, the seed yield of black cumin was increased 1.57 times. This emphasizes that the increase in yield with water use in black cumin production is limited. Finally, the results of this investigation showed that black cumin is tolerant to water deficit.

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