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EFFECT OF WATER STRESS AND POTASSIUM FERTILIZER ON THE GROWTH, YIELD AND COMPOSITION OF ESSENTIAL OIL OF FENNEL PLANT

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ABSTRACT

Two field experiments were carried out at Sakha Agricultural Research Station during the 2009 and 2010 seasons to investigate the impact of water stress treatments (40, 60 and 80% depletion from available soil water) and potassium fertilizer levels (18, 24 and 30kg K_2O/fed) as potassium sulphate on the growth, yield and essential oil of fennel plants. The obtained results showed that supplying plants with a water level of 40% from available soil water and 30kg K_2O/fed were effective on raising the productivity of fruit yield and essential oil. The interaction between these two treatments gave the best results. Concerning essential oil constituents, methyl chavicol (estragole) was the major compound, followed by limonene, fenchone, anethole, α pinene, myrcene and β pinene. The values of consumptive use, water applied and water storage in the effective root zone were clearly affected by irrigation treatments where the highest values for the three studied parameters were increased under I_1 (irrigation at depletion of 40% from available water, consequently, the values of these parameters can be arranged descendingly as follows: $I_1 > I_2 > I_3$ while, the mean values of water application efficiency can be arranged descendingly in order of $I_3 > I_2 > I_1$.

Keywords: *Foenciulum vulgare*, water stress, potassium fertilizer, oil yield, essential oil, water use consumptive, water applied.

INTRODUCTION

The problem of limited water supply is becoming more and more urgent in Egypt due to the following features of water status. Arable land in Egypt is entirely most dependent on irrigation because the amount of rainfall is negligible and ranges from zero to 150-200 mm in the southern part and northern one, respectively. So, Agriculture under such conditions of rainfall in Egypt of no significant magnitude. Main source of fresh surface water is the River Nile. Its sources are beyond the boundaries of Egypt, which constitute one of the tail end countries of the Nile basin. Egypt's annual share of the Nile water is about 55.5 milliard cubic metre. Other water resources such as groundwater and rainfall are of less in magnitude.

One approach for adaptation to drought conditions would be switching to locally adapted plants which are not only considered as cash-crops for farmers but also as alternatives to current commercial agronomic crops.

The local plants are more adapted to local environmental conditions than commercial agronomic crops. A considerable number of medicinal and aromatic plants are locally adapted and considered as native to arid zones of the world (Bannayan *et al.,* 2006). Since fennel (*Foeniculum vulgare* Mill.) is one of the most important medicinal plants grown within the Mediterranean region, in Europe and Egypt, it's export value amounts 10 million US $ from Egypt. Investigations to improve the possibilities of growing fennel also on newly reclaimed land within Egypt have been done. The Egyptian government might be in collaboration with the who seeks to protect these plants that serve as sources for pharmaceutical compounds and who might increase the export of these plants from Egypt to all over the world (Egypt Magazine, 2000).

Fennel (*Foeniculum vulgare* Mill.) belongs to the family Umbelliferae (Apiaceae), is a short lived herb, indigenous to Europe and cultivated in India, China and Egypt (Wichtel and Bisset, 1994). It's an aromatic herb whose fruits contain essential oil which is used for many purposes by human .The oil of fennel regulates the peristaltic functions of the gastrointestinal tract,and relieves the spasms of intestines (Fathy *et al.,* 2002). Externally, the oil relieves muscular and rheumatic pains. The seeds have a traditional reputation as an aid to weight loss and longevity. The major constituent of fennel oil is anethole (Braun and Franz, 1999). Plant nutrition is one of the most important factors that increases plant production. Potassium is considerd one of the major nutrients and it is very important element in growth and development of plants. It is necessary in young growing tissues for cell elongation and possibly for cell division. It is very mobile in plants and therefore circulates freely and has vital role in maintenance of turgor pressure. It helps in several physiological processes and uptake of other nutrient elements (Mengel and Kirkby, 1982). It also plays an important role in activation of more than 60 enzyme systems in plants. It has a role in stomatal respiration, photosynthetic transfer ,and crop development. Since intensive use of farm land might go along with mismanagement leading to loss of soil fertility and together with these reduction of physical and microbiological soil parameters under these conditions making fertilization of the soil with potassium a most to avoid plants reduction symptoms. In addition it also plays an important role in irrigation where it helps plants to be tolerant for water stress.

However, studies on agronomic factors such as water stress and potassium fertilization on the growth, yield and composition of essential oil of fennel have not been sufficiently investigated until now.

This study aimed to evaluate the effect of irrigation regimes and potassium fertilization on the vegetative growth, yield, essential oil content, some water relationships and their main constituents of *Foeniculum vulgare*. Mill and studying the water regime in the soil.

MATERIALS AND METHODS

The present investigation was carried out at Sakha Agricultural Research Station during the two successive seasons of 2008/2009 and 2009/2010. Seeds of fennel were obtained from Medicinal and Aromatic Plants Department, Agricultural Research Center, Egypt and were sown in the field on October15th in the two seasons in hills at 35 cm distances on rows 60 cm apart in plots of 70m^2 (7*10) as the area of each irrigation treatment and the area of each fertilizer treatment was 7m^2. The soil of the experimental field was clay-loam with pH of 7.95, Ec of 1.74 mm hos/cm, available N of 39.40 ppm, available P of 8.37 ppm, available K of 209.30 ppm and organic matter of 1.6% (Jackson, 1967). Soil bulk density was determined according to Klute (1962). Other soil properties were analyzed before planting and presented in Table (1). Meteorological measurements during the course of the study were recorded in Table (2).

Table (1): Some properties of the studied soil site before planting

Soil depth (cm.)	Mechanical analysis			Soil texture	Bd (g/cm^3)	F.C(%)	P.W.P.(%)	AW
	Sand%	Silt%	Clay%					
0-15	29.08	35.6	35.32	Clay loam	1.20	40.2	22.01	18.19
15-30	28.6	33.4	38.0	Clay loam	1.22	38.3	19.9	18.4
30-45	28.7	34.5	36.8	Clay loam	1.25	36.2	18.6	17.6
45-60	28.9	34.6	36.5	Clay loam	1.38	35.7	17.9	17.8

Where:
Bd = Soil bulk density (g/cm^3)
F.C = Soil field capacity (%)
P.W.P = Permanent wilting point
A.W = Soil available water.

Table (2): Average climatic data for Sakha area during the two growing season of 2008 and 2009.

Month	Air temperature	Relative humidity R.H(%)	Solar radiation (jul/m^2)	Evaporation (cm/day)	Rainfall (mm/month)	Wind velocity (m/sec)
October	22.55	61.9	12.0	0.426	0.0	1.0
November	18.56	69.3	8.7	0.332	0.0	1.0
December	14.5	72.6	7.0	0.211	0.11	1.1
January	16.2	77.5	9.8	0.229	0.2	1.3
February	17.8	83.8	13.8	0.279	0.61	1.4
March	18.5	74.4	15.0	0.479	0.0	1.7
April	22.4	73.4	22.2	0.532	0.0	1.5
May	21.8	69.2	22.6	0.703	0.0	1.5

The experimental layout was factorial in a complete randomized design (CRD), with three replications. The study contained 9 treatments, which represented all combinations between 3 irrigation treatments at 40, 60 and 80%depletion from available water (I_1, I_2 and I_3). Then three potassium fertilization rates as potassium sulphate were added in two portions after 45 and 90 days from sowing. The doses were18, 24, 30 kg K_2O/fed (K_1, K_2, K_3).

The plants were harvested on May 3rd in the both seasons and the following data were recorded:

A. Vegetative growth characters:

1. Plant height (cm).
2. Number of branches/plant.

B. Flowering and yield characters:

1. Number of umbels per plant.
2. Weight of 1000 seeds (g).

3. Fruits yield per plant(g).
4. Fruits yield per fed(kg).

C. Essential oil:

Oil percentage of the fruits was determined according to British Pharmacopoeia, (1963), Essential oil yield/fed. was calculated by multiplying oil (%) by fennel fruits yield. GC/Mass analysis of volatile oil of each treatment was performed with specification of the apparatus used according to Robert, (1995).

D. Chemical analysis:

Mineral content included, nitrogen percentage using kjeldhal method described by Hach *et al.*(1985), phosphorus percentage was estimated according to A.O.A.C., (1970) and potassium percentage was determined by flame photometer using the method described by Brown and Lilleland, (1946).

E. Amount of water applied:

The amount of irrigation water applied was measured by using a calibrated set of cut-throat flume (20*90 cm),(Early, 1975).

F. Water consumptive use (C.U.):

Water consumptive use (C.U.) was calculated according to Israelson and Hansen, (1962) as follows:

$$Cu = \sum_{i=1}^{i=n} \frac{P_{w2} - P_{w1}}{100} \, x \, Bd \, x \, Di$$

where:

Cu = water consumptive use in cm.

P_{w1} = Soil moisture percent before irrigation in the 1st layer

P_{w2} = Soil moisture percent after irrigation in the 1st layer.

Bd = Soil bulk density **(**g/cm^3**)** of the i layer of the soil.

Di = Depth of i Th layer of the soil, (cm).

i = Number of soil layers sampled in root zone depth.

G. Water application efficiency:

Water application efficiency, is the ratio of the average depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied (Michael, 1978).

The experimental data were statistically analyzed according to Steel and Torrie (1980). The least significant difference (LSD) at 5% level was used to compare between means of treatments (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

A. Vegetative growth characters:

Data presented in Table (3) indicated that increasing percentage of depleted water from available water decreased both plant height and number of branches/plant. The highest mean values due to irrigation treatments were recorded with plants that received the highest amounts of water (I_1) irrigation at 40% depletion from available water. The pronounced effect of increasing irrigation on plant height and number of branches may be attributed to that the availability of sufficient moisture around the root concentrated and thus led to a greater proliferation of root biomass resulting in the higher absorption of nutrients and water leading to production of higher vegetative biomass (Singh *et al.,* 1997). Increasing potassium doses increased both plant height and number of branches/plant without significant differences between treatments except for number of branches/plant in the first season as the increasing was significant at the highest dose of 30 kg K_2O/fed in the both seasons. These results are in a great harmony with those found by Fodor and Kadlicsko (2006) who concluded that increasing rates of NPK fertization improved most of the growth parameters. The interaction effect was not significant in the two seasons for plant height but for number of branches/plant in the first season the effect was significant. The highest values of plant height were produced from the treatment of irrigation at 40% depletion from available water and fertilized with 30 kg K_2O/fed in the two seasons. The highest values of number of branches were produced from the treatment of irrigation at depletion of 40% from available water and fertilized with 30 kg K_2O/fed in the first season and the treatment of irrigation at depletion of 60% from available water and fertilized with 30 kg K_2O without significant differences with the treatment of irrigation at depletion of 80% from available water and fertilized with 30 kg K_2O in the second season. The stimulatory effects of applying potassium on vegetative growth may be attributed to the well known functions of potassium in plant life, as described in the introduction. The increase in vegetative growth characters with potassium fertilization is in agreement with the findings of Kandil (2002)on fennel , Singh *et al.* (2005) on lemon grass and Singh and Gamesha Rao (2009)on patchouli .

Table (3): Effect of irrigation and potassium fertilizer on plant height (cm) and number of branches/plant of *Foeniculum vulgare* Mill. Plant during the two seasons.

Treatments		Plant height (cm)		Number of branches/plant	
		1st season	2nd season	1st season	2nd season
Irrigation	I_1	139.56	141.78	11.03	11.81
	I_2	135.86	141.22	10.59	11.36
	I_3	134.83	140.44	10.38	10.30
Potassium	K_1	134.82	138.34	9.47	9.67
	K_2	137.37	141.32	10.23	10.71
	K_3	138.56	143.78	12.30	16.09
Irrigation x Potassium	I_1K_1	136.80	138.40	9.80	10.20
	I_1K_2	139.40	140.53	10.53	11.07
	I_1K_3	142.47	146.40	12.77	12.80
	I_2K_1	134.40	138.77	9.40	10.57
	I_2K_2	133.17	141.13	10.33	11.63
	I_2K_3	140.00	143.77	12.03	13.23
	I_3K_1	133.27	137.87	9.20	8.23
	I_3K_2	141.60	192.30	9.83	9.43
	I_3K_3	129.63	141.17	12.10	13.23
Irrigation (I)*		N.S	N.S	N.S	N.S
Potassium (K)*		N.S	N.S	1.80	N.S
(I) x (K)*		N.S	N.S	1.79	N.S

*** LSD at 5% level (I) irrigation at: 40, 60, 80% depletion from available water; (K)potassium fertilizer: 18, 24, 30 kg K_2O/fed, respectively.**

B. Flowering and yield characters:

1. Number of umbels and weight of 1000 seeds:

Data in Table (4) show that number of umbels and weight of 1000 seeds were not significantly influenced by irrigation treatments except for weight of 1000 seeds in the second season that highly significant influenced. The irrigation at 40% depletion from available water produced the highest number of umbels/plant as 26.32 and 26.45/plant in the two seasons, respectively as well as the highest weight of 1000 seeds as 8.04 and 8.32 gm in the two seasons, respectively.

Table (4): Effect of irrigation and potassium fertilizer on number of umbels/plant and weight of 1000 seeds (gm) of *Foenciulum vulgare* Mill. plants during the two seasons.

Treatment		Number of umbels/plant		Weight of 1000 seed (gm)	
		1st season	2nd season	1st season	2nd season
Irrigation	I_1	26.32	26.45	8.04	8.32
	I_2	25.56	25.60	7.78	8.25
	I_3	25.67	25.79	7.22	7.51
Potassium	K_1	23.10	23.32	6.36	6.66
	K_2	25.34	26.10	7.66	8.34
	K_3	28.40	29.14	9.02	9.08
Irrigation x Potassium	I_1K_1	22.93	22.83	6.60	6.80
	I_1K_2	25.13	26.70	7.93	8.60
	I_1K_3	28.73	29.43	9.60	9.56
	I_2K_1	23.13	23.83	6.46	6.80
	I_2K_2	25.23	26.07	8.00	9.00
	I_2K_3	28.33	29.47	8.90	9.00
	I_3K_1	23.23	23.30	6.03	6.40
	I_3K_2	25.66	25.53	7.06	7.43
	I_3K_3	28.13	28.53	8.56	8.70
Irrigation (I)*		N.S	N.S	N.S	4.35
Potassium (K)*		3.24	2.84	7.32	6.38
(I) x (K)*		N.S	N.S	1.79	N.S

*** LSD at 5% level (I) irrigation at: 40, 60, 80% depletion from available water; (K)potassium fertilizer: 18, 24, 30 kg K_2O/fed, respectively.**

These results are in agreement with those of Champolivier and Merrien (1996) who reported that water stress did not affect one thousand seeds weight in rapeseed (*Brassica napus*). The application of (K_3) at 30 kg K_2O/fed produced significantly the highest number of umbels/plant and weight of 1000 seeds compared to (K_1) of 18 kg K_2O/fed. A sufficient supply of various potassium compounds is, therefore, required in each plant cell for its proper functioning. Generally, the enhancing effect of K fertilization on plant growth may be due to the positive effects of potassium on activation of photosynthesis and metabolic processes of organic compounds in plants. The increase in number of umbels/plant and weight of 1000 seeds/plant with potassium fertilization is in agreement with the results reported by Mohamed and Abdue (2004)on fennel and Fodor and Kadlicsko (2006) on white mustard. The interaction effect on number of umbles/plant and weight of 1000 seeds/plant was not significant in both seasons. The highest values of number of umbles/plant and weight of 1000 seeds were produced from the treatment of irrigation at depletion of 40% from available water and fertilization with 30 kg K_2O/fed in the two seasons. This might be due to that increasing of vegetative growth under irrigation treatment of I_1 comparing with other irrigation treatments of I_2 and I_3. Also under I_1 irrigation treatment plants were more healthy and carried a higher number of effective branches take their requirements of nutrients by good distribution for their roots. These results are in agreement with those obtained by Yadav *et al.* (1997) on mustard.

2. Fruits yield per plant and per feddan:

Results obtained in Table (5) indicated that treatment of irrigation at 40% depletion from available water led to increase fruits yield/plant and/fed which gave the highest values of these parameters as 38.08 and 43.68 gm/plant and 689.05 and 786.28 kg/fed. in both seasons, respectively. This may be attributed to that fennel may easily be exposed to stress due to water deficit. as mentioned by Peteropoulos *et al.* (2008) on parsley.

Such stress causes a reduction in biomass, as expressed by mean foliage and root weights, as well as leaf number per plant, and probably results from a disruption of photosynthesis, transpiration and other metabolic processes (Sarker, *et al.,* 2005 on egg plant). Increasing potassium doses significantly increased fruits yield/plant and/fed in the two seasons. The highest values of fruits yield/plant and/fed were obtained from the doses of K_3 as 30 kg K_2O/fed in both seasons. These findings are in harmony with those obtained by Amin and Patel (2001)on fennel . The interaction effect was not significant in both seasons. The highest values of fruits yield/plant and/fed were produced from the treatment of I_1K_3(irrigation at 40% depletion from available water and 30 kg K_2O/fed) as 44.41 and 50.98 gm/plant and 813.39 and 917.76 kg/fed in the two seasons, respectively. This result contrasts with those of Said Al-Ahl *et al.* (2009) on oregano who showed that increasing levels of water stress reduced growth and yield due to reduction in photosynthesis and plant biomass and under increasing water stress level photosynthesis was limited by low CO_2 availability due to reduced stomatal and mesophyll conductance. Drought stress is associated with stomatal closure and thereby with decreased CO_2 fixation. The superiority of the plants that received the highest rate of irrigation treatments in producing the heaviest fruits yield/plant and/fed was in agreement with these of Amin and Patel (2001) on fennel and Moeini ALishah *et al.* (2006) on basil .

C. Essential oil % and yield/fed.

Data in Table (6) revealed that both water quantities and potassium application and their interaction affected the percentage of essential oil and essential oil yield/fed in fennel in both seasons. The mean values of essential oil due to water irrigation treatments showed that increasing water depletion from 40 to 80% from available water decreased the percentage of essential oil and essential oil yield/fed. These result are in agreement with those of Zehtab-Salmasi *et al.* (2001)who reported that water stress reduced oil yields from anise ,Singh and Ramesh(2000) reported also that water deficit strees reduced the oil yield of rosemary on a hectare basis, but oil yield on a plant fresh weight basis did not appear to be affected.

Table (5): Effect of irrigation and/or potassium fertilizer on fruits yield/plant and fruits yield/fed of *Foeniculum vulgare* Mill. Plants during the two seasons.

Treatment		Fruits yield/plant (gm)		Fruits yield/fed (gm)	
		1st season	2nd season	1st season	2nd season
Irrigation	I_1	38.08	43.68	689.05	786.28
	I_2	37.66	42.01	685.44	707.30
	I_3	37.08	38.63	663.48	683.42
Potassium	K_1	30.43	35.10	543.76	631.90
	K_2	39.33	43.59	708.00	784.72
	K_3	43.06	45.63	786.21	820.38
Irrigation x Potassium	I_1K_1	34.18	40.56	615.36	730.08
	I_1K_2	38.38	43.95	690.84	824.22
	I_1K_3	44.41	50.98	813.39	917.76
	I_2K_1	31.70	35.21	570.60	633.90
	I_2K_2	37.95	44.85	683.16	747.59
	I_2K_3	43.33	41.54	750.12	807.18
	I_3K_1	25.41	29.54	744.32	531.72
	I_3K_2	41.66	41.95	750.00	719.16
	I_3K_3	44.17	41.67	795.12	799.38
Irrigation (I)*		N.S	4.35	N.S	89.06
Potassium (K)*		7.32	6.38	122.10	106.8
(I) x (K)*		N.S	N.S	N.S	N.S

*** LSD at 5% level (I) irrigation at: 40, 60, 80% depletion from available water; (K)potassium fertilizer: 18, 24, 30 kg K_2O/fed, respectively.**

Table (6): Effect irrigation and potassium fertilizer on the essential oil percentage and essential oil yield of *Foeniculum vulgars* Mill. plants during the two seasons.

Treatments		Essential oil%		Essential oil yield L/fed	
		1st season	2nd season	1st season	2nd season
Irrigation	I_1	1.52	1.56	10.47	12.27
	I_2	1.39	1.42	9.52	10.04
	I_3	1.36	1.37	9.02	9.36
Potassium	K_1	1.39	1.37	7.56	8.66
	K_2	1.41	1.42	9.98	11.14
	K_3	1.45	1.48	11.40	12.14
Irrigation x Potassium	I_1K_1	1.34	1.35	8.25	9.86
	I_1K_2	1.48	1.50	10.22	12.36
	I_1K_3	1.55	1.63	12.61	14.96
	I_2K_1	1.48	1.48	8.45	9.38
	I_2K_2	1.52	1.57	10.38	11.74
	I_2K_3	1.34	1.41	10.05	11.38
	I_3K_1	1.36	1.38	10.12	7.34
	I_3K_2	1.36	1.39	10.20	10.00
	I_3K_3	1.35	1.35	10.73	10.79
Irrigation (I)*		0.01	0.06	0.50	0.68
Potassium (K)*		0.03	0.06	1.42	1
(I) x (K)*		0.06	N.S	0.07	N.s

*** LSD at 5% level (I) irrigation at: 40, 60, 80% depletion from available water; (K)potassium fertilizer: 18, 24, 30 kg K_2O/fed, respectively.**

Essential Oil Constituents:

Data in Table (7) showed that seven components were identified in fennel oil as methyl chavicol (estragole), limonene, fenchone, anethole, α pinene, myrccene and β pinene. The major components in fennel seed oil are estragole, more than 77%, and limonene, more than 32%. This result agrees with that of Braun and Franz, (1999) who found that anethole, estragole, fenchone and limonene are the major constituents of fennel essential oil which represent 93% of the fennel oil. In some natural populations in various areas estragole was found as the major component (Garcia Jimenenz *et al.,* 2000). The percentage of methyl chavicol (estragole) and limonene was slightly affected by irrigation and K treatments; whereas the fertilization with 30 kg K_2O/fed (K_3) and irrigation at depletion of 60% from available water (I_2) recorded the highest estragole % (77.57%) and fertilization with 24 kg K_2/fed (K_2) and irrigation at depletion 60% of from available water (I_2) recorded the highest limonene % (33.05%). The changes in the components quality occurred by using different irrigation treatments and potassium fertilization levels may be due to their effect on the metabolism and on these enzyme responsible for the components synthesis. Also, some variations may be due to the different climatic factors , handling collection and ripening times. These results are in harmony with those of Ormeno *et al.* (2007) and Blanch *et al.* (2009)on *Pinus halepensis*

Table (7): Effect of irrigation and potassium treatments on volatile oil components of fennel plants .

Identification	I_1			I_2			I_3		
	K_1	K_3	K_3	K_1	K_3	K_3	K_1	K_3	K_3
α pinene %	0.79	0.88	0.97	0.98	0.74	0.88	0.88	1.53	1.44
Myrccne %	0.07	0.09	-	0.07	0.14	0.08	0.02	0.04	0.34
β pinene %	0.03	0.05	0.20	0.05	0.03	0.25	0.25	0.40	0.75
Limonene %	28.37	27.84	26.63	15.44	33.05	13.23	15.88	14.64	13.03
Fenchone %	2.83	2.76	3.11	3.68	2.91	5.96	5.46	5.23	5.33
Methylchavicol (Estragole) %	63.70	64.62	66.86	73.66	58.74	77.57	74.77	74.40	75.32
Anethole %	1.04	0.91	0.82	3.14	1.43	0.58	0.75	2.53	1.70
Unknown %	3.17	2.85	1.41	2.99	2.96	1.45	1.99	1.23	2.84
Total identified	96.83	97.15	98.59	97.01	97.04	98.55	98.01	98.77	97.16

D. Chemical analysis:

N, P and K percentages:

Data Presented in Table (8) clearly illustrated that the mean values of the three major elements were affected by irrigation treatments, where the highest mean values were recorded under I_1 irrigation treatment (irrigation at depletion of 40% from available water) in the two growing seasons and the mean values are 2.62, 2.69 and 0.24, 0.23 and 2.99 and 3.04% for N, P and K in the first and second growing seasons, respectively. Increasing the mean values for the three studied elements (N, P and K) under I_1 irrigation treatment might be due to increasing amount of water applied under these conditions and hence, increasing its availability, which led to increasing uptake of these elements in comparison with the other irrigation treatments which gave lowest values. The mean values for the three studied elements can be arranged descendingly in order $I_1 > I_2 > I_3$ in the two growing seasons. These results are in harmony with those obtained by Leithy *et al.* (2006) on rosemary and Bannayan *et al.* (2008) on black cumin and plantago.

Table (8): Effect of irrigation and potassium fertilizer on N, P and K % by *Foeniculum vulagre* Mill. plants in the two growing seasons.

Treatments	N%		P%		K%	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
I_1	2.62	2.69	0.24	0.23	2.99	3.04
I_2	2.47	2.68	0.23	0.19	2.96	3.03
I_3	2.44	2.49	0.22	0.16	2.89	2.80
K_1	2.00	2.11	0.16	0.16	2.06	2.24
K_2	2.52	2.60	0.21	0.19	2.94	2.74
K_3	3.00	3.15	0.34	0.34	3.84	3.93
I_1K_1	1.98	2.03	0.32	0.33	2.03	3.27
I_1K_2	2.50	2.45	0.22	0.20	2.90	2.25
I_1K_3	3.20	3.27	0.36	0.37	3.996	41.03
I_2K_1	2.01	3.20	0.18	0.34	2.04	2.15
I_2K_2	2.43	2.65	0.20	0.18	3.03	2.98
I_2K_3	2.89	3.20	0.16	0.16	3.80	3.95
I_3K_1	2.03	2.11	0.35	0.16	2.10	2.20
I_3K_2	2.64	2.70	0.22	0.20	2.90	2.89
I_3K_3	2.92	3.00	0.14	0.16	3.75	3.80
Irrigation (I)*	0.072	0.12	0.041	0.041	0.04	0.19
Potassium (K)*	0.045	0.079	0.32	0.32	0.03	0.16
(I) x (K)*	0.080	0.11	0.056	0.056	0.056	0.28

LSD at 5% level (I) irrigation at: 40, 60, 80% depletion from available water; (K)potassium fertilizer: 18, 24, 30 kg K_2O/fed, respectively.

Data in the same Table showed that the mean values of N, P and K were clearly affected by potassium fertilization, where the highest values were recorded under the highest level of potassium fertilization of K_3 (30 kg K_2O/fed). On the contrary, the lowest values were recorded under the lowest level of K (18 kg K_2O/fed) in the two growing seasons. These results are in agreement with those obtained by Kandil on fennel (2002). Also, data in the same table showed that, the best interaction effect between I and K was recorded under I_1K_3 in the two growing seasons.

Amount of water applied (m^3/fed.)

Data presented in Table (9) clearly showed that the values of water applied were increased under I_1 irrigation treatment in comparison with the other two irrigation treatments of I_2 and I_3. The highest values were 3200.12 and 3252.90 m^3/fed due to I_1 treatment. but the lowest were recorded under I_3 irrigation treatment as 2061.50 and 2110.50 m^3/fed due to in the first and second growing seasons, respectively. Amount of water applied can be arranged descendingly in order $I_1 > I_2 > I_3$. This might be due to increasing number of irrigations accompanied with reducing irrigation period and hence increasing amount of water applied. These results are in harmony with those obtained by Amin and Patel (2001) on fennel.

Table (9): Effect of irrigation treatments on amount of water applied during the studied growing seasons.

Irrigation treatments	2009		2010	
	cm^3	m^3/fed.	cm^3	m^3/fed.
I_1	76.19	3200.12	77.45	3252.90
I_2	61.55	2585.10	62.83	2639.00
I_3	49.08	2061.50	50.25	2110.50

I_1: irrigation at depletion of 40% from available water.
I_2: irrigation at depletion of 60% from available water.
I_3: irrigation at depletion of 80% from available water.

Water consumptive use (m^3/fed.)

Data Presented in Table (10) clearly showed that the mean values of water consumptive use during the studied growing seasons were affected by irrigation treatments. Data revealed that the highest values were recorded under I_1 irrigation treatment (irrigation at depletion of 40% from available water) in the two growing seasons comparing with the other irrigation treatments of I_2 and I_3 and the mean values were 1920.07, 1951.74, 1551.06, 1583.4 and 1236.9, 1266.3 m^3/fed. for I_1, I_2 and I_3 in the first and second growing seasons, respectively. So, the mean values of water consumptive use can be arranged descendingly in order of $I_1 > I_2 > I_3$.

Increasing the mean values of water consumptive use under conditions of I_1 irrigation treatment of comparing with the two other irrigation treatments I_2 and I_3 might be due to that I_1 irrigation treatment led to decreasing irrigation interval, and increasing number of irrigations, consequently, increasing amount of applied water, so, the amount of water stored in the soil will be more and the values of water consumptive use will be high under I_1 irrigation treatment in comparison with other irrigation treatments of irrigation in a long period with a low number of irrigations and amount of irrigation water is low, therefore, decreasing the values of water consumptive use. Also under I_2 and I_3 irrigation treatments the soil conditions were dry and the mean values of water consumptive use are low. These results are in a great harmony with those obtained by Amin and Patel , (2001)on fennel.

Table (10): Fennel water consumptive use during the studied growing seasons.

Irrigation treatments	2009		2010	
	cm	m^3/fed.	Cm	m^3/fed.
I_1	45.72	1920.07	46.47	1951.74
I_2	36.93	1551.06	37.70	1583.4
I_3	29.45	1236.9	30.15	1266.3

I_1: I_1:irrigation at depletion of 40% from available water.
I_2: irrigation at depletion of 60% from available water.
I_3: irrigation at depletion of 80% from available water.

Water application efficiency.

Data Presented in Table (11) showed that the mean values of water application efficiency were clearly affected by irrigation treatments in the two growing seasons. The highest mean value was recorded under I_3 irrigation treatment (depletion of 80% from available water) and the value was 71% in the two growing seasons. On the contrary, the lowest mean values were recorded under I_1 (irrigation at depletion of 40% from available water) as were 64.0 and 61.0% in the first and second growing seasons, respectively. These results are in harmony with those obtained by Yadav. *et al.* (1997)on mustard.

Table (11): Water application efficiency(%) during the studied growing seasons.

Irrigation treatments	2009	2010
I_1	64	61
I_2	66	66
I_3	71	71

I_1:irrigation at depletion of 40% from available water.
I_2:irrigation at depletion of 60% from available water.
I_3:irrigation at depletion of 80% from available water.

Stored water in the effective root zone (m^3/fed.)

Data Presented in Table (12) illustrated that the values of stored water in the effective root zone were clearly affected by the studied irrigation treatments, where the highest mean values were recorded under I_1 irrigation treatment (irrigation at depletion of 40% from available water) comparing with the other irrigation treatments of I_2 and I_3. The highest values were 2060.78 and 2000.14 m^3/fed. in the first and second growing seasons, respectively. On the other hand, the lowest values were recorded under I_3 irrigation treatment (irrigation at depletion of 80% from available water) and the values were 1470.86 and 1500.33 m^3/fed. in the first and second growing seasons, respectively. Finally, amount of stored water in the effective root zone can be arranged descendingly in order of $I_1 > I_2 > I_3$ in the two growing seasons.

Increasing amount of stored water in the effective root zone under I_1 irrigation treatment might be due to increasing number of irrigations under the conditions of this treatment because of reducing irrigation interval, consequently, increasing amount of applied water and hence, increasing stored water in the effective root zone. These results are in a great harmony with those obtained by Yadav. *et al.* (1997).

Table (12): Effect of irrigation treatments on water storage in the soil (m^3/fed.) during the studied growing seasons

Irrigation treatments	2009	2010
I_1	2060.78	2000.14
I_2	1714.55	1730.60
I_3	1470.86	1500.33

I_1: irrigation at depletion of 40% from available water.
I_2: irrigation at depletion of 60% from available water.
I_3: irrigation at depletion of 80% from available water.

Conclusion

Decreasing irrigation levels increased the production of fennel and the optimum irrigation levels for the highest yields of fruits and essential oil was 40% from available soil water.

Potassium fertilizer increased fruit yield and essential oil production under well-watered condition at 40% from available soil water as the treatment of (I_1K_3) gave the best results in all studied characters.

The amount of water applied, water consumptive use and water application efficiency when plants were irrigated at 40% from available water were approximately 3250, 1950 m^3/fed and 61%, respectively.

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تـأثير الإجهـاد المـائى والتسـميد البوتاسـى علـى النمـو والمحصـول والمكونـات الكيميائية للزيت العطرى لنبات الشمر

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**** قسم بحوث المقننـات المائيـة والـرى الحقلـى ـ معهد بحـوث الأراضـى والميـاه والبيئـة ـ مركـز البحوث الزراعية.**

أجريت تجربتان حقليتان فى محطـة البحـوث الزراعيـة بسـخا خـلال موسـمى النمـو ٢٠٠٨/٢٠٠٩م ، ٢٠٠٩/٢٠١٠م لدراسـة تـأثير معـاملات الإجهـاد المـائى وهـى الـرى عنـد اسـتنفاذ ٤٠ ، ٦٠ ، ٨٠% مـن المـاء الميسـر ومسـتويات التسـميد البوتاسـى ١٨ ، ٢٤ ، ٣٠كجـم بـو٢أ/فـدان علـى صـورة سـلفات البوتاسـيوم علـى النمـو و المحصـول والمكونـات الكيميائية للزيت لنبات الشمر.

وقد أوضحت النتائج أن الرى عند استنفاذ ٤٠% من الماء الميسر والتسميد بمعدل ٣٠كجم بو٢أ/فدان أدت إلى زيادة الإنتاج وكذلك الزيت.واعطى التفاعل بين تلك المعاملات أحسـن النتـائج بالنسـبه للمحتـوى الكيمـاوى مـن الزيـت حيـث كـان إسـتراجول هـو المكـون الاساسى تلاه الليمونيين ، الفينشون ، أنيثيول ، الفابانين ، المرسين ثم البيتا باينين). بالنسبه لقيم الاستهلاك المائى والماء المضاف وكذلك الماء المخزن بمنطقة الجذور للمادة الفعالة فقد تأثرت بصورة واضحة بمعاملات الـرى حيث سجلت أعلـى القيم للمقـاييس المدروسـة تحت المعاملـة I_1 (رى عنـد اسـتنفاذ ٤٠% مـن المـاء الميسـر) وكـذلك القـيم بالنسـبه للمقـاييس المدروسة يمكن ترتيبها تنازليا $I_1 > I_2 > I_3$. وعلى العكس من ذلك متوسطات القيم بالنسبه لكفاءة إضافة المياه يمكن ترتيبها تنازليا $I_3 > I_2 > I_1$.

قام بتحكيم البحث

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