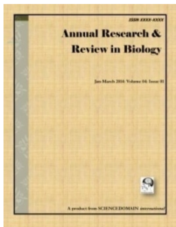

Annual Research & Review in Biology
4(12): 1968-1979, 2014

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Effect of Irrigation and Planting Date on Yield and Water Use Efficiency of Ajowan (*Carum copticum*)

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Authors' contributions

This work was carried out in collaboration between all authors. Author HN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author AE managed the analyses of the study. Authors MS and GM managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

Received 9th September 2013
Accepted 25th September 2013
Published 6th March 2014

ABSTRACT

Aims: This study was conducted to evaluate the effect of irrigation regimes and different planting dates on yield and water use efficiency of ajowan.
Place and Duration of Study: The study was carried out during 2009/2010 and 2010/2011 seasons in Birjand, Iran.
Methodology: Experimental design was split plot based on randomized complete block with three replications. Irrigation intervals (irrigation cut at the beginning of flowering and complete irrigation) as the main factor and six planting dates (December 6, December 21, January 5, February 29, March 30 and April 30) as sub factors.
Results: Results showed that the highest and lowest seed yields and number of seeds per plant was from planting dates of February 29 and March 30, respectively. Results showed that late planting decreased seed yield, number of umbels per plant and number of seeds per plant; but increased number of seeds per umbel and 1000-seed weight. Winter planting had higher yield and biomass water use efficiency compared to spring planting but seed water use efficiency and harvest index were not affected by planting date. The effect of the water stress treatment on plants' reproductive structures caused

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decreases to seed yield, seed water use efficiency and seed harvest index.
Conclusion: In general, these showed that winter planting in conditions of drought stress resulted in higher biomass water use efficiency.

Keywords: Ajowan; irrigation; planting date; yield; WUE.

1. INTRODUCTION

Water deficiency is one of the most important factors limiting plant growth and yield which is the reduction of product quality and lack water soil or air, often during the plant life cycle even outside of the semi-arid and dry areas occurs [1]. Some studies have shown that stress caused by lack of water led to numerous morphological, physiological and biochemical plant changes [2]. Therefore, agricultural production in conditions of water shortage presents a major challenge to producers that is set to continue in the future, especially in countries faced with drought, which require the development of new techniques and modern cropping systems with higher water use efficiency (WUE).

Reference [3] has identified the following two patterns associated with water stress: 1- Alternate: when stress can occur at anytime, 2- Continuous: when soil moisture levels are continuously depleted over a growing season; a condition that is especially prevalent in regions with a Mediterranean climate. There are three mechanisms that can contribute to decreased yield from drought stress: decrease of the photosynthetic active radiation absorption (decrease of the canopy development), decreases in radiation use efficiency and harvest index [4]. On this basis, plants have three major lines of defensive against drought stress: decreasing the pressure of potential stress by reducing the leaf area and increasing leaf thickness, development of roots towards the moisture by deep soil penetration and stomatal closure [5]. Environmental factors such as rainfall, moisture, temperature and light as well as cropping factors such as planting date can influence the rate of available water and ultimately affect the yield. At the same time, a plant's response to water stress depends on the duration and severity of that stress and the particular stage of a plant's development [6].

Plant adaptation to drought conditions include: 1- escape from drought (in which the plant completes its life cycle before the onset of full continuous drought), 2- avoidance of drought (in which the plant increases water absorption and minimizes water loss) and 3- drought tolerance, (in which a plant continues its growth in stress conditions and at the same time, increases its water capacity) [7]. One strategy of crop management for decreasing the effects of drought stress is to decrease soil evapotranspiration. Perhaps the easiest method of decreasing the ratio of soil evaporation to transpiration (E_s/E_t) is to increase a crop's growth rate in the early growing season and throughout the early planting period [8], which ultimately increases a crop's ability to compete due to more rapid canopy closure [9]. Thus, planting date is an important consideration to alleviate the effects of drought stress (especially late season stress).

Interest in producing medicinal and aromatic plants and demand for natural products is increasing all over the world, so special attention to these plant species is important. Apart from monetary value, medicinal plants are compatible with conditions that others plants are not able to tolerate [10]. Every year a greater number of farmers turn to the cultivation of medicinal plants but insufficient awareness of their ecological requirements and of planting, crop management and harvest stages have hindered success [11]. Ajowan, with the scientific name of *Carum copticum* is one of the most important plants of the Apiaceae family that originated from the Eastern Mediterranean area [12]. This plant has low water requirement but its resistance to medium and severe drought stress has not yet been fully understood and only a little research has been reported on it.

Reference [13], by applying irrigation treatments at field capacity percentages of 60%, 80% and 100%, concluded that increasing drought stress decreased the dry and fresh weights of the plant ajowan significantly. However, increasing the severity of drought stress did not decrease the Co_2 absorption rate, the total amount of chlorophyll and the Co_2 concentration in the plant, but decreased stomatal conductivity and the transpiration rate. Reference [14], by investigating the effects of three irrigation intervals of 7, 14 and 21 days on ajowan, reported that the greatest number of umbels per plant, umbels per square meter and the greatest 1000-seed weight were obtained from irrigation intervals of 7 and 14 days and that there was significant difference between them and those related to the interval of 21 days. In this experiment, the maximum seed yield (46.4 $g.m^{-2}$) was from the irrigation interval of 7 days and that was significantly different from those yields resulting from irrigation at 14 and 21 day intervals.

Water use efficiency is a physiological parameter that can be used to evaluate plant performance in moisture stress. In fact, by using this parameter the quantitative relationship between plant growth and water use can be investigated [15]. Research by [16] on water use efficiency of German Chamomile showed that the greatest WUE was obtained from an irrigation level of 50 and 75 mm evaporation from the evaporation pan compared to 25 and 100 mm evaporation. Considering the nature of the trait of water use efficiency, there are two effective work methods to increase it. One method is increasing photosynthesis and accumulation of photosynthetic materials and the other is to decrease evapotranspiration from the soil surface. In early planting, due to intervention at the rapid growth stage of the plant with lower temperatures and higher relative environmental humidity, it is possible to accelerate the assimilation process as well as facilitating use of seasonal rainfall that reduces irrigation requirements; therefore, increasing water use efficiency. In many plants, autumn planting causes increased tillering and vegetative cover compression which leads to an increase of leaf area index, increased radiation absorption and photosynthesis and plant canopy that produces shading on the soil surface and decreases soil evaporation. Although in early planting, due to rainfall uncertainties, it is possible that initially, plant germination faces difficulties or high densities in the winter that may confront the plant with water shortage in the late season (the seed filling stage). Reduce of the yield, impact of stress, mainly is due to shortening of plant growth stages and the plant size.

There is limited research specific to planting date of ajowan, however studies have reported decreased yield with late planting [17]. In the experiment, plants related to the planting date of September 1 had the greatest seed yield, dry weight and number of umbels per plant due to being subjected to optimum temperatures. Reference [18] showed that late planting in ajowan was associated with a failure to germination. The greatest amount of yield and the greatest number of umbellets per plant were obtained from the second planting date (28 March) and the highest 1000-seed weight was obtained from the first planting date (6 March). [19] in an experiment on fennel compare some traits of the plant in three sowing dates (September 14, October 14 and November 14) in Pakistan indicated that the highest number of umbels per plant, seeds per umbel, 1000-seed weight and seed yield were related to planting date of October 14, while [20] showed that planting date of October 1had more fresh and dry weight compare to September 15 one. [21] In a research on coriander in India it was demonstrated that the greatest number of umbels per plant, seeds per umbel, biological yield and seed yield were obtained from the planting date of October 15 compared to later planting dates of October 30 and November 15.

This research was done to determine an appropriate planting date for ajowan in full irrigation and stress conditions. In other words, perhaps success of certain planting dates in water stress conditions allowed enough time for the region's farmers to start the second planting after harvesting the ajowan crop. Besides, earlier planting, which permits plant establishment and the coincidence of its rapid growth with the cool and humid weather can decrease water use and increase WUE.

2. MATERIALS AND METHODS

This experiment was performed in Agricultural Research center of Islamic Azad University Birjand branch, Iran in two successive growth season of 2009/2010 and 2010/2011. The longitude, latitude and altitude of Birjand are 59º 13', 32º 53' and 1491 meters, respectively. Climate of Birjand is dry and warm with mean annual rainfall of 172mm. Figs. 1 and 2 shows the daily temperature and monthly rainfall during the experiment.

Experimental design was split plot based on randomized complete block with three replications. Two irrigation treatments (termination of the irrigation at the start of flowering and complete irrigation) and 6 planting dates (December 6, December 21, January 5, February 29, March 30 and April 30) were as main plot and sub plot, respectively Table 1. Each sub plot had three ridges. The length of the ridges and distance between them were 4 and 0.7m, respectively. Sowing was conducted on the two sides of the ridges. Distance between plants after thinning was 15cm. Before planting and when preparing the land, 120 $kg.ha^{-1}$ triple superphosphate and 150 $kg.ha^{-1}$ Potassium Sulphate were added to the soil. Urea (200$kg.ha^{-1}$) was added to the soil equally in two stages: before planting, and at the start of flowering.

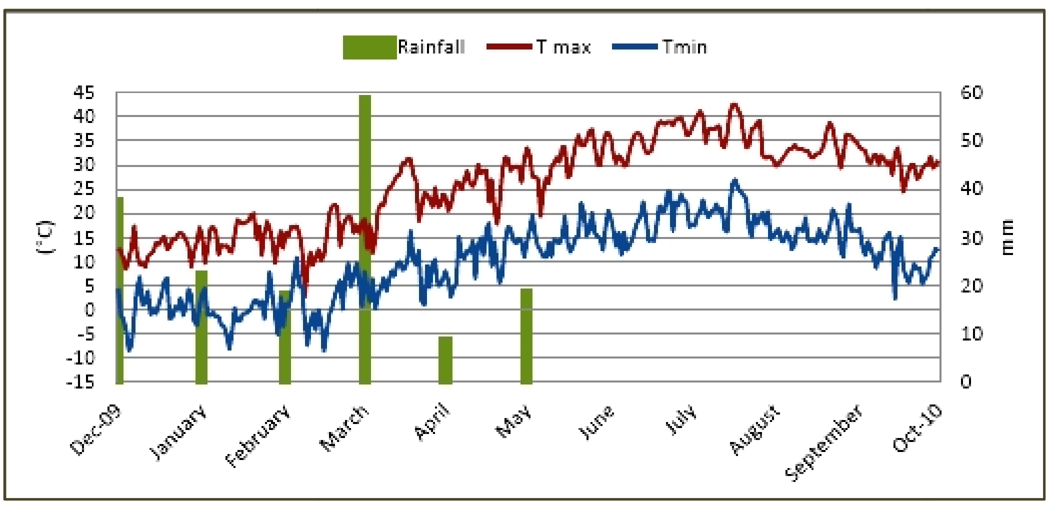

Fig. 1. Daily temperature and monthly rainfall during experiment in the first year (2009/2010)

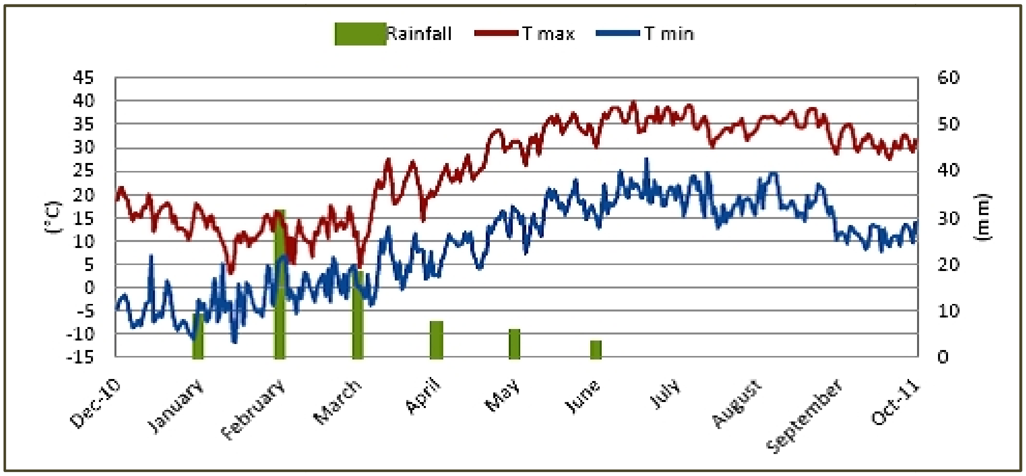

Fig. 2. Daily temperature and monthly rainfall during experiment in the second year (2010/2011)

Pressurized system with hose and contour was used for irrigating the plots. Irrigation was conducted every four days until seedling emergence and after that it was done weekly. In the water stress treatment, at the start flowering, the irrigation stopped completely. The number of irrigation from emergence to maturing was 13 to 22 depending on the treatment type. Table 2 shows the irrigation volume consumed in different treatments. Weed control was done by hand as and when required.

After seed maturation biomass and seed yield were determined by harvesting one square meter of each plot (considering the border effect). Yield components including: number of umbels per plant (in 10 plants sample), number of seeds per umbel (in 10 umbels), number of seeds per plant, and 1000-seed weight were determined. Evaluations for seed and biomass water use efficiencies were determined from the below equations:

WUE (g.l) = Grain (Biomass) Yield/WCU)
WCU = Water consumptive used

The harvest index was determined from the ratio of seed yield to total biomass.
Data analysis was conducted by MSTATC and SAS softwares and the means were compared by Duncan's multiple range test at 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Effect of Irrigation on Seed Yield and Its Components

Seed yield was significantly affected by irrigation treatment in two years and decreased as a result of stress. Water stress decreased the seed yield by 67% and 42% in the first and second year respectively Table 3. Other researchers have also reported a decrease in seed yield due to water stress in ajowan [14], fennel [22], cumin [23] and coriander [24].

Investigation into yield components (the number of umbels per plant, number of seeds per umbel, number of seeds per plant and 1000-seed weight) shows that only number of seeds per umbel in the first year and the number of seeds per plant in both years were significantly affected by the irrigation treatment and decreased due to stress Table 3. Also, Table 5 demonstrates a positive and significant correlation between number of seeds per plant and number of seeds per umbel with seed yield. Long-term stress, especially in high temperatures in plant fecundity stages, can decrease the yield significantly due to a decrease in the number and size of seeds [7]. Fig. 3 shows that there is a straight linear relationship between seed yield and number of seed per plant in both year (R^2= 0.791 and R^2=0.924).

A decrease in number of seeds per umbel and seeds per plant in water stress conditions can be the result of water shortage during the seed filling stage that shortens the flowering and kernel stages and induces fertilization failure. As the 1000-seed weight was not affected by stress, plants probably tried to preserve the existing situation and prevent a decrease in the size of seeds; this is suggested by the weak correlation between the 1000-seed weight and seed yield Table 5. Some studies show that the most difference was observed in stress condition as a result of changes in number of seeds per square meter [7].

The non-significant decrease in number of umbels per plant in stress conditions is as a result of indeterminate growth of the ajowan plant and production of umbels even in water shortage conditions. Considering the significant decrease in the number of seeds per umbel and seeds per plant, those umbels formed in water shortage conditions did not produce seeds.

In general, drought during the growing period caused a decrease of water use efficiency, biomass and number of seeds; and drought that occurred in the late growing season affected seed filling. Preferential allocation of biomass production to roots and shortened stages of flowering and seed filling in stress conditions that resulted in a decreased harvest index Table 3, demonstrating that there was a decreased seed yield resulting from drought stress.

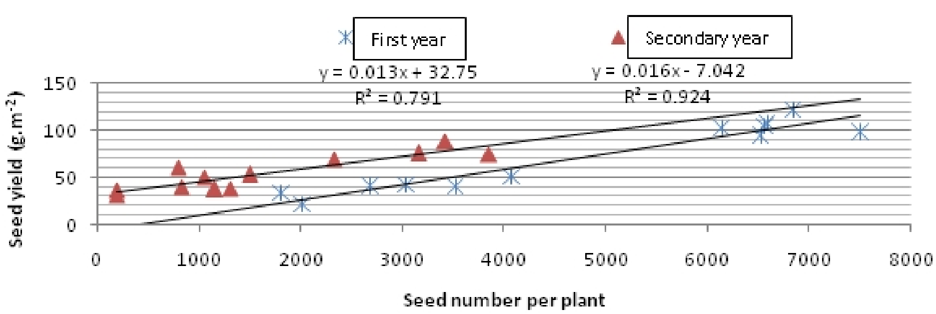

Fig. 3. Seed yield's relationship with number of seed per plant

3.2 Effect of Planting Date on the Seed Yield and Its Components

Seed yield was significantly affected by planting date only in the second year so that the highest and lowest seed yields were in the second year (59.2 $g.m^{-2}$ and 37.5 $g.m^{-2}$) from planting dates of February 29 and March 30, respectively (Table 3).

Temperature and humidity are two important factors in plant growth. Winter planting facilitates plant development during favorable environmental conditions, thus utilizing existing resources such as adequate humidity; this produces better plant establishment resulting in higher yield from these plants compared those planted in March and April. Other researchers have also reported a decrease of seed yield due to late planting; in ajowan [17,18], fennel [19], cumin [25] and coriander [26]. Although less success was due to the coincidence of vegetative stages and hot climate, those plants produced from the last date (April 30) were not significantly different from those of March 30 because the last days of flowering and the seed filling stage coincided with the cooler weather of late summer and early autumn.

Results of the investigation of yield components in Table 3 show that in the first year it was only 1000-seeds weight that was affected by planting date and the effect of planting date on other yield components were not significant; but in the second year all yield components, except 1000-seed weight, were affected by planting date. The greatest number of umbels per plant and seeds per plant were from winter planting, but the greatest number of seeds per umbel related to the planting date of April 30 (Table 3); a likely reason is coincidence of the flowering and kernel stages with the cooler autumnal weather. This late planting resulted in an increase of 1000-seeds weight the likely reason being the non-coincidence of the kernel stage and hot dry climate of the middle summer and the fact that this stage was lengthy.

Table 3 shows that the interaction effect of irrigation and planting date on none of the yield components and seed yield was significant but the greatest amount for seed yield was from complete irrigation conditions in both the first and second years from planting dates of March 30 and February 29, respectively.

3.3 Biomass Yield

Biomass yield was significantly affected by irrigation in the first year and decreased under stress (Table 3). In the second year, although the application of stress caused biomass yield to decrease by 17%, this decrease was not significant. Reference [13] has also reported a decrease of biological yield of ajowan in drought stress conditions. Considering that ajowan is an indeterminate plant and that it is possible that this plant grows vegetatively after flowering, this decrease of biomass yield due to lack of irrigation at the flowering stage is not unexpected.

Table 3 show that biomass yield was affected by planting date only in the second year and that the greatest biomass yield was from the planting date of January 5 due to better plant establishment and use of the favorable environmental conditions. Late planting caused a significant decrease in biomass due to the accumulation of photosynthetic materials from the shorter vegetative growing period. Other researchers have also reported a decrease of biomass in late planting in ajowan [17], fennel [19,20] and cumin [25].

3.4 Water Use Efficiency (WUE) and Harvest Index

The effect of irrigation on biomass water use efficiency was not significant in both years. However, seed WUE decreased in both years due to stress, this decrease was only significant in the first year (Table 3). Given that seed WUE has a high correlation with seed yield (Table 5), decrease of seed yield due to stress from water shortage has certainly affected WUE. In principle, each factor that contributes to increasing yield will also increase WUE and each factor that decreases evapotranspiration, while not having an adverse effect on yield; will increase WUE [15].

Table. 1. Plan of one replication in one year

Drough Stress						Full Irrigation					
January 5	April 30	December 6	December 21	March 30	February 29	April 30	December 21	February 29	January 5	December 6	March 30

Table 2. Irrigation volume consumed in different treatments

Irrigation treatments	Drought stress						Full irrigation					
Planting dates	**6 December**	**21 December**	**5 January**	**29 February**	**30 March**	**30 April**	**6 December**	**21 December**	**5 January**	**29 February**	**30 March**	**30 April**
Year	**2009/2010**											
WCU (lit)	440	480	520	560	600	640	680	680	720	800	800	800
Year	**2010/2011**											
WCU (lit)	540	660	660	660	660	650	420	510	450	510	520	500

Table 3. The effect of irrigation and planting date on seed yield and yield components of ajowan

	Seed yield ($g.m^{-2}$)		Umbel number per plant		Seed number per umbel		Seed number per Plant		1000-seed weight (g)		Bimass yield ($g.m^{-2}$)		Seed-WUE ($g.l^{-1}$)		Biomass-WUE ($g.l^{-1}$)		Seed-HI	
Year	**09/10**	**10/11**	**09/10**	**10/11**	**09/10**	**10/11**	**09/10**	**10/11**	**09/10**	**10/11**	**09/10**	**10/11**	**09/10**	**10/11**	**09/10**	**10/11**	**09/10**	**10/11**
Irrigation																		
Drought stress	37.9^{b}	35.5^{b}	56.7	53.7	52.39^{b}	42.3	2858.8^{b}	2153.4^{b}	0.82	0.71	127.9^{b}	205.4	0.07^{b}	0.06	0.24	0.42	0.30^{b}	0.17^{b}
Cpmplete irrigation	104.6^{a}	61.2^{a}	92.3	69.9	75.52^{a}	59.6	6698.5^{a}	4003.4^{a}	0.94	0.67	229.0^{a}	247.3	0.14^{a}	0.09	0.30	0.37	0.45^{a}	0.25^{a}
LSD	34.22	20.63	n.s.	n.s.	9.85	n.s.	1491.2	1199.4	n.s.	n.s.	95.61	n.s.	0.05	n.s.	n.s.	n.s.	0.05	0.08
Sowing date																		
6 December	72.7	51.3^{ab}	80.9	70.2^{a}	58.7	44.5^{b}	4803.0	3280.2^{ab}	0.88^{bc}	0.70	177.9	233.3^{b}	0.12	0.08	0.31	0.41^{b}	0.39	0.22
21 December	72.6	49.3^{ab}	77.6	63.1^{a}	67.5	54.1^{ab}	5302.0	3360.6^{a}	0.81^{bc}	0.65^{a}	182.8	250.8^{b}	0.12	0.08	0.31	0.43^{ab}	0.38	0.20
5 January	69.3	54.0^{a}	81.4	79.6^{a}	70.0	45.9^{b}	5513.5	3507.7^{a}	0.72^{c}	0.67	164.0	291.3^{a}	0.10	0.09	0.25	0.48^{a}	0.39	0.18
29 February	61.5	59.2^{a}	63.6	75.4^{a}	68.1	44.9^{b}	4082.3	3510.2^{a}	0.82^{bc}	0.75	185.7	251.0^{b}	0.08	0.09	0.26	0.42^{ab}	0.30	0.22
30 March	77.3	37.5^{b}	80.8	45.1^{b}	50.1	51.7^{b}	4331.3	2338.6^{c}	1.10^{a}	0.70	183.1	172.7^{c}	0.10	0.06	0.25	0.29^{c}	0.39	0.20
30 April	74.4	38.8^{b}	62.7	37.6^{b}	69.1	64.7^{a}	4640.3	2473.4^{bc}	0.98^{ab}	0.68	177.3	159.6^{c}	0.10	0.07	0.25	0.33^{c}	0.40	0.23
LSD	n.s.	12.78	n.s.	17.09	n.s.	11.54	n.s.	841.7	0.18	n.s.	n.s.	37.84	n.s.	n.s.	n.s.	0.06	n.s.	n.s.

-Means at least with one similar letter in each column, have not significant different at 5%

The effect of planting date on the biomass water use efficiency was only significant in the second year (Table 3) so that winter planting facilitated appropriate initial growth because plants benefited from seasonal rainfall but seed-WUE and seed harvest index were not significantly affected by planting date in both years (Table 3). In general, it can be said that the easiest method to decrease soil evapotranspiration in order to increase WUE and thus improve yield is by increasing the growth rate of a crop early in the growing season. As shown in Table 3, late planting caused a decreased of the biomass water use efficiency. The shorter growing period from late planting prevented the dry material from further accumulation and caused a decrease of the canopy mass and as a result, the biomass WUE decreased.

The seed harvest index was significantly affected by irrigation in both years and decreased due to water stress, the likely reason being that there was more decrease of seed yield compared to biomass yield in drought stress conditions (high correlation of seed yield to harvest index).

Table 4 shows that the interaction effect of irrigation and planting date on biomass yield and WUE was significant in the second year. So that, in stress conditions, the planting date of January 5 and in complete irrigation conditions, the planting date of February 29 had greater biomass yields and WUE. The coincidence of the rapid growth stage of ajowan (stem elongation and branching stages) and the cooler weather of the early spring caused further accumulation of the assimilates in plants from those earlier planting dates and as a result, the biomass increased.

Table 4. Interaction effects of irrigation and planting dates on biomass yield and biomass water use efficiency of ajowan

Planting date Levels	Biomass yield ($g.m^{-2}$)				Biomass-WUE ($g.l^{-1}$)			
	Drought stress		Full irrigation		Drought stress		Full irrigation	
Year	**09/10**	**10/11**	**09/10**	**10/11**	**09/10**	**10/11**	**09/10**	**10/11**
6 December	144.1	227.3^{ab}	211.6	239.3^{c}	0.328	0.454^{ab}	0.311	0.367^{bc}
21 December	149.1	254.4^{a}	216.4	247.1^{bc}	0.310	0.489^{ab}	0.318	0.374^{abc}
5 January	108.4	276.3^{a}	219.6	306.3^{ab}	0.208	0.541^{a}	0.292	0.428^{ab}
29 February	115.1	184.7^{bc}	256.3	317.3^{a}	0.205	0.404^{b}	0.320	0.480^{a}
30 March	131.0	147.4^{c}	235.1	197.9^{cd}	0.218	0.288^{c}	0.294	0.299^{c}
30 April	119.8	142.7^{c}	234.9	176.4^{d}	0.214	0.339^{bc}	0.293	0.326^{bc}
LSD	n.s.	56.86	n.s.	56.86	n.s.	0.10	n.s.	0.10

-Means at least with one similar letter in each column, have not significant different at 5%

Table 5. The correlation coefficients for some traits of ajowan

Traits	1-Biomass yield		2-Seed yield		3-Umbel number per plant		4-Seed number per umbel		5-Seed number per plant		6-1000-seed wieght		7-Seed-WUE		8-Biomass-WUE		9-Seed HI	
Years	09/10	10/11	09/10	10/11	09/10	10/11	09/10	10/11	09/10	10/11	09/10	10/11	09/10	10/11	09/10	10/11	09/10	10/11
1	1	1																
2	0.957**	0.378	1	1														
3	0.836**	0.934**	0.898**	0.283	1	1												
4	0.740**	-0.560	0.758**	0.197	0.478	-0.686	1	1										
5	0.905**	0.348	0.961**	0.934**	0.900**	0.248	0.810**	0.278	1	1								
6	0.502	-0.132	0.471	0.563*	0.423	-0.072	-0.403	-0.414	0.248	-0.743	1	1						
7	0.885**	-0.026	0.499	0.775**	0.921**	-0.181	0.701**	0.460	0.951**	0.634*	0.356	-0.208	1	1				
8	0.732**	0.776**	0.664**	0.208	0.668**	0.646*	0.489	-0.450	0.682**	0.113	0.209	0.234	0.800**	0.228	1	1		
9	0.775**	-0.425	0.910**	0.541	0.879**	-0.480	0.620*	0.696**	0.885**	0.430	0.442	-0.280	0.932**	0.748*	0.565*	-0.351	1	1

**: Significant at 5% probability, **: Significant at 1% probability*

4. CONCLUSION

On the whole, results of this experiment showed that winter planting was more successful, evident from relatively high yields. Considering water shortages that the world will face in the future, winter planting in those environments susceptible to water stress conditions will have higher water use efficiency compared to spring planting.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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