Egypt. J. Hort. **Vol. 50**, No. 2, pp. 247-263 (2023)

Egyptian Journal of Horticulture

https://ejoh.journals.ekb.eg/

جمعية فلاحة البساتين المصرية
THE EGYPTIAN HORTICULTURE SOCIETY

Evaluating the Impact of Biochar and Foliar Application of Potassium Silicate on the Growth and Productivity of Ajwain (*Trachyspermum ammi* L) Plant Under Water Stress in The Newly Reclaimed Soil Conditions

Mohamed G.R. Sarhan[1] and Abeer M. Shehata[2]

[1] *Soil, Water and Environment Res. Inst., Agricultural Research Center, Egypt.*

[2] *Medicinal & Aromatic Plants Res. Dept., Horticulture Res. Inst., Agricultural Research Center, Egypt.*

WORLDWIDE food creation is seriously hampered by drought. Biochar and potassium silicate are essential for how crops use their energy, whether under favorable or adverse conditions. They may also make plants more drought tolerant. Ajwain (*Trachyspermum ammi* L) is a medicinal and aromatic plant that is cultivated mainly for its seed, herb, and volatile oil. This present study was carried out to evaluate the effects of biochar and foliar application of potassium silicate K_2SiO_3 under irrigation intervals (3, 4, and 5 days) on growth, fruits yield, essential oil, and its main components as well as chemical constituents of Ajwain in filed experiments conducted at the Experimental Farm of East of Malawi, El-Minia Governorate, Egypt during the two seasons of 2020/2021 and 2021/2022. A split plot design in four replications was used. Three irrigation intervals in main plot biochar and potassium silicate treatments and/or in sub plot. Results showed that irrigation every 3 and 4 days produced the highest yield with higher quality parameters. While irrigation every 5 days gave highly significant positive values of water use efficiency. Biochar + sprays of K-silicate produced the highest fruit yield. Irrigation every 3 and 4 days combined with biochar + foliar spray of K-silicate achieved the highest values of fruit yield and its components. These results show that biochar + K-silicate treatment can increase water use efficiency and produce high fruit yield.

Keyword: Irrigation intervals, Biochar, Potassium silicate, Vegetative growth, Yield parameters, Water used efficiency, Ajwain.

Introduction

The principal difficulties to edit creation in parched and semi-dry locales incorporate environmental change, water shortage, an absence of foundation, quick populace development, and urbanization. The essential ecological component decreasing harvest efficiency overall is dry season (Farouk et al., 2018 and Pang et al., 2019). Around 25% of the world's agrarian grounds were impacted by the dry season, and it was anticipated that number would ascend to 30-40% by the 2090s (Burke et al., 2006 and Jajarmi, 2009). Because of its huge consequences for morpho-physical, physio-biochemical, and sub-atomic variables that adjust different metabolic cycles, including photosynthesis and water retention, prompting development and yield decline, dry spell pressure has altogether diminished the yield of many harvests by 17-70% (Sheshbahreh et al., 2019).

As 85% of the nation's all out water supply is utilized by the horticulture business, and most of on-ranch water system frameworks are

Corresponding author: Mohamed G.R. Sarhan, E-mail: g.muhamed78@gmail.com, Tel. 01282002432
(Received 02/04/2023, accepted 21/06/2023)
DOI: 10.21608/EJOH.2023.203765.1238

insufficient as well as having unfortunate water system necessities, rural expansion in Egypt requests a lot of water system water that is as of now deficient to address customary issues. Considering this, it is suggested that water systems be planned for understanding with climate related factors, and the deficiency water system hypothesis ought to be acknowledged with a negligible yield decrease (Farouk and Omar, 2020). Given the shortage of accessible water for agribusiness, shortfall water system is extremely useful and significant for expanding water efficiency (Bhagyawant et al., 2015).

The beneficial inventive methodology for using crop efficiency and water use productivity (WUE) has as of late been empowered by expanded rivalry for scant water assets. Subsequently, shortfall water system should be perceived as being very reasonable, straightforward, and fundamental for expanding WUE limit (Farouk and Metwally, 2019). One of the coherent methodologies in such manner has been to apply supplements or soil corrections (Yang et al., 2020). Potassium silicate and biochar are accordingly used to increment crop improvement and efficiency in both ordinary and distressing circumstances. Given its qualities, which incorporate being non-destructive, non-contaminating, reasonable, accessible, and having both monetary and natural effectiveness right now, it is a palatable treatment inside manageable horticulture creation.

An astonishing measure of conversation has been given to biochar (a carbon-based item), which might be an indispensable wellspring of natural assets. The aftereffects of various investigations show that adding biochar to establish soil both under ordinary and water-scant circumstances further developed plant development and efficiency (Yang et al., 2020). The valuable impacts of biochar on plants might be owing to its upgrades in their ability to adsorb phytotoxic natural atoms, as well as the way that it supports the movement of gainful microorganisms (Warnock et al., 2007 and Novak et al., 2012). Biochar additionally assists plants with better keeping up with their water balance.

Potassium silicate has as of late been utilized in crop development to check the adverse consequences of dry season (Tarabih et al., 2007 and Salim, 2014). The third major macronutrient that plants expect for typical or upsetting circumstances is potassium. By supporting photosynthetic capacity, shielding chloroplasts from oxidative pressure, controlling stomatal capabilities, improving water status, enacting various proteins, advancing expanded cell development and phloem stacking, and causing osmotic change in addition to net carbon osmosis, potassium assumes an urgent part in advancing dry season resistance (Damon and Rengel, 2007). The supplement silicon (Si) is essential for high-yielding harvest species like fragrant plants, grains, vegetables, and vegetables. Under specific developing circumstances, Si can be found in follow sums, and plants without Si may not get an adequate number of supplements. Si inadequacy brought down glucose levels, expanded illness commonness and bug assaults, exacerbated withering, and supported post-collect fall. It additionally diminished photosynthesis and brought down glucose levels. These are all pressure related side effects. (Schmidt et al., 1999 and Kandil et al., 2020). Moreover, it advances the plant’s solid development and is fundamental for cell improvement and separation. (Liang et al., 2005). Dry season pressure, salt pressure, heat pressure, and oxidative harm can be generally diminished with silicon treatment. Because of its better water maintenance, silicon assumes a positive part in dry season conditions and advances photosynthesis. (Hattori et al., 2005; and El-Naggar et al., 2020).

In the case of aromatic plants water stress may cause changes in the yield and composition of their essential oils. Secondary metabolites are synthesized by plants due to plant adaptation in response to biotic and abiotic stresses (infection, water stress, cold stress, high visible light). Drought stress affects essential oil percentage and essential oil content differently, because drought stress increases the essential oil percentage but decreases shoot biomass, therefore essential oil content decreases (Pitchersky and Gang, 2000; and Aliabadi et al., 2009). Ajwain is an aromatic spice that is grown primarily for its seeds, herbs, and volatile oil. Ajwain (*Trachyspermum ammi* L.) is an important seed spice plant, belonging to the Apiaceae family. Seeds 2-3 mm long, grey-brown in color. Its characteristic smell and taste are due to the presence of essential oil (2-4%). Ajwain oil is a major source of thymol (Rathore et al., 2014). Ajwain is also known by other names Ajowan and Ajwan as well as (*Carum copticum* L.). Ajwain is an annual herb up to 90 cm high, with flowers and small brown seeds, native to arid and semi-arid regions of Egypt (Jeet et al., 2012).

In order to reduce the stress caused by water scarcity on the ajwain, we investigate the irrigation intervals to produce the highest yield as well as the effectiveness of biochar and foliar potassium silicate spraying.

Materials and Methods

This field explore was directed at Farm located at East of Mallawi, El-Minia Governorate, Egypt during two successive seasons (2020/2021 and 2021/2022). The objective of this investigation was to study the effect of irrigation intervals, biochar, and spraying potassium silicate on the growth, productivity, and phytochemical production of ajwain (*Trachyspermum ammi* L.) plants under newly reclaimed sand soil conditions. Seeds were obtained from Sekem company, El-Sharkia Governorate, the seeds were sown in the field on 15th and 20th October 2020 and 2021, respectively at distances of 25 cm between hills (thinned to two plants/hill) A month after laying the seed and 100 cm between rows (80640 plant/ha). A drip irrigation system was adopted in this experiment using GR, polyethylene drip line of 16 mm diameter and 4 liter per hour discharge with dripper.

Composed sample of experimental farm Soil were collected and analyzed according to A.O.A.C. (1990) and the data is listed in Table (1). The irrigation water analyses were illustrated in Table (2).

A split-plot design with four replicates was used in this experiment, during the two seasons. The treatments were: The irrigation intervals treatment (3, 4, and 5 days) in the main plot and stimulators, 0.0 (control), 3 cm^3/l potassium silicate, 5 ton/ha biochar, and 3 cm^3/l potassium silicate + 5 ton/ha biochar in the sub-plots.

The irrigation intervals treatments began 21 days after the sowing date and all treatments were irrigated twice a day for one hour, Irrigation was every 3 days before the start of the experimental treatments. Applied water for these treatments (every 3, 4, and 5 days) were recorded in Table 3 as the same in the two seasons.

TABLE 1. Physical and chemical analysis of the experimental farm soil.

Soil properties	2020/2021	2021/2022
Physical properties		
Particle size distribution:		
Clay (%)	7.05	5.11
Silt (%)	16.74	23.11
Sand (%)	78.21	71.76
Texture grade	Loamy sand	Loamy sand
Chemical properties		
pH (1:2.5 soil-water suspension)	7.80	7.90
EC, (soil paste ds m^{-1})	2.63	2.79
Organic matter (%)	0.31	0.25
$CaCO_3$ (%)	7.11	6.05
Available N (mg kg)	3.10	5.50
Available P (mg kg)	1.10	1.70
Available K (mg kg)	32.50	27.70

TABLE 2. Irrigation water analysis of the experimental.

Seasons	pH	E.C. (dS m^{-1})	Soluble cations (mg L^{-1})				Soluble anions (mg L^{-1})			
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}
2020/2021	7.7	1.6	3.35	2.93	9.20	0.46	0.0	1.72	12.17	2.05
2021/2022	7.8	1.5	3.11	2.86	9.14	0.80	0.0	1.85	11.93	2.13

Biochar

The biochar of sugarcane bagasse waste was produced locally through slow burning under limited oxygen condition and incorporated at 5 ton biochar/ha rates into the soil. The biochar was added before sowing during land preparation. Some important characteristics of the sugarcane bagasse biochar is given in Table 4 according to Klute, (1986).

Potassium silicate

The liquid K-silicate (K_2SiO_3 content as 10% K_2O and 25% SiO_2) was obtained from Abo Ghaneima Company Trade and Agencies, Alexandria-Abu Qir and applied was sprayed three times at 30, 45, and 60 days after sowing, respectively.

All plants had received the recommended doses of N, P and K fertilization throw the drip irrigation system, as well as the common agriculture practices.

Harvesting

The plants were harvested at 2nd week of May during the two experimental seasons.

Data recorded

a. *Vegetative growth characteristics:* at the beginning of flowering, plant height (cm) and the number of branches/plant as well as fresh weights of herb plant (g). Then, the fresh plants were taken and dried under shading then enter the oven at a temperature of 40-60 degrees Celsius to obtain the air-dried weight (g).

b. *Fruit yield* measurements were recorded at harvesting time: the number of umbels per plant, weight of 1000 fruits (g) and fruit yield/plant (g). So, the fruit yield/ha (kg) were calculated.

c. *Determination of essential oil % and yield:*

Fruit essential oil of ajwain was extracted using hydro distillation according to the method described in Egyptian Pharmacopoeia (1984). Sample of 100 g fruits put into 1000 ml flask to distillate in water. After four hours of distillation, the volatile oil was done. Then, the volatile oil percentage was calculated as ml/100 grams of seeds or fruits using the following equation:

$$\text{Volatile oil percentage} = \frac{\text{oil volume in the graduated tube}}{\text{dry weight of samples}} \times 100$$

Based on essential oil %, the volatile oil yield/ha was calculated.

TABLE 3. Irrigation water amount applied of the experimental.

Irrigation interval treatments	Water applied	
	m^3/feddan	m^3/ha
Every 3 days	2586	6206
Every 4 days	2057	4936
Every 5 days	1740	4176

TABLE 4. **Some physicochemical properties of the studied sugarcane bagasse biochar.**

Biochar property	Value
pH	7.2
EC dS m^{-1}	3.4
Total carbon g kg^{-1}	316
Total N g kg^{-1}	12.8
Total P g kg^{-1}	2.9
Total K g kg^{-1}	6.7
C/N ratio	24.5
Bulk density	0.21
Ash%	12.7

d. Pigment content determination:

Chlorophyll a, b and carotenoid were determined in leaf fresh samples (mg/g F.W.) as described by Saric (1967).

e. NPK determination:

The chemical analysis was carried out on dried leaves samples obtained from the different treatments for the determination of N, P and K% as described by A.O.A.C (1990).

f. Water use efficiency (WUE) was calculated according to the method described by Israelsen and Hansen (1962).

$$WUE = \frac{\text{Grain yield kg/ha}}{\text{Total water used m3/ha}} \times 100$$

Statistical analysis

The obtained data were statistically analyzed using analysis of variance according to method described by Snedecor and Cochran (1980). Duncan's multiple range for comparing the difference between treatment mean was used at the probability level of 0.05.

Results and Discussion

Effect of irrigation intervals, biochar, and foliar spraying of K-silicate on vegetative growth characters

Regarding the effect of irrigation intervals, biochar, and foliar spraying of potassium silicate on ajwain plants. Data illustrated in Table (5) shows that, ajwain plants height, number of branches plant^{-1} and fresh and dry weight significantly decreased as a result of increasing the irrigation intervals from three days to five days in both experimental seasons. Where irrigated ajwain plants every 3 days give the taller plants and the highest number of branches plant^{-1}, fresh and dry weight followed by those irrigated every 4 days, the data take a similar line during the two seasons.

TABLE 5. Effect of irrigation intervals, biochar, and foliar spraying of potassium silicate and their interaction treatments on plant height, number of branches/plant, fresh and dry weight of ajwain during the two seasons 2020/2021 and 2021/2022.

Irrigation intervals	Stimulators	Plant height (cm)		Number of branches/plant		Fresh weight of herb/plant (g)		Dry weight of herb/plant (g)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
3 days	control	60.2d	61.9d	10.5d	10.7d	153.7d	156.1d	58.4d	59.3d
	K_2SiO_3	62.5c	65.0c	12.1c	12.5c	159.1c	160.4c	60.1c	62.1c
	Biochar (BO)	65.7b	67.3b	14.2b	14.9b	164.3b	166.3b	62.4b	64.0b
	K_2SiO_3+BO	68.4a	69.6a	16.5a	17.1a	171.6a	175.5a	65.3a	67.1a
4 days	0.0	56.5e	57.7e	10.0e	10.4e	141.3e	143.6e	53.7e	55.9e
	K_2SiO_3	59.2d	60.4d	11.8c	12.1c	148.0d	150.1d	56.7d	57.8d
	Biochar (BO)	65.7b	67.2b	14.2b	14.6b	164.0b	166.0b	62.5b	63.9b
	K_2SiO_3+BO	68.3a	69.4a	16.4a	17.0a	171.2a	174.1a	64.9a	67.0a
5 days	control	52.3g	53.5g	8.10g	8.20g	130.2g	132.5g	50.7g	52.1f
	K_2SiO_3	54.8f	56.1f	9.40f	9.6f0	137.1f	139.3f	52.2f	52.6f
	Biochar (BO)	57.6ed	57.8ed	10.7d	10.8d	143.7e	146.1e	52.5f	56.1e
	K_2SiO_3+BO	60.4d	62.1d	11.9c	12.0c	150.9d	155.2d	59.1d	59.9d
Mean of irrigation intervals	3 days	64.2a	66.0a	13.3a	13.8a	162.2a	164.6a	61.5a	63.1a
	4 days	62.4b	63.7b	13.1b	13.5b	156.1b	158.5b	59.5b	61.2b
	5 days	56.3c	57.4c	10.0c	10.2c	140.5c	143.3c	53.6c	55.2c
Mean of stimulators	control	56.3d	57.7d	9.5d	9.8d	141.7d	144.1d	54.3d	55.8d
	K_2SiO_3	58.8c	60.5c	11.1c	11.4c	148.1c	149.9c	56.3c	57.5c
	Biochar (BO)	63.0b	64.1b	13.0b	13.4b	157.3b	159.5b	59.1b	61.3b
	K_2SiO_3+BO	65.7a	67.0a	14.9a	15.4a	164.6a	168.3a	63.1a	64.7a

Means designed by the same letter at each cell are not significantly different at the 5% level according to Duncan s multiple range tests.

While, the shortest ajwain plants and the lowest values of number of branches plant^{-1} and fresh and dry weight were obtained from the plants irrigated every 5 days intervals, during two seasons.

The negative effect of increasing irrigation intervals on vegetative growth characteristics of *Trachyspermum ammi* plants may be due to poor availability of moisture around plant roots in the root zone, poor root growth or lack of nutrient uptake (Razmjoo et al., 2008). These results coincided with those obtained for the ajwain plant (Trachyspermum ammi) by Zeid et al. (2014), Ghassemi et al. (2017) and Meena et al. (2017), the authors confirmed that increasing irrigation intervals (decreasing the number of irrigation times) reduces all vegetative growth characteristics. Ibrahim et al. (2020) showed that fennel plants irrigated every 7 days gave the highest values for growth traits. However, fennel plants irrigated every 3 days recorded the lowest values for growth traits.

Table (5) shows the significant effect of stimulators on plant height, number of branches/ plant and fresh and dry weights of herb/plant of ajwain during the 2020/2021 and 2021/20222 seasons. The tallest plant height and the highest number of branches/plant values, maximum values of fresh and dry weights of herb/plant were recorded when the plants received foliar applications of K-silicate + biochar. Contrary, untreated plants present the lowest parameters in both seasons. The application of biochar to sandy soils is anticipated to have an impact on the soil's moisture content, pH, organic matter (OM), and carbon dioxide content (CEC), which in turn may have an impact on the microbial biomass and fate of heavy metals bioavailability in the amended soil (Steiner, 2015). In addition, the silicon deposition in the cell wall can increase the height of the ajwain plant by making ajwain leaves and the stems become more erect, which reduces the mutuality Shading, thus increasing the rate of plant photosynthesis because of better high interception and vegetative improvement growth. These results are in harmony with those observed By Ranganathan et al. (2006), Ghanbari (2011), and Pati et al. (2016).

The interaction between irrigation intervals, biochar, and foliar spray with K-silicate had major effect plant height, number of branches/plant as well as fresh and dry weight of herb/plant of ajwain in both the 2020/2021 and 2021/2022 seasons (Table 5). The greatest values of these traits were recorded when ajwain plants were irrigated every 3 and 4 days with biochar + foliar spraying with K-silicate. Whereas the lowest values resulted from irrigation every 5 days without stimulators in both growing seasons.

Effect of irrigation intervals, biochar, and foliar spraying of K-silicate on yield attributes characters of ajwain plant

It was cleared from the results in Table and Figure 1 that increasing the irrigation intervals had a negative effect on the number of umbels/ plant. Hence, the highest values of the number of umbels/plant, 1000 fruits weight, fruit yield/ plant, and fruit yield/ha were obtained by irrigated ajwain plants every 3 days in the 1st and 2nd seasons, respectively. While, treated ajwain plants with watered every 5 days gave the lowest values of the number of umbels/plant, 1000 fruits weight, fruit yield/plant, and fruit yield/ha in the 1st and 2nd seasons, respectively.

Drought stress can reduce the grain yield of medicinal and aromatic plants by reducing the yield index (HI). This can occur even in the absence of a significant decrease in the dry matter accumulation of total medicinal and aromatic plants if a short period of stress coincides with the critical growth phase around flowering (Earle and Davies, 2003). During the breeding period, the lack of water can shorten the time period from seed formation to pollen falling off and shorten the grain filling time. (Barnabas et al., 2007). There is also a significant amount of literature on the effect of water deficiency on yield components of medicinal and aromatic plants (Farouk and Omar, 2020).

Results in Table 6 revealed that stimulators potassium silicate + biochar had significant effects on number of umbels/plant, weight of 1000 fruits, fruit yield/plant, and fruit yield/ha in both seasons. As compared with other treatments, the highest values occurred when ajwain plants were sprayed by K-silicate + biochar, whereas the lowest values occurred without stimulators treatments in two seasons. Number of umbels/ plant increased parallel with increasing K-silicate spraying + biochar by 32.30 and 31.19%, weight of 1000 fruits increased by 7.78 and 8.70%, fruit yield/plant increased by 27.54 and 26.76%, and fruit yield/ha increased by 27.05 and 27.33% as compared without the stimulator's treatments, in the first and the second seasons respectively. The beneficial effects may also be attributed to the nutrients that are naturally present in biochar,

TABLE 6. Effect of irrigation intervals, biochar, and foliar spraying of potassium silicate and their interaction treatments on number of umbels/plant, weight of 1000 fruits, fruit yield/plant, and fruit yield/ha of ajwain plant during the two seasons 2020/2021 and 2021/2022.

Irrigation intervals	Stimulators	Number of umbels/plant		Weight 1000 fruits (g)		Fruit yield/plant (g)		Fruit yield/ha (kg)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
3	0.0	50.7f	53.2f	0.90	0.91	5.8d	5.9d	461.0d	467.8d
	K_2SiO_3	60.3d	62.7d	0.95	0.97	6.1c	6.4c	484.8c	493.7c
	Biochar (BO)	69.8b	68.0b	0.95	0.97	6.8b	6.9b	541.7b	547.2b
	K_2SiO_3+BO	71.9a	73.0a	0.94	0.96	7.3a	7.5a	582.2a	593.0a
4	0.0	46.8g	48.2g	0.83	0.83	4.9f	5.2f	391.2f	398.6f
	K_2SiO_3	57.6e	58.1e	0.90	0.91	5.8d	5.9d	463.4d	474.0d
	Biochar (BO)	65.1c	68.2c	0.95	0.96	6.8b	6.9b	537.6b	546.7b
	K_2SiO_3+BO	71.3a	73.1a	0.95	0.97	7.4a	7.6a	579.1a	592.6a
5	0.0	40.3h	43.0h	0.76	0.78	4.4g	4.6g	347.8g	353.3g
	K_2SiO_3	47.8g	48.2g	0.81	0.83	4.8f	4.9f	384.0f	396.0f
	Biochar (BO)	57.1e	54.5e	0.81	0.82	5.5e	5.7e	432.5e	441.1e
	K_2SiO_3+BO	60.3d	63.6d	0.81	0.83	6.1c	6.3c	483.6c	493.0c
Mean of irrigation intervals	3	63.2a	64.2a	0.94a	0.95a	6.5a	6.7a	517.4a	525.4a
	4	60.2b	61.9b	0.91a	0.92a	6.2b	6.4b	493.0b	503.0b
	5	51.4c	52.3c	0.80b	0.82b	5.2c	5.4c	412.1c	421.0c
Mean of stimulators	0.0	45.9d	48.1d	0.83b	0.84b	5.0d	5.2d	400.1d	406.6d
	K_2SiO_3	55.2c	56.3c	0.89a	0.90a	5.6c	5.7c	444.0c	454.6c
	Biochar (BO)	64.0b	63.6b	0.90a	0.92a	6.4b	6.5b	504.0b	511.7b
	K_2SiO_3+BO	67.8a	69.9a	0.90a	0.92a	6.9a	7.1a	548.4a	559.4a

Means designed by the same letter at each cell are not significantly different at the 5% level according to Duncan s multiple range tests.

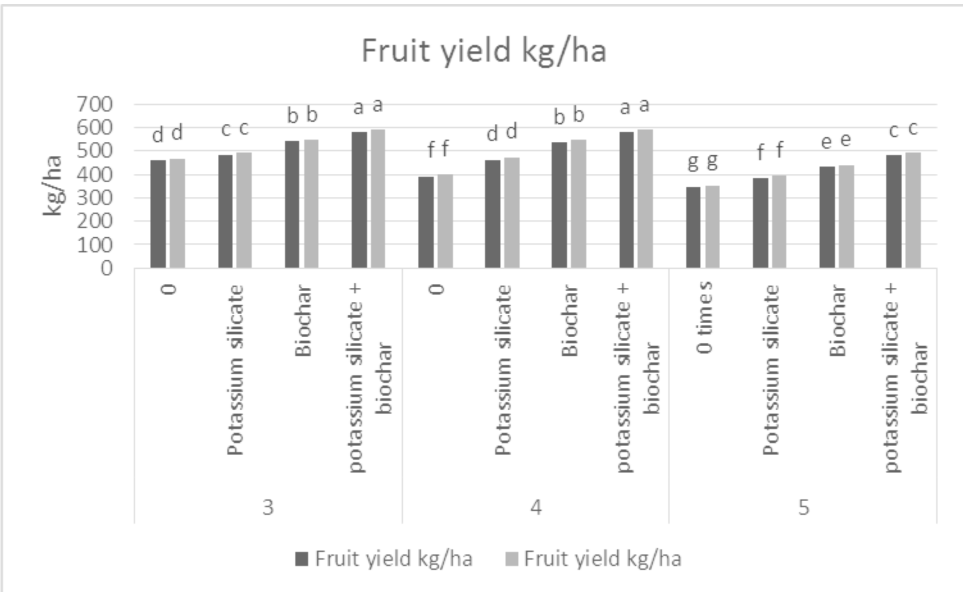

Fig. 1. Effect of irrigation intervals, biochar, and foliar spraying of potassium silicate and their interaction treatments on fruit yield/ha of ajwain during the two seasons 2020/2021 and 2021/2022.

but whose availability is element dependent (Angst and Sohi, 2013). Also, this enhancement of number of umbels/plant, weight of 1000 fruits, fruit yield/plant, and fruit yield/ha because of potassium silicate application may be due to the efficacy of silicon in enhancing the absorption of carbohydrates in ajwain fruits, resulting in an improved filling rate of ajwain. Similar results were obtained, also from some researchers Arab et al. (2011) Gholami and Falah (2013) and Dallagnol et al. (2014).

The interaction between irrigation intervals (3, 4 and 5 days) and frequencies of stimulators had a significant effect on the number of umbels/plant, fruit yield/plant, and fruit yield/ha, but not significant on weight of 1000 fruits of ajwain in both seasons. The largest values for these traits were recorded when ajwain plants were irrigated every 3 days followed by those irrigated at 4 days intervals under foliar spraying with K-silicate + biochar. While the plants values were obtained from the plants irrigated every 5 days under without stimulators in both growing seasons.

Effect of irrigation intervals biochar, and foliar spraying of K-silicate on essential oil contents and leaves photosynthetic pigment of ajwain plant.

Results in Table (7) regarding essential oil percentage, contrary to all studied traits that the increase in the irrigation intervals led to an increase in the essential oil percentage in fruits of ajwain plants. Hence, the highest values of essential oil percentage were attained with IR_3 irrigated Ajwain plants every 5 days, which amounted to (5.1 and 5.2%) in the 1st and 2nd seasons, respectively. Contrary, irrigated ajwain plants every 3 days caused the lowest values of essential oil percentage in the 1st and 2nd seasons, which amounted to (4.6 and 4.7%) respectively. The influence of differential investigated irrigation intervals treatment on oil yield/ha, Table (7) displays obviously that there wasn't significant effect between irrigated ajwain plants every 3 days and every 4 days which resulted in the highest values of the oil yield/ha in both seasons. While the lowest amount of the oil yield/ha obtained from the ajwain plants irrigated every 5 days, in both seasons. The effect of irrigation intervals on the percentage of essential oils may be due to their effect on enzyme activity and metabolism for essential oil production (Simon et al., 1992, and Khalid 2006). Water stress may increase the essential oil content of medicinal and aromatic plants because in stress, more metabolites are produced in plant cells and substances that prevent oxidation in these stressed cells (Farahani et al., 2009). On the other hand, Penka (1978) indicated that essential oils are a product of respiratory catabolic processes that are enhanced under water deficiency. Thus, drought stress increases the essential oil content and decreases the essential oil content of medicinal and aromatic plants under drought conditions due to reduced fruit yield. These results closely match those reported by Rezaei-Shayana et al. (2017); and Ghassemi-Golezani et al., (2018a) on ajowan, and Ali et al., (2020); and Ibrahim et al. (2020) on fennel, they mentioned that the percentage of oil increased as a result of the increase in irrigation periods. While the oil production decreased with increasing irrigation periods.

Data presented in Table (7) demonstrated that there was a negative effect of the irrigation intervals on the chlorophyll a, where the highest values of the chlorophyll a scored by ajwain plants irrigated every 3 days, in the 1st and 2nd seasons. While irrigated ajwain plants every 5 days caused the lowest values of the chlorophyll, during the 1st and 2nd seasons. Increasing the irrigation intervals were reduced the chlorophyll b content of ajwain plants, as shown in Table (7) the largest values of the chlorophyll b were obtained from the ajwain plants irrigated every 3 days without significant differences after 4 days in both seasons, respectively. However, irrigated ajwain plants every 5 days gave the lowest values in both seasons. Furthermore, the different irrigation intervals treatments had a marked impact on the values of carotenoids of ajwain plants in the two seasons, the results indicated that irrigated ajwain plants every 3 days produced the largest values of carotenoids. In the meantime, the lowest values carotenoids achieved with irrigated ajwain plants every 5 days. These findings are supported by Azhar et al. (2011) on ajwain, Abd El-Razik et al. (2015) on chervil, Mohammad pour et al. (2015) on Achillea, and Pishva et al. (2020). on cumin, which reported that the content of chlorophyll a, chlorophyll b, and carotenoids decreased with increasing water stress. On the other hand, there is no significant effect of irrigation periods on chlorophyll content in ajwain plants, according to Zeid et al. (2014).

The results presented in Table 7 showed that stimulators potassium silicate + biochar had a significant effect on the essential oil%, oil yield/ha, chlorophyll a, chlorophyll b, and carotenoid

TABLE 7. Effect of irrigation intervals, biochar, and foliar spraying of potassium silicate and their interaction treatments on essential oil, oil yield/feddan, chlorophyll a, chlorophyll b, and carotenoids of ajwain during the two seasons 2020/2021 and 2021/2022.

Irrigation intervals	Stimulators	Essential oil (%)		Oil yield/ha (L)		Chlorophyll a (mg/g)		Chlorophyll b (mg/g)		Carotenoids (mg/g)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
3	0.0	4.4de	4.5c	20.28e	21.05f	0.81c	0.82c	0.35d	0.35d	0.32d	0.31d
	K_2SiO_3	4.1f	4.2d	19.87e	20.74f	0.85b	0.85b	0.37c	0.37c	0.34c	0.34c
	Biochar (BO)	4.7c	4.9b	25.46c	26.81c	0.88a	0.88a	0.39b	0.40b	0.36b	0.36b
	K_2SiO_3+BO	5.0ab	5.1ab	29.11a	30.24a	0.91a	0.92a	0.41a	0.42a	0.39a	0.40a
4	0.0	4.6cd	4.6c	17.98f	18.34g	0.74e	0.75e	0.32e	0.32e	0.30d	0.29d
	K_2SiO_3	4.8c	4.9b	22.25d	23.23d	0.77d	0.77d	0.34d	0.34d	0.32d	0.32d
	Biochar (BO)	5.2a	5.3a	27.96b	28.97b	0.89a	0.88a	0.39b	0.39b	0.36b	0.36b
	K_2SiO_3+BO	5.2a	5.3a	30.12a	31.42a	0.91a	0.91a	0.41a	0.42a	0.38a	0.40a
5	0.0	4.8c	4.8b	16.70f	16.97h	0.70f	0.71f	0.30f	0.31f	0.26f	0.27f
	K_2SiO_3	5.1a	5.2a	19.58e	20.59f	0.73e	0.73e	0.33de	0.33de	0.28e	0.29e
	Biochar (BO)	5.2a	5.3a	22.49d	23.38d	0.77d	0.78d	0.35d	0.35d	0.31d	0.33d
	K_2SiO_3+BO	5.2a	5.3a	25.15c	26.14c	0.80c	0.81c	0.37c	0.38c	0.34c	0.35c
Mean of irrigation intervals	3	4.6c	4.7c	23.81a	24.70a	0.86a	0.87a	0.38a	0.39a	0.35a	0.35a
	4	4.9b	5.0b	24.14a	25.15a	0.83b	0.83b	0.37a	0.37a	0.34a	0.34a
	5	5.1a	5.2a	21.02c	21.89c	0.75c	0.76c	0.33b	0.34b	0.30b	0.31b
Mean of stimulators	0.0	4.6b	4.6b	18.41d	18.70d	0.75b	0.76b	0.32c	0.33b	0.29d	0.29d
	K_2SiO_3	4.7b	4.8b	20.88c	21.82c	0.78b	0.78b	0.35b	0.35b	0.31c	0.32c
	Biochar (BO)	5.0a	5.2a	25.20b	26.62b	0.85a	0.85a	0.38a	0.38a	0.34b	0.35b
	K_2SiO_3+BO	5.1a	5.2a	27.96a	29.09a	0.87a	0.88a	0.40a	0.41a	0.37a	0.38a

Means designed by the same letter at each cell are not significantly different at the 5% level according to Duncan s multiple range tests.

in both seasons compared to other treatments. The highest values occurred when ajwain plants were sprayed with potassium silicate + biochar, contrary the lowest values were obtained from untreated plants with stimulators, in the two seasons. Numerically, the essential oil% increased by potassium silicate spraying + biochar by 7.84 and 11.54%, the oil yield/ha increased by 34.16 and 35.72%, chlorophyll a increased by 13.79 and 13.64%, chlorophyll b increased by 20.00 and 19.51%, and carotenoid increased by 21.62 and 23.68% compared to the comparison coefficients (without stimulators) in the first and second seasons, respectively. Biochar improves dry or sandy soils' ability to retain water, thereby enhancing soil quality and lowering irrigation needs. The modification of the soil's porosity is the primary cause of the increased water holding capacity and improved saturated hydraulic conductivity. Sandy soils are poor at retaining water because they have dominant macro- and meso-pore systems and little to no organic material or clay. Another important factor to keep in mind is bulk density, which is directly impacted by the use of biochar. (Novak et al., 2009). Si has a role in inhibiting ethylene, which reduces the speed of aging and death of harvested plant parts. Si is beneficial for the chlorophyll content and helps the crops maintain their freshness for a longer period with a better appearance. Thus, Si has a positive effect on both crop yield and quantity (Balakhnina and Borkowska, 2013).

The interaction between irrigation intervals and stimulators had significant effect on oil yield/ha, chlorophyll a, chlorophyll b, and carotenoid of ajwain in both experimental seasons as shown in Table 7. The best values of these traits were recorded when ajwain plants were irrigated every

3 and 4 days under foliar spraying with K-silicate + biochar. Whereas the lowest values resulted from irrigation every 5 days under without stimulators in both growing seasons. For the oil yield, the greatest values of oil yield were recorded when ajwain plants were irrigated every 3 and 4 days under biochar and foliar spraying with K-silicate + biochar.

Effect of irrigation intervals and foliar spraying of K-silicate on mineral status and water use efficiency of ajwain plant

Data illustrated in Table (8) clearly indicated that the highest values of the nitrogen, phosphorus and potassium percentage were obtained by irrigating ajwain plants every 3 days in the two seasons. On the opposite side, the lowest nitrogen and potassium percentage was obtained by irrigating the ajwain plants every 5 days on the other hand, there isn't significant differences between irrigation plants after 4 days and after 5days on phosphorus % in the two seasons. The present findings are generally consistent with those previously reported by Ghassemi et al. (2019) on Ajwain; and Pishva et al. (2020) on Cumin. Who proved that increasing the irrigation periods led to a decrease in the chemical components such as (nitrogen, phosphorus, and potassium) in the herbs.

The results present in Table 8 and Figure 2 regarding that the water use efficiency was contrary to all the traits studied, which the increase in irrigation intervals led to an increase in the water use efficiency of the ajwain plants. Thus, the highest values of the ratio of water use efficiency with irrigated ajwain plants every 4 days which amounted to (0.100 and 0.102 kg/m^3) were achieved in the first and second seasons, respectively. In contrast, ajwain plants irrigated every 3 days caused the lowest water use efficiency values in the first and second seasons, which were (0.083 and 0.085 in the first and second seasons, respectively). These results support those obtained by Elgammal and Maswada (2013), and Shi et al. (2002) showed WUE was higher in dry farming treatment because yields fell relatively less than the irrigation water supply. However, a higher WUE could be achieved by linking deficit stress in the somewhat late vegetative stage of maturity.

TABLE 8. Effect of irrigation intervals, biochar foliar spraying of potassium silicate and their interaction treatments on nitrogen, phosphorus, and potassium concentration as well as water use efficiency of ajwain during the two seasons 2020/2021 and 2021/2022.

Irrigation intervals	Stimulators	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Water use efficacy (WUE kg/m^3)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
3	control	1.85d	1.71d	0.25	0.28	2.64d	2.75e	0.074e	0.075e
	K_2SiO_3	1.90bc	1.83c	0.26	0.28	2.85c	2.90d	0.078e	0.079e
	Biochar (BO)	1.97b	1.90b	0.26	0.27	3.01b	3.11b	0.087d	0.088d
	K_2SiO_3+BO	2.13a	2.01a	0.25	0.28	3.15a	3.27a	0.094d	0.096d
4	control	1.61f	1.48f	0.22	0.24	2.41e	2.46f	0.079e	0.081e
	K_2SiO_3	1.76e	1.62e	0.22	0.25	2.60d	2.69e	0.094c	0.096c
	Biochar (BO)	1.82d	1.73d	0.21	0.24	2.83c	2.88d	0.109b	0.111b
	K_2SiO_3+BO	1.93b	1.85c	0.22	0.24	2.96b	3.01c	0.117a	0.120a
5	0.0	1.44g	1.38g	0.20	0.22	2.22f	2.31g	0.083d	0.084d
	K_2SiO_3	1.60f	1.49f	0.20	0.23	2.41e	2.47f	0.092c	0.095c
	Biochar (BO)	1.73e	1.66e	0.21	0.22	2.62d	2.68e	0.104b	0.106b
	K_2SiO_3+BO	1.81d	1.73d	0.20	0.22	2.81c	2.90d	0.116a	0.118a
Mean of irrigation intervals	3	1.96a	1.86a	0.26a	0.28a	2.91a	3.01a	0.083b	0.085b
	4	1.78b	1.67b	0.22b	0.24b	2.70b	2.76b	0.100a	0.102a
	5	1.65c	1.57c	0.20b	0.22b	2.52c	2.59c	0.098a	0.101a
Mean of stimulators	control	1.63d	1.52d	0.22	0.25	2.42d	2.51d	0.079d	0.080d
	K_2SiO_3	1.75c	1.65c	0.23	0.25	2.62c	2.69c	0.088c	0.090c
	Biochar (BO)	1.84b	1.76b	0.23	0.24	2.82b	2.89b	0.100b	0.102b
	K_2SiO_3+BO	1.96a	1.86a	0.22	0.25	2.97a	3.06a	0.109a	0.111a

Means designed by the same letter at each cell are not significantly different at the 5% level according to Duncan s multiple range tests.

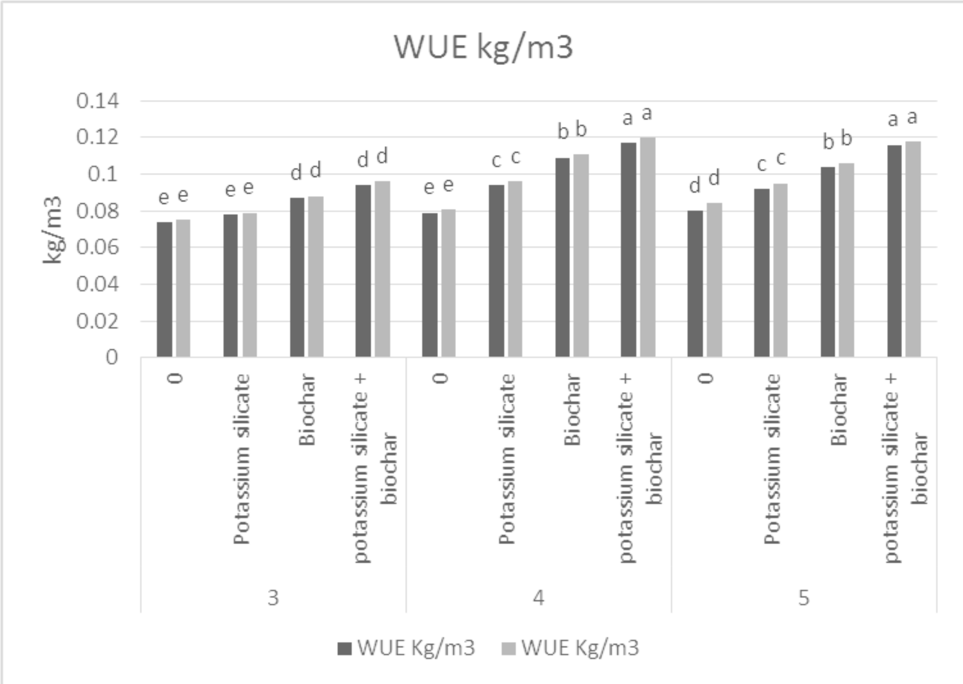

Fig. 2. Effect of irrigation intervals, biochar, and foliar spraying of potassium silicate and their interaction treatments on water use efficiency of ajwain during the two seasons 2020/2021 and 2021/2022.

Results shows in Table (8) declared that, stimulators had a significant effect on N, and K concentration as well as water use efficiency in both seasons. Compared without stimulators treatments, except for the concentration of phosphorus is not significant. The highest values were recorded when ajwain plants were sprayed on potassium silicate + biochar, while the lowest values were recorded without stimulators treatments in the seasons 2020/2021 and 2021/2022. Nitrogen concentration increased by spraying potassium silicate + biochar by 16.84 and 18.28%, potassium concentration increased by 18.52 and 17.97%, and water use efficacy increased by 26.40 and 27.78% compared to the control treatments (without stimulators) in the first and second seasons, respectively. The soil had been fertilized with bagasse biochar had higher levels of N, P, and K than either of the fertilized controls. This suggests that nitrification-based N mineralization has improved. Suppression of denitrification enzymes might have prevented additional losses (Van Zwieten et al., 2009). Further, potassium silicate is also a source of potassium, which plays an important role in increasing the rate of photosynthesis and increasing stored carbohydrates and grain fillers (Szczerba et al., 2009). These positive effects are among the applications of silicon in improving rice grain yield, as obtained by Hakim et al. (2012).

The interaction between irrigation intervals with stimulators had a significant effect on nitrogen and potassium %, but not significant effect on phosphorus% of ajwain in both seasons. The highest values for these traits were recorded when ajwain plants were irrigated every 3 days under foliar spray with K-silicate + biochar. While the lowest values resulted from irrigation every 5 days under without stimulators in both growing seasons. For, the water use efficiency the highest values for these traits were recorded when irrigated every 4 and 5 days under foliar spray with K-silicate + biochar.

Effect of irrigation intervals, biochar, and foliar spraying of K-silicate on major compounds of ajwain plant oil

Data illustrated in Table (9) showed the effect of irrigation intervals period (3, 4 and 5 days) and stimulators on percentage of the major's compounds of chemical ajwain fruit oil, expressed in % from the total oil contents, during the two experimental seasons. The data showed that there were four major's compounds (Thymol, Y-terpinene, P-cymene and β-Pinene) and significantly affected by the treatments. Regarding the Thymol and Y-terpinene percentages, it's clear that increasing the irrigation interval periods from 3 to 5 days significantly decreased the two compounds concentration. However, the highest concentrations were obtained from the plants irrigated each three days intervals and reserved K-silicate + biochar (64.4 & 64.5 for Thymol and 25.5 & 27.2 for Y-terpinene compounds) during the two experimental seasons. In the same line, increasing the frequencies of stimulators application from without to potassium silicate + biochar combines with significant increase in the two compounds concentrations.

On the other hand, increasing the irrigation intervals period from 3 days to 4 days significantly increased the concentrations of P-cymene and β-Pinene. While increase the interval irrigation period from 4 to 5 days had a negative effect on the two compounds concentrations. Furthermore, parallel increasing the frequencies of K-silicate application + biochar significantly increases the concentrations of these two major compounds.

The interaction between irrigation intervals period and stimulators treatments and its effect on the chemical composition of oil, it was significant, in the two seasons. The plants received potassium silicate + biochar and irrigated each three days present the highest percentages of Thymol and Y-terpinene. However, those received K-silicate + biochar and irrigated each 4 days present the highest percentages of P-cymene and β-Pinene in their fruits. On the opposite side, the plants without received stimulators and irrigated each five days recorded the lowest concentrations from the four compounds (Thymol and Y-terpinene, P-cymene and β- Pinene) in their fruits, during the two growing seasons.

TABLE 9. Effect of water stress, biochar, and K-silicate treatments on major compounds of ajwain fruit oil, expressed as % from total oil contents, during the two experimental seasons (2020/2021 and 2021/2022).

Irrigation intervals	stimulators	Thymol%		Y-terpinene%		P-cymene%	β-pinene%		
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
3	0.0	40.4f	43.3e	17.3e	18.4e	9.3 c	10.2d	3.2d	3.1c
	K_2SiO_3	51.7d	50.6c	19.7d	18.7e	9.8c	10.6d	4.3b	3.9b
	Biochar (BO)	55.8c	58.7b	22.7b	21.8c	11.3b	11.7b	4.5b	5.1a
	K_2SiO_3+BO	58.4a	58.5a	24.0a	23.7a	12.0a	12.1a	4.7a	5.1a
4	0.0	38.3f	40.1f	15.4f	16.1f	7.2f	7.6g	2.1e	2.0e
	K_2SiO_3	44.5e	46.2d	17.4e	18.2e	8.8d	8.8f	2.4e	2.6cd
	Biochar (BO)	50.6d	50.7c	21.3c	20.5d	8.6d	11.9c	3.3d	2.9c
	K_2SiO_3+BO	55.8b	57.6b	22.7b	23.4b	11.5b	11.1c	3.8c	3.2c
5	0.0	32.3h	30.1i	15.0f	14.6g	6.9f	6.5h	1.7f	1.5f
	K_2SiO_3	35.6g	32.8h	17.4e	14.7g	6.9f	8.4f	1.9f	1.6f
	Biochar (BO)	45.4e	34.1g	19.7d	15.2g	8.1e	9.6e	2.1e	1.8ef
	K_2SiO_3+BO	49.6d	34.2g	19.8d	16.3f	8.7d	9.9e	2.2e	2.1e
Mean of irrigation intervals	3	51.58a	52.78a	20.93a	20.65a	8.28a	11.15a	4.2a	4.3a
	4	47.30b	48.65b	19.20b	19.55b	9.03a	9.85b	2.9b	2.7b
	5	40.73c	32.81c	17.98c	15.20c	7.65b	8.60c	1.98c	1.75c
Mean of stimulators	0.0	37.0d	37.83d	15.90d	16.37d	4.70d	8.1d	2.3d	2.2d
	K_2SiO_3	43.93c	43.20c	18.17c	17.20c	8.50c	9.27c	2.87c	2.70c
	Biochar (BO)	50.60b	47.83b	21.23b	19.17b	9.33b	11.07b	3.30b	3.27b
	K_2SiO_3+BO	54.60a	50.10a	22.17a	21.13a	10.73a	11.03a	3.57a	3.47a

Means designed by the same letter at each cell are not significantly different at the 5% level according to Duncan s multiple range tests.

Conclusions

Based on the obtained results, treating the ajwain plants with stimulators beneficial to alleviate the adverse effects of water-stress. The possible mechanism involved in the improvement of vegetative growth, yield, and quality characters is the increase of WUE in ajwain plants. From the results obtained, we find that there was no significant effect among the Ajwain plants irrigated every 3 days and every 4 days for fruit yield and oil yield/ha in both seasons, in addition to saving 1270 m3/ha of water that can be used in any other crops when watering Ajwain plants every 4 days. Based on this investigation, under water stress, we can recommend that the application of K-silicate foliar spraying + biochar, which can increase WUE and can result in high fruit yield, its components and quality such oil yield under irrigation every 4 days interval under the study conditions and the similar conditions. Through the results obtained in the research, it can be recommended to use 3 cm3/l potassium silicate + 5 ton biochar/ha with irrigation every 4 days for the ajwain plants under sandy soil conditions.

Acknowledgment

The authors would like to express their gratitude to all staff members of Soil, Water & Environment Research Institute and Horticulture Research Institute, Agricultural Research Center, Egypt

Funding statements

Soil, Water & Environment Research Institute and Horticulture Research Institute, Agricultural Research Center, Egypt.

Conflict of interests

The authors declare no conflict of interest in the publication of this work.

References

A.O.A.C. (1990) *Official Methods of Analysis*, Association of Analytical chemists. Washinton D.C., I, 73-74.

Abd El-Razik, T.M., Hegazy, M.H., Amer, H.M., Wahba, H.E., Hendawy, S.F. and Hussein, M.S. (2015) Effect of potassium silicate as anti-transpiration on growth, essential oil of chervil plant under Egyptian conditions. *International Journal of PharmTech Research*, **18**(10), 32-39.

Ali, Q., Shahid, S., Ali, S., El-Esawi, M.A., Hussain, A.I., Perveen, R., Iqbal, N., Rizwan, M., Alyemeni, M.N., El-Serehy, H.A. and Al-Misned F. A. (2020) Fertigation of Ajwain (*Trachyspermum ammi* L.) with Fe-Glutamate Confers Better Plant Performance and Drought Tolerance in Comparison with $FeSO_4$. *Journal of Sustainability*, **12**, 1-30.

Aliabadi, F.H., Valadabadi, S.A.R., Daneshian, J. and Khalvati, M.A. (2009) Evaluation changing of essential oil of balm (*Melissa officinalis* L.) under water deficit stress conditions. *J. Med. Plant. Res.,* **3**(5), 329-333.

Angst, T.E. and Sohi, S.P. (2013) Establishing release dynamics for plant nutrients from biochar. *GCB Bioenergy*, **5**, 221–226.

Arab R., Dastan, S., Mobasser, H. and Ghanbari, A. (2011) Effect of silicon and sycoses application on yield components and quantity yield of rice (*Oryza sativa* L.) In Iran. *Proceeding of the 5th Int. Conf. on Silicon in Agriculture, 13th – 18th September, Beijing, China.*

Azhar, A., Hussain, B., Ashraf, M.Y. and Abbasi, K.Y. (2011) Water stress mediated changes in growth, physiology and secondary metabolites of desi ajwain (*Trachyspermum ammi* L.). *Pak. J. Bot.,* **43**, 15-19.

Balakhnina, T. and Borkowska, A. (2013) Effects of silicon on plant resistance to environmental stresses. *International Agrophysics*, **27**, 225–232.

Barnabas, B., Jager, K. and Feher, A. (2007) The effect of drought and heat stress on reproductive processes in cereals. *Plant Cell Environ*., **31** (1), 11-38.

Bhagyawant, R.G., Gorantiwar, S.D. and Dahiwalkar, S.D. (2015) Effect of deficit irrigation on crop growth, yield and quality of onion under surface irrigation. *American-Eurasian J. Agric. & Environ. Sci.,* **15**(8), 1672-1678.

Burke, E.J., Brown, S.J. and Christidis, N. (2006) Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. *J. Hydrometeorol.,* **7**, 1113-1125.

Dallagnol, L., Rodrigues, F., Mielli, M. and Ma J. (2014) Rice grain resistance to brown spot and yield are increased by silicon. *Trop Plant Pathol*, **39**(1), 56- 63.

Damon, P.M. and Rengel, Z. (2007) Wheat genotypes differ in potassium efficiency under glass house and field conditions. *Aust. J. Agric. Res.*, **58**, 816-823.

Earl, H. and Davis, R.F. (2003) Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. *Agron. J.,* **95**, 688- 696.

Egyptian Pharmacopoeia (1984) *The English Text of Egyptian Pharmacopoeia*. U.S. Government Printing Office, 2265 p.

Elgamaal, A.A. and Maswada, H.F. (2013) Response of three yellow maize hybrids to exogenous salicylic acid under two irrigation intervals. *Asian J. Crop Sci.*, **5**, 264–274.

El-Naggar, M.E., Abdelsalam, N.R., Foudo, M.M.G., Mackled, M.I., Al-Jaddadi, M.A.M., Ali, H.M., Siddiqui, M.H. and Kandil, E.E. (2020) Soil application of nano silica on maize yield and its insecticidal activity against some stored insects after the post-harvest. *Nanomaterials*, **10**(4), 739.

Farahani, H.A., Valadabadi, S. A., Daneshian, J., Shiranirad, A.H. and Khalvati, M.A., (2009) Medicinal and aromatic plants farming under drought conditions. *J. Hortic,* **1**, 86-92.

Farouk, S. and EL-Metwally, I.M. (2019) Synergistic responses of drip-irrigated wheat crop to chitosan and/or silicon under different irrigation regimes. *Agricultural Water Management*, **226**, 105807.

Farouk, S. and Omar, M.M. (2020) Sweet basil growth, physiological and ultrastructural modification and oxidative defense system under water deficit and silicon forms treatment. *Journal of Plant Growth Regulation*, **39**, 1307-1331.

Farouk, S., Arafa, S.A. and Nassar, R.M.A. (2018) Improving drought tolerance in corn (*Zea mays* L) by foliar application with salicylic acid. *Int. J. Environ.,* **7**(3), 104-123.

Ghanbari, A (2011) Silicon application and nitrogen on yield and yield components in rice (*Oryza sativa* L.) in two irrigation systems. *Int. J. of Biological, Agricultural, Food and Biotechnological Engineering*, **5**(2), 40-47.

Ghassemi, S., Ghassemi-Golezani, K. and Salmasi, S.Z. (2019) Changes in antioxidant enzymes activities and physiological traits of ajowan in response to water stress and hormonal application. *Scientia Horticulturae*, **246**,957-964.

Ghassemi, S., Ghassemi-Golezani, K., Zehtab-Salmasi, S. and Alizadeh-Salteh S. (2017) Improving essential oil content and yield of ajowan organs under water stress by application of salicylic acid and abscisic acid. *Inter. J. of Plant Prod.,* **11**(3),425-435.

Ghassemi-Golezani, K., Ghassemi, S. and Salmasi, S.Z. (2018a) Changes in essential oil-content and composition of ajowan (*Carum copticum* L.) seeds in response to growth regulators under water stress. *Scientia Horticulturae*; **231**, 219-226.

Gholami, Y. and Falah, A. (2013) Effects of two different sources of silicon on dry matter production, yield, and yield components of rice, Tarom Hashemi variety and 843 lines. *Int. J. Agri. Crop Sci.,* **5**(3), 227-231.

Hakim, Y., Khan, A., Shinwari, Z., Kim, D., Waceas, M., Kamran, M. and Junglee, I. (2012) Silicon treatment to rice (*Oryza sativa* L. *cv "Gopumbyeo*") plants during different growth periods and its effects on growth and grain yield. *Pak. J. Bot.,* **44**(3), 891- 897.

Hattori, T., Inanage, S., Arak, H., An, P., Morita, S., Luxová, M. and Lux, A. (2005) Application of silicon enhanced drought tolerance in Sorghum bicolor. *Physiologia Plantarum,* **123**, 459–466.

Ibrahim, M.E., Abd Rabbu, H.S., Motawe, H.M. and Hussein, M.S. (2020) Improved growth, yield of seeds and oil production of fennel (*Foeniculum vulgare* var. vulgare) plants. *Journal of Materials and Environmental Science*, **11**(7), 1112-1120.

Israelsen, D. and Hansen, V. (1962) *Flow of water into and through soil*. In Irrigation Principles and Practices 3rd ed., Willey, New York.

Jajarmi, V. (2009) Effect of water stress on germination indices in seven wheat cultivars. *World Aca Sci Eng Tech.,* **49**, 105-106.

Jeet, K., Devi, N., Narender, T., Sunit, T., Lalit, S. and Raneev, T. (2012) *Trachyspermum ammi* (Ajwain). A comprehensive Review. *International Research Journal of Pharmacy*, 3 (5),133-138.

Kandil, E.E., Abdelsalam, N.R., Aziz, A.E., Ali, H.M. and Siddiqui, M.H. (2020) Efficacy of nanofertilizer, fulvic acid and boron fertilizer on sugar beet (*Beta vulgaris* L.) yield and quality. *Sugar Tech.,* **22**, 782–791.

Khalid, K.h.A. (2006) Influence of water stress on growth, essential oil, and chemical composition of herbs (*Ocimum* sp.). *Int. Agrophysics*, 20, 289-296.

Klute, A. (1986) *Methods of soil analysis*. Part 1 – Physical and mineralogical methods. 2nd ed. SSSA Book Series No. 5. SSSA and ASA, Madison, WI.

Liang, Y., Sun, W., Si, J. and Römheld, V. (2005) Effects of foliar-and root-applied silicon on the enhancement of induced resistance to powdery mildew in *Cucumis sativus*. *Plant Pathol*. 54, 678–685.

Meena, R., Naruka, I.S., Shaktawat, R.P.S., Kushwah, S.S. and Kanwar, J. (2017) Effect of irrigation and nitrogen levels on growth, yield and quality of ajowan (*Trachyspermum ammi* L.). *Environment and Ecology*, **35**(2A), 890-894.

Mohammad pour, M., Negahban, M., Saeedfar, S., Salehi, P.S. and Javadi, H. (2015) Effect of drought stress on some of the biochemical characteristics of three Achillea Populations (*Achillea vermicularis*). *Russian J. of Biological Res*., **4**(2), 68-80.

Novak, J.M., Busscher, W.J., Laird, D.L., Ahmedna, M., Watts, D.W. and Niandou, M.A. S. (2009) Impact of Biochar amendment on fertility of a Southeastern coastal plain soil. *Soil Science*, **174**, 105-112.

Novak, J.M., Busscher, W.J., Watts, D.W., Amonette, J.E., Ippolito, J.A. and Lima, I.M. (2012) Biochars impact on soil-moisture storage in an ultisol and two aridisols. *Soil Sci.*, **177**, 310-320.

Pang, Z., Tayyab, M., Islam, W., Tarin, M. W. K., Sarfaraz, R., Naveed, H., Zaman, S., Zhang, B., Yuan, Z. and Zhang, H. (2019) Silicon-mediated improvement in tolerance of economically important crops under drought stress. *Applied Ecology and Environmental Research,* **17**(3), 6151-6170.

Pati, S., Pal, B., Badole, S., Hazra, G. and Mandal, B. (2016) Effect of silicon fertilization on growth, yield and nutrient uptake of rice. *Commun soil Sci. Plant Anal*., 47, 284-290.

Penka M. (1978) Influence of irrigation on the contents of effective substances in official plants. *Acta Hort*., 73, 181-197.

Pishva, Z.K., Amini-Dehaghi, M., Bostani, A. and Naji, A.M. (2020) Biological and chemical nitrogen fertilizer impact on cumin (*Cuminum cyminum* L.) under different irrigation regimens. *J. Herbmed Pharmacol*., **9**(1), x-x.

Pitchersky, E. and Gang, D.R. (2000) Genetics and biochemistry of secondary metabolites in plants: An evolutionary perspective. *Trends Plant Science,* **5**(10), 439-445.

Ranganathan, S., Surarchala, V., Rajesh, Y., Prasad, M., Padmakumari, A. and Voleti, S. (2006) Effect of silicon sources on its deposition, chlorophyll content, and disease and pest resistance in rice. *Biologia Plantarum*, **50**(4), 713-716.

Rathore S.S., Saxena, S.N. and Singh, B. (2014) Potential health benefits of major seed spices. *Int. J. Seed Spices*, **3** (2), 1-12.

Razmjoo, K., Heydarizadeh, P. and Sabzalian, M.R. (2008) Effect of salinity and drought stresses on growth parameters and essential oil content of *Matricaria chamomilla*. *Int. J. Agric. & Bio.*, 10, 451-454.

Rezaei-Chiyaneh, E., Pirzad, A., Hosseini, B. and Madani, S.H. (2017) Effect of different levels of irrigation and harvesting time on some agronomical characteristics and oil production of *Carum copticum* L. *Environmental Stresses in Crop Sci*., **9**(4), 329-338.

Salim, B.B. (2014) Effect of boron and silicon on alleviating salt stress in maize. *Middle East Journal of Agriculture Research,* **3**(4), 1196-1204.

Saric, M. (1967) Chlorophyll Determination Univerzitet U Noveon Sadu Praktikum iz fiziologize Biljaka-Beograd, *Hauena Anjiga*, 215.

Schmidt, R., Zhang, X. and Chalmers, D. (1999). Response of photosynthesis and superoxide dismutase to silica applied to creeping bent grass grown under two fertility levels. *J. Plant Nutr*., **22**, 1763–1773.

Sheshbahreh, M.J., Dehnavi, M.M., Salehi, A. and Bahreininejad, B. (2019) Effect of irrigation regimes and nitrogen sources on biomass production, water and nitrogen use efficiency and nutrients uptake in coneflower (*Echinacea purpurea* L.). *Agricultural Water Management*, 213, 358-367.

Shi, Q., Zeng, X., Li, M., Tan, X. and Xu, F. (2002). Effects of different water management practices on rice growth. *Water-Wise Rice Prod.* 1, 3–14 (2002).

Simon, J.E., Reiss-Buhenheinra, D., Joly, R.J. and Charles, D.J. (1992) Water stress induced alterations in essential oil content and composition of sweet basil. *Journal of Essential Oil Research* 4, 71-75

Snedecor, G.W. and Cochran, W.G. (1980) *Statistical Methods 7th Edin*. Iowa State Univ., Press, Iowa, USA.

Steiner, C. (2015) Considerations in Biochar Characterization. Agricultural and Environmental Applications of Biochar: Advances and Barriers. *Soil Science Society of America*, Inc., Madison, WI.

Szczerba, M., Britto, D. and Kronzucher, H. (2009) K^+ transport in plants: physiology and molecular biology. *J. Plant Physiology*, 166, 447-466.

Tarabih, M.E., El-Eryan, E.E. and El-Metwally, M.A. (2014). Physiological and pathological impacts of potassium silicate on storability of Anna apple fruits. *American Journal of Plant Physiology*, 9(2), 52-67.

Van Zwieten, L., Kimber, S., Morris, S., Chan, Y.K., Downie, A., Rust, J., Joseph, S. and Cowie, A. (2009) Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant and Soil (online)* DOI: 10.1007/s11104-009-0050-x.

Warnock, D.D., Lehmann, J., Kuyper, T.W. and Rillig, M.C. (2007) Mycorrhizal responses to biochar in soil and concepts and mechanisms. *Plant Soil*, 300, 9-20.

Yang, A., Akhtar, S.S., Lin, L.,Fu, Q., Li, Q., Naeem, M.A., He, X., Ze, Z. and Sven-Erik, J. (2020) Biochar Mitigates Combined Effects of Drought and Salinity Stress in Quinoa. *Agronomy,* 10(912), 1-14.

Zeid, F.A., Omer, E.A., Amin, A.Y. and Hanafy, S.A.H. (2014) Effect of putrescine and salicylic acid on Ajwain plant (*Trachyspermum ammi*) at vegetative stage grown under drought stress. *International J. of Agric. Sci. and Res*., **4**(6),61-79.

تقييم تأثير الفحم الحيوي والرش الورقي لسيليكات البوتاسيوم على نمو وإنتاجية نبات الاجوان تحت الاجهاد المائي في ظروف الاراضي المستصلحة حديثا

محمد جمال رمضان سرحان [١] وعبير محمد شحاته [٢]
[١] معهد بحوث الاراضي والمياه والبيئة - مركز البحوث الزراعية - مصر.
[٢] قسم بحوث النباتات الطبيه والعطريه - معهد بحوث البساتين - مركز البحوث الزراعية - مصر.

يعوق الجفاف إنتاج الغذاء في جميع أنحاء العالم بشكل خطير، ويعتبر الفحم الحيوي والرش الورقي بسيليكات البوتاسيوم ضروريين لكيفية استخدام المحاصيل لطاقتها، سواء في ظل ظروف مواتية أو معاكسة. كما أنها قد تجعل النباتات أكثر تحملا للجفاف. الاجوان هو نبات طبي وعطري يزرع أساسا للبذور والأعشاب والزيوت المتطايرة. تم إجراء تجربه لتقييم آثار الفحم الحيوي والرش الورقي لسيليكات البوتاسيوم تحت فترات الري (3 و 4 و 5 أيام) على النمو ومحصول الثمار والزيت العطري ومكوناته الرئيسية وكذلك المكونات الكيميائية للاجوان في المزرعة التجريبية شرق مدينه ملوي بمحافظة المنيا بمصر خلال موسمي 2020/2021 و 2021/2022. تم استخدام تصميم قطع منشقه مره واحده في أربع مكررات. وكانت فترات الري في القطع الرئيسيه ومعاملات الفحم الحيوي والرش الورقي بسيليكات البوتاسيوم في القطع الفرعيه. أظهرت النتائج أن الري كل 3 و4 أيام ينتج أعلى عائد مع معايير جودة أعلى. في حين أن الري كل 5 أيام أعطى قيم إيجابية كبيرة للغاية من كفاءة استخدام المياه. أنتج الفحم الحيوي + الرش بالسيليكات أعلى محصول للثمار. حقق الري كل 3 و 4 أيام مع الفحم الحيوي + الرش الورقي من السيليكات أعلى قيم لمحصول الثمار ومكوناته. تظهر هذه النتائج أن معالجة الفحم الحيوي + السيليكات يمكن أن تزيد من كفاءة استخدام المياه وتنتج محصول عالي من الثمار.

من النتائج التي تم الحصول عليها ، نجد أنه لم يكن هناك تأثير معنوي بين نباتات الاجوان المروية كل 3 أيام وكل 4 أيام لمحصول الثمار ومحصول الزيت/هكتار في كلا الموسمين، فبالتالي نوصي بري نباتات الاجوان كل 4 ايام مع البيوشار والرش بسليكات البوتاسيوم.