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Integrated Effects of Biochar and Potassium Silicate on Borage Plant Under Different Irrigation Regimes in Sandy Soil

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Abstract: Drought represents a critical constriction for food production worldwide. Biochar (Bo) and potassium silicate (K-Si) occupy a crucial role in crops' metabolic processes under normal or stress conditions and may induce drought tolerance. Two field experiments were done at the El Qassasein Research Farm, El Qassasein Horticulture Research Station, Ismailia province, Egypt, in 2017/2018 and 2018/2019 seasons as a split-plot design with three replications, for considering the defensive function of Bo and/or Si on borage plant growth, yield, oil constituents and water use efficiency under various irrigation levels. The experimental treatments included three irrigation water regimes (100, 80 and 60% of daily reference evapotranspiration 'Et_o') as the major factor, in addition to Bo and/or K-Si (water, 0.5% K-Si as a foliar application, Bo at 4 or 6 t/fed as soil additive; K-Si plus 4t/fed Bo; and K-Si plus 6 t/fed Bo) as the sub-factor. Water stress significantly decreases plant growth, yield, ion percentage and photosynthetic pigment. However, soil amendment with biochar and K-Si foliar application had a positive effect in mitigating the injury of drought on borage plants. Furthermore, biochar and K- Silicate treatments significantly enhanced borage vegetative growth characters, yield characters and fixed oil %. Application of K-Si+ 4 t/fed Bo gave the maximum plant growth and yield features, sustaining plant water status, along with enhanced physiological trials under irrigation regimes. Overall, this investigation recommends that the application of K-Si plus 4 t/fed Bo had the impending to mitigate the drought effects, improving water use efficiency besides increasing the seed and oil yield.

Key words: Biochar · *Borago officinalis* L. · Drought · Silicon · Water productivity · Water use efficiency · Yield

INTRODUCTION

Global climate changes, scarceness of water, unsatisfactory infrastructure, rapid population growth rate and urbanizations represent the chief impediments for crop production within arid and semi-arid regions. Drought represents the chief natural restrictions that limiting crop productivity all over the world [1-3]. The drought was affected about 25% of the world's agricultural lands and predictable to achieve about 30-40% by 2090s [4, 5]. Drought stress has decreased the yield of numerous crops by 17-70% as a result of their tremendous influences of morpho-anatomical and physio-biochemicals as well as molecular aspects that will modify diverse metabolic processes, including photosynthesis, water absorption, leading to growth and yield decline [1, 6, 7].

In Egypt, agricultural extension requests a huge amount of irrigation water that's by now not sufficient to suit the conventional necessities, given that 85% of total available water is consumed by the agriculture sector and the majority of the on-farm irrigation systems have low effectiveness, plus poor irrigation prerequisite. Therefore,

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scheduling irrigation according to weather factors should be appropriate and the principles of deficit irrigation should be accepted with a simple level of reduction in yield [7]. Deficit irrigation is very useful and important for increasing water productivity in view limitation of water resources in agriculture [8].

Newly, rising competition for inadequate water resources has encouraged the gainful innovated approach for exploiting water use efficiency (WUE) and crop productivity. Hence, deficit irrigation should be established as extremely practical, easy and vital for improving WUE capacity [2, 8]. Application of soil amendment or nutrients has been one of the rational strategies in this regard [1, 7, 9]. Therefore, biochar (Bo) and potassium silicate (K-Si), are utilized for improving crop development and productivity under normal or stressful conditions. It is a satisfactory treatment within sustainable agriculture production owing to its features, like, non-corrosive, non-pollutant nature, low-priced, availability and present both economic and ecological efficiency.

Biochar (carbon reach product) has attracted surprising deliberation as potentially imperative biological resources. Various researches have established that Bo supplementation improved plant growth and productivity under either normal or water deficit conditions [9]. The positive effect of Bo on plants may result from its roles in rising water maintenance ability; improving their capacity to adsorb phytotoxic organic molecules and motivates valuable microbes activity [10-12].

Potassium silicate (K-Si) was newly utilized in nullifying the undesirable effect of drought on crop growth [13, 14]. Potassium represents the 3rd significant macronutrient necessary for plant development under normal or stress conditions. Potassium plays an imperative function in inducing drought tolerance by sustaining photosynthetic aptitude, defensive chloroplasts from oxidative stress, regulating stomatal functions, improving water status, activation of multiple enzymes, increased cell expansion and phloem loading and inducing osmotic adjustment plus net carbon assimilation [15, 16].

Silicon (Si) is regularly accepted to be a precious nutrient for crop productivity. Several studies have established that Si alleviates the negative effect of the stressful condition [3, 17]. Si in part compensate the depressing effect of drought by its function as a crucial physio-mechanical barrier, accelerating enzymes activity, regulating gene expression, dropping evapotranspiration or control of stomatal conductance, enhancing osmotic adjustment capacity by accretion of solutes includes proline and potassium, reduce drought-induced oxidative stress, activate photosynthetic enzyme i.e., ribulose biphosphate carboxylase and $NADP^+$-dependent glycerladehyde-3-phosphate dehydrogenase [7, 18-22].

Borage (*Borago officinalis* L.; a power food) is used as a vegetable or as oil-seed crops. Seeds of borage are used from ancient in traditional medicine for the treatment of swelling and inflammation, coughs and other respiratory complaints [23]. Borage oil contains a substantial amount of γ-linolenic (all-cis-6, 9, 12-octadecatrienoic) acid, which is essential fatty acid needed for all animals and human nutrition, that represents an important intermediate of indispensable compounds in the body, such as prostaglandin E1 and its derivatives. Moreover, because of the higher content of essential fatty acids, that has a great potential to prevent cancer, cardiovascular diseases and infectious diseases [24].

Exogenous application of Bo and/or K-Si has been established to have an encouraging effect on drought tolerance in diverse plant species. Despite identified encouraging effects of Bo or Si independently, whether they have additive or synergistic effects on alleviating drought injuries is uncertain and not studied. Consequently, the purpose of this study was to decide whether the application of Bo alone or synergistically interacting with Si would repress drought-injuries in the borage plant. This work was designed to progress understanding the defensive function of Bo and/or Si application on borage plant growth, some physiological parameters, water use efficiency and yield under well-watered and water-deficit stress conditions.

MATERIALS AND METHODS

Field Location: Two field experiments were carried out during the two successive winter seasons of 2017/2018 and 2018/2019, on the El Qassasein Research Farm (30° 34’ 51.7’’N 31° 56’ 15.6’’ E and mean altitude above sea level 21 m), El Qassasein Horticulture Research Station (HRI, ARC), El Qassasein region, Ismailia Governorate, Egypt.

The experimental region is recognized as the arid climate with low precipitation winter and hot dry summer. The Agrometeorological data of the experimental region were secured from the meteorological station of Bilbies (Lat. 30:66°, Long. 31.95° and Elevation 24.8 m) and recorded as an average monthly weather data for the two growing seasons (Table 1).

Table 1: Some meteorological data and reference evapotranspiration (Et_o) at the experimental site, at 2017/2018 and 2018/2019 seasons

Season	2017/2018							2018/2019						
Month	Tmax	Tmin	RH	WS	RF	SS	Et_o	Tmax	Tmin	RH	WS	RF	SS	Et_o
October	30.0	17.4	52.6	2.2	0.0	9.5	4.61	31.6	19.1	52.6	2.1	0.0	9.5	4.72
November	25.1	13.7	58.3	1.8	0.0	8.5	3.01	26.6	15.4	58.3	1.7	0.1	8.5	3.13
December	21.8	11.7	63.2	1.8	4.3	7.7	2.31	21.0	10.7	63.2	2.6	6.0	7.7	2.63
January	19.6	8.9	52.1	2.4	9.1	7.1	2.76	19.3	7.1	52.1	2.5	8.0	7.1	2.77
February	22.9	10.6	55.5	1.4	6.0	7.7	2.71	21.2	8.0	55.5	2.0	2.0	7.7	2.93
March	29.0	12.5	55.3	1.7	0.4	8.4	4.11	23.8	9.8	55.3	2.1	0.0	8.4	3.82
April	30.7	14.5	48.0	1.8	0.0	9.4	5.33	27.8	12.8	48.0	1.9	0.1	9.4	4.98
Mean	28.2	14.8	53.8	1.9	19.8	78	3.55	27.3	14.2	53.8	2.1	16.2	78	3.57

Where: T. max., T. min.=maximum and minimum temperatures °C; W.S= wind speed (m/ Sec); R.H.= relative humidity (%); R.F = rain full (mm/ month), SS = sunshine Hr, Et_o= reference evapotranspiration (mm/day)

Table 2: Soil characteristics of the experiment site

Particles size distribution (%)			
Coarse sand	36.31	Clay	6.81
Fine sand	51.87	Texture class	Sand
Silt	4.91	----	----
Chemical properties			
O. M (%)	0.41	Available N (KCl-extract)	8.10
EC dSm^{-1}	0.31	Available P (Na - bicarbonate extract)	23.00
pH 1:2.5 soil: water suspension	8.10	Available K (NH4 - acetate extract)	108.00
Soil moisture constants (% by weight) and bulk density (g cm^{-3})			
Depth, cm	0-75	Bulk density(g cm-3)	1.41
Field capacity %	11.4	Available water (mm)	80.4
Wilting point %	3.8	----	----

Physical and Chemical Properties of the Experimental Soil: The experimental soil samples were collected from consecutive depths of (0-15 till 60 cm depths) for physical and chemical analysis. The chemical properties of the soil samples; were determined according to the methods outlined by Page *et al.* [25]. Soil moisture content was gravimetrically determined, which field capacity was determined in the field, permanent wilting point by using a pressure membrane apparatus and the bulk density using the core method to a depth of 60 cm according to Klute [26]. Physical and chemical analyses and soil water contents of the soil are shown in Table 2.

Treatments and Experimental Design: A split-plot design with three replicates under a drip irrigation system was used for the current study. The main plots were dedicated to three diverse irrigation levels (100, 80 and 60% of daily reference evapotranspiration 'Et_o'). Meanwhile, the sub-plot were randomly allocated to 6 treatments (no soil amendment or foliar application; foliar application of potassium silicate 'K-Si' at the rate of 0.5%; soil amendment with biochar 'Bo 4' at 4 ton/fed; Bo 4 plus K-Si; soil amendment with biochar 'Bo 6' at 6 ton/fed; Bo 6 plus K-Si). The 18 treatments were replicated three times, creation a total of 54 plots (each plot was 16 m^2 contained 5 ridges 70 cm apart, with 3 m wide bordered regions.

Crop Husbandry: Before sowing the experimental field was plowed and soil leveled. The fertilizers were applied according to the recommendation of the Ministry of agriculture and land reclamation, Egypt. Farmyard manure had been added at the rate of $5m^3$/fed then was thoroughly mixed with the surface layer before sowing. Nitrogen, phosphorus and potassium fertilizer (200, 200, 100 kg/fed) were added as ammonium sulfate (33% N); calcium superphosphate (15.5 P_2O_5), potassium sulfate (48% K_2O) respectively. The phosphorous was added to the soil during field preparation, while both nitrogen and potassium were added individually in two equal doses after one month from sowing and at full bloom. The experimental location was divided into three main plots and biochar was added at 0, 4 and 6 ton/fed once adding phosphorous fertilizer.

Borage seeds were obtained from Medicinal and Aromatic Plants Res. Dept., HRI, ARC, Egypt. Seeds were sown on 25th September in both seasons in hills at 35 cm apart and then thinned for one plant/hill after one month from sowing. Before sowing, seeds of borage were inoculated with bioinoculants (*Azotobacter chroccoccum*, *Microhiza* and *Bacillus circulans*) that were provided by the General Organization for Agriculture Equalization Fund (G.O.A.E.F.), Egyptian Ministry of Agriculture, at the rate of 2 kg/ fed. Irrigation was done immediately after sowing for uniform emergence and establishment of plants for four weeks before starting three irrigation regimes treatments. Irrigation level treatments were applied after thinning using a surface drip system. The K-Si were sprayed thrice at 45, 60, 75 days from sowing to run-off at the rate of 20 liters per plot in at early morning using a back sprayed after adding 0.01% tween 20 as a surfactant to ensure optimal penetration into the leaves.

Estimation of Irrigation Water Applied (IWA): The total irrigation water applied of the borage plants in the experimental region was calculated by computing the estimated reference evapotranspiration (Et_o) using the Penman-Monteith equation included in the "CROPWAT 8" model described in FAO 56 [27]. Then, Irrigation water applied was calculated according to Vermeiren and Jopling [28].

$$IWA = \frac{EToxI}{Ea}$$

where:

IWA = Irrigation water applied (mm and m^3/fed).
Et_o = Reference evapotranspiration (mm day^{-1}).
I = Irrigation intervals (days)
Ea = Irrigation application efficiency of the drip irrigation system (90%).

Water Productivity (WP): Water productivity refers to (seed yield kg / m^3 of water apply) was calculated according to Vites, [29] as follows:

$$WP = \frac{\text{Seed yield (kg/fed)}}{\text{Seasonal WA } (m^3/\text{fed})}$$

Data Recorded: After 85 days from sowing in both growing seasons, 9 plants/replicate, were randomly selected to determine plant height (cm), branches number/plant and fresh and dry weights (g/plant). Besides, total chlorophyll and total carotenoid were extracted from a fresh blade in the third upper leaf (terminal leaflet) and determined according to Saric *et al.* [30]. The shoots of 9 plants in each replicate (85 days after sowing) were dried at 7 °C for 72 hours and finally ground and then nitrogen, phosphorus and potassium were determined according to Cottenie *et al.* [31]. Proline content in dry leaves was determined according to Bates *et al.* [32].

At the harvesting time (End of March), the number of inflorescence/plant and seed yield per plant (g) were recorded. The fixed oil percentage was determined in the air-dried seeds of borage as the following; approximately 10 g of dry borage seeds was sampled for each replicate and prepared for the soxhlet extractor. The extraction time has been 6h for each sample and oils were recovered by distilling the solvent in a rotary evaporator at 40°C.

Fatty acids methyl esters Propagated from total lipid by using a rapid method according to the method of ISO 12966-2, [33]. Whereas, fatty acid methyl esters were formed by trans-esterification with methanolic potassium hydroxide as an intermediate stage before saponification takes place. Approximately 0.1g of the oil was placed in a 5ml screw-top test tube and isooctane (2ml) was added to the tube then the tube was shaken. Methanolic potassium hydroxide solution (0.1ml, 2N) was put on the cap fitted with a PTEE-joint, tighten the cap and shaken vigorously for 30 seconds tube was left to stratify until the upper solution became clear and the upper layer containing the ethyl was decanted. The isooctane solution is suitable for injection into the gas chromatograph.

Gas-Liquid Chromatographic (GLC) of Methyl Esters of Fatty Acids: Fatty acids methyl esters were injected into (HP6890 series GC) apparatus provided with a DB-23 column (60m x 0.32mm x 0.25 im). The carrier gas was N2 with a flow rate of 1.5ml/min, splitting ratio of 1:50. The injector temperature was 250°C and that of the flame ionization detector (FID) was 280°C. The temperature setting was as follows: 150°C to 210°C at 5°C /min and then held at 210°C for 25min. peaks were identified by comparing the retention times obtained with stander methyl esters.

Statistical Analysis: The collected data statistically analyzed by Statistical Analysis of variance using COSTAT (version 6.3.0.3.) Statistical software and the significant differences among treatment means were compared using the LSD test according to Gomez and Gomez [34].

RESULTS AND DISCUSSION

Seasonal Water Apply: Values of seasonal water apply of borage plants were recorded in Table 3. The overall averages of seasonal water apply in the 1st season and 2nd season were 2044 m^3/fed and 1998 m^3/ fed, respectively. It is evident that increasing Et_o % values caused a positive increase in seasonal water apply at both seasons since the borage plants received 2554, 2045 and 1533 m^3 water/ fed in the first season and 2495, 1999 and 1499 m^3water/ fed in the second season when irrigated at 100%, 80% and 60% of Et_o treatments, respectively. Regarding the monthly water applies, the data presented in Table 3 clearly showed that there was a positive correlation between the temperature and monthly water applies.

Table 3: Monthly water applies (m^3/fed) for Borage grown at (El Qassasein region, Ismailia Governorate, Egypt during 2017/2018 and 2018/2019 seasons

Season	2017/2018 season			2018/2019 season		
Months	100% Et_o	80% Et_o	60% Et_o	100% Et_o	80% Et_o	60% Et_o
October	613	491	370	601	479	361
November	395	315	235	378	302	227
December	344	277	206	302	244	181
January	361	290	218	361	290	218
February	344	277	206	319	256	193
March	496	395	298	533	428	319
Seasonal	2554	2045	1533	2495	1999	1499
Over all averages	2044			1998		

Et_o= reference evapotranspiration (mm/day)

Table 4: Water productivity (kg seeds /m^3/fed) of Borage as affected by irrigation regime, biochar and K- Silicate treatments during 2017/2018 and 2018/2019 seasons

Season	2017/2018				2018/2019			
Soil amendment	Irrigation treatment							
	100% Et_o	80% Et_o	60% Et_o	Average	100% Et_o	80% Et_o	60% Et_o	Average
Water (C)	0.11	0.16	0.12	0.13	0.12	0.17	0.12	0.14
Potassium silicate (KS)	0.12	0.17	0.13	0.14	0.13	0.19	0.13	0.15
Biochar 4t/acre (B4)	0.17	0.23	0.19	0.20	0.19	0.25	0.22	0.22
B4+ KS	0.19	0.24	0.20	0.21	0.21	0.27	0.24	0.24
Biochar 6t/acre (B6)	0.14	0.20	0.15	0.16	0.16	0.21	0.17	0.18
B6 + KS	0.16	0.21	0.17	0.18	0.18	0.23	0.19	0.20
Average	0.15	0.20	0.16	0.17	0.17	0.22	0.18	0.19

Et_o= reference evapotranspiration (mm/day)

Water Productivity (WP): Data in Table (4) indicated that water deficit considerably increased WP relative to well-watered plants (100% Et_o), in both seasons. The greatest WP being 0.20 and 0.22 kg seed/m^3 water were obtained under 80% Et_o in the first and second seasons, respectively compared with 100% Et_o.

Application of Bo or K-Si as well as their combinations markedly increased WP in either the first or second season relative to non-treated plants, where the maximum WP was recorded at the treatment of Bo amendment at the rate of 4 t/fed plus foliar application of K-Si (0.21 and 0.24 kg seed / m^3 water) with an increase percentage were 41 and 38% in the 1st and 2nd seasons respectively.

Regarding the interaction effects between irrigation regimes and either Bo or K-Si, the data in the same Table proved that application of Bo or K-Si under all watering regimes enhanced WP as compared with untreated plants under such watering regimes. The highest WP (0.24 and 0.27 kg seed/m^3 water) were recorded in the 1st and 2nd seasons when soil amended with 4 t/fed Bo plus shoot spraying with K-Si in the first and second seasons respectively.

Results, confirmed that acceptable water stress enhanced WP in both experimental seasons matching to well-watered plants, similar results have been proofed by Farouk and El-Metwally [2] and Sheshbahreh *et al.* [6]. Conversely, Bo and/or K-Si under well-watered or water deficit treatment improved WP. This raises possibly owing to its influences on photosynthetic pigment biosynthesis, photosynthesis processes, osmotic adjustment and antioxidant capacity, which causes an increase in leaf area, root growth root and distribution and so increasing the water and ion absorption, as proof in the current study (leading to increase seed yield with a reasonable amount of water under irrigating at 80% Et_o) and extra untimely researches [7, 35].

Vegetative Growth Characters: Data presented in Table (5) showed that the irrigation regimes and either Bo and/or K-Si and their interactions induces a significant effect on borage plant growth attributes, in terms, plant height, branches number/plant, as well as fresh and dry weight g/plant during both growing seasons. Severe drought (60% Et_o) significantly decline plant height, the number of branches/plant, shoot fresh weight and shoot dry weight by 32, 37, 38, 21% in the first season as well as by 31, 30, 41 and 22% in the 2nd season respectively as compared with 100% Et_o.

Table 5: Effect of irrigation regimes, mitigating substances and their interactions on vegetative growth trails of 85 days borage plants during 2017/2018 & 2018/2019 seasons, Means of three replications are presented with ±SE

	Plant Height (cm)		No. of Branches/plant		Shoot FW (g)		Shoot DW (g)	
Treatment	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Irrigation regimes								
100%Et_o (W1)	72.5 ±1.85	74.92±1.97	17.39±1.06	19.61±1.23	1037.01±29.7	1085.37±33.01	156.66±6.97	164.07±7.57
80% Et_o (W2)	82.6±1.56	85.22±1.73	19.73±1.15	22.39±1.33	1128.5±39.79	1194.35±46.5	192.16±9.43	200.24±10.11
60% Et_o (W3)	48.9±1.58	51.27±1.74	10.94±0.78	13.56±0.93	641.92±31.94	639.53±30.84	122.17±7.23	127±7.26
LSD 0.05	1.10	1.17	0.86	0.98	6.73	8.35	1.82	1.98
Mitigating substances								
Water (C)	57.0±5.06	58.7±5.1	10.55±1.21	12.22±1.17	717.26±75.00	746.06±75.31	107.01±8.11	110.98±8.19
Potassium silicate (KS)	62.8±5.01	64.83±5.07	12.44±1.20	14.00±1.23	785.63±81.89	822.34±80.87	124.56±10.15	130.10±9.75
Biochar 4t/Fed (B4)	73.4±4.88	76.56±4.93	19.88±1.58	23.11±1.60	1028.66±76.71	1106.13±95.25	182.3±11.02	190.56±11.30
B4+ KS	77.1±5.36	80.64±5.38	21.77±1.88	25.11±1.85	1119.64±91.07	1177.85±98.04	199.98±13.03	210.18±14.15
Biochar 6t/Fed (B6)	66.9±5.14	69.04±5.15	14.66±1.02	17.00±1.01	924.72±73.29	960.95±77.76	157.19±8.24	163.97±9.16
B6 + KS	70.7±4.63	73.03±4.65	17.00±1.35	19.66±1.37	984.93±78.22	1025.19±83.99	170.93±10.57	177.28±11.07
LSD 0.05	1.55	1.66	1.22	1.39	9.51	11.80	2.56	2.80
Irrigation regimes and mitigating substances								
W1 + C	59.0±0.66	60.96±0.96	11.66±0.33	13.00±0.57	848.83±7.16	878.13±7.07	110.98±0.84	115.04±1.06
W1 + KS	67.5±0.98	69.50±1.05	13.33±0.33	14.66±0.88	924.20±4.16	958.46±5.61	130.01±1.28	134.80±1.49
W1 + B4	78.5±0.42	81.80±0.58	21.33±0.88	25.00±0.57	1142.26±6.52	1201.03±7.95	180.23±1.99	189.51±1.67
W1 + B4 + KS	82.3±0.76	85.60±0.92	23.66±0.88	26.33±0.88	1205.60±6.67	1274.56±7.69	195.40±2.22	206.94±2.67
W1 + B6	72.6±0.78	74.56±0.75	15.66±0.88	17.66±0.88	1021.16±3.42	1068.40±2.60	158.73±2.58	165.57±1.50
W1 + B6 + KS	75.1±0.69	77.10±0.92	18.66±0.88	21.00±0.57	1080.00±8.07	1131.66±8.17	164.62±0.86	172.55±1.12
W2 + C	73.3±1.21	75.20±0.98	14.00±0.57	15.66±0.88	844.80±4.59	914.30±4.50	132.83±0.96	137.05±1.27
W2 + KS	77.3±0.98	79.50±1.21	16.00±0.57	17.66±0.88	973.26±4.42	1008.23±5.64	156.65±0.71	161.22±0.88
W2 + B4	87.2±1.01	90.36±1.21	24.33±0.88	27.33±0.88	1218.56±5.57	1377.86±5.22	221.34±2.38	230.10±2.62
W2 + B4 + KS	92.5±1.40	96.16±1.75	27.00±0.57	30.66±0.88	1383.06±6.96	1458.50±5.33	247.14±1.80	260.64±1.69
W2 + B6	81.0±0.92	83.40±1.21	17.33±0.88	19.66±1.20	1116.03±7.53	1159.56±8.92	184.76±1.86	194.75±1.68
W2 + B6 + KS	84.1±0.66	86.66±0.73	20.33±1.20	23.33±1.20	1195.30±7.74	1247.66±8.19	210.24±2.03	217.65±3.08
W3 + C	38.6±1.24	39.93±1.16	6.00±0.57	8.00±0.57	418.16±4.28	455.76±5.22	77.22±1.02	80.84±1.27
W3 + KS	43.7±1.33	45.50±0.87	8.00±0.57	9.66±0.66	459.43±5.29	500.33±5.47	87.02±1.00	94.27±1.63
W3 + B4	54.6±0.48	57.53±0.49	14.00±0.57	17.00±0.57	725.16±3.10	739.50±12.61	145.31±0.90	152.07±0.76
W3 + B4 + KS	56.6±0.95	60.16±1.04	14.66±0.88	18.33±0.88	770.26±3.32	800.50±3.28	157.42±1.17	162.97±0.97
W3 + B6	46.9±0.76	49.16±0.72	11.00±0.57	13.66±0.88	636.96±6.55	654.9±12.25	128.09±1.28	131.58±1.94
W3 + B6 + KS	53.0±0.92	55.33±0.63	12.00±0.57	14.66±0.88	679.50±3.82	696.23±2.34	137.93±0.86	141.63±0.83
LSD 0.05	2.70	2.87	2.11	2.41	16.48	20.45	4.44	4.86

Et_o= reference evapotranspiration (mm/day)

Soil amended with Bo and K-Si significantly increased all vegetative growth parameters of borage. The greatest plant height (77.1 and 80.64 cm), number of branches/plant (21.77 and 25.11), shoot fresh weight (1119.64 and 1177.8 g) and shoot dry weight (199.98 and 210.18 g) respectively in the first and second seasons were obtained under the interaction effect of 4 t/fed Bo plus K-Si foliar application and followed by soil amended with 4 t/fed Bo only, that was recorded a value near to those of 4 t/fed Bo plus K-Si.

As for the interaction effects, the data in the same Table proved that application of Bo rates with or without K-Si under 80% Et_o irrigation regime significantly increased borage plant growth in relation to untreated-well watered plants (100% Et_o), the most effective in this regard was 4 t/fed Bo plus K-Si foliar application. On the contrary, under severe drought (60% Et_o) Bo soil amended and/or K-Si calmed the negative effect of water deficit relative to untreated-well watered plants. Compared with the untreated severe drought-affected plant, application of Bo (4 t/fed) plus K-Si give the maximum plant height (56.6 and 60.16 cm), the number of branches/plant (14.66 and 18.33), shoot fresh weight (770.26 and 800.50 g) and shoot dry weight (157.42 and 162.97 g) in the experimental seasons.

Drought stress seriously restricts crop establishment and represses its productivity as the statement previously [6, 36]. It is well known that water stress accelerated a huge number of biochemical and molecular processes that influenced plant growth [37, 38]. The decreasing effect of water deficit on plant growth may result from a decline in cell turgor and enlargement and/or the blocking up of conductive tissue (xylem and phloem) that will hamper water and nutrient translocation [39.40]. Furthermore, water deficit may be reduced the uptake of the essential nutrients [41] as well as evoked oxidative burst [1, 38]. Likewise, water deficit generally disrupts the biosynthesis of the phytohormone leading to increasing the ABA concentration associated with reducing the IAA, GA_3 and zeatin [42]. Finally, drought stress may be repression photosynthetic efficiency by inhibiting ribulose bisphosphate carboxylase oxidase and mutilation of ATP assimilation that was needed for plant growth [43].

Some previous reports recorded the beneficial effect of Bo on plant establishment [44, 45]. The encouragement of biochar on plant growth may be resulted from its role in improving soil water holding capacity and soil physio-chemical and biological attributes [11, 12]. Moreover, Bo contains multiple volatile compounds that have easy and simple biodegradable which can support the plant establishment [46, 47].

Application of K-Si compensated to various degrees for the disappointing effect of water deficit on plant growth [7, 48]. Several promising mechanisms tied with stress alleviation by Si in different crops have been recognized. Si acts as a mechanical or physiological obstacle in plants and not only acts as cell wall strengthening but is also actively involved in some biochemical pathways [49, 50]. Si may be decreased the transpiration, preserving a superior net photosynthetic rate, intensifying the antioxidant defense system in the plant cell [7, 51]. Besides, Si supplementation improved the plant water status, which imitates improved water use efficiency and ion percentage as indicated in the present study and earlier research on different plant species [2, 6, 35]. Moreover, Si application may be increased leaf primordial differentiation and reduced the plastochron period that directs to improved plant biomass accumulation [48].

Photosynthetic Pigment and Proline Concentration: Significant differences were established amongst watering regimes treatments as well as either Bo rates or K-Si for total chlorophyll, total carotenoids and proline concentrations (Table 6). Total chlorophyll and carotenoid concentrations were significantly increased at 80% Eto above 100% Eto. On the other hand, 60% Eto significantly decreased total chlorophyll by 25 and 24% as well as total carotenoid by 21 and 26% respectively relative to 100% Eto in the 1st and 2nd seasons. Alternatively, water deficit significantly increased the concentration of proline and the highest concentration was recorded at 60% Eto in both seasons.

Soil amendment with two rates of Bo and/or foliar application of K-Si significantly increased either total chlorophyll or carotenoid concentration as compared with untreated plants. The most effective in this concern was the treatment of 4 t/fed Bo plus the foliar application of K-Si that is increased total chlorophyll and carotenoids by 108 and 113% in the first season and by 136 and 108% in the second season respectively. Concerning proline concentration, the data in the same Table showed that application of K-Si lonely or combined with Bo rates significantly increased proline concentration relative to untreated plants, meanwhile application of Bo only at both levels significantly decreased proline concentration.

egarding the interaction effect, soil amended by 4 or 6 t/fed Bo with or without K-Si under 80% Et_o significantly increased total chlorophyll, carotenoids and proline concentrations as compared with untreated well-watered plants (100% Et_o). Meanwhile, foliar spraying with K-Si with or without Bo significantly increased total chlorophyll and proline concentrations; yet, all interactions under 60% Et_o significantly increased total carotenoid except foliar spraying with K-Si that decreased it.

The decreasing effect in chlorophyll concentration with water stress is a regularly well-known occurrence in numerous plants [1, 37, 52]. This decline may result from a decrease in biosynthesis of the chief chlorophyll pigment complexes encoded by the cab gene family or to the destruction of chiral macro-aggregates of the light-harvesting chlorophyll ‘a’ or ‘b’ pigment-protein complexes that protect the chloroplasts and/or to the creation of proteolytic enzymes, in special, chlorophyllase [53, 54]. The reduction in chlorophyll as observed in the existing research has been ascribed to the loss of chloroplast membranes, extreme swelling, the warp of the lamellae vesiculation and the hyperaccumulation of plastoglobules [55]. Caser *et al.* [56] established that carotenoid plays a vital purpose in protecting varied processes from ROS injuries. At this time, the existence of a steady amount of carotenoids throughout the experiment proposes a hopeful function to cope with oxidative injuries.

There are some reports that proved the positive effect of biochar on increasing the concentration of photosynthetic pigments [57, 9]. The considerable boost in photosynthetic pigment concentration by Si application

Table 6: Effect of irrigation regimes, mitigating substances and their interactions on Total Chlorophyll concentration (mg/g FW), Total Carotenoids (mg/g FW) and Proline content (mg/100 g) of 85 days borage plants during 2017/2018 & 2018/2019 seasons, Means of three replications are presented with ±SE

	Total Chlorophyll		Total Carotenoids		Proline	
Treatment	1st year	2nd year	1st year	2nd year	1st year	2nd year
Irrigation regimes						
100% Et_o (W1)	0.986 ±0.062	1.043±0.058	0.76± 0.03	0.75±0.03	54.11±3.250	56.74±3.348
80% Et_o (W2)	1.321±0.085	1.461±0.100	0.91± 0.04	0.91±0.05	69.18± 2.938	72.26± 3.026
60% Et_o (W3)	0.737±0.038	0.784±0.039	0.60± 0.05	0.55±0.05	78.10±3.122	80.43± 3.053
LSD 0.05	0.037	0.052	0.03	0.05	0.468	0.730
Mitigating substances						
Water (C)	0.659±0.062	0.709±0.061	0.44±0.04	0.45±0.04	64.78±3.306	67.29±3.262
Potassium silicate (KS)	0.759±0.045	0.880±0.077	0.64±0.08	0.59±0.08	73.09±3.383	75.59±3.236
Biochar 4t/Fed (B4)	1.205±0.113	1.294±0.119	0.86±0.04	0.87±0.06	56.07±3.220	58.76±3.316
B4+ KS	1.377±0.113	1.513±0.179	0.95±0.04	0.94±0.04	85.18±4.098	87.97±3.922
Biochar 6t/Fed (B6)	0.985±0.076	1.047±0.078	0.80±0.05	0.76±0.06	47.49±4.373	49.92±4.503
B6 + KS	1.099±0.090	1.131±0.093	0.84±0.04	0.83±0.05	76.17±2.887	79.34±2.931
LSD 0.05	0.053	0.074	0.04	0.07	0.662	1.033
Irrigation regimes and mitigating substances						
W1 + C	0.628±0.045	0.661±0.14	0.51±0.02	0.52±0.01	52.32±0.56	54.90±0.57
W1 + KS	0.701± 0.029	0.792±0.005	0.71±0.01	0.70±0.01	60.33±0.89	63.14±0.60
W1 + B4	1.185±0.029	1.197±0.006	0.85±0.02	0.83±0.02	45.84±0.34	48.22±0.35
W1 + B4 + KS	1.333±0.021	1.358±0.028	0.88±0.03	0.89±0.03	70.41±0.73	73.53±0.75
W1 + B6	0.974±0.036	1.100±0.023	0.80±0.04	0.77±0.01	30.27±0.37	32.18±0.38
W1 + B6 + KS	1.095± 0.012	1.150±0.018	0.83±0.03	0.82±0.02	65.49±0.66	68.46±0.67
W2 + C	0.885± 0.020	0.941±0.010	0.53±0.01	0.55±0.03	67.23±0.34	70.26±0.35
W2 + KS	0.921± 0.005	1.177±0.034	0.87±0.02	0.76±0.08	75.61±0.16	78.87±0.16
W2 + B4	1.604± 0.040	1.749±0.005	1.00±0.02	1.06±0.08	54.42±0.02	57.06±0.02
W2 + B4 + KS	1.851± 0.066	2.176±0.161	1.09±0.03	1.11±0.04	86.47±0.36	90.06±0.37
W2 + B6	1.250± 0.007	1.288±0.015	0.96±0.01	0.97±0.06	53.57±0.21	56.18±0.22
W2 + B6 + KS	1.412± 0.017	1.435±0.066	0.99±0.03	1.20±0.05	77.80±0.25	81.14±0.26
W3 + C	0.465± 0.011	0.527±0.006	0.29±0.03	0.29±0.01	74.80±0.16	76.71±1.30
W3 + KS	0.656± 0.057	0.670±0.040	0.35±0.03	0.30±0.03	83.33±0.25	84.74±0.75
W3 + B4	0.827± 0.010	0.937±0.014	0.74±0.01	0.71±0.06	67.96±0.13	71.00±0.13
W3 + B4 + KS	0.947±0.014	1.006±0.014	0.87±0.02	0.84±0.03	98.67±0.08	100.30±1.23
W3 + B6	0.731± 0.035	0.753±0.009	0.64±0.01	0.53±0.02	58.65±0.51	61.42±0.53
W3 + B6 + KS	0.792± 0.031	0.807±0.008	0.70±0.02	0.66±0.01	85.22±0.50	88.43±0.76
LSD 0.05	0.091	0.091	0.07	0.11	1.147	1.789

Et_o= reference evapotranspiration (mm/day)

is in harmony with those of Ghasemi Pirbalouti *et al.* [58]; Safoora *et al.* [35] and Farouk and Al-Sanoussi [59]. These increases may be accredited to well-organized ROS scavenging systems that will have otherwise injured the chlorophyll by antioxidant enzymes and solutes [7]. The carotenoids present roles as a light receptor and photo-system shielded against ROS, which it can build up carotenoid. Consequently, Si application hastens the buildup of carotenoids in photosynthetic tissues [60].

Along with environmental stresses, most plants accumulate a variety of osmolytes like proline (Pro) and total sugars to stabilizing membranes and/or macromolecular structures [37, 52] and work as a signal to adjust mitochondrial functions, manipulate cell proliferation and elicit specific gene expression required for plant recovery from stress [61]. Proline may also function as a potent scavenger of ROS and defend the cellular components against oxidative injury [37]. A familiar characteristic of organic osmolytes is that they can build up to high levels without interfering with regular physio-biochemical processes; definitely, they are hydrophilic and can substitute water at the surface of proteins or membranes without distressing protein structure. The accumulation of proline due to silicon forms application observed in the current study indicates the defensive function of silicon against drought. Although results about the effect of silicon forms on osmolytes accumulation under drought are scant, additional researchers had documented a similar result [9, 48, 50]. Under stress conditions, the accumulation of

Table 7: Effect of irrigation regimes, mitigating substances and their interactions on NPK percentage of 85 days borage shoot during 2017/2018 & 2018/2019 seasons, Means of three replications are presented with ±SE

Treatment	Nitrogen %		Phosphorus %		Potassium %	
	1st year	2nd year	1st year	2nd year	1st year	2nd year
Irrigation regimes						
100% Et_o (W1)	2.821±0.087	2.906±0.111	0.543±0.023	0.652±0.028	2.275±0.053	2.375±0.064
80% Et_o (W2)	3.136±0.131	3.255±0.126	0.691±0.044	0.829±0.052	2.574±0.093	2.670±0.078
60% Et_o (W3)	2.435±0.083	2.534±0.068	0.417±0.020	0.501±0.024	2.076±0.054	2.112±0.053
LSD 0.05	0.125	0.144	0.033	0.039	0.128	0.055
Mitigating substances						
Water ©	2.284±0.092	2.393±0.101	0.375±0.024	0.450±0.029	1.974±0.087	2.012±0.092
Potassium silicate (KS)	2.501± 0.093	2.562± 0.082	0.471± 0.034	0.565±0.041	2.127±0.060	2.220±0.061
Biochar 4t/Fed (B4)	3.093± 0.119	3.178± 0.162	0.649± 0.056	0.779±0.068	2.466±0.084	2.566±0.092
B4+ KS	3.431± 0.195	3.533± 0.171	0.720± 0.066	0.864±0.079	2.696±0.165	2.813±0.132
Biochar 6t/Fed (B6)	2.615± 0.095	2.767± 0.094	0.517± 0.032	0.621±0.038	2.261±0.054	2.305±0.087
B6 + KS	2.858± 0.089	2.956± 0.122	0.570± 0.041	0.684±0.049	2.326±0.063	2.398±0.068
LSD 0.05	0.177	0.203	0.046	0.055	0.181	0.079
Irrigation regimes and mitigating substances						
W1 + C	2.370±0.055	2.380±0.098	0.388±0.031	0.465±0.124	1.984±0.170	2.01±0.052
W1 + KS	2.520± 0.047	2.527±0.129	0.507±0.0401	0.608±0.165	2.118±0.170	2.213±0.049
W1 + B4	3.120±0.132	3.200±0.282	0.622±0. 008	0.746±0.040	2.364±0.083	2.569±0.050
W1 + B4 + KS	3.343±0.031	3.543±0.240	0.666±0. 020	0.800±0.081	2.657±0.093	2.823±0.017
W1 + B6	2.700± 0.150	2.870±0.202	0.517±0. 020	0.621±0.085	2.240±0.260	2.287±0.012
W1 + B6 + KS	2.873± 0.080	2.920±0.178	0.559±0. 032	0.671±0.139	2.288±0.052	2.368±0.054
W2 + C	2.537± 0.031	2.700±0.150	0.446±0. 006	0.535±0.028	2.256±0.250	2.318±0.033
W2 + KS	2.787± 0.124	2.820±0.075	0.549±0. 046	0.659±0.187	2.320±0.071	2.423±0.029
W2 + B4	3.450± 0.005	4.120±0.045	0.853±0. 031	1.024±0.126	2.787±0.248	2.877±0.032
W2 + B4 + KS	4.083± 0.234	6.627±0.141	0.965±0. 008	1.158±0.033	3.113±1.407	3.260±0.070
W2 + B6	2.833±0.115	2.923±0.124	0.620±0. 040	0.744±0.162	2.440±0.072	2.510±0.011
W2 + B6 + KS	3.127± .0112	3.340±0.034	0.710±0. 035	0.852±0.145	2.530±0.330	2.637±0.029
W3 + C	1.947±0.083	2.100±0.026	0.292±0. 020	0.350±0.082	1.683±0.110	1.716±0.092
W3 + KS	2.197± 0.026	2.340±0.037	0.356±0. 018	0.427±0.071	1.943±0.265	2.031±0.057
W3 + B4	2.710± 0.131	2.710±0.086	0.472±0. 027	0.567±0.011	2.246±0.04	2.261±0.049
W3 + B4 + KS	2.867± 0.166	2.936±0.018	0.529±0. 043	0.635±0.184	2.318±0.253	2.356±0.046
W3 + B6	2.313± 0.040	2.510±0.032	0.415±0. 012	0.498±0.051	2.104±0.108	2.122±0.023
W3 + B6 + KS	2.577± 0.038	2.610±0.115	0.441±0.008	0.529±0.037	2.159±0.239	2.195±0.049
LSD 0.05	0.307	0.353	0.081	0.095	0.313	0.135

Et_o= reference evapotranspiration (mm/day)

Pro has been attributed to an improved activity of biosynthesizing enzymes, accompanied by a decline in Pro catabolism. The exogenous supplementation of Si has been recognized to persuade the P5CS1gene encoding δ1-pyrroline-5-carboxylate syntheses, a key enzyme implicated in the Pro biosynthesis [62].

Ion: It is evident from data in Table (7) that the percentages of N, P and K significantly affected by irrigation levels, Bo and K-Si treatments. Normally, N, P and K percentages increased with increasing water supply to reach the maximum (N% 3.136 and 3.255, P% 0.691 and 0.829 and K% 2.574 and 2.670 in both seasons, respectively) in shoots of plants irrigated with the second regime level (80% Et_o). While, the least values of N, P and K percentages were of plants irrigated with the third regime level (60% Et_o).

As well as, the similar trend gained by the applying of Bo and K-Si foliar application treatments, which significantly raised values of the of N, P and K percentages to reach their maximum values with the treatment of Bo 4 t/fed plus K-Si spraying.

In the same Table, we could notice that there was a significant effect by combination with the different irrigation regimes levels, Bo and K-Si treatments on the different chemical compositions in both seasons. The highest percentages of N% (4.083 and 6.627), P% (0.965 and1.158) and K% (3.113 and 3.260) were of combination with 80% Et_o + Bo (4ton/fed) + K-Si in the two seasons, respectively.

The reduction in ions % under water stress has been formally recognized in a lot of crops [1, 38]. The reduction in N% can be attributed to a reduction in nitrate reductase activity which is linked to the photosynthesis activity and the convenience of carbon skeletons [63]. The decrease in K% under drought may be clarified by the information that the water scarcity manipulates stomatal regulation, leading to reduced photosynthetic capability and also the uptake of K ions to preserve and regulate turgidity and stomatal control as recorded by Sarani *et al.* [64].

Biochar also could increase the availability of nutrients and plant nutrient uptake. There for, application of alternate root-zone drying irrigation. The mechanism caused by alternate root-zone drying irrigation and biochar not only increased ABA production and also maintained water supply and ionic balance, thus securing higher intrinsic water use e?ciency. Biochar can affect hydraulic properties and nutrient retention in arable soils [9, 57]. Rashtia *et al.* [45] suggested a positive effect of root exudates and biochar interactions on facilitating N turnover and uptake by plant roots in biochar amended treatments, due to higher total N concentrations in their rhizosphere layer than root-free zones. Increasing the application rate of biochar, which increases the water holding capacity inside the root zone leading to enhanced and mitigate water stress on plants.

The function of silicon in increasing N, P and K% are not completely unstated and several corresponding researchers recognized the present investigation. For example, Alzahrani *et al.* [48]; Zargar *et al.* [65]; Farouk and Omar [7] postulated that silicon supplementation increased the content of ions in the plant tissue. The constructive effect might be attributed to the enhancement of ion uptake throughout, maintaining membrane permeability and/or almost certainly giving a better-developed root system. Consequently, Pei *et al.* [66] confirmed that Si application, to the plants, enhanced cellular membrane fluidity, ion selectivity and hasten ion uptake.

Yield Characters: Date presented in Table (8) showed that the highest number of inflorescence/plant, seed yield/plant (g), fixed oil % and oil yield/plant (ml) were obtained with 80% Et_o, on the other hand, irrigation at 60% Et_o gave the lowest values of studied characteristics in the 1st and 2nd season relative to 100% Et_o.

Foliar application of K-Si alone or in combinations with both Bo rates significantly increased yield trials than the untreated plants. The most effective treatment in this regard was 4 t/fed Bo plus K-Si that increased the number of inflorescence, seed yield/plant, oil% and oil yield by 77, 66, 28 and 111% in the first season and by 86, 71, 30 and 115% in the second seasons, respectively relative to untreated control plants (Table 8).

Under 80% Et_o, application of Bo and/or K-Si significantly increased yield attributes relative to untreated control plants. On the other hand, under 60% Et_o, the application of Bo or K-Si alleviated the harmful effect of water deficit. While, application of 4 t/fed Bo plus K-Si increased the number of inflorescence by 90 and 105%, seed yield per plant by 72 and 92%, oil % by 38 and 40% and oil yield/plant by 139 and 171% in the 1st and 2nd seasons, respectively relative to untreated drought-affected plants (60% Et_o only). Water deficit is a widespread ecological stress attribute that constantly decreases the crop yield of several plants [2, 36]. This decline effect could be resulted from falling plant growth as indicated before, resulting in less biomass production and hamper translocation of photo assimilate towards the developing fruits and/or accelerating flower and fruit abortion [67, 68]. Moreover, water deficit affected plant production by inducing pollen grain swollen and filament development diminished that was resulted in decreasing in yield [69].

Biochar as a soil amendment could be a wise approach for enhancing water use efficiency and crop productivity in arid and semi-arid areas [41, 70, 71]. Moreover, the interactive effect of biochar and alternate root-zone drying irrigation defiantly adjusted the balance between chemical signal (leaf ABA) and hydraulic signal (leaf water potential). Thus, intrinsic water use efficiency and yield in alternate root-zone drying irrigation were significantly enhanced compared to deficit irrigation [9]. The biochar application increased yield under drought stress. Also increased photosynthesis, nutrient uptake and modified gas exchange characteristics in drought-stressed plants in sandy soil.

The yield improvement by K-Si matched the maintenance of superior net photosynthetic rate and recovers the source-sink relationships. Additionally, Si may be deposition under the leaf epidermis which may result in a physical barrier that may reflect most of the solar radiation fallen on the leaves and that cause better cooling for leaf tissues which consequently leads to enhancement of photosynthetic rate, water status, carbohydrate metabolism and element uptake under water deficit [72]. Such improvement was found to mitigate the detrimental effect of water deficit on the partitioning of assimilates during the period of flower bud initiation. Thus, the mitigation improved flower formation and development [73].

Table 8: Effect of irrigation regimes, mitigating substances and their interactions on flowering and yield trails at harvesting and after harvesting of borage during 2017/2018 & 2018/2019 seasons, Means of three replications are presented with ±SE

	No of inflorescence		Seed yield /plant		Oil %		Oil yield ml/plant	
Treatment	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Irrigation regimes								
100% Et_o (W1)	135.5±5.76	145.05±6.68	10.04±0.47	10.99±0.49	29.56±0.57	30.20±0.61	3.01±0.19	3.37±0.22
80% Et_o (W2)	148.39±7.14	157.89±8.03	10.93±0.40	11.78±0.42	30.73±0.53	31.38±0.58	3.39±0.18	3.74±0.20
60% Et_o (W3)	80.44±4.00	89.72±4.99	6.49±0.30	7.03±0.40	20.89±0.56	21.51±0.61	1.37±0.09	1.55±0.13
LSD 0.05	2.49	2.47	0.06	0.076	0.09	0.09	0.02	0.03
Mitigating substances								
Water (C)	86.22±7.97	90.55±8.05	6.85±0.55	7.39±0.64	23.68±1.57	24.056±1.58	1.68±0.22	1.86±0.26
Potassium silicate (KS)	100.56±8.75	106.00±8.87	7.51±0.62	8.10±0.73	25.11±1.56	25.55±1.57	1.96±0.26	2.16±0.29
Biochar 4t/Fed (B4)	141.89±12.53	155.11±12.60	10.65±0.74	11.54±0.75	29.26±1.54	30.10±1.55	3.19±0.37	3.56±0.38
B4+ KS	153.33±12.86	168.44±12.80	11.40±0.81	12.52±0.77	30.32±1.55	31.27±1.55	3.55±0.40	4.01±0.41
Biochar 6t/Fed (B6)	117.78±10.00	125.78±10.15	8.83±0.67	9.59±0.75	26.37±1.56	26.92±1.56	2.41±0.29	2.67±0.33
B6 + KS	128.89±10.79	139.44±10.65	9.67±0.70	10.43±0.78	27.63±1.50	28.27±1.51	2.75±0.31	3.05±0.36
LSD 0.05	3.53	3.49	0.080	0.11	0.13	0.13	0.03	0.04
Irrigation regimes and mitigating substances								
W1 + C	99.33±2.03	104.00±1.73	7.34±0.05	8.07±0.05	26.03±0.04	26.41±0.03	1.91±0.02	2.11±0.01
W1 + KS	114.67±2.03	120.00±2.08	8.03±0.04	8.82±0.06	27.69±0.13	28.13±0.01	2.22±0.02	2.47±0.03
W1 + B4	157.33±2.03	170.66±2.60	11.73±0.03	12.78±.04	31.85±0.03	32.69±0.03	3.73±0.01	4.17±0.01
W1 + B4 + KS	167.67±2.60	182.66±2.60	12.80±0.07	13.78±0.06	32.91±0.02	33.86±0.01	4.21±0.02	4.67±0.02
W1 + B6	131.00±2.31	139.33±2.02	9.62±0.03	10.82±0.04	28.84±0.04	29.40±0.04	2.77±0.01	3.19±0.05
W1 + B6 + KS	143.00±1.73	153.66±1.76	10.70±0.03	11.7±0.04	30.05±0.05	30.70±0.02	3.21±0.01	3.61±0.02
W2 + C	104.67±1.45	109.00±1.73	8.47±0.078	9.22±0.05	27.55±0.05	27.95±0.05	2.32±0.03	2.60±0.40
W2 + KS	121.00±2.64	127.00±2.64	9.35±0.05	10.18±0.09	28.77±0.02	29.22±0.03	2.68±0.01	2.97±0.01
W2 + B4	175.33±2.33	188.66±2.72	12.50±0.03	13.27±0.12	32.84±0.06	33.07±0.06	4.10±0.01	4.47±0.05
W2 + B4 + KS	188.67±4.10	203.66±3.75	13.23±0.05	14.34±0.08	33.93±0.03	34.88±0.04	4.48±0.02	5.00±0.04
W2 + B6	143.67±2.40	152.00±2.08	10.66±0.06	11.32±0.08	30.11±0.04	30.67±0.04	3.20±0.02	3.46±0.02
W2 + B6 + KS	157.00±2.64	167.00±2.08	11.37±0.05	12.31±0.07	31.18±0.040	31.83±0.02	3.54±0.01	3.91±0.02
W3 + C	54.67±1.45	58.66±1.45	4.73±0.05	4.90±0.03	17.45±0.24	17.80±0.24	0.82±0.02	0.87±0.01
W3 + KS	66.00±1.53	71.00±1.73	5.15±0.04	5.28±0.07	18.87±0.05	19.30±0.07	0.96±0.01	1.01±0.01
W3 + B4	93.00±1.15	106.00±1.73	7.70±0.06	8.57±0.05	23.09±0.06	23.92±0.05	1.74±0.03	2.04±0.02
W3 + B4 + KS	103.67±1.20	119.00±1.15	8.16±0.03	9.44±0.05	24.14±0.05	25.06±0.06	1.96±0.01	2.36±0.02
W3 + B6	78.67±1.45	86.00±1.15	6.24±0.03	6.61±0.03	20.15±0.05	20.69±0.05	1.25±0.01	1.36±0.01
W3 + B6 + KS	86.67±0.88	97.66±0.88	6.94±0.01	7.34±0.058	21.64±0.04	22.26±0.05	1.50±0.01	1.63±0.01
LSD 0.05	6.11	6.04	0.14	0.19	0.22	0.23	0.05	0.07

Et_o= reference evapotranspiration (mm/day)

Fixed Oil Constituents (Fatty Acids): Data presented in Table 9 and Figure 1 showed that, fatty acids composition of borage seeds oil of second season samples for control and the most effective treatment (biochar at 4t./fed. and potassium silicate foliar application) under the different irrigation regimes levels (60%, 80% and100% Et_o). Fifteen fatty acids were identified by Gas-Liquid chromatographic (GLC). Some of these fatty acids were saturated (ranged from16.66 to 18.14% of total fatty acids) as myristic, palmitic, margaric, stearic, arachidic and behenic and the most predominant saturated fatty acid was palmitic acid (C16:0), its highest percentage (13.55%) was of plants under the second irrigation regime W2 (80% of Et_o) compared to the third irrigation regime level W3 (60% of Et_o) which recorded (12.15%).

On the other hand, There were nine unsaturated fatty acids were identified including palmitoleic, margar-oleic, oleic, linoleic, gamma-linolenic (Omega-6), α-linolenic (Omega-3), cis-11-eicosenoic, erucic and nervonic acid. Total unsaturated fatty acids ranged from 81.84 to 83.19% of total fatty acids composition. The unsaturated linoleic acid (all cis-9, 12- octadecadienoic) represented the majority of total fatty acids composition followed by gamma-linolenic (all cis-6, 9, 12-octadecatrienoic acid) or oleic (cis-9 octadecenoic), From the same table, it was observed that fatty acids composition was affected by the irrigation regime. Where, there was an increase of Linoleic acid in the samples of the third irrigation regime W3 (60 % Et_o), while this acid recorded minimum values in the samples of the first irrigation regime W1 (100% Et_o).

Table 9: GLC fractionation of borage fixed oil from 2018/2019 samples for control and the most effective treatment of mitigating substances under the different irrigation regimes

	Treatments					
Fatty acids	W1 (100%Et$_o$)	W1+B4t. + KS	W2 (80%Et$_o$)	W2+B4t. + KS	W3 (60%Et$_o$)	W3+B4t. + KS
Myristic acid (C14:0)	0.09	0.09	0.10	0.08	0.08	ND
Palmitic acid (C16:0)	13.35	13.21	13.55	13.49	12.15	12.61
Palmitoleic acid*(C16:1)	0.22	0.20	0.25	0.20	0.21	0.23
Margaric acid (C17:0)	0.07	0.05	0.06	0.05	0.06	0.05
Margaroleic acid * (C17:1)	0.02	0.02	0.02	0.02	0.02	0.02
Stearic acid (C18:0)	3.68	4.09	3.97	3.75	4.03	4.01
Oleic acid * (C18:1)	19.66	18.79	18.30	15.93	18.33	18.48
Linoleic acid* (C18:2)	35.89	36.18	35.93	37.26	36.05	36.06
ã-linolenic acid*(Omega-6, C18:3n6)	18.64	18.98	19.55	21.13	20.34	19.72
á-linolenic acid* (Omega-3 C18:3n3)	0.15	0.15	0.16	0.12	0.14	0.18
Arachidic acid C20:0	0.23	0.26	0.27	0.23	0.26	0.28
cis-11-Eicosenoic acid* (C20:1)	4.02	3.85	3.77	3.77	3.80	3.88
Behenic acid (C22:0)	0.15	0.18	0.19	0.15	0.19	0.19
Erucic acid* (C22:1)	2.46	2.55	2.42	2.47	2.71	2.72
Nervonic acid* (C24:1)	1.34	1.39	1.44	1.30	1.59	1.53
Total Saturated (%)	17.57	17.88	18.14	17.75	16.77	17.14
Total Unsaturated (%)	82.4	82.11	81.84	82.2	83.19	82.82

*= Unsaturated fatty acids

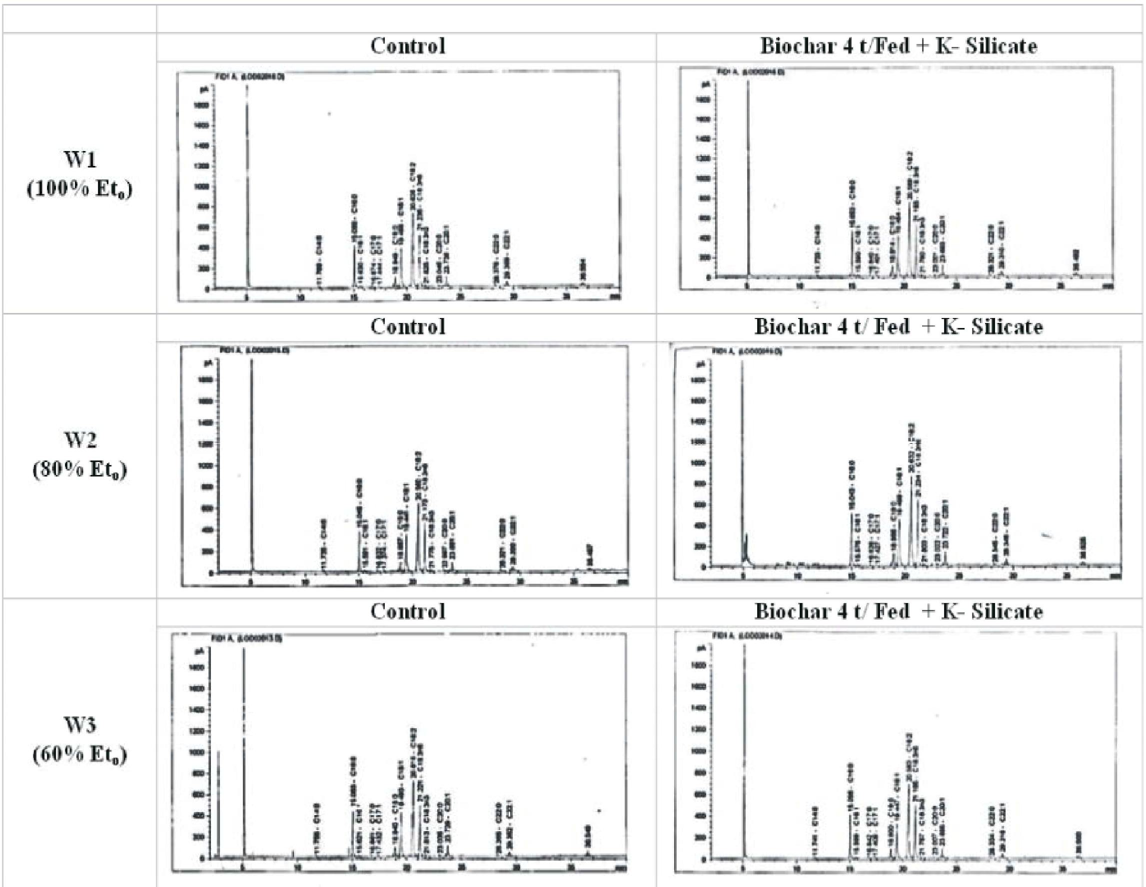

Fig. 1: Influence of irrigation regimes and mitigating substances on Borage fixed oil for control and the most effective treatment samples of the second season of 2018/2019

The same Table 9 clarified that there was a reverse relation between Linoleic (C18:2) and oleic acid (C18:1), where the best increase of Linoleic content was of the treatment of 80% Et_o +biochar (4 t/ fed) + potassium silicate which recorded 37.26%, while oleic acid recorded an increase under W1 (100% Et_o) irrigation. It was noticed that, with the increase of Linoleic acid, the oleic acid decreased.

Another inverse relation was noticed between α-Linolenic acid (C18:3) and Linoleic acid (C18:2). Highly record of α-Linolenic acid (the precursor of prostaglandin E1) which is useful to human health was of plants treated with the treatment of W3(60% Et_o) + biochar (4 t/ fed) + potassium silicate. This may be related to the positive effect of potassium silicate and biochar to alleviate the adverse effect of drought.

Concerning Omega-6 values, it recorded the highest values (21.13%) in samples of W2 (80% Et_o)+biochar (4 t/fed + potassium silicate in comparison to W1(100% Et_o) treatment which recorded a low value (18.64%). These results are consistent with the fact that many useful properties of borage seed oil are attributed to its high δ-linolenic acid content (GLA, C18:3n6), which constitutes 15–22% of the fixed oil [74]. GLA is an essential Omega-6 polyunsaturated fatty acid and must be provided in the food because it cannot always be easily manufactured within the human body. In humans, gamma-linolenic (Omega-6) supplementation is effective in the prevention and/or treatment of various degenerative pathologies such as osteoporosis, diabetes, cancer and is very important in human nutrition [75-77].

Drought stress-related concentration increase is a common feature for all different classes of natural products [78]. On the other hand, Potassium and silicon play a vital role in maintaining plant water potential, photosynthetic activity, the synthesis, transformation and storage of carbohydrates in plants which are precursors of secondary plant products [14, 79].

Our results are in the same line with those obtained by Del Río *et. al.* [74] on Borage; Özcan [80] on Boraginaceae and Khattab *et. al.* [81] on Borage.

CONCLUSION

The current study suggests that biochar and/or potassium silicate advance drought tolerance and may be considered a potential regulator of agricultural production under a scarcity of water. This makes an enormous donation not single to saving water in arid and semiarid lands, in the situation of climate alteration adaptation strategies, but also to regional and national economic development.

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