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Response of Salt-affected Sage (*Salvia officinalis* L.) to Biochar Amendment

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Abstract: Due to the limited availability of fresh water, it is imperative to find methods for balancing the population's resource management and utilize salt water instead of fresh water while irrigating plants. Sage plant is one of the most important medicinal plants suitable for expanding their cultivation in Salt-affected new reclaimed lands. Consequently, a field trial during two consecutive seasons of 2019 and 2020 was implemented under a split-plot design، aiming to assess the role of biochar addition (0, 2, 4 ton fed^{-1}) in mitigating the drastic effect of saline water [450 (as control), 1000, 2000, 3000, and 4000 mgL^{-1}]. Various parameters, including plant height, number of branches, dry weight, essential oil percentage and yield as well as chlorophyll a and b, carotenoids, N, P, K, and carbohydrates were determined. Additionally, indicators of plant tolerance to salinity, such as proline and MDA (malondialdehyde) were also determined. The results indicate a decline in growth traits, photosynthetic pigments, and chemical constituents with an increase in the salinity level of irrigation water. Conversely, the values of proline and MDA exhibited an upward trend as the salinity of irrigation water increased. On the other hand, the addition of biochar enhanced the performance of sage under salinity conditions. The highest values for the studied traits (except for proline and MDA which exhibited the opposite trend) were observed with the highest biochar rate (4 ton fed^{-1}), followed by plants treated with 2 ton fed^{-1}, and finally, the control treatment. These findings not only contribute to our understanding of sage plant adaptation to saline conditions but also highlight the potential of biochar as a beneficial amendment in enhancing plant performance under salinity stress.

Key words: Salinity, Biochar, Proline, Malondialdehyde, Sage, Yield.

INTRODUCTION

The world is currently grappling with a critical challenge the scarcity of freshwater resources. As the world's population continues to grow, it is becoming increasingly important to strike a careful balance between the growing population and the wise use of limited resources including saline water (**Elsherpiny, 2023)**. This necessity, however, demands a comprehensive understanding of plant responses to salinity and innovative strategies to enhance their tolerance (**Liu, 2017)**.

Medicinal and aromatic plants, being integral to human sustenance, stand at the forefront of this challenge. Exploring the potential of saltwater irrigation for these crops could significantly contribute to water conservation and sustainable agriculture. This, however, necessitates thorough research and investigation to unravel the intricacies of plant adaptation to varying salinity levels (**Abd–Elhady, 2023)**.

Sage, or *Salvia officinalis* L., is a vibrant shrub in the *Lamiaceae* family. This plant originated in the Middle East and the Mediterranean regions, and it has since spread to various parts of the world. Sage has been used extensively to treat a variety of illnesses including cancer due to its flavoring qualities **(Valiyari *et al.,* 2013; Ghorbani and Esmaeilizadeh, 2017**).

Furthermore, it contains a multitude of beneficial secondary metabolites that fall into different chemical classes, including phenolic derivatives, terpenoid compounds, and essential oils **(Arikat *et al.*, 2004).** Furthermore, sage extract analysis revealed a number of biological activities, including the capacity to prevent neurovegetative illnesses and exhibit anti-inflammatory, anti-microbial, hypoglycemic, and anti-diabetic properties **(Akhondzadeh *et al.*, 2003 and Garcia *et al.*, 2016**). In contemporary times, it continues to play a significant role in the production of various medical and pharmaceutical preparations (**El-Feky and Aboulthana, 2016).**

One innovative approach for raising plant tolerance to salinity is the incorporation of biochar derived from agricultural residues with soil. Biochar, a carbon-rich material produced through the pyrolysis of organic matter, has demonstrated its prowess in enhancing soil properties and plant performance. Specifically, biochar is hypothesized to play a pivotal role in mitigating salinity stress. Understanding the interaction between biochar and sage plants under varying salinity conditions can unveil novel pathways for sustainable agriculture in arid and saline-affected regions **(Patel *et al.* 2017).**

Biochar, when incorporated into soil, acts as a stable carbon sink, influencing soil structure, nutrient availability, and water retention. Its porous structure and high surface area contribute to enhanced water retention, reducing the impact of salt stress on plants. **(Farooq *et al.*, 2020).** Biochar serves as a valuable amendment in mitigating the detrimental effects of salinity in irrigation water by functioning as a versatile soil conditioner. Its high surface area facilitates ion exchange, aiding in nutrient retention and preventing the uptake of toxic ions by plant roots (**Patel *et al.*, 2017)**. The porous structure enhances water holding capacity, providing a consistent water supply and reducing the risk of water stress in saline environments. Improved soil structure and aeration promote root growth, while the stimulation of microbial activity enhances nutrient cycling and overall soil fertility (**Akhtar *et al.*, 2015)**.

Thus, the main objective of this research work was to assess sage plant responses to salinity stress and investigate the salinity-alleviating potential of biochar and its impacts on sage morphological, biochemical, and physiological characteristics. By expanding our understanding of these complex interactions, we pave the way for sustainable and resilient cultivation practices that are paramount in the face of escalating water scarcity and soil salinity concerns. This is particularly crucial in the context of reclaiming and cultivating lands that face salinity challenges, offering a potential solution to regions struggling with water scarcity and soil salinity.

MATERIAL AND METHODS

A field experiment was undertaken during two consecutive seasons of 2019 and 2020 at a private farm, El-Serw City (31_14019.2100 N, 31_39013.6400 E; 16 m ASL), Damietta, Egypt.

Experimental design

A split-plot design with three replicates assessed the tolerance of sage plants to saline water (S1= 450 (as control), S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1}) as the primary factor by biochar application (B0= 0, B1= 2, B2= 4 ton fed^{-1}) to enhance sage plant tolerance to salinity as the sub-main factor. Biochar rates were added to the experimental soil during the field preparation.

Soil sampling

As part of routine procedures, a soil sample was collected before the transplantation process at a depth of 0.0-30.0 cm. Subsequently, the analysis of the soil sample was conducted according to the method outlined by **Smith and Mullins (1991),** as the characteristics of the soil are detailed in Table 1. On the other hand, the experimental soil samples after the first season were collected after the second harvest at a depth of 0.0-30.0 cm. and their characteristics are detailed in Table 2.

Biochar properties

Biochar preparation involved utilizing plant residues, specifically rice and wheat straw, soybean, and maize stover. This process was carried out at a temperature range of 400-500 °C for a duration of 30 minutes without the presence of oxygen, following the methodology outlined by **Wang and Wang (2019).** The characteristics of the studied biochar are detailed in Table 2. The analysis of the biochar was conducted following the procedures outlined by **Tandon (2005).**

Preparation of saline irrigation water

To achieve the desired salinity levels in irrigation water, seawater and various dilutions with tap water were employed. The attributes of the initial seawater are outlined in Table 3. The analysis of the tested seawater was carried out in accordance with the procedures specified by **Tandon (2005).**

Table 1. Properties of the experimental soil before transplantation

Properties and units		Values
pH *		8.130
EC dSm^{-1} **		1.750
OM %		1.120
Water holding capacity %		22.31
Mechanical analysis %	**Coarse sand**	8.1300
	Fine sand	41.470
	Silt	29.160
	Clay	21.240
Texture class		Sandy clay loam
Available Nutrients (mgKg^{-1})	**Nitrogen**	38.17
	Phosphorus	6.020
	Potassium	193.3

Table (2). Properties of biochar prepared

Properties and units	Values
Cations exchange capacity, Cmol kg^{-1}	69.73
pH	8.79
EC, dSm^{-1}	3.16
Organic carbon, %	48.63
Total nitrogen,%	1.14
Total phosphorus,%	0.59
Total potassium,%	0.63

Table (3). Characteristics of the initial seawater

Properties and units	Values
pH	7.700
EC, mg L^{-1}	39200
Ca^{++}, meq L^{-1}	3.300
Mg^{++}, meq L^{-1}	139.0
Na^{+}, meq L^{-1}	500.0
Cl^{-}, meq L^{-1}	590.0
SO_4^{--}, meq L^{-1}	16.00

Experimental set up

Seeds of the common sage variety of sage were acquired from the Medicinal and Aromatic Department, Horticulture Research Institute (HRI). Initially, sage seeds were planted in nursery beds on November 15 of each season under investigation. Once the seedlings reached a height of 10-15 cm, they were transplanted to the field on March 15 of each season, with a spacing of 30 cm between the plants in the presence of freshwater. Three days post-planting, the soil was lightly irrigated for experimental stabilization of the seedlings. Biochar was applied one week before the transplanting process, adhering to the specified treatments. The studied irrigation treatments commenced from the second irrigation event after transplanting. Ammonium sulphate, (33.5% N) was added at a rate of 300 Kg per feddan *via* two equal doses; the first was added after one month from transplanting, while the second dose was added after the first cut. Calcium superphosphate (6.7% P) was incorporated at a rate of 200 Kg per feddan during soil preparation. Also, organic fertilizer was applied at a rate of 5 ton compost per feddan before the seedling date throughout soil preparation. Potassium as potassium sulfate (39.8% K) was added at a rate of 100 Kg per feddan in two equal doses; each K dose was added at one week after nitrogen dose addition. It is noteworthy that the experimental subplot area measured 9 m², consisting of three rows (each 3 meters in length and 60 cm in width). The separation between the main treatments was maintained at 3 meters.

Cut practices

Harvesting practices involved two cuts in each of the studied seasons. The initial cut was performed on June 15, and the subsequent cut on September 15 of each season.

Determination of essential oil percentage constituents of sage herb

Sage air dry herb samples (100g/sample) were hydro-distillation for 3 hours using a Clevenger-type distillation apparatus according to Guenther, (1972) to determine volatile oil percentage.

Essential oil components

The Gas Chromatograph of the second season 1st cut oil selected samples was done at the Laboratory of Medicinal and Aromatic Plants Research Dept., (HRI, ARC) using DsChrom 6200 Gas Chromatograph equipped with a flame ionization detector for separation of volatile oil constituents. The analysis conditions were as follows: -The chromatograph apparatus was fitted with capillary column BPX-5, 5% phenyl (equiv.) polysillphenylene-siloxane 30m x 0.25mm ID x 0.25µm film.

The temperature program ramp increase with a rate of 10º C / min from 70º to 200º C. Flow rates of gases were nitrogen at 1 ml / min, hydrogen at 30 ml / min and 330 ml /min for air. Detector and injector temperatures were 300º C and 250º C, respectively. The obtained chromatogram and report of GC analysis for each sample were analyzed to calculate the percentage of main components of volatile oil.

Measurement traits

Measurements and determination of attributes detailed in Table 4 were carried out on five randomly selected plants at both cut times.

Table (4). Methods, formula, and references of measurements

Measurements	Methods and formula	References
	Growth criteria	
Plant height (cm), No. of branches plant^{-1}, fresh and dry weights (g plant^{-1}& ton fed^{-1} for each cut)	Manually and visually	----------------
	Photosynthetic pigments	
Chlorophyll a, b and total as well as carotene(mg g^{-1} F.W)	80% Acetone, spectrophotometrically	**Rajput and Patil, (2017)**
	Indicators of oxidative stress	
Proline (μmol.g^{-1})	Toluene fraction, spectrophotometrically	**Teklić *et al.* (2010)**
Malondialdehyde (MDA, biomarker of lipid peroxidation, μmol.g^{-1})	Spectrophotometrically	**Davey *et al.* (2005)**
	Leaf chemical constituents	
Digesting the plant samples	Mixed of $HClO_4 + H_2SO_4$	**Peterburgski (1968)**
N, P, K (%)	Micro-kjeldahl, spectrophotometrically and flame photometer, respectively	**Walinga *et al.* (2013)**
Carbohydrates(%) and oil (% & ml plant-1& Kg fed^{-1} for each cut)		**A.O.A.C. (2000)**

Statistical analysis

The statistical analysis of the acquired data was carried out using **CoStat version 6.303, copyrighted (1998-2004).** The methods employed for the analysis were in accordance with the guidelines provided by **Gomez and Gomez (1984).**

RESULTS AND DISCUSSION

1. Growth criteria and photosynthetic pigments

Table 5 presents the impact of irrigation water salinity treatments and biochar soil addition on growth criteria, including plant height (cm), No. of branches plant^{-1}, fresh and dry weights (g plant^{-1}& ton fed^{-1} for each cut) for the first cut during both study seasons. Similarly, Table 6 displays the corresponding data for the second cut. Additionally, Tables 7 and 8 outline the effects of the studied treatments on photosynthetic pigments, including chlorophyll a, b, total, and carotene (mg g^{-1} in fresh weight) for the first and second cuts, respectively.

The findings reveal a gradual decrease in growth traits and photosynthetic pigments with an elevation in the salinity level of irrigation water from 450 to 4000 mgL^{-1}. Specifically, the highest values for all the mentioned traits were observed in plants irrigated with fresh water (EC value=450mgL^{-1}). On the other hand, plants cultivated in soil treated with 4 tons of biochar per fed exhibited the highest values, followed by those treated with 2 tons of biochar per fed. In contrast, the control group, lacking biochar treatment, exhibited the lowest values. Generally, it can be noticed that the incorporation of biochar proved advantageous in enhancing the overall performance of sage under varying salinity degrees in irrigation water, ranging from 1000 to 4000 mgL^{-1}. The same trend was found for both cuts as well as for both studied seasons.

Increased salinity levels in irrigation water can induce osmotic stress in sage plants. The heightened concentration of salts in the soil diminishes water potential, rendering water absorption more challenging for the plants. Consequently, this difficulty in water uptake impacts crucial physiological processes. The imbalance of ions induced by salinity, particularly the excessive accumulation of sodium ions (Na^+) and chloride ions (Cl^-), disrupts the regular uptake of essential nutrients by sage plants (**Patel *et al.*, 2017)**. This disruption negatively affects nutrient transport and interferes with vital metabolic functions. Accumulated sodium ions in plant tissues interfere with enzymatic activities, protein synthesis, and overall cellular functions in sage plants. Additionally, salinity stress often leads to a reduction in chlorophyll content, impacting the photosynthesis process. This diminished photosynthetic activity results in decreased plant growth, yield, and overall productivity **(Farooq *et al.*, 2020)**.

Biochar's porous structure enhances soil water retention, helping to counteract the osmotic stress caused by high salinity. This increased water holding capacity ensures a more stable water supply for sage plants (**Patel *et al.*, 2017)**. Biochar possesses a high ion exchange capacity, enabling it to hold onto cations and anions, preventing their harmful accumulation in plant tissues. Biochar application can improve nutrient availability in the soil. Biochar fosters a favorable environment for beneficial soil microorganisms, which plays a crucial role in nutrient cycling and can contribute to mitigating the negative effects of salinity on sage plants. Biochar's ability to improve soil structure and increase organic matter content can contribute to a healthier soil environment, aiding in the reduction of oxidative stress in sage plants. In the same line, **Akhtar *et al.*, 2015** on potato, found that increasing salinity levels resulted in significant reductions in shoot biomass, root length and volume as well as tuber yield. On the other side, at each salinity level the incorporation of biochar increased shoot biomass, root length and volume as well as tuber yield. They also clarified that, the addition of biochar can significantly mitigate salinity stress on reductions of photosynthetic rate and midday leaf water potential because biochar increased photosynthetic rate and midday leaf water potential (**Akhtar *et al.*, 2015**).

In summary, biochar acts as a multifaceted soil amendment by addressing the harmful effects of salinity on sage. Its water retention, ion exchange, and nutrient-enhancing capabilities contribute to raising the plant's tolerance to salinity, promoting overall resilience and sustainable cultivation in saline-affected environments.

Table (5). Effect of irrigation water salinity and biochar rates on growth parameters of sage plants at the first cut during the two successive seasons (2019-2020)

Treatments		Plant height, cm		No. of branches $plant^{-1}$		Fresh weight, g $plant^{-1}$		Dry weight, g $plant^{-1}$		Dry weight, ton 1st cut^{-1} fed^{-1}	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor: Salinity of irrigation water											
S_1: 450 mg L^{-1}		39.06a	40.40a	14.22a	16.00a	166.06a	170.41a	48.53a	49.61a	1.068a	1.091a
S_2: 1000 mg L^{-1}		37.52b	38.94b	12.89b	14.78b	152.07b	153.59b	43.59b	44.49b	0.959b	0.979b
S_3: 2000 mg L^{-1}		35.34c	36.60c	11.67c	12.67c	133.88c	136.61c	37.39c	38.16c	0.823c	0.840c
S_4: 3000 mg L^{-1}		33.64d	34.88d	10.44d	11.56d	120.11d	121.48d	32.44d	33.15d	0.714d	0.729d
S_5: 4000 mg L^{-1}		31.52e	32.67e	8.67e	9.44e	96.70e	98.58e	25.51e	26.12e	0.561e	0.575e
LSD at 5%		**0.23**	**0.38**	**0.82**	**0.80**	**0.42**	**0.28**	**0.10**	**0.10**	**0.002**	**0.002**
Sub main factor: Biochar											
B_0: Without biochar		33.87c	35.14c	10.47c	11.60b	120.47c	122.73c	32.59c	33.27c	0.717c	0.732c
B_1: Biochar (2 ton fed^{-1})		35.83b	37.05b	11.87b	13.33a	137.22b	139.44b	39.16b	39.84b	0.862b	0.877b
B_2: Biochar (4 ton fed^{-1})		36.56a	37.91a	12.40a	13.73a	143.60a	146.24a	40.72a	41.80a	0.896a	0.920a
LSD at 5%		**0.36**	**0.36**	**0.48**	**0.48**	**0.48**	**0.45**	**0.14**	**0.13**	**0.003**	**0.003**
Interaction											
S_1	**B_0**	37.40de	38.71cd	13.00cd	15.00b	152.21e	156.34e	43.76e	44.76e	0.963e	0.985e
	B_1	39.50ab	40.90ab	14.67ab	16.33a	169.86b	174.68b	49.76b	50.88b	1.095b	1.119d
	B_2	40.27a	41.59a	15.00a	16.67a	176.10a	180.22a	52.07a	53.19a	1.146a	1.170b
S_2	**B_0**	35.60g	36.99f	11.67ef	12.67cde	133.71h	136.06h	37.20h	37.92h	0.818h	0.834h
	B_1	38.17cd	39.44c	13.33cd	15.67ab	158.00d	158.10d	45.76d	46.72d	1.007d	1.028d
	B_2	38.80bc	40.40b	13.67bc	16.00ab	164.50c	166.62c	47.80c	48.82c	1.052c	1.074c
S_3	**B_0**	33.17ij	34.42hi	10.00h	11.00fg	116.04k	118.22k	31.19k	31.87k	0.686k	0.701k
	B_1	36.10fg	37.39ef	12.33def	13.33cd	139.74g	142.41g	39.41g	40.22g	0.867g	0.885g
	B_2	36.77ef	37.99de	12.67cde	13.67c	145.87f	149.21f	41.56f	42.40f	0.914f	0.933f
S_4	**B_0**	32.37jk	33.61ij	9.67hi	10.33gh	110.32l	111.32l	28.99l	29.49l	0.638l	0.649l
	B_1	33.90hi	35.09h	10.33gh	12.00ef	121.90j	123.40j	33.13j	33.79j	0.729j	0.743j
	B_2	34.67h	35.95g	11.33fg	12.33de	128.12i	129.72i	35.18i	36.16i	0.774i	0.796i
S_5	**B_0**	30.80l	31.98k	8.00j	9.00i	90.09o	91.71o	21.81o	22.32o	0.480o	0.491o
	B_1	31.47l	32.42k	8.67ij	9.33hi	96.61n	98.61n	27.76m	27.61n	0.611n	0.607n
	B_2	32.30k	33.61j	9.33hi	10.00ghi	103.39m	105.42m	26.96n	28.43m	0.593m	0.625m
LSD at 5%		**0.81**	**0.81**	**1.08**	**1.08**	**1.07**	**1.01**	**0.30**	**0.30**	**0.007**	**0.006**

Means within a column followed by a different letter (s) are statistically different at 0.05 level, where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

Table (6). Effect of irrigation water salinity and biochar rates on growth parameters of sage plant at the second cut during two successive seasons (2019-2020)

Treatments		Plant height, cm		No. of branches plant^{-1}		Fresh weight, g plant^{-1}		Dry weight, g plant^{-1}		Dry weight, ton 2nd cut^{2} fed^{-1}	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
2nd cut											
Main factor: Salinity of irrigation water											
S_1: 450 mg L^{-1}		45.41a	47.09a	25.22a	25.67a	216.51a	219.98a	62.68a	63.87a	1.379a	1.405a
S_2: 1000 mg L^{-1}		43.82b	45.31b	24.11b	24.56b	200.21b	204.30b	56.81b	58.26b	1.250b	1.282b
S_3: 2000 mg L^{-1}		41.73c	43.16c	22.89c	21.78c	179.19c	181.24c	49.24c	50.32c	1.083c	1.107c
S_4: 3000 mg L^{-1}		40.08d	41.49d	21.78d	20.67d	163.02d	166.16d	43.01d	43.80d	0.946d	0.964d
S_5: 4000 mg L^{-1}		37.21e	38.64e	17.44e	18.56e	135.92e	137.81e	33.73e	34.55e	0.742e	0.760e
LSD at 5%		**0.42**	**0.71**	**1.11**	**1.09**	**0.38**	**0.42**	**0.09**	**0.14**	**0.002**	**0.003**
Sub main factor: Biochar addition											
B_0: Without biochar		40.14c	41.61c	21.13c	20.67c	163.31c	165.91c	43.50c	44.46c	0.957c	0.978c
B_1: Biochar (2 ton fed^{-1})		42.02b	43.55b	22.53b	22.80b	183.23b	186.08b	50.64b	51.74b	1.114b	1.138b
B_2: Biochar (4 ton fed^{-1})		42.79a	44.26a	23.20a	23.27a	190.37a	193.70a	53.14a	54.28a	1.169a	1.194a
LSD at 5%		**0.41**	**0.37**	**0.44**	**0.43**	**0.60**	**0.56**	**0.17**	**0.17**	**0.004**	**0.004**
Interaction											
S_1	**B_0**	43.90de	45.67d	24.33cd	24.00c	200.12e	203.75e	56.98e	58.04e	1.253e	1.277e
	B_1	45.77ab	47.39ab	25.33ab	26.33a	221.18b	224.40b	64.43b	65.64b	1.417b	1.444b
	B_2	46.57a	48.19a	26.00a	26.67a	228.21a	231.79a	66.63a	67.94a	1.466a	1.495a
S_2	**B_0**	41.82gh	43.13f	22.67fg	22.33de	179.32h	182.49h	48.66h	50.01h	1.071h	1.100h
	B_1	44.56cd	46.09cd	24.67bc	25.33b	207.07d	211.03d	59.63d	61.11d	1.312d	1.344d
	B_2	45.08bc	46.72bc	25.00bc	26.00ab	214.24c	219.38c	62.16c	63.67c	1.367c	1.401c
S_3	**B_0**	39.61ij	40.97hi	21.67hi	19.67g	158.36k	159.76k	41.51k	42.43k	0.913k	0.934k
	B_1	42.36fg	43.97e	23.33ef	22.67d	186.28g	188.46g	51.65g	52.84g	1.136g	1.162g
	B_2	43.22ef	44.53e	23.67de	23.00d	192.93f	195.50f	54.55f	55.70f	1.200f	1.225f
S_4	**B_0**	38.92j	40.49i	21.00i	19.33gh	151.47l	154.02l	39.06l	39.76l	0.859l	0.875l
	B_1	40.18i	41.61gh	22.00gh	21.00f	165.26j	168.77j	43.63j	44.42j	0.960j	0.977j
	B_2	41.12h	42.37fg	22.33gh	21.67ef	172.33i	175.69i	46.34i	47.21i	1.019i	1.039i
S_5	**B_0**	36.44l	37.80k	16.00l	18.00i	127.28o	129.54o	31.28o	32.06o	0.688o	0.705o
	B_1	37.22kl	38.67j	17.33k	18.67hi	136.34n	137.72n	33.86n	34.69n	0.745n	0.763n
	B_2	37.98k	39.47j	19.00j	19.00gh	144.14m	146.16m	36.04m	36.90m	0.793m	0.812m
LSD at 5%		**0.92**	**0.83**	**0.99**	**0.98**	**1.35**	**1.26**	**0.37**	**0.38**	**0.009**	**0.008**

Means within a column followed by a different letter (s) are statistically different at 0.05 level, where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

Table (7). Effect of irrigation water salinity and biochar rates on photosynthetic pigments of sage plant at the first cut during two successive seasons (2019-2020)

Treatments		Chlorophyll a (mg g^{-1} F.W) 1st season	Chlorophyll a 2nd season	Chlorophyll b 1st season	Chlorophyll b 2nd season	Total chlorophyll 1st season	Total chlorophyll 2nd season	Carotene 1st season	Carotene 2nd season
1st cut									
Main factor: Salinity of irrigation water									
S1: 450 mg L-1		1.050a	1.070a	0.604a	0.615a	1.654a	1.685a	0.482a	0.490a
S_2: 1000 mg L^{-1}		1.019b	1.038b	0.591b	0.600b	1.610b	1.638b	0.470b	0.479b
S_3: 2000 mg L^{-1}		0.978c	0.994c	0.573c	0.584c	1.551c	1.578c	0.456c	0.464c
S_4: 3000 mg L^{-1}		0.942d	0.959d	0.561d	0.571d	1.503d	1.530d	0.443d	0.453d
S_5: 4000 mg L^{-1}		0.893e	0.911e	0.549e	0.550e	1.442e	1.461e	0.424e	0.430e
LSD at 5%		**0.002**	**0.009**	**0.008**	**0.005**	**0.007**	**0.008**	**0.002**	**0.004**
Sub main factor: Biochar addition									
B_0: Without biochar		0.947c	0.960c	0.561c	0.569c	1.508c	1.529c	0.444c	0.452c
B_1: Biochar (2 ton fed^{-1})		0.985b	1.005b	0.577b	0.589b	1.562b	1.594b	0.458b	0.466b
B_2: Biochar (4 ton fed^{-1})		0.998a	1.018a	0.589a	0.594a	1.587a	1.612a	0.463a	0.472a
LSD at 5%		**0.003**	**0.007**	**0.005**	**0.004**	**0.007**	**0.008**	**0.002**	**0.003**
Interaction									
S_1	**B_0**	1.023e	1.041d	0.590cd	0.596c	1.614d	1.637d	0.472d	0.477de
	B_1	1.055b	1.077ab	0.609ab	0.621a	1.664b	1.698b	0.484b	0.493b
	B_2	1.071a	1.091a	0.613a	0.627a	1.684a	1.719a	0.491a	0.500a
S_2	**B_0**	0.978h	0.989f	0.573fg	0.584de	1.551g	1.573f	0.457f	0.465gh
	B_1	1.035d	1.055cd	0.597bc	0.607b	1.632c	1.662c	0.475d	0.483cd
	B_2	1.044c	1.069bc	0.603ab	0.609b	1.647c	1.678c	0.479c	0.489bc
S_3	**B_0**	0.932k	0.952h	0.559hi	0.565fg	1.491j	1.517h	0.439i	0.448jk
	B_1	0.994g	1.013e	0.577ef	0.589cd	1.571f	1.602e	0.462e	0.468fg
	B_2	1.008f	1.018e	0.585de	0.597c	1.593e	1.615	0.466e	0.475ef
S_4	**B_0**	0.920l	0.929i	0.553i	0.559gh	1.473k	1.488ei	0.434j	0.444k
	B_1	0.946j	0.968gh	0.564ghi	0.574ef	1.510i	1.542g	0.445h	0.454ij
	B_2	0.960i	0.980fg	0.568fgh	0.579e	1.528h	1.559f	0.449g	0.461hi
S_5	**B_0**	0.880o	0.889k	0.531j	0.542i	1.411m	1.431k	0.418l	0.426m
	B_1	0.895n	0.912j	0.540j	0.552h	1.435l	1.463j	0.425k	0.430lm
	B_2	0.905m	0.932i	0.575efg	0.557gh	1.481jk	1.489i	0.430j	0.435l
LSD at 5%		**0.007**	**0.016**	**0.012**	**0.010**	**0.016**	**0.018**	**0.004**	**0.007**

Means within a column followed by a different letter (s) are statistically different at 0.05 level, where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

Table (8). Effect of irrigation water salinity and biochar rates on photosynthetic pigments of sage plant at the second cut time during two successive seasons (2019-2020)

Treatments		Chlorophyll a		Chlorophyll b		Total chlorophyll		Carotene	
		2^{nd} cut (mg g^{-1} F.W)							
		1^{st} season	2^{nd} season	1^{st} season	2^{nd} season	1^{st} season	2^{nd} season	1^{st} season	2^{nd} season
Main factor: Salinity of irrigation water									
S1: 450 mg L-1		1.185a	1.200a	0.876a	0.885a	2.061a	2.084a	0.582a	0.589a
S_2: 1000 mg L^{-1}		1.148b	1.175b	0.825b	0.832b	1.973b	2.007b	0.556b	0.563b
S_3: 2000 mg L^{-1}		1.098c	1.107c	0.755c	0.765c	1.853c	1.872c	0.519c	0.526c
S_4: 3000 mg L^{-1}		1.062d	1.077d	0.703d	0.712d	1.765d	1.788d	0.487d	0.494d
S_5: 4000 mg L^{-1}		0.995e	1.007e	0.614e	0.622e	1.609e	1.630e	0.428e	0.434e
LSD at 5%		**0.008**	**0.019**	**0.004**	**0.003**	**0.012**	**0.020**	**0.005**	**0.005**
Sub main factor: Biochar addition									
B_0: Without biochar		1.061c	1.084b	0.704c	0.711c	1.765c	1.795c	0.485c	0.491c
B_1: Biochar (2 ton fed^{-1})		1.107b	1.119a	0.768b	0.778b	1.876b	1.897b	0.522b	0.528b
B_2: Biochar (4 ton fed^{-1})		1.125a	1.137a	0.792a	0.800a	1.916a	1.937a	0.536a	0.544a
LSD at 5%		**0.011**	**0.021**	**0.007**	**0.006**	**0.013**	**0.021**	**0.003**	**0.002**
Interaction									
	B_0	1.149de	1.163cd	0.825e	0.833e	1.974e	1.996cd	0.555e	0.560e
S_1	**B_1**	1.196ab	1.214ab	0.891b	0.902b	2.087b	2.115a	0.590b	0.596b
	B_2	1.210a	1.223a	0.913a	0.919a	2.123a	2.142a	0.601a	0.612a
	B_0	1.101gh	1.164cd	0.758h	0.764h	1.859h	1.928e	0.521h	0.527h
S_2	**B_1**	1.164cd	1.172bc	0.846d	0.853d	2.010d	2.025bc	0.567d	0.574d
	B_2	1.177bc	1.189abc	0.871c	0.878c	2.049c	2.067b	0.580c	0.588c
	B_0	1.049jk	1.056gh	0.683k	0.692k	1.733k	1.748g	0.477k	0.483k
S_3	**B_1**	1.112fg	1.122def	0.780g	0.792g	1.892g	1.913e	0.534g	0.540g
	B_2	1.132ef	1.143cde	0.802f	0.812f	1.934f	1.955de	0.546f	0.554f
	B_0	1.035kl	1.052ghi	0.666l	0.674l	1.700l	1.726g	0.463l	0.471l
S_4	**B_1**	1.067ij	1.079fg	0.710j	0.719j	1.777j	1.798f	0.493j	0.499j
	B_2	1.085hi	1.099efg	0.733i	0.742i	1.818i	1.841f	0.506i	0.512i
	B_0	0.972n	0.985j	0.588o	0.594o	1.560o	1.579i	0.411o	0.416o
S_5	**B_1**	0.996mn	1.008ij	0.615n	0.625n	1.611n	1.633h	0.428n	0.433n
	B_2	1.018lm	1.029hij	0.639m	0.649m	1.657m	1.678h	0.447m	0.454m
LSD at 5%		**0.025**	**0.047**	**0.016**	**0.001**	**0.029**	**0.047**	**0.008**	**0.005**

Means within a column followed by a different letter (s) are statistically different at 0.05 level, where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

2. Indicators of oxidative stress

Indicators of oxidative stress *i.e.,* proline (µmol.g^{-1}) and malondialdehyde (MDA, biomarker of lipid peroxidation, µmol.g^{-1}) of plants as affected by the salinity of irrigation water treatments and biochar soil addition are presented in Table 9 for 1st cut and Table 10 for 2nd cut during both studied seasons. The results indicate that the values of proline and MDA exhibited an upward trend as the salinity of irrigation water increased. On the contrary the values of proline and MDA exhibited a descending trend as the biochar rate. Consistent patterns were observed for both cuts and across both study seasons. These findings suggest that salinity stress contributes to heightened oxidative stress indicators in plants, while biochar application demonstrates a potential mitigating effect, underscoring its role in ameliorating oxidative stress in sage plants subjected to varying salinity conditions. The results obtained align with those of **Abd–Elhady (2023)**.

3. Chemical and biochemical constituents

Table 11 details the influence of irrigation water salinity treatments and biochar soil addition on leaf chemical and biochemical constituents, encompassing N, P, K, and carbohydrate (%) for the first cut during both study seasons. Correspondingly, Table 12 provides the relevant data for the second cut. The results indicate that the values of chemical and biochemical constituents decreased as the salinity level of irrigation water, increased Notably, the highest values for all the specified traits were observed in plants irrigated with fresh water (EC value=450mgL^{-1}). Aldo, plants grown in soil treated with 4 tons of biochar per fed exhibited the highest values, followed by those treated with 2 tons of biochar per fed, while the control group without biochar treatment displayed the lowest values. Overall, the incorporation of biochar demonstrated benefits in enhancing the overall performance of sage under varying salinity levels in irrigation water, spanning from 1000 to 4000 mgL^{-1}. This consistent trend was observed for both cuts and across both study seasons.

The observed decline in chemical and biochemical constituents, with increasing salinity levels in irrigation water from 450 to 4000 mgL^{-1} can be attributed to the detrimental effects of salinity stress on sage plants. Elevated salinity induces osmotic stress, disrupting water uptake and nutrient absorption. This, in turn, negatively impacts essential metabolic functions and biochemical processes, leading to a decrease in nutrient content. Additionally, the presence of high concentrations of specific ions, such as sodium, can contribute to ionic toxicity, interfering with enzymatic activities and cellular functions (**Mehdizadeh *et al.* (2019)**. On the other hand, the positive impact of biochar on these traits can be attributed to its ability to enhance soil structure, water retention, and nutrient availability. Biochar, acting as a soil amendment, mitigates the adverse effects of salinity by improving the overall soil environment, thereby promoting better nutrient uptake and plant performance. These findings are in agreement with those of **Anwari *et al.* (2020).** In this regard, **Akhtar *et al.*, 2015,** worked on potato and clearly demonstrated that, the addition of biochar can significantly mitigate salinity stress due to its high salt sorption capacity and by increasing K+ availability. They also concluded that, increasing salinity levels resulted in significant reductions of photosynthetic rate and midday leaf water potential. At each salinity level, the incorporation of biochar increased photosynthetic rate and midday leaf water potential, decreased Na+, Na+/K+ ratio and increased K+ content in xylem with biochar amendment which also indicated its ameliorative effects on potato plants in response to salinity stress.

Table (9). Effect of irrigation water salinity and biochar rates on Indicators of oxidative stress (proline and MDA) of sage plant at the first cut time during two successive seasons (2019-2020)

Treatments		1st cut			
		Proline, µmol g^{-1}		MDA, µmol g^{-1}	
		1st season	2nd season	1st season	2nd season
Main factor: Salinity of irrigation water					
S_1: 450 mg L^{-1}		4.16e	4.25e	4.62e	4.73e
S_2: 1000 mg L^{-1}		4.57d	4.69d	4.90d	5.01d
S_3: 2000 mg L^{-1}		5.54c	5.66c	5.83c	5.94c
S_4: 3000 mg L^{-1}		5.87b	5.97b	6.18b	6.32b
S_5: 4000 mg L^{-1}		6.67a	6.82a	6.94a	7.08a
LSD at 5%		**0.06**	**0.05**	**0.09**	**0.10**
Sub main factor: Biochar addition					
B_0: Without biochar		5.76a	5.89a	6.06a	6.19a
B_1: Biochar (2 ton fed^{-1})		5.27b	5.39b	5.62b	5.74b
B_2: Biochar (4 ton fed^{-1})		5.04c	5.15c	5.41c	5.52c
LSD at 5%		**0.06**	**0.07**	**0.06**	**0.05**
Interaction					
	B_0	4.71k	4.81k	5.05k	5.16k
S_1	**B_1**	4.03n	4.10n	4.47n	4.59n
	B_2	3.75o	3.83o	4.32o	4.43o
	B_0	4.95j	5.10j	5.26j	5.38j
S_2	**B_1**	4.51l	4.62l	4.83l	4.93l
	B_2	4.24m	4.34m	4.63m	4.72m
	B_0	6.03e	6.16e	6.31e	6.44e
S_3	**B_1**	5.38h	5.51h	5.70h	5.81h
	B_2	5.21i	5.32i	5.49i	5.58i
	B_0	6.26d	6.37d	6.52d	6.65d
S_4	**B_1**	5.77f	5.87f	6.13f	6.27f
	B_2	5.57g	5.68g	5.89g	6.04g
	B_0	6.86a	7.02a	7.14a	7.31a
S_5	**B_1**	6.68b	6.85b	6.95b	7.10b
	B_2	6.46c	6.60c	6.71c	6.85c
LSD at 5%		**0.12**	**0.16**	**0.13**	**0.11**

Means within a column followed by a different letter (s) are statistically different at 0.05 level, where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

Table (10). Effect of irrigation water salinity and biochar rates on Indicators of oxidative stress (proline and MDA) of sage plant at the second cut time during two successive seasons (2019-2020)

Treatments		Proline, μmol g^{-1} 1st season	Proline, μmol g^{-1} 2nd season	MDA, μmol g^{-1} 1st season	MDA, μmol g^{-1} 2nd season
2nd cut					
Main factor: Salinity of irrigation water					
S_1: 450 mg L^{-1}		2.61e	4.25e	3.35e	4.73e
S_2: 1000 mg L^{-1}		2.91d	4.69d	3.59d	5.01d
S_3: 2000 mg L^{-1}		3.67c	5.66c	4.19c	5.94c
S_4: 3000 mg L^{-1}		3.97b	5.97b	4.44b	6.32b
S_5: 4000 mg L^{-1}		4.70a	6.82a	4.97a	7.08a
LSD at 5%		**0.03**	**0.05**	**0.03**	**0.10**
Sub main factor: Biochar addition					
B_0: Without biochar		3.90a	5.89a	4.37a	6.19a
B_1: Biochar (2 ton fed^{-1})		3.50b	5.39b	4.05b	5.74b
B_2: Biochar (4 ton fed^{-1})		3.31c	5.15c	3.91c	5.52c
LSD at 5%		**0.04**	**0.07**	**0.03**	**0.05**
Interaction					
S_1	**B_0**	3.02k	4.81k	3.68k	5.16k
	B_1	2.50n	4.10n	3.26n	4.59n
	B_2	2.30o	3.83o	3.12o	4.43o
S_2	**B_0**	3.23j	5.10j	3.83j	5.38j
	B_1	2.85l	4.62l	3.53l	4.93l
	B_2	2.66m	4.34m	3.42m	4.71m
S_3	**B_0**	4.06e	6.16e	4.52e	6.44e
	B_1	3.55h	5.51h	4.11h	5.81h
	B_2	3.40i	5.32i	3.95i	5.58i
S_4	**B_0**	4.29d	6.37d	4.69d	6.65d
	B_1	3.89f	5.87f	4.39f	6.27f
	B_2	3.73g	5.68n	4.24n	6.04n
S_5	**B_0**	4.90a	7.02a	5.12a	7.31a
	B_1	4.70b	6.85b	4.96b	7.10b
	B_2	4.49c	6.60c	4.84c	6.85c
LSD at 5%		**0.09**	**0.16**	**0.06**	**0.11**

Means within a column followed by a different letter (s) are statistically different at a 0.05 level, where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

Table (11). Effect of irrigation water salinity and biochar rates on leaf chemical constituents of sage plant at the first cut time during two successive seasons (2019-2020)

Treatments		N		P		K		Carbohydrates	
		1st cut							
		(%)							
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor: Salinity of irrigation water									
S_1: 450 mg L^{-1}		2.08a	2.12a	0.253a	0.256a	2.02a	2.05a	41.90a	42.88a
S_2: 1000 mg L^{-1}		1.96b	2.01b	0.242b	0.246b	1.90b	1.94b	39.89b	40.54b
S_3: 2000 mg L^{-1}		1.83c	1.87c	0.230c	0.233c	1.72c	1.75c	37.33c	37.81c
S_4: 3000 mg L^{-1}		1.72d	1.75d	0.218d	0.221d	1.60d	1.63d	35.34d	36.08d
S_5: 4000 mg L^{-1}		1.55e	1.59e	0.201e	0.204e	1.43e	1.45e	32.26e	32.78e
LSD at 5%		**0.06**	**0.06**	**0.002**	**0.002**	**0.05**	**0.02**	**0.10**	**0.17**
Sub main factor: Biochar addition									
B_0: Without biochar		1.73c	1.77c	0.219c	0.221c	1.61c	1.64c	35.45c	36.24c
B_1: Biochar (2 ton fed^{-1})		1.85b	1.89b	0.232b	0.234b	1.77b	1.80b	37.88b	38.52b
B_2: Biochar (4 ton fed^{-1})		1.91a	1.95a	0.236a	0.240a	1.82a	1.85a	38.70a	39.31a
LSD at 5%		**0.03**	**0.03**	**0.003**	**0.001**	**0.03**	**0.04**	**0.13**	**0.12**
Interaction									
S_1	**B_0**	1.96de	2.00de	0.243cd	0.245d	1.90de	1.93cd	39.85e	40.86e
	B_1	2.11ab	2.15ab	0.256ab	0.259b	2.05ab	2.07a	42.48b	43.46b
	B_2	2.16a	2.20a	0.261a	0.265a	2.11a	2.14a	43.36a	44.32a
S_2	**B_0**	1.82gh	1.87fg	0.228f	0.231g	1.74gh	1.77fg	37.30h	38.19h
	B_1	2.01cd	2.06cd	0.247c	0.250c	1.94cd	1.98bc	40.78d	41.37d
	B_2	2.07bc	2.12bc	0.253b	0.257b	2.01bc	2.06ab	41.58c	42.07c
S_3	**B_0**	1.70j	1.74j	0.216hi	0.219j	1.54j	1.58ij	34.67k	35.19k
	B_1	1.88fg	1.92fg	0.235e	0.238f	1.80fg	1.82ef	38.29g	38.68g
	B_2	1.93ef	1.97ef	0.238de	0.242e	1.84ef	1.86de	39.02f	39.56f
S_4	**B_0**	1.66jk	1.69jk	0.211ij	0.214k	1.53j	1.55jk	33.96l	34.84l
	B_1	1.73ij	1.76ij	0.219gh	0.222i	1.62i	1.65hi	35.64j	36.38j
	B_2	1.78hi	1.82hi	0.223fg	0.226h	1.67hi	1.70gh	36.42i	37.03i
S_5	**B_0**	1.51m	1.55m	0.196l	0.198n	1.37l	1.39l	31.45o	32.11o
	B_1	1.55lm	1.59lm	0.202k	0.204m	1.45k	1.47kl	32.21n	32.68n
	B_2	1.60kl	1.64kl	0.206jk	0.209l	1.47jk	1.49k	33.13m	33.55m
LSD at 5%		**0.07**	**0.07**	**0.006**	**0.003**	**0.07**	**0.08**	**0.28**	**0.27**

Means within a column followed by a different letter (s) are statistically different at 0.05 level, where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

Table (12). Effect of irrigation water salinity and biochar rates on leaf chemical constituents of sage plant at the second cut time during two successive seasons (2019-2020)

Treatments		N		P		K		Carbohydrates	
		2nd cut (%)							
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor: Salinity of irrigation water									
S_1: 450 mg L^{-1}		2.20a	2.29a	0.279a	0.282a	2.09a	2.14a	44.78a	45.49a
S_2: 1000 mg L^{-1}		2.12b	2.20b	0.267b	0.270b	2.00b	2.04b	42.81b	43.47b
S_3: 2000 mg L^{-1}		2.00c	2.07c	0.252c	0.256c	1.86c	1.90c	40.31c	40.96c
S_4: 3000 mg L^{-1}		1.90d	1.96d	0.242d	0.246d	1.76d	1.80d	38.32d	39.15d
S_5: 4000 mg L^{-1}		1.76e	1.83e	0.225e	0.228e	1.63e	1.66e	35.42e	35.92e
LSD at 5%		**0.006**	**0.04**	**0.003**	**0.004**	**0.03**	**0.03**	**0.23**	**0.12**
Sub main factor: Biochar addition									
B_0: Without biochar		1.91b	1.98b	0.243c	0.246c	1.78c	1.81c	38.49c	39.04c
B_1: Biochar (2 ton fed^{-1})		2.02a	2.10a	0.256b	0.259b	1.90b	1.94b	40.81b	41.55b
B_2: Biochar (4 ton fed^{-1})		2.06a	2.13a	0.261a	0.265a	1.94a	1.98a	41.69a	42.41a
LSD at 5%		**0.04**	**0.04**	**0.003**	**0.002**	**0.04**	**0.02**	**0.16**	**0.14**
Interaction									
S_1	**B_0**	2.10cd	2.19cd	0.267de	0.269e	2.00cde	2.04cd	42.78e	43.36e
	B_1	2.24ab	2.32ab	0.282ab	0.285b	2.12ab	2.18a	45.38b	46.09b
	B_2	2.28a	2.36a	0.287a	0.292a	2.16a	2.21a	46.17a	47.02a
S_2	**B_0**	2.01de	2.07ef	0.253gh	0.256f	1.87fg	1.92e	40.38h	40.96h
	B_1	2.16bc	2.24bc	0.272cd	0.275d	2.05bcd	2.07c	43.65d	44.37d
	B_2	2.21ab	2.29ab	0.276bc	0.280c	2.09abc	2.13b	44.39c	45.07c
S_3	**B_0**	1.88fgh	1.95ghi	0.238jk	0.241i	1.73hij	1.77gh	37.74k	38.33k
	B_1	2.05d	2.13de	0.257fg	0.260f	1.91ef	1.94e	41.17g	41.87g
	B_2	2.08cd	2.14de	0.263ef	0.267e	1.96def	2.00d	42.03f	42.70f
S_4	**B_0**	1.84ghi	1.91hij	0.235kl	0.244hi	1.70ijk	1.74hi	37.02l	37.62l
	B_1	1.91fg	1.98gh	0.242ij	0.245h	1.77hi	1.82fg	38.38j	39.46j
	B_2	1.95ef	2.00fg	0.248hi	0.251g	1.81gh	1.85f	39.55i	40.37i
S_5	**B_0**	1.72j	1.79k	0.220n	0.223l	1.59l	1.61k	34.50o	34.95o
	B_1	1.77ij	1.84jk	0.226mn	0.229k	1.63kl	1.67j	35.45n	35.94n
	B_2	1.80hij	1.87ijk	0.230lm	0.233j	1.67jkl	1.71ij	36.31m	36.87m
LSD at 5%		**0.10**	**0.09**	**0.006**	**0.004**	**0.10**	**0.05**	**0.36**	**0.31**

Means within a column followed by a different letter (s) are statistically different at 0.05 level, where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

4. Oil yield Characters

Tables 13 and 14 delineate the impact of the studied treatments on oil yield (% & ml plant^{-1} & Kg fed^{-1} for each cut) for the first and second cuts, respectively. Oil yield characters in terms of, oil percentage, oil yield ml plant-1 and oil yield kg fed^{-1} each cut were decreased as the salinity level of irrigation water, increased Notably, the highest values for all the specified traits were observed in plants irrigated with fresh water (EC value=450mgL^{-1}). Plants grown in soil treated with 4 tons of biochar per fed recorded the highest values, followed by those treated with 2 tons of biochar per fed, while the control treatment plants without biochar displayed the lowest values. Overall, the incorporation of biochar demonstrated benefits in enhancing the overall performance of sage under varying salinity levels in irrigation water, ranging from 1000 to 4000 mgL^{-1}. This trend was observed for the first and second cuts and during the two growing seasons for the potential role of biochar in ameliorating the impact of salinity stress on sage plants oil yield parameters. Our results were in the same line with **Mehdizadeh *et al.* (2019)** results. The results **Akhtar *et al.*, 2015**, also suggested that the incorporation of biochar might be a promising approach for enhancing crop productivity in salt-affected soils.

5. Essential oil constituents

Data in Table 15 illustrate the effect of irrigation water salinity and biochar in most active treatments on sage volatile oil components percentages of the 2020 season (second cut samples), compared to untreated plants. Twenty components were determined, seventeen were distinct compounds were identified and three were not identified. From the identified constituents, α-Thujone (ranging from 25.76 to 30.52%) was the dominant component fraction in the sage oil, followed by Camphor (ranging from 19.09 to 27.21%) as a predominant component. The β-Thujone component (ranging from 10.64 to 17.96 %) ranked third after α-Thujone and β-Thujone while 1,8-Cineole (ranging from 5.90 to 7.35%) ranked fourth. The other main components were β-Pinene (ranging from3.19 to6.33 %), Camphene (ranging from 1.27 to 4.76 %), Humulene (ranging from 2.40 to 4.10%) and Caryophyllene oxide (ranging from 1.20 to 3.51 %). The interaction treatments of S2 (1000 mgL^{-1}) B2 (4 ton fed^{-1}) and S3 (2000 mgL^{-1}) B2 (4 ton fed^{-1}) gave the highest values of α-Thujone to record 30.01and 30.52%, respectively. Such a profile is similar to the reports of other authors on sage under salinity stress with α-Thujone as the dominant component of sage herb essential oil, like Es‑**sbihi *et al.* (2021) and Noémi *et al.* (2023).**

6. Post-harvest soil properties

Data presented in Table 16 elucidates the influence of irrigation water salinity treatments and the addition of biochar to soil on key soil parameters, namely nitrogen (N), phosphorus (P), potassium (K) concentrations (mg kg^{-1}), soil electrical conductivity (EC) in (dSm-1), and soil water holding capacity (WHC, %) (Combined data over both seasons). The impact of irrigation water salinity treatments on the studied soil parameters was generally inconclusive, with the exception of soil EC, which exhibited a discernible correlation with the salinity level in the irrigation water. Specifically, the soil EC value demonstrated an upward trend in tandem with the increasing salinity level in the irrigation water.

Conversely, the biochar treatments exhibited a clear and comprehensive effect on all the examined soil parameters. As the biochar application rate increased, there was a notable elevation in the concentrations of nitrogen (N), phosphorus (P), and potassium (K) in the soil (mg kg^{-1}). Furthermore, the soil water holding capacity (WHC), expressed as a percentage, demonstrated an increase with escalating biochar rates. Intriguingly, in direct contrast to the trend observed with salinity, the soil EC value exhibited a marked decrease as the biochar application rate increased.

Table (13). Effect of irrigation water salinity and biochar rates on oil yield of sage plant at the first cut time during two successive seasons (2019-2020)

Treatments		Oil, %		Oil yield, g plant^{-1}		Oil yield, Kg 1st cut^{-1} fed^{-1}	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
1st cut							
Main factor: Salinity of irrigation water							
S_1: 450 mg L^{-1}		0.60a	0.63a	0.294a	0.312a	6.46a	6.87a
S_2: 1000 mg L^{-1}		0.54b	0.55b	0.238b	0.249b	5.24b	5.47b
S_3: 2000 mg L^{-1}		0.47c	0.49c	0.178c	0.189c	3.92c	4.15c
S_4: 3000 mg L^{-1}		0.40d	0.42d	0.132d	0.139d	2.90d	3.07d
S_5: 4000 mg L^{-1}		0.33e	0.33e	0.084e	0.087e	1.85e	1.92e
LSD at 5%		**0.03**	**0.04**	**0.011**	**0.017**	**0.25**	**0.37**
Sub main factor: Biochar addition							
B_0: Without biochar		0.42b	0.43c	0.142c	0.150c	3.12c	3.31c
B_1: Biochar (2 ton fed^{-1})		0.48a	0.50b	0.198b	0.208b	4.36b	4.57b
B_2: Biochar (4 ton fed^{-1})		0.51a	0.52a	0.215a	0.228a	4.73a	5.01a
LSD at 5%		**0.03**	**0.02**	**0.010**	**0.007**	**0.23**	**0.15**
Interaction							
S_1	**B_0**	0.55cde	0.57cd	0.239cd	0.257d	5.27cd	5.65d
	B_1	0.62ab	0.64ab	0.310a	0.328b	6.82a	7.21b
	B_2	0.64a	0.66a	0.332a	0.353a	7.30a	7.77a
S_2	**B_0**	0.46fg	0.48fg	0.170ef	0.181g	3.73ef	3.97g
	B_1	0.57bcd	0.58cd	0.262bc	0.269d	5.77bc	5.93d
	B_2	0.59abc	0.61bc	0.282b	0.296c	6.20b	6.51c
S_3	**B_0**	0.40ghi	0.41hi	0.126hi	0.132i	2.77hi	2.90i
	B_1	0.49ef	0.51ef	0.192e	0.206f	4.22e	4.54f
	B_2	0.52de	0.54de	0.217d	0.228e	4.78d	5.01e
S_4	**B_0**	0.37hij	0.39ij	0.108ij	0.114j	2.38ij	2.50j
	B_1	0.41ghi	0.43hi	0.137gh	0.144i	3.01gh	3.18i
	B_2	0.43fgh	0.44gh	0.150fg	0.160h	3.30fg	3.52h
S_5	**B_0**	0.30k	0.31l	0.066k	0.070l	1.45k	1.53l
	B_1	0.33jk	0.33kl	0.091j	0.090k	2.00j	1.99k
	B_2	0.35ijk	0.36jk	0.095j	0.102jk	2.09j	2.24jk
LSD at 5%		**0.06**	**0.04**	**0.023**	**0.016**	**0.51**	**0.34**

Means within a column followed by a different letter (s) are statistically different at 0.05 level, where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

Table (14). Effect of irrigation water salinity and biochar rates on oil yield of sage plant at the second cut time during two successive seasons (2019-2020)

Treatments		2nd cut					
		Oil, %		Oil yield, g plant^{-1}		Oil yield, Kg 1st cut^{-1} fed^{-1}	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor: Salinity of irrigation water							
S_1: 450 mg L^{-1}		0.63a	0.66a	0.397a	0.421a	8.73a	9.27a
S_2: 1000 mg L^{-1}		0.58b	0.60b	0.333b	0.355b	7.33b	7.81b
S_3: 2000 mg L^{-1}		0.52c	0.54c	0.261c	0.275c	5.74c	6.04c
S_4: 3000 mg L^{-1}		0.47d	0.49d	0.203d	0.217d	4.47d	4.78d
S_5: 4000 mg L^{-1}		0.39e	0.40e	0.131e	0.140e	2.88e	3.08e
LSD at 5%		**0.03**	**0.01**	**0.018**	**0.005**	**0.40**	**0.12**
Sub main factor: Biochar addition							
B_0: Without biochar		0.47c	0.49c	0.211c	0.223c	4.65c	4.91c
B_1: Biochar (2 ton fed^{-1})		0.53b	0.56b	0.279b	0.298b	6.14b	6.56b
B_2: Biochar (4 ton fed^{-1})		0.56a	0.58a	0.305a	0.323a	6.70a	7.11a
LSD at 5%		**0.02**	**0.01**	**0.007**	**0.003**	**0.16**	**0.07**
Interaction							
S_1	**B_0**	0.59c	0.60e	0.334e	0.349e	7.35e	7.68e
	B_1	0.65a	0.68b	0.419b	0.444b	9.21b	9.78b
	B_2	0.66a	0.69a	0.438a	0.471a	9.63a	10.35a
S_2	**B_0**	0.52ef	0.54h	0.254h	0.272h	5.60h	5.98h
	B_1	0.60bc	0.62d	0.356d	0.381d	7.82d	8.38d
	B_2	0.63ab	0.65c	0.389c	0.412c	8.57c	9.06c
S_3	**B_0**	0.45hi	0.46k	0.188k	0.194k	4.14k	4.27k
	B_1	0.55de	0.57g	0.282g	0.303g	6.21g	6.67g
	B_2	0.57cd	0.59f	0.313f	0.327f	6.88f	7.19f
S_4	**B_0**	0.44i	0.46k	0.171l	0.182l	3.75l	4.00l
	B_1	0.48gh	0.50j	0.208j	0.224j	4.58j	4.92j
	B_2	0.50fg	0.52i	0.230i	0.247i	5.07i	5.43i
S_5	**B_0**	0.35k	0.37n	0.110o	0.120o	2.41o	2.63o
	B_1	0.39j	0.40m	0.131n	0.140n	2.88n	3.08n
	B_2	0.42i	0.44l	0.153m	0.161m	3.36m	3.54m
LSD at 5%		**0.03**	**0.01**	**0.016**	**0.006**	**0.35**	**0.15**

Means within a column followed by a different letter (s) are statistically different at 0.05 level, where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

Table (15). Effect of irrigation water salinity and biochar most active treatments and control onsage volatile oil components percentages of 2020 season (second cut samples)

ID	components \ treatments	S1 B0 (control)	S1 B2	S2 B2	S3 B2	S4 B2	S5 B2
		Area%	Area%	Area%	Area%	Area%	Area%
1	α-Pinene	0.46	1.96	2.15	0.36	1.38	1.51
2	Camphene	4.76	3.15	1.27	3.56	2.20	4.55
3	β-Pinene	6.33	3.71	5.85	4.59	3.19	4.59
4	Myrcene	1.89	1.16	0.82	1.10	5.59	1.39
5	p-Cymene	0.84	0.64	0.43	0.73	1.24	0.77
6	Limonene	1.89	1.28	1.66	1.45	1.51	1.51
7	1,8-Cineole	6.84	6.29	7.10	6.31	5.90	7.35
8	γ-Terpinene	1.04	0.83	0.70	0.87	0.99	0.87
9	α-Thujone	27.75	29.98	30.01	30.52	27.08	25.76
10	β-Thujone	14.90	16.94	10.87	16.73	10.64	17.96
11	Camphor	19.09	21.34	23.28	21.67	27.21	19.71
12	unkown	0.46	0.30	0.47	0.38	0.59	0.40
13	Borneol	0.59	0.58	1.44	0.51	1.34	0.45
14	α-Terpineol	3.82	1.21	0.71	0.43	0.47	0.48
15	Bornyl acetate	2.55	3.03	2.34	0.89	3.00	1.32
16	unkown	0.27	1.28	0.36	2.50	0.38	3.25
17	β-caryophyllene	1.22	1.37	1.76	1.30	1.80	1.41
18	Humulene	2.42	2.40	4.10	2.70	2.48	2.83
19	unkown	0.71	0.79	1.18	1.03	1.83	1.21
20	Caryophyllene oxide	2.15	1.75	3.51	2.38	1.20	2.73
Total identified components		98.56	97.63	97.99	96.09	97.2	95.14

Where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-1}

Table (16). Properties of the experimental soil samples after harvest (combined data over both seasons)

Soil after harvest		N $mg.kg^{-1}$	P $mg.kg^{-1}$	K $mg.kg^{-1}$	EC dSm^{-1}	WHC %
S_1	B_0	41.74	8.08	207.9	1.93	23.03
	B_1	43.02	8.62	218.7	1.87	25.93
	B_2	43.20	8.68	220.1	1.90	26.31
S_2	B_0	41.84	8.15	209.2	2.06	24.07
	B_1	43.38	8.78	222.0	1.98	25.74
	B_2	43.58	8.86	223.2	2.02	26.21
S_3	B_0	41.93	8.21	211.4	2.17	23.58
	B_1	43.77	8.94	225.3	2.14	24.99
	B_2	43.93	9.03	227.0	2.15	26.15
S_4	B_0	41.44	8.33	213.3	2.24	23.50
	B_1	44.13	9.09	228.4	2.22	25.85
	B_2	44.26	9.19	230.3	2.19	26.07
S_5	B_0	42.16	8.49	215.4	2.35	23.62
	B_1	44.41	9.26	231.6	2.30	26.03
	B_2	44.59	9.35	233.4	2.32	26.24

Where S1= 450, S2= 1000, S3= 2000, S4= 3000, and S5= 4000 mgL^{-1} and B0= 0, B1= 2, B2= 4 ton fed^{-}

The unclear impact of irrigation water salinity on most soil parameters may be attributed to complex interactions and dependencies within the soil-plant-water system. Salinity levels might not have a direct and consistent effect on soil nutrient concentrations and water-holding capacity. The increase in soil electrical conductivity (EC) with rising salinity levels in irrigation water is consistent with the well-known principle that salinity increases the ability of water to conduct electricity. This can be attributed to the accumulation of soluble salts in the soil, affecting its electrical properties (**Akhtar *et al.*, 2015)**. The positive impact of biochar on soil nutrient concentrations (N, P, K) could be attributed to the inherent nutrient content of biochar itself and its ability to improve nutrient retention and availability in the soil. Biochar acts as a nutrient reservoir, promoting nutrient exchange between the soil and plant roots. The increase in soil water-holding capacity (WHC) with higher biochar rates is likely due to the porous structure of biochar, enhancing soil structure and water retention. Biochar's porous nature can create a more favorable environment for water storage and availability to plants. The decrease in soil electrical conductivity (EC) with increasing biochar rates suggests a potential ameliorative effect of biochar on soil salinity. Biochar may assist in mitigating the adverse impacts of salinity by altering the ion exchange capacity and promoting better water retention in the soil (**Mehdizadeh *et al.* (2019)**.

In summary, while irrigation water salinity showed a clearer influence on soil electrical conductivity, biochar additions demonstrated a positive impact on soil nutrient concentrations and water-holding capacity while mitigating the adverse effects of salinity on the soil.

Conclusion

It can be concluded that increasing salinity levels in irrigation water adversely impacted growth traits, photosynthetic pigments, and chemical constituents of sage plants. On the other hand, the incorporation of biochar emerged as a noteworthy strategy to mitigate the adverse effects of salinity on sage plants. The highest values for most measured traits were observed with the highest biochar rate (4 ton fed^{-1}), followed by the 2 ton fed^{-1} treatment, outperforming the control treatment. These findings not only contribute to our understanding of sage plant adaptation to saline conditions but also highlight the potential of biochar as a beneficial amendment in enhancing plant performance under salinity stress. Therefore, the study provides insights into agricultural practices in regions facing water scarcity and salinity challenges in salt-affected croplands. Thus results recommendation is to assess the biochar rate of 4 ton fed^{-1} to sage cultivation under salinity stress condition for improving growth and productivity as well as salinity stress mitigation

Conflicts of interest

Authors have declared that no competing interests exist.

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