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Evaluation of rapeseed performance under different irrigation levels and eucalyptus biochar

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A B S T R A C T

Given the arid and semi-arid conditions prevalent in Iran, along with the pressing need for effective water resource management, this study examines the impact of agricultural and horticultural residues converted into biochar on the drought tolerance of rapeseed. The objective of the experiment was to evaluate the yield and various components of the Hyola 50 rapeseed variety, an important global source of edible oil, under conditions of water deficit and differing levels of biochar application. The research was conducted at the Shahid Chamran University of Ahvaz's research farm, utilizing a completely randomized block design. The experimental treatments included four irrigation levels (100%, 85%, 70%, and 60% of the crop's water requirements) and two biochar application levels (1% and 2% by weight), each replicated three times. The traits analyzed encompassed yield, plant height, the number of pods per plant, oil content, and thousand-seed weight. The findings revealed that water deficit significantly reduced both yield and its components. Conversely, introducing biochar notably enhanced plant height, the number of pods per plant, and overall yield. However, no significant effects were observed on thousand-seed weight or oil content. The results showed that applying deficit irrigation at 15% does not cause a significant decrease in yield. This study also showed that adding biochar less than 2% by weight to the soil will not have a significant effect on rapeseed plant yield. The results showed that deficit irrigation reduced yield by 40%, plant height by 17%, and thousand-seed weight by 21%. Adding biochar at a level of 2% by weight improved the number of pods per plant by 7%, plant height by 11%, and yield by 18% at a significant level.

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1. Introduction

Deficit irrigation is a management strategy in which plants experience water stress during specific growth stages or throughout the entire growing season. Various methods of deficit irrigation are employed, where farmers may reduce irrigation at certain growth stages while maintaining full irrigation in others or apply reduced amounts of water in each cycle to optimize the use of available water resources (Liu et al., 2024). In recent years, biochar has gained attention as a soil amendment (a source of organic carbon) and as a means of carbon sequestration in agricultural soils. Biochar is produced from plant biomass and agricultural residues such as wheat straw, maize, rice husks, sugarcane bagasse, wood, manure, or leaves through a thermochemical process known as pyrolysis, which involves slow and low-oxygen burning of organic materials (Glaser and Birk, 2012). The application of biochar to soil has been recognized as an effective strategy for achieving the Sustainable Development Goals (SDGs) of the United Nations and promote sustainable agricultural development, as it can enhance soil fertility and soil carbon sequestration, and improve soil water conditions, thus improving crop water and nutrient absorption efficiency and increasing yield (Kumar and Bhattacharya, 2021) Rapeseed (Brassica napus L.) is one of the most important oilseed crops, with its seeds containing 40–45% oil and its meal being rich in protein (35–40%). Due to its favorable composition of unsaturated fatty acids and low levels of saturated fatty acids (~7%), rapeseed oil is considered one of the highest quality edible oils (Bakhshi et al., 2023). In recent decades, rapeseed cultivation in Iran has increased due to its adaptability to various climates, high oil and protein quality, and suitability for animal feed (Heshmatpure and Yousefi Rad, 2012).

Another promising solution involves utilizing plant residues by converting them into biochar. Biochar has attracted considerable interest as a material capable of mitigating global warming, given its high Iran potential for reducing greenhouse gas emissions and storing carbon in soil for extended periods. Studies have shown that biochar enhances soil water retention and nutrient availability, improves aeration, and regulates microbial activity in the soil (Lou et al., 2017). Research indicates that factors such as the raw material used for biochar production, processing temperature, soil characteristics, crop type, and irrigation method directly affect biochar performance (Shi et al., 2020; Chandra et al., 2020) investigated the effects of rice husk biochar on nutrient absorption in soil and reported that biochar enhances nutrient retention on its surface and releases them gradually for plant use. One of the objectives of this study was to investigate the effect of biochar pyrolyzed at 400 degrees Celsius on rapeseed yield. application of biochar and nitrate fertilizer under rainfed cultivation conditions had a significant effect on root morphology, grain yield, nitrogen absorption and use of rapeseed, but these effects were different with different rates of urea and biochar application and increased the number of seeds per pod by 22% and rapeseed grain yield by 46% (Tian et al., 2020). Similarly, found that water deficit stress reduced rapeseed oil yield but had no significant impact on oil percentage (Zali et al., 2019).

Environmental stresses, especially drought stress, are among the most important factors reducing the growth and development of oilseed crops such as rapeseed in arid and semi-arid regions. The aim of this study is to investigate the effect of biochar and biosulfur on grain yield and some ecophysiological traits of rapeseed under drought stress conditions in winter cultivation. Along with the increasing population growth and the need for more food production, the expansion of agricultural production and its adverse effects on soil and water resources has increased. Drought stress is one of the most important limiting factors for agricultural production in the world, affecting various aspects of plant growth and causing reduced and delayed germination, reduced shoot growth, and reduced dry matter production (Liu, 2024).

Drought stress in Iran is one of the most important limiting factors for physiological and nutritional growth of plants, leading to reduced biomass and yield (Ihuoma and Madramootoo, 2017). On the other hand, adding biochar to the soil can be important due to the role that carbon plays in chemical, biological, and physical processes in the soil (Berek et al., 2011). In fact, biochar, due to its special physicochemical properties such as porosity and specific surface area, High, high resistance to biodegradation, being rich in absorbable elements and materials, high cation exchange capacity and having high water retention capacity play an important role in the physical, chemical and biological properties of the soil (Lehmann and Joseph, 2009). Therefore, considering Iran's location in an arid and semi-arid region and also the severe reduction in rainfall types and the fall in groundwater levels, any reduction in water consumption in the agricultural sector can be very important and significant.

Therefore, considering Iran's location in an arid and semi-arid region and also the severe reduction in rainfall types and the fall in groundwater levels, any reduction in water consumption in the agricultural sector can be very important and significant. Therefore, the purpose of this research is to investigate the effect of eucalyptus tree pruning biochar on grain yield, oil content and some rapeseed traits under drought stress conditions. This study is novel in its simultaneous evaluation of deficit irrigation and eucalyptus biochar in experimental plots, a topic not previously explored in Iran. The existence of large resources produced from eucalyptus pruning in the tropical regions of Iran justifies paying more attention to the production of this eucalyptus biochar.

2. Material and methods

2.1. Location and site characteristics

This study was conducted as a factorial experiment based on a completely randomized block design at the research farm of the Faculty of Water Engineering, Shahid Chamran University of Ahvaz, over two agricultural years (2021–2022). The study site is located in southwestern Iran at a latitude of 31°30'N, a longitude of 48°65'E, and an altitude of 18 meters above sea level. According to long-term meteorological data (25-year period) from the Ahvaz synoptic station, the region experiences an average annual rainfall of 230.3 mm, a relative humidity of 48.93%, a maximum monthly average temperature of 33.00°C, a minimum monthly average temperature of 17.94°C, and an annual mean temperature of 25.36°C.

2.2. Agricultural practices

Soil preparation was carried out in October 2021, involving plowing, disking, and leveling the land. Plots with dimensions of 1 × 2 m were established, and Hyola 50 rapeseed seeds were manually sown on November 22, 2021, at a density of approximately 30–35 kg per hectare. Fertilizer application was based on soil test results and was provided at the four-leaf stage and rosette stage through both foliar application and soil incorporation.

Fig. 1. Illustration of biochar being incorporated into soil alongside the measurement of irrigation water volume.

Irrigation scheduling was based on the soil's field capacity (FC) and permanent wilting point (PWP), with 50% of the plant-available water (MAD = 50%) being depleted before irrigation. Gravimetric soil moisture content was measured to determine irrigation needs. Irrigation was applied using a flood irrigation method. The formulas for net irrigation depth, leaching requirement, and gross irrigation depth are presented in Eqs. 1–3. Fig. 1 illustrates the field preparation and water application measurement process. Irrigation volume was measured for each plot using a mechanical water volume meter (WI).

$$Fn = (FC - m) \times D \qquad (1)$$

In Eq. 1, Fn: Net irrigation depth (mm), FC: Field capacity (% volumetric moisture), m: Soil moisture before irrigation (% volumetric moisture), and D: Root depth (cm).

$$Fg = \frac{F_n}{E_a(1 - L_R)} \qquad (2)$$

In Eq. 2, F_g = Gross irrigation depth.

$$LR = \frac{EC}{5EC - ECa} \qquad (3)$$

In Eq. 3, the leaching requirement (LR), irrigation water salinity (ECiw, in ds/m), and the salinity of the soil saturated extract (ECe, in ds/m) are related to the plant's tolerance limit to salinity for achieving 100% yield.

2.3. Biochar preparation

In this study, biochar was produced from pruned eucalyptus wood using pyrolysis at 400°C in an oxygen-limited environment. The resulting biochar was ground into powder and incorporated into the soil of experimental plots. Biochar treatments included a control (0%), 1% by weight (B2), and 2% by weight (B3), mixed into the soil to the rooting depth. Biochar was measured using a digital scale for each plot, and then, similar to conventional agricultural operations, a complete mixing of biochar and soil was carried out using a hand shovel to a depth of 30 cm, and a biochar and soil mixture was obtained using a rake.

2.4. Irrigation treatments

Irrigation treatments included a control (100% of crop water requirements, I1) and three deficit irrigation levels: 85% (I2), 70% (I3), and 60% (I4) of water requirements. Deficit irrigation was applied after the four-leaf stage and continued until the end of the growing season. The layout of experimental blocks is shown in Fig. 2, where "R" represents the replication number of each plot.

$I_2B_2R_1$	$I_4B_1R_1$	$I_1B_3R_3$	$I_3B_2R_1$
$I_1B_2R_2$	$I_4B_3R_3$	$I_4B_2R_3$	$I_3B_3R_2$
$I_4B_1R_3$	$I_4B_3R_2$	$I_1B_2R_3$	$I_1B_3R_1$
$I_4B_1R_2$	$I_3B_1R_1$	$I_1B_1R_2$	$I_3B_1R_3$
$I_4B_2R_1$	$I_3B_3R_1$	$I_2B_3R_2$	$I_3B_2R_2$
$I_4B_2R_2$	$I_1B_2R_1$	$I_2B_1R_3$	$I_1B_1R_1$
$I_2B_2R_2$	$I_2B_3R_1$	$I_3B_3R_3$	$I_1B_3R_2$
$I_2B_3R_3$	$I_3B_1R_2$	$I_2B_2R_3$	I_2B_{1R2}
$I_2B_1R_1$	$I_3B_2R_3$	$I_4B_3R_1$	$I_1B_1R_3$

Fig. 2. Layout of experimental plots.

2.5. Sampling and data analysis

At physiological maturity, when seeds were fully developed and approximately 50% of the seed pods had turned brown, ten representative plants were randomly selected from the central rows of each plot to minimize edge effects. The following agronomic traits were evaluated. Plant Height Measured (in cm) from the soil surface to the tip of the main stem using a graduated meter stick, with the mean height calculated per plot. Total seed weight per plant was determined using a precision digital balance, and yield per plot was extrapolated accordingly A random subsample of seeds was weighed, and the weight of 1,000 seeds was calculated to estimate seed size and uniformity. Quantified through hexane extraction using a Soxhlet apparatus, with oil content expressed as a percentage of seed dry weight. Plants were collected from the middle rows to ensure data consistency and reduce border influence. High-precision digital scales and standardized Suxhlet extraction protocols were employed to ensure reproducibility. Data normality was tested, and analysis of variance (ANOVA) was performed using SPSS software. The normality of the data was checked using the skewness and kurtosis interval method and the Kolmogorov-Smirnov test, and the significance test was performed using the Duncan method. Fig. 3 shows the growth stages and sampling process. Table 1 presents the physical and chemical properties of the soil used in the study. In Table 2 some properties of eucalyptus biochar are shown. Also, Table 3 irrigation water specifications is shown.

Fig. 3. View of plant growth stages and required measurements.

Table 1. Physical and chemical properties of soil.

Parameter	Value	Parameter	Value
Clay (%)	27	Pb (g/cm^3)	1.40
Silt (%)	25	N (%)	47
Sand (%)	48	N (%)	0.05
Soil Texture	Sandy loam	Na (mg/kg)	14
ECe (dS/m)	2.6	Ca (mg/ kg)	173
pH (no units)	7.3	K (mg/ kg)	59
Organic Matter (%)	0.73	CEC (cmol/kg)	6.23
FC (%)	17	AEC (cmol/kg)	1.42
PWP (%)	8	-	-

Table 2. Some properties of eucalyptus biochar.

Parameter	AEC	CEC	P	O	S	H	C	N	EC	pH
Unit	(cmol/kg)	(cmol/kg)	(mg/kg)	(%)	(%)	(%)	(%)	(%)	(dS/m)	-
Value	9.41	13.73	0.61	11.4	0.74	1.7	28.5	2.1	6.91	7.7

Table 3. Irrigation water specifications.

SO_4	Cl	HCo_3	K	Na	Mg	Ca	(Mgr/Lr)TDS	(Ds/m) Electrical conductivity	(pH)
Milliequivalents per liter									
8.29	12.27	3.51	0.1	13.3	4.1	7.4	1360	2.64	7.5

3. Results and discussion

The total water consumption for rapeseed during the growing season was 631 mm. Water deficit treatments applied after the four-leaf stage resulted in consumptions of 518 mm, 466 mm, and 430 mm for the 85%, 70%, and 60% irrigation levels, respectively. Following data normalization, analysis of variance (ANOVA) was conducted using Duncan's test. Table 4 presents the ANOVA results for yield and yield components. The findings revealed that irrigation levels significantly influenced plant height, thousand-seed weight, biomass, and oil percentage. Biochar application significantly affected pod number per plant, plant height, and yield, but no significant impact was observed on oil percentage. The interaction between irrigation levels and biochar significantly affected oil percentage but did not result in significant differences for pod number, plant height, or yield. These results align with those of (Oladele et al., 2019), who reported that increasing biochar levels enhanced crop yield. Similarly, demonstrated that biochar application mitigates the adverse effects of drought stress by increasing antioxidant activity and soil fertility.

Table 4. Simple variance analysis for the studied traits.

Source	DF	Mean squares					
		Number of pods	Plant height	TSW	Oil %	Biomass	Yield
Irrigation levels	3	** 69/8960	** 04/1004	** 73/7829	** 43/53	** 30/7375	** 44/4993044
Biochar levels	2	*53/3120	* 36/403	ns86/1420	ns58/0	ns44/2728	* 00/1932100
Irrigation*Biochar	6	ns 53/1597	ns 51/147	ns 68/905	* 21/24	ns 52/836	ns 22/480822
Error	24	39/1306	17/110	75/944	58/7	94/1540	56/501780

ns, * & **: not significant, significant at 1% and 5% probability level.

3.1. Mean performance of treatments

The variations in mean yield under different irrigation and biochar treatments are presented in Fig. 4. The control treatment (full irrigation) achieved the highest yield, averaging 4,736 kg/ha, whereas the lowest yield was observed in the treatment with 60% irrigation, averaging 2,993 kg/ha. Statistical analysis indicated that all irrigation levels significantly affected crop yield. However, the I2 treatment, which supplied 85% of the water requirement, showed no statistically significant difference compared to the control, despite a yield reduction of 528 kg/ha. Among the biochar treatments, the highest yield was recorded in the B3 treatment, with 4,429 kg/ha, demonstrating a significant improvement compared to the control (no the biochar application). This finding aligns with the study conducted by Katuwal et al. (2020), who reported that increasing biochar levels in agricultural soils enhances canola yield. Conversely, the B2 treatment, with an average yield of 3,825 kg/ha, did not result in a statistically significant difference compared to the control.

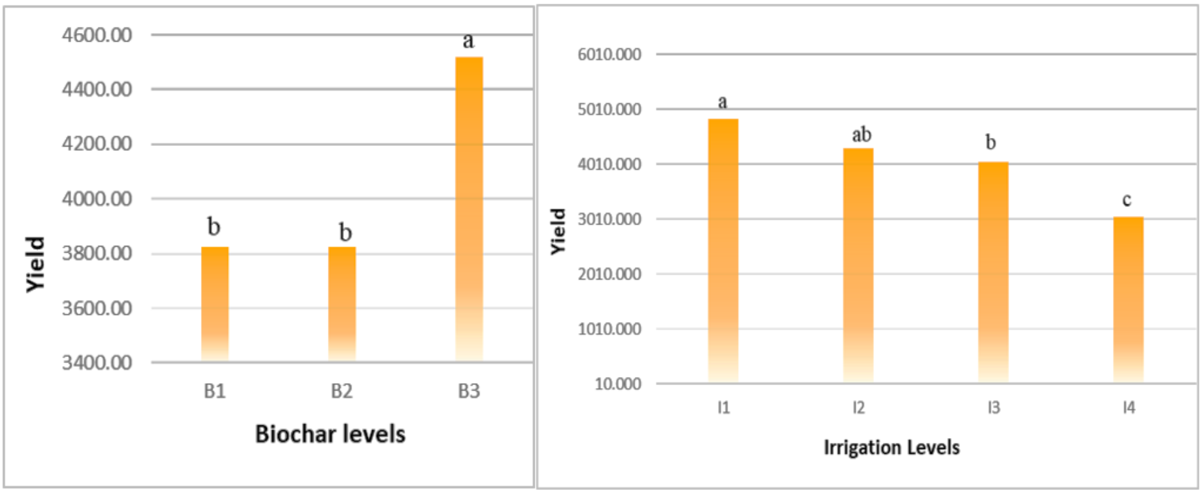

Fig. 4. Changes in average yield due to deficit irrigation and biochar treatments.

The variations in the mean thousand-seed weight (g) are illustrated in Fig. 5. The highest mean value was recorded for the control treatment (I1) at 365 g, while the lowest was observed in treatment I4 at 294 g. Although treatment I2 showed a 25 g reduction in thousand-seed weight compared to the control, this difference was not statistically significant. Conversely, significant reductions in seed weight were observed under other deficit irrigation treatments, highlighting the impact of water stress. Additionally, a statistically significant difference was detected between the 70% (I3) and 60% (I4) water requirement treatments. a study performed a coupling of meta-analysis and structural equation model (SEM) based on the establishment of a dataset containing 981 sets of observations. The results demonstrated that biochar significantly and durably boosted crop yield, and biochar also has shown an average increase of 36.2% in SOC over a monitoring period exceeding 2 years. Crop yields increased by an average of 16% after biochar application for the long-term scale, although the increase varied across crop types, and biochar application performed better on corn and wheat than paddy rice production (Jiang et al., 2024).

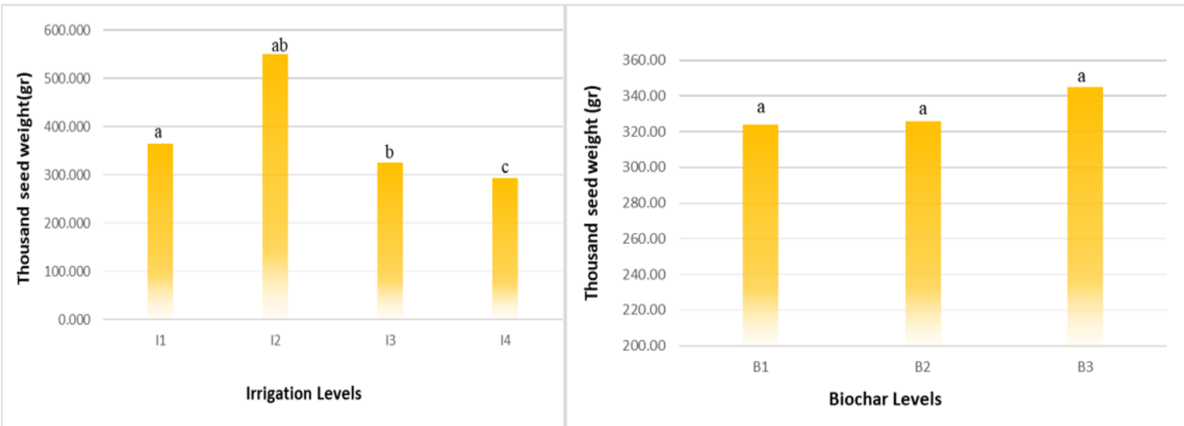

Fig. 5. Changes in average thousand seed weight due to deficit irrigation and biochar treatments.

The average change in canola plant height for different levels of irrigation and biochar is shown separately in Fig. 6. The difference between the highest treatment (138 cm) and the lowest treatment with 115 cm is about 17%, which indicates a significant decrease with the application of deficit irrigation, which is related to treatments I1 and I4, respectively. Other deficit irrigation levels, despite the difference, do not show a significant difference.

The average change table for biochar treatments shows that increasing eucalyptus biochar at a level of 2% (treatment B3) caused a 9% increase compared to the control treatment (without biochar), but this difference was not significant. Treatment B2 with a height of 122 cm shows a 4% difference compared to the control treatment.

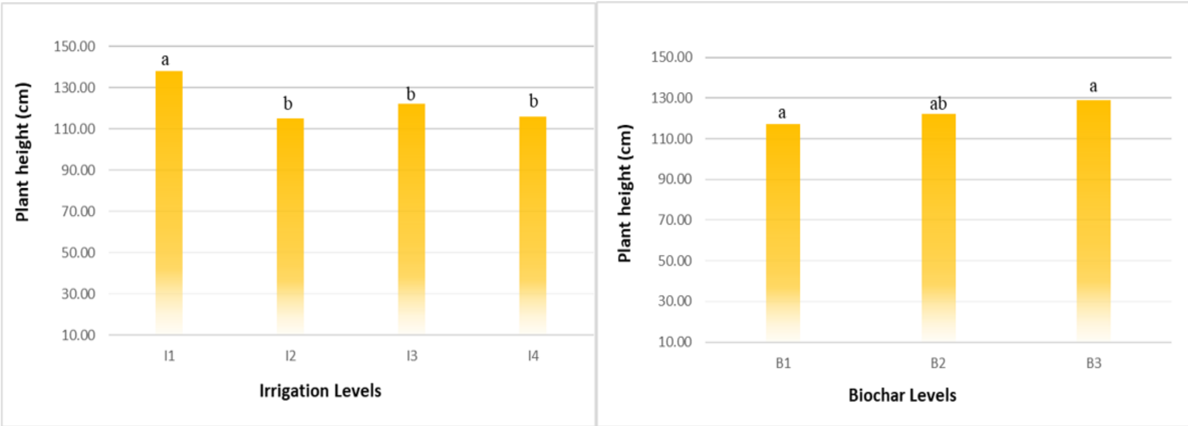

Fig. 6. Changes in average plant height due to deficit irrigation and biochar treatments.

Fig. 7 shows the changes in rapeseed oil percentage. The highest oil percentage was related to the control irrigation treatment with 36% oil and the lowest was related to the B4 treatment with 30% oil, which was the only significant difference observed between these two treatments, and the other treatments did not have significant differences. Increasing biochar at a level of 2% (B3 treatment) did not increase the oil percentage compared to the control treatment, and no significant difference was observed in this regard. Zali et al. (2019) studied the effect of drought stress on the oil percentage and fatty acid percentage in rapeseed, which showed that drought stress, despite reducing the oil percentage, did not cause a significant difference.

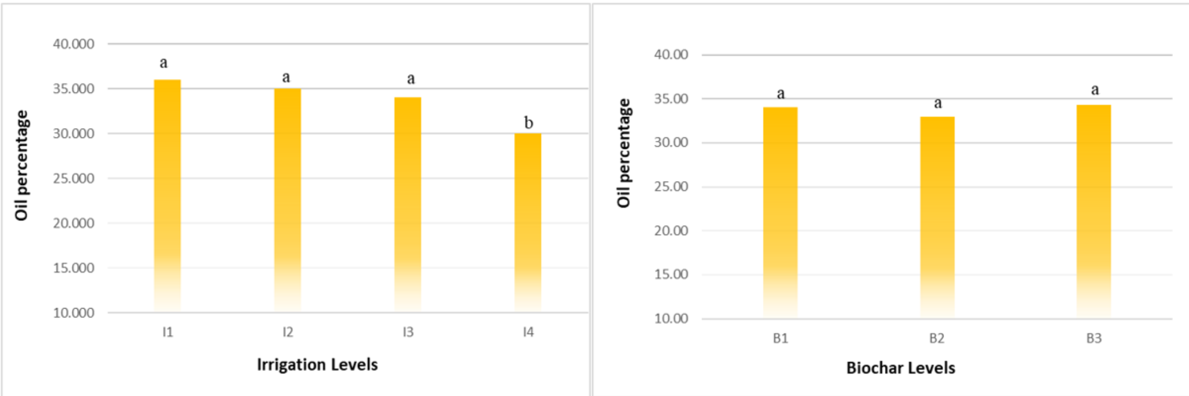

Fig. 7. Changes in average seed oil percentage due to deficit irrigation and biochar treatments.

Fig. 8 shows the changes in yield in the combined treatments of irrigation levels and biochar. The highest yield in the combined treatments was related to the control treatment with 5133 kg/ha and the lowest was related to the I4B1 treatment with 2616 kg/ha, which indicates the effect of biochar on drought stress tolerance in rapeseed. After that, the I2B3 and I3B3 treatments had the highest yield. The I3B1 and I3B2 treatments were in the same order (no significant effect) but had a significant difference with the control treatment. Also, the I4B1, I4B2, and I4B3 treatments were in a significant group, meaning they did not differ significantly from each other but had a significant difference with the control treatment. After these three treatments, the I3B1 and I3B2 treatments had the greatest yield reduction compared to the control treatment. Moridsadat et al. (2022) showed in a study that increasing the level of biochar in the soil improves the tolerance of drought stress (up to 80% of water requirement) by the plant, which is consistent with the results of this study.

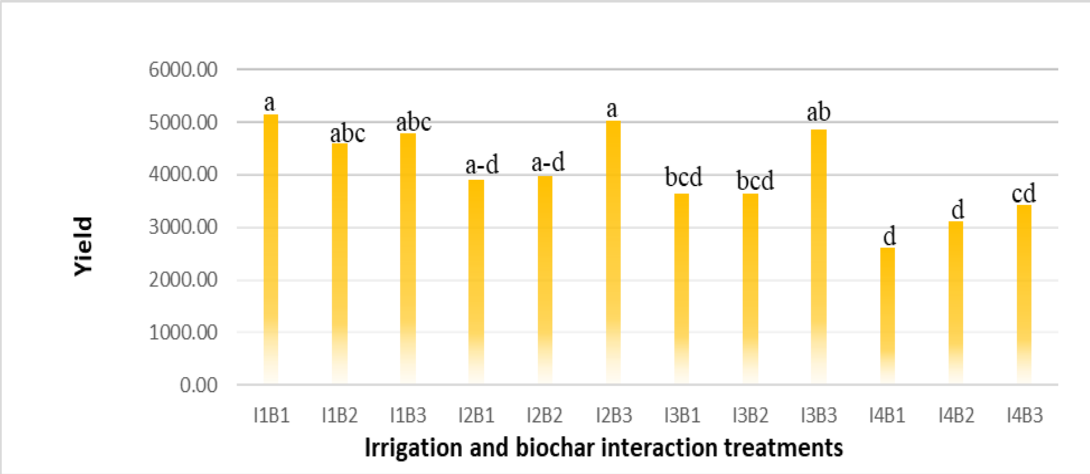

Fig. 8. Changes in average yield (kg/ha) due to interaction levels of deficit irrigation and biochar.

According to Fig. 9, the highest number of pods per plant due to deficit irrigation and biochar levels was related to the I1B3 treatment with 220 and the lowest was related to the I4B3 treatment with 83 pods per plant, both of which also had a significant difference with the control treatment. The other treatments did not have a significant difference despite the percentage difference. Karimi Movahedi (2023) conducted a study on the effect of biochar on rapeseed yield under drought stress conditions. His results showed that adding 3 tons and 6 tons per hectare of biochar to the arable soil had a significant effect on the number of pods per plant, which is not consistent with the results of this study. The reason for its inconsistency with the results of the present study can be attributed to the difference in ambient temperature between Karaj and Ahvaz. The heat of the air causes a sharp increase in drought stress and brings the results of the treatments closer to each other.

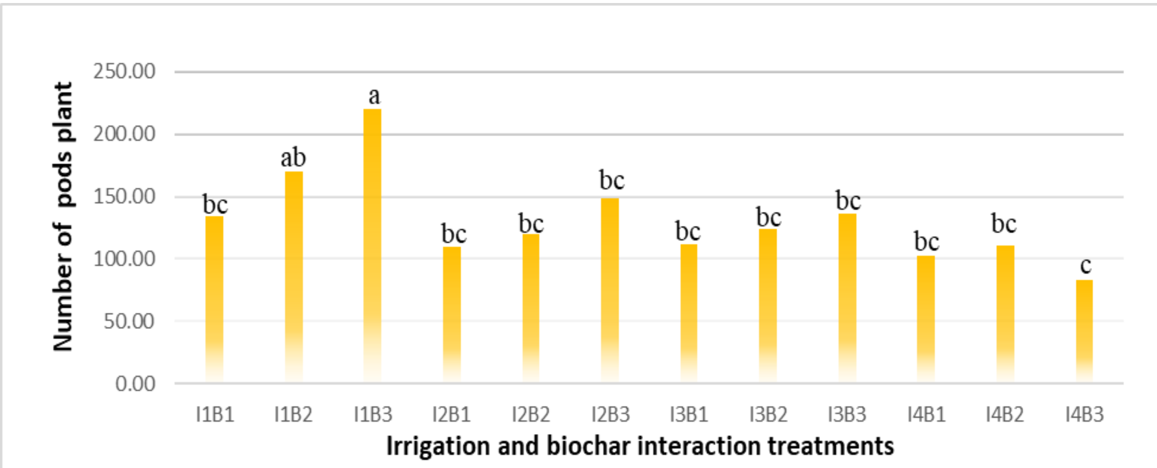

Fig. 9. Changes in the average number of sedges per plant due to interaction levels of deficit irrigation and biochar.

The highest plant height in the I1B3 treatment was 153 cm and the lowest height in the I2B1 treatment was 106 cm, which were 18 and 15 percent different from the control treatment, respectively, and this difference was significant. The results show that the combined effect of biochar reduces the effects of drought stress on plant height, and the other treatments, despite the reduction in plant height, did not show a significant difference. Poormansour et al. 2019 showed in his study of the effect of biochar and deficit irrigation that increasing biochar at a level of 1.5 percent by weight improves the height trait of wheat, which is consistent with the results of this study. The results are shown in Fig. 10. Although increasing biochar levels improved 1000-grain weight, except for the treatment without water stress (I1), increasing the use of eucalyptus biochar did not cause a significant change during drought stress. Treatment I1B3 with 392 grams and treatment I4B1 with 272 grams had the highest and lowest 1000-grain weight, respectively. Reducing irrigation water by 40%

reduced rapeseed grain weight by 20%, but increasing biochar at 2% (B3) only reduced grain weight by 6%, indicating the positive effect of eucalyptus biochar (Fig. 11). Mir et al. (2021) also achieved similar results in improving plant performance under drought stress conditions by adding 2.5% biochar by weight.

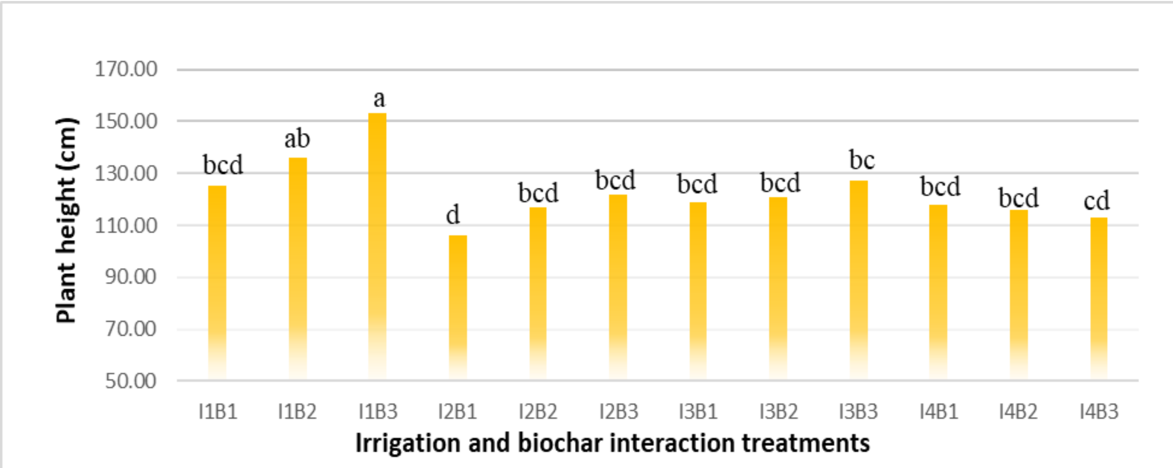

Fig. 10. Changes in the average number of sedges per plant due to interaction levels of deficit irrigation and biochar.

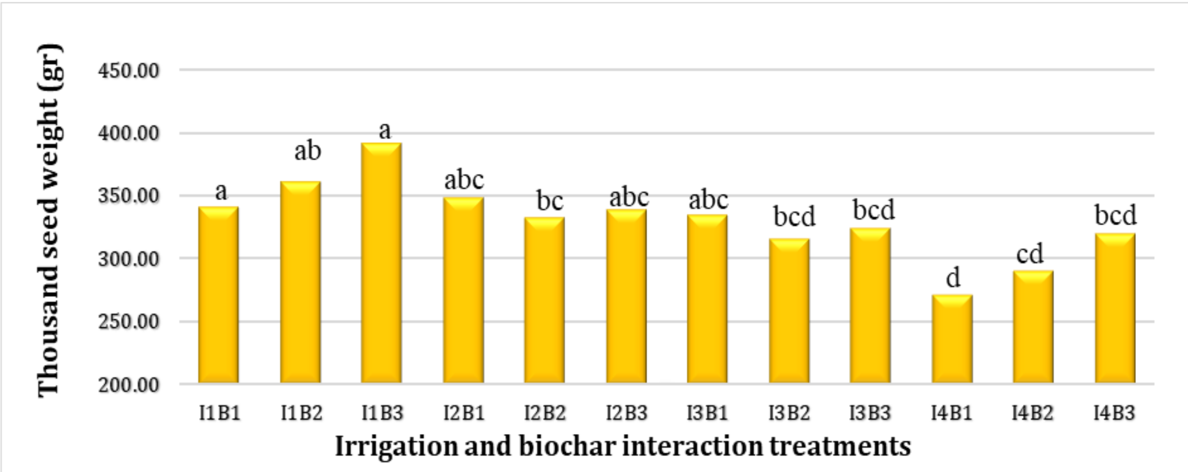

Fig. 11. Changes in the average weight of thousand seed due to interaction levels of deficit irrigation and biochar.

4. Conclusion

The results of comparing the means showed that adding biochar to the soil improves the yield of rapeseed and in treatments where drought stress is applied during the plant growth period, it improves the yield and brings the results closer to the control treatment. The results showed that adding biochar did not cause a significant effect on yield components such as oil percentage, number of pods per plant, but it caused a significant difference in the trait of thousand-seed weight. The results showed that applying deficit irrigation at 15% does not cause a significant decrease in yield. This study also showed that adding biochar less than 2% by weight to the soil will not have a significant effect on rapeseed plant yield. Although the physicochemical characteristics of the soil were not measured at the end of the study, according to the analysis of the biochar used in this study, it is likely that the application of biochar to the soil improved the absorption of elements and consequently had a positive effect on the yield of rapeseed plants. Biochar reduces the leaching of agricultural fertilizers, thereby helping them be absorbed by plants and improving crop yield. a study showed Biochar can potentially change the soil physico-chemical environment significantly, this evaluation did by Four biochar treatments of 0, 10, 50, and 100 t ha^{-1} based on the former 2 year's results. The results indicated that increasing BAR significantly increased Na^+, K^+, and soil nutrient contents in cotton and sugarbeet fields (Qi et., al 2024). It is also likely that the increase in soil moisture retention capacity with the application of biochar has led to the plant's resistance to water deficit conditions. According to the results obtained in areas with a lack of available water resources, using a level of 2% biochar at a shallow depth of cultivation and deficit irrigation with 80% of the water requirement can be recommended for better productivity. Given that the temperature at which biochar is prepared is very effective in its properties and effects on water-soil-plant relationships, different temperatures such as 300 and 200 degrees Celsius can be used in other research to find the optimal temperature for producing eucalyptus biochar.

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