Effect of Biochar and Moisture Regimes on the Physiology and Yield of Maize

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Abstract

In the face of declining water resources and increasing need for water requirements for agricultural purposes under changing climatic conditions. Nowadays the world is an overlay with a lot of problems for crop production among them drought is the most harmful. The three maize hybrids (Dk-2088, Yh-5427, and Dk-6317) were sown on 16 February 2023 to explore the suitable level of biochar under different moisture regimes (100% ETC, 80%ETC, 60% ETC,) level of biochar was applied at the rate of 0 tons/ha (no Biochar), 5 tons per hectare, and 10 tons per hectare (The experiment was conducted in a split-plot design according to RCBD). The present study was conducted in the village Hardas Pur district (Gujrat) at locations 32°38.37′N, and 74°9.00′E to identify the appropriate level of biochar under three moisture regimes (100%, 80% and 60%). The research focuses on adding activated biochar to the soil applied at the rate of 5 tons ha−1, 10 tons ha−1, and 0 tons ha−1 under three water deficit conditions FI, Full irrigation treatments, OI optimum irrigation, 80%, and DI deficit irrigation 60%. Biochar treatment under optimum irrigation gave better growth and yield than deficit irrigation. The application of biochar significantly mitigated the reduction in thousand-seed weight and seed weight per cob under water deficit conditions, improving these traits by 8.02-28% compared to non-amended soil. The highest values were observed in DK-6317 under full irrigation, with marked improvements across hybrids and irrigation levels. This research highlights biochar's effectiveness in enhancing maize growth, yield, and physiological traits under full, optimum, and deficit irrigation regimes. Amending soil with 10 tons per hectare of biochar significantly improved soil health and agricultural productivity, showcasing its potential as a sustainable soil amendment.

Keywords: Biochar, Soil, Chlorophyll, Hybrid, Klin

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Introduction

Extremely growing population, urbanization, industrialization and varying climatic conditions pose serious environmental threats all over the world. Among developing countries, Pakistan is the leading victim and facing the serious threats of these changes (Sajjad et al., 2022). Agricultural systems need to be highly water-use efficient to fulfil the demands of a world population that is increasing gradually (Dietzel et al., 2016; Munyasya et al., 2022). Excessive fertilization threatens sustainable agricultural developmental goals. (Gomiero et al., 2011) And causes serious ecological and environmental problems like biodiversity loss and pollution of soil (Bruulsema, 2018), biodiversity loss (Li et al., 2023), and water pollution (Geza et al., 2021), which can lead to low productivity. Thus, using soil management techniques with confined irrigation is essential to achieving high water-fertilizer use efficiency and maintaining the natural environment. Biochar is a versatile spongy material with a large surface area and small size, large surface area, high adsorption capacity, and excessive carbon content that gathered a lot of attention. (Khalili et al., 2020; Obia et al., 2020; Hale et al., 2021; Tian et al., 2021). The major reason behind these abnormal climatic conditions is primarily because of increasing temperature and scarcity of water abruptly affecting the production and yield of crops qualitatively as well as quantitatively over the past century, drought conditions are predominant around the globe and major regions of Pakistan have been under moderate to severe drought conditions (Khan et al., 2020). While future predictions are very threatening, regarding availability around the globe (Kim et al., 2022). Increasing levels of carbon dioxide and temperature enhance the rate of evapotranspiration, subsequently, plants need a large quantity of water to fulfil their basic need for water. Moreover, due to the increasing population all over the world, the requirement for food can be fulfilled by overutilizing land resources, but this phenomenon can lead to the deterioration of soil and loss the essential nutrients and minerals from the soil if overharvesting and sowing of crops cannot managed appropriately (Jahan et al., 2020). Various types of soil amendments, involving organic matter, animal manure, gypsum, and lime are employed to enhance soil fertility. At present applying different doses of biochar to the soil is the most effective and eco-friendly method for maintaining and protecting the fertility of soil. (Kloss, S. et al.2014). Current research has shown that biochar is a useful agricultural practice for enhancing the uptake of water and soil conditions in farmland and increasing the yield of crop and fertilizer use efficacy because of its distinctive architecture (Clough et al., 2013: Laghari et al., 2015: Haider et al., 2017: Lin et al., 2017). Biochar has a spongy structure that persuades an adsorption ability for water and nutrients and can slow the release of moisture and nutrients to enhance the growth of plants. Biochar has a strong influence on soil nitrogen and it can increase leaf photosynthesis (Kamman et al., 2011: Ali et al., 2020). The addition of activated biochar to soil has a useful strategy to increase the effectiveness of using (i) To identify the influence of biochar application on soil. (ii) To recommend the suitable level of irrigation regimes and application of biochar to increase the maize physiological and yield attributes.

Materials and Methods

Production and Activation of Biochar

Acacia wood branches were used to produce the biochar. The biochar was prepared and heated at a kiln typically temperature of 20 ℃ until reaching a temperature of 350 ℃ to 400 ℃ having pyrolysis for three fifty hours.

Research Location and Treatment

The research was directed from 18 February to 15 June 2023 in the village Hardaas Pur, Gujrat Pakistan (32°38.37'N, 74°9.00'E) to categorize the suitable amendment of biochar under different irrigation regimes. The soil was collected at a depth of 0.00-0.20-meter layer pH was determined by ISO 10390 and electrical conductivity was identified by the method of Rayment & Higginson (1990).

Climatic condition:

The monthly climatic data were collected from Lahore metrological departments from February 2023 to June 2023. The data showed that the highest temperatures were recorded during May and June (35.5°C and 36.3°C), while the lowest temperatures were recorded during February (8 °C and 20 °C).

Estimation of Physiological Parameters

The leaf membrane stability index was identified by using the procedure of Premachandra et al. (1990). The chlorophyll content was determined by Arnon ((1949), and initially 0.1 g of leaf material was ground with five mL of 80% acetone. After centrifugation, the supernatant was taken and absorbance values were recorded at 645 nm, and 663 nm, and the values were determined by using the following formula:

$$Total\ chlorophyll\ content = 20.2(A645) + 8.02\ (A663)$$

Yield analysis

After gathering of maize crop, the following yield-related parameters were recorded seed weight per cob (g) and thousand seed weight with the help of an electrical weighing balance. These parameters help to assess the overall productivity of maize crops**.**

Data analysis

The experiment was conducted in a split-plot design according to RCBD. The data were examined by using the MINITAB 19 software by applying three-way ANOVA through general linear model (GLM) and multivariate analysis. A 95% confidence level was used to assess the level of significance between the treatments.

Results

Physiochemical Analysis of soil.

The soil physiochemical attributes are presented in Table 1. The EC (electrical conductivity) was considerably higher (28.6-41.5%) although slightly enhanced in pH in Biochar-amended soil 6.97% to 5.60% were recorded when compared with non-amended soil. The soil amended with B1 (5 tons-1) and B2(10 tons-1) enhanced organic matter (15-230%) as compared to B0 (control soil).

Physiological parameters

The three-way ANOVA of maize hybrid in (5tonsh^{-1}) and B2(10 tons-1) biochar-amended soil demonstrates that soil amended with biochar considerably enhanced the membrane stability index (MSI) by (18% to 28. 5%). The highest membrane stability index was recorded in maize hybrid Dk-6317 i.e. 67.6% while in Dk-2088 and Yh-5427 (62.1% and 52.6%). Moreover, the treatment 100% ETC (full irrigation) gave a higher membrane stability index than at 80% (OI) and 60% ETC, the membrane stability index was enhanced by 64.5, 62.1, and 57.8 as compared to other ETC without biochar. The three-way (ANOVA) was used to determine the connection of total chlorophyll contents under three moisture regimes of 100%, 80% and 60% of ETc, amendment level with (0,5,10 tonnes acre^{-1}) and three maize hybrid (Dk-2088, Dk-6317, and Yh-5427) at reproductive stage. The result demonstrated that the soil amended with B1 (5tonsh^{-1}) and B2 (10tonsh^{-1}) revealed that total chlorophyll contents were enhanced by 20.2% to 25.6% in contrast to B0 (0tonsh^{-1}) soil without biochar. Furthermore, the treatment 100% ETC (full irrigation) gave the highest total chlorophyll content in contrast to 80% ETC (OI) and 60%ETC (DI) ETC, the total chlorophyll content was increased by 7.19, 6.80 and 6.72 as compared to non-amended soil.

Yield analysis

The thousand seed weight and seed weight per cob of the maize hybrid treated with biochar and various watering schedules showed a significant impact, according to the three-way ANOVA. The shortage of water caused a reduction in both thousand seed weight and weight per cob while supplementation of biochar mitigated the reduction of thousand seed weight and seed weight per cob by 8.02% to 27.1%, (16.5% to 28%) when compared with B0 (soil without biochar). The highest thousand-seed weight and seed weight per cob was observed in Dk-6317 (368 g: 106.5), followed by Yh-5427 (323 g: 104%) and Dk-2088 (271 g: 101 g). Moreover, the treatment under 100% ETC (full irrigation) gave the highest thousand-seed weight in contrast to 80% (OI) and 60% ETC, the thousand-grain weight was increased by 465:124, 382:120 and 246:85.6 when compared with non-amended soil.

Discussion

The soil amended with activated biochar enhances the soil organic matter, Ph, and electrical conductivity associated with the high content of carbon in biochar (Joseph et al., 2020; Qi et al., 2020). Furthermore, the soil amended with activated biochar enhanced the organic molecules of the soil. In recent research, because activated biochar oxidizes and produces acids in the soil, it was observed that the soil treated with biochar increased the pH (Premalatha et al., 2023). In plant cells, water stress usually increases oxidative stress, which can cause destabilization and damage to the membrane. Because of membrane lipid peroxidation brought on by the buildup of reactive oxygen species (ROS), dehydrated plants showed a decrease in MSI. (Abd El-Mageed et al., 2021). In plant cells, water stress usually increases oxidative stress, which can cause instability and damage to the membrane, because of membrane lipid peroxidation brought on by the buildup of reactive oxygen species (ROS), dehydrated plants showed a decrease in MSI. (Yildirim et al., 2021).The plants growing in biochar-enriched soil provide higher MSI values in contrast to non-amended soil under comparable shortage conditions. This condition supported the usage of biochar in the soil to enhance the membrane stability of plants and also increase the ability of cell membranes to tolerate the water shortage. Water stress imposed a harmful influence on maize crops and yield attributes under various environmental conditions (Sampathkumar et al., 2013). The amendment of biochar in soil mitigated the water deficit condition because it enhanced the moisture retention and water holding capacity under field conditions.

Maize is sensitive to shortage of water and drought-induced meaningful change to plant physiology and biochemistry. Drought stress damages the photosynthetic pigments and leads to the deterioration of PS1 and PSII of thylakoid membranes (Moustakas et al., 2022, Benešová et al., 2012). The drought stress reduced the total chlorophyll content and it also damaged the ultrastructure of chloroplast in thylakoid membranes that are associated with antennae complex (Shao et al., 2016). Under mild drought stress the photochemical activity decreases in (PSII) QA to PQH2, but in case of severe drought stress the electron transport chain is hindered from PSII to PSI. Photosystem II is more affected by drought stress than photosystem I, this causes a reduction in the movement of electrons through PSII in reaction centres (Liu et al., 2018). The extreme level of drought due to changing climate conditions causes a significant reduction in (PSII), inactivation of oxygen-evolving complex and generation of reactive oxygen species which causes a reduction of photosynthetic pigment in the thylakoid membrane (Shakeel et al., 2022). Recently, it was noted that the plants grown in activated biochar-amended soil significantly increased the total chlorophyll

content in B1 and B2 soil under full irrigation, optimum irrigation and deficit irrigation. Biochar soil has great potential to enhance the soil structure, water retention and enhance the water holding capacity of soil, especially in low-fertility soil with limited water resources. It has greater potential to increase the viable strategy for maintaining climate change and minimize the atmospheric carbon dioxide level and contents of carbon pool in soil for a longer duration.

Conclusion

The current research demonstrates the potential of biochar in enhancing maize growth, yield, and other physiological attributes under varying irrigation regimes, including, full, optimum, and deficit irrigation. The findings indicate that biochar supplementation significantly improves maize physiology and yield parameters compared to untreated soil. Moreover, soil amended with 10 tons per hectare of biochar proved more effective than 5 tons per hectare, achieving superior positive outcomes. The field application of biochar underlines its capacity to enhance soil health and agricultural productivity, reinforcing its viability as a sustainable soil amendment. Future research should focus on optimizing biochar application rates, exploring its synergies with other soil amendments, and assessing long-term environmental and economic impacts on diverse crops and farming systems.

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Conflict of interests

The authors have no relevant financial or non-financial interests to disclose.

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Table: 1. Physicochemical analysis of the soil

Electrical conductivity (EC), pH, 0rganic matter, in to B1 (5 tons ha^{-1}), B2(10 tons ha^{-1}, and B0 (without biochar).

No.	Parameters	(B0) A0 tons ha^{-1}	(B1)5 tons ha $^{-1}$	(B2)10 tons ha^{-1}
1	EC (ds m-1)	0.97±0.001a	0.87±0.04 b	0.72±0.001 c
2	pH	7.31±0.02 b	7.72±0.02 a	7.82±0.06 a
3	Organic matter	0.263±0.02 c	0.66±0.01 b	0.87±0.01 a

This means sharing different alphabets (a–c) are significantly different at P<0.05. ± Value indicates the standard deviation of three replicates.

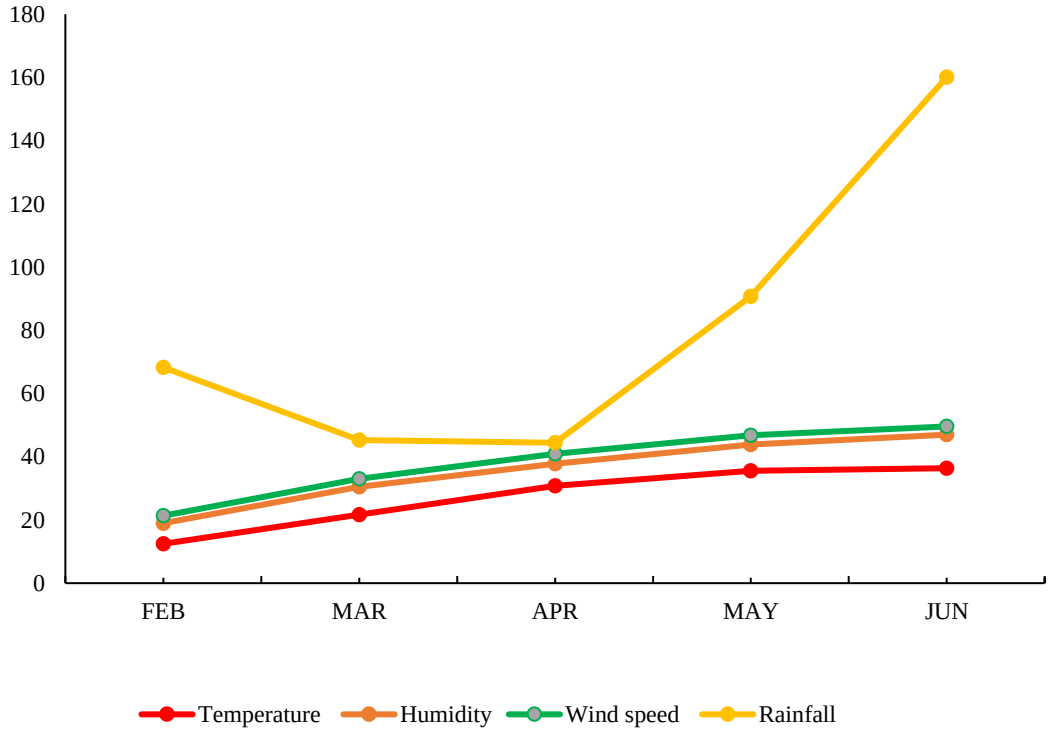
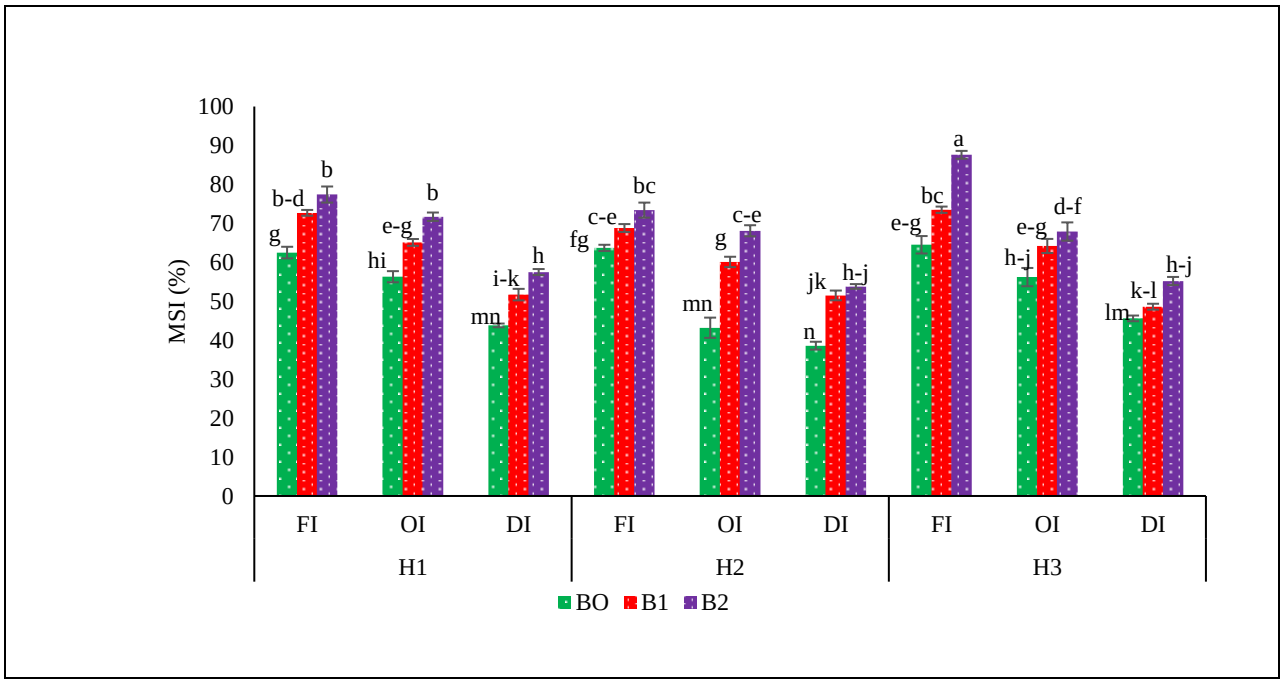
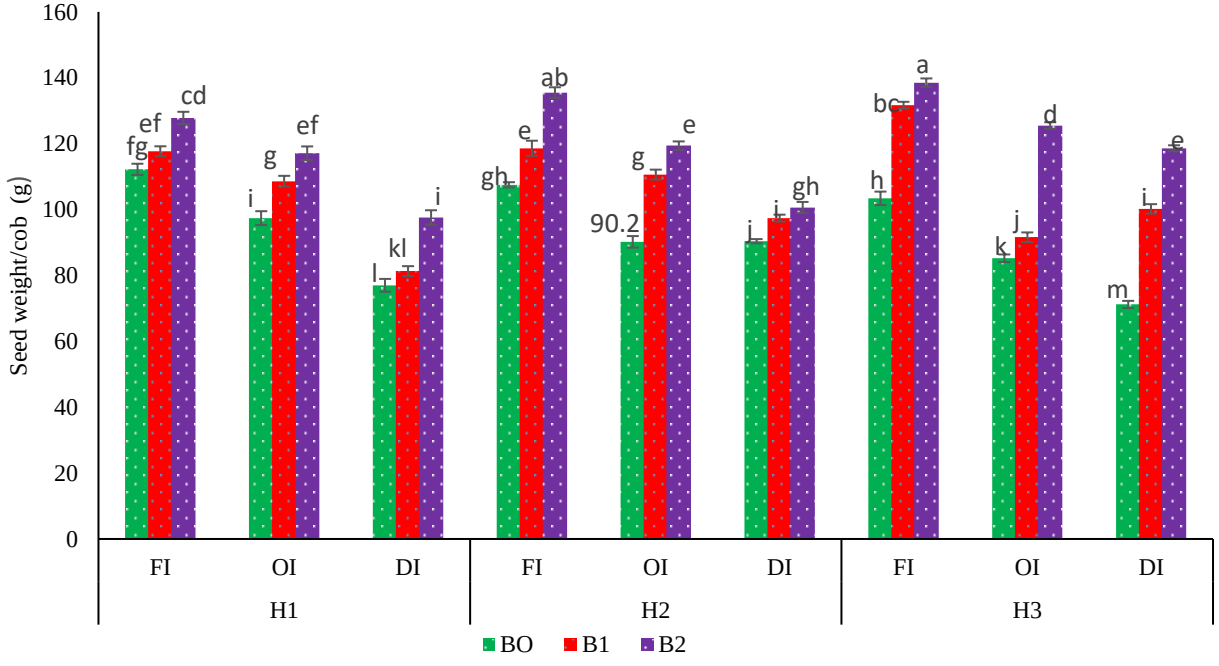


Fig 1. Weather data of Temperature, Humidity, Wind speed and Rainfall

(a)


MSI (%)
100
90
80
70
60
50
40
30
20
10
0
g
b-d
b
hi
e-g
b
mn
i-k
h
fg
c-e
bc
mn
g
c-e
n
jk
h-j
e-g
bc
a
h-j
e-g
d-f
lm
k-l
h-j
FI
OI
DI
H1
H2
H3
BO
B1
B2

(b)


Seed weight/cob (g)
160
140
120
100
80
60
40
20
0
fg
ef
cd
i
g
ef
l
kl
i
gh
e
ab
90.2
g
e
j
i
gh
h
bc
a
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j
d
m
i
e
FI
OI
DI
H1
H2
H3
BO
B1
B2

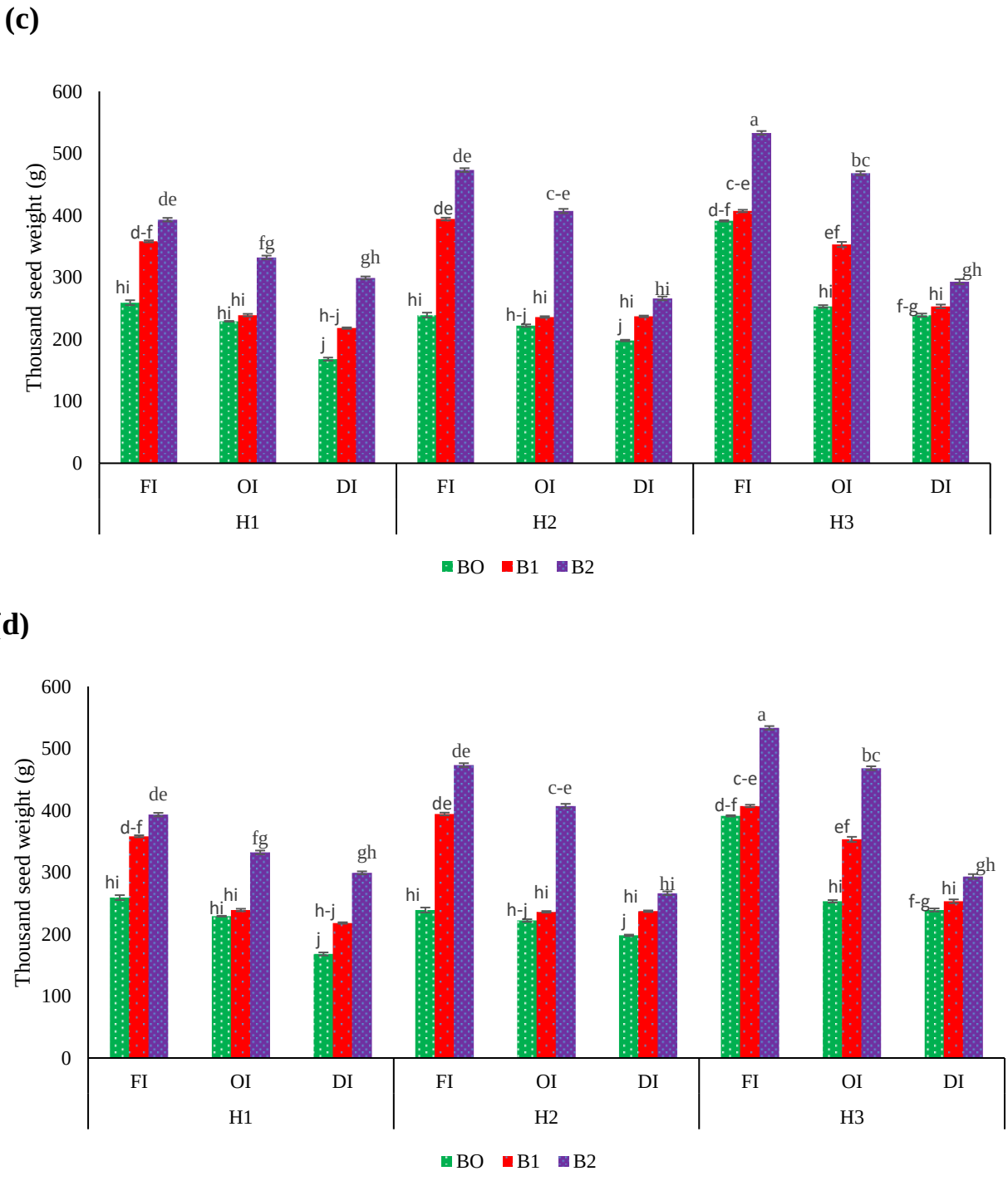

Fig. 2. Impact of 0 tons ha^{-1} (B0), 5 tons ha^{-1} (B1), 10 tons ha^{-1} (B2) activated biochar amendment in soil on three maize hybrids DK-2088 (H1), Yh-5427 (H2), DK-6317 (H3) on **(c)** Seed weight/ cob**)** (b) Thousand seed weight under Full irrigation (FI), Optimum irrigation (OI), and Deficit irrigation (DI)