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Effects of Drought and Biochar Treatments on Some Morphological and Physiological Parameters in Turkish Hazelnut Seedlings

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Abstract

This study investigates the responses of 3-year-old Turkish hazelnut (*Corylus colurna*) seedlings to drought stress and biochar treatments, focusing on critical morphological and physiological parameters. Hazelnut, an important agricultural crop, is increasingly affected by drought due to global climate change. To mitigate these effects, biochar and the adoption of deep-rooted hazelnut systems have gained attention. The study exposed seedlings to varying levels of irrigation and biochar treatments. Results show that drought stress significantly reduced relative height growth (RHG) and relative diameter growth (RDG), while biochar had no effect on RHG and negatively impacted RDG. Decreased irrigation consistently lowered both RHG and RDG under irrigation and biochar interaction. Physiological parameters, including leaf gas exchange parameters (E, gs, Anet, WUE, iWUE, Ci/Ca) and relative water content (RWC), revealed that drought influenced these variables, whereas biochar showed no significant effect. Drought-stressed seedlings exhibited lower net photosynthesis (Anet) and stomatal conductance (gs), with no notable differences in other photosynthesis-related parameters under irrigation and biochar interaction. Chlorophyll and carotene levels also decreased under low irrigation; higher biochar doses exacerbated these reductions. Overall, the study underscores the importance of water availability in hazelnut cultivation, as it had a more pronounced impact on hazelnut morphology and physiology than biochar. However, the limited study period and biochar treatment on topsoil may have influenced these results.

Kuraklık ve Biyoçar Uygulamalarının Türk Fındığı Fidanlarında Bazı Morfolojik ve Fizyolojik Parametrelere Etkisi

Makale bilgisi

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Anahtar Kelimeler:
- Klorofil
- İklim değişikliği
- *Corylus colurna*
- Biyokömür
- Fotosentez

Öz

Bu çalışmada kuraklık stresine ve biyokömür uygulamalarına maruz bırakılan 3 yaşındaki Türk fındığı (*Corylus colurna*) fidanlardaki bazı morfolojik ve fizyolojik parametrelere verdiği tepkiler değerlendirilmeye çalışılmıştır. Önemli bir tarımsal ürün olan fındık, küresel iklim değişikliği nedeniyle kuraklıktan giderek daha fazla etkilenmektedir. Bu etkileri azaltmak için biyokömür uygulamaları ve derin köklü fındık sistemlerinin benimsenmesi dikkat çekmektedir. Çalışmada fıdanlar çeşitli seviyelerde sulama ve biyokömür uygulamalarına maruz bırakılmıştır. Çalışma sonucunda, kuraklığa maruz kalan fidanlarda göreceli boy (RHG) ve çap büyümesinin (RDG) kontrol grubuna göre daha düşük olduğu, biyokömür uygulamasının ise RHG'ye bir etkisinin olmadığı ancak RDG'yi olumsuz yönde etkilediği tespit edilmiştir. Her iki faktörün etkileşimi altında hem RHG hemde RDG'nin azalan sulama miktarıyla genel olarak azaldığı tespit edilmiştir. Fizyolojik parametrelerden yaprak gaz değişim parametreleri (E, gs, Anet, WUE, iWUE, Ci/Ca) ile bağıl su içeriği (RWC) değerlendirildiğinde uygulamalar bazında sulamanın etkisinin olduğu ama biyokömürün bir etkisinin olmadığı tespit edilmiştir. Her iki faktörün etkisi altında ise kurak stresine maruz kalan fidanların daha az net fotosentez (Anet) ve stoma iletkenliği (gs) değerlerine sahipken diğer fotosentez parametrelerinde istatistiki bir farklılık tespit edilememiştir. Ayrıca, düşük sulanan fidanların klorofil ile karoten miktarları genellikle daha düşük çıkmıştır. Biyokömür dozunun artışı fidanlardaki bu değerlerin azalmasına sebep olmuştur. Genel olarak, Türk fındığının morfoloji ve fizyolojisi üzerinde suyun biyokömür'den daha fazla etkisi olduğu söylenebilir. Ancak, çalışma süresinin kısıtlı olması ve biyokömür uygulamasının toprak yüzeyinden yapılması bu sonuçları etkilemiş olabilir.

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INTRODUCTION

Perhaps one of the most important problems that humanity has faced in the last century is global climate change. The global climate change changes affect humans as well as all ecosystems on our planet and all living plants, animals, and microorganisms in these ecosystems (Arıcak et al., 2024; Canturk et al., 2024). However, plant communities that do not have an effective movement mechanism will be most affected by these changes in the climate (Erturk et al., 2024). Due to Türkiye's geographical location, it has arid and semiarid regions, and the herbaceous and woody species in those regions are negatively affected by global climate change (Yıldız et al., 2021; Yıldız et al., 2022).

One of the most negative aspects of global climate change is the drought due to the decrease in precipitation and the increase in temperature and evaporation (Koç, 2022a). In addition, the scarcity of water resources, the opening of more agricultural areas to meet the nutritional needs of the increasing human population, and the increase in the amount of water to irrigate these areas make these adverse conditions even worse for other plant communities. These adverse conditions negatively affect plant communities exposed to dry conditions and stress plants (Seleiman et al., 2021; Cobanoglu et al., 2023). If these adverse conditions continue for a long time, some plants adapt to these changing environmental conditions, while others cannot adapt and end their lives (Cantürk, 2023).

Drought stress is one of the most common environmental stresses affecting growth and yield and induces many physiological, biochemical, and molecular responses in plants. Accordingly, plants can develop tolerance mechanisms that will allow them to adapt to limited environmental conditions (Seleiman et al., 2021). For example, plants reduce their leaf areas to adapt to dry conditions, reduce transpiration by reducing the number of stomata and stomatal openings on the leaves, increase the development of deep root systems and capillary roots, and maximize water absorption in the soil with these capillary roots by extending their roots deeper into the soil (Seleiman et al., 2021; Cantürk, 2023). In addition, photosynthesis, one of the physiological events that occur in the leaves of plants, is negatively affected by drought stress. While the amount of leaf water, net assimilation (net photosynthesis) rate, stomatal conductance, transpiration amount, and photosynthetic pigments are negatively affected in plants exposed to drought stress, internal water use efficiency generally increases (Koç, 2022b; Koç and Nzokou, 2023).

Nutrients are another important factor in plant growth and development (Erdem et al., 2024). However, plants under drought stress cannot take enough plant nutrients from the soil through their roots, adversely affecting plant growth, development, and many metabolic activities in the plant cell (Seleiman et al., 2021; Cantürk, 2023). Plant nutrient uptake is highly affected by the amount of available water in the soil, root morphology, soil properties, amount and quality of fertilizer, and irrigation (Shults et al., 2020; Sargıncı et al., 2022). However, many studies have reported that plant nutrient intake decreases under drought stress (Shafiq et al., 2021; Koç and Nzokou, 2022; Xiao et al., 2023).

Fertilization is extremely important in plant growth. Many types of natural and artificial fertilizers are used. However, especially in recent years, biochar, obtained from natural wastes, stands out because it is obtained from natural wastes (zero waste management) and because it positively affects plants (Tüfenkçi and Yerli, 2023).

A useful soil conditioner is biochar, which is a substance with a structure like coal that is created when biomass is thermally decomposed by pyrolysis at high temperatures and low oxygen levels (Tüfenkçi and Yerli, 2023). In addition to being an environmentally friendly material, biochar, rich in organic carbon content, increases carbon stocks in the soil, regulates soil fertility, and saves water by increasing the soil's water-holding capacity (Yang et al., 2020). Furthermore, biochar provides more water storage opportunities due to its spongy and porous structure, allowing effective irrigation water management (Qiu et al., 2022). In addition to providing nutrients to the soil, biochar contributes positively to improving soil fertility by increasing the availability of plant nutrients (Zhu et al., 2017; Khan et al., 2024). Biochar, which improves the soil's cation exchange capacity and increases the surface area, supports plant growth and development by retaining water and nutrients in the soil (Egamberdieva et al., 2017; Dey et al., 2023).

Using biochar, plants subjected to a variety of abiotic challenges can readily overcome these adverse stress conditions (Semida et al., 2019). Because of all these advantageous qualities, biochar stands out as a useful organic material that improves water efficiency and controls soil moisture in dry environments. In the literature review, there are a limited number of studies determining the effect of biochar on plants exposed to drought stress for woody species. In addition, no study was found in the literature in which drought stress and biochar were applied together to Turkish hazelnuts, and morphological and physiological changes in the plant were determined.

In this study, Turkish hazelnut (*Corylus colurna*), an important agricultural plant of Türkiye, has been produced in large quantities due to the transition to the single-tree hazelnut production system in recent years and planted in hazelnut groves. This species is an important agricultural plant of our country and is the subject of the study because it is used as a substrate in grafting and has a deep root system, so it will adapt better to global climate change. This study evaluated changes in some morphological and physiological parameters in 3-year-old Turkish hazelnut seedlings treated with different irrigation and biochar treatments.

MATERIAL AND METHOD

This study was carried out in a semi-automatic greenhouse located in Gümüşova district of Düzce province, Türkiye. The greenhouse, which was closed with transparent plastic, was open at both ends, and the sides were left open between 0.5-1.5 m to provide airflow and prevent temperature increase. During the study period (May 22 - August 1, 2024), the average temperature of the greenhouse was approximately 32 °C, while the maximum and minimum temperatures were measured as 52 °C and 12 °C, respectively.

Plant Material and Containerization Substrates

The seedlings used in the study were grown from seeds obtained from Turkish hazelnut trees that were naturally growing in the Mengen district of Bolu province in 2020. The seeds were planted in planting beds in 2021, and the germinated seeds remained in the planting beds for one year. Soil, forest soil, and peat (1:1:1 volume) were prepared as tube-filling material. 1-year-old seedlings were placed in black plastic polyethylene tubes (12 cm x 12 cm x 25 cm) and grown for two years in the greenhouse of Düzce University, Faculty of Forestry, with their care (irrigation, weeding, etc.). A total of 90 tube seedlings with close lengths and diameters were selected for this study. At the beginning of the study, the average length of the seedlings was 52.54 (±12.37) cm, and their diameter was 7.28 (±1.66) mm. Within the scope of the study, 3-year-old tube seedlings were taken to a special greenhouse in the Gümüşova district of Düzce province (40°51'16" North 31°01'02" East) on May 22, 2024. In the study, trial designs (9 different trial groups) for 3 different irrigation amounts and 3 different doses of biochar treatments were established. Information on the experimental treatment groups is given in Table 1.

Table 1. Information about the experimental design of the study

Treatment groups	Irrigation	Biochar
T1 (W3xB0)	Irrigated at 100% of field capacity every day (W3)	No biochar applied (B0)
T2 (W3xB1)	Irrigated at 100% of field capacity every day (W3)	Low dose biochar applied (20 g/kg) (B1)
T3 (W3xB2)	Irrigated at 100% of field capacity every day (W3)	High dose biochar applied (40 g/kg) (B2)
T4 (W2xB0)	Irrigated at 50% of field capacity every day (W2)	No biochar applied (B0)
T5 (W2xB1)	Irrigated at 50% of field capacity every day (W2)	Low dose biochar applied (20 g/kg) (B1)
T6 (W2xB2)	Irrigated at 50% of field capacity every day (W2)	High dose biochar applied (40 g/kg) (B2)
T7 (W1xB0)	Irrigated at 25% of field capacity every day (W1)	No biochar applied (B0)
T8 (W1xB1)	Irrigated at 25% of field capacity every day (W1)	Low dose biochar applied (20 g/kg) (B1)
T9 (W1xB2)	Irrigated at 25% of field capacity every day (W1)	High dose biochar applied (40 g/kg) (B2)

Irrigation Treatment

In the study, after creating a trial design (9 different trial groups) for 3 different irrigation and 3 different doses of biochar treatment on the same day (May 22, 2024), biochar treatment at different doses (0, 20, 40 g/kg) was made from the soil surface and mixed with the topsoil. An automatic irrigation system was established to water the seedlings, and the seedlings were watered with 40 ml of water per day (the amount required to reach field capacity) with spring water for approximately one month. On June 26, 2024, different irrigation amounts (drought stress) were started to be applied, and the water amounts were determined daily [100-50-25 ml], and the seedlings were watered with these amounts for 20 days. Starting from July 15, 2024, the field capacity was determined again by taking into account the increasing temperature and plant growth, and the seedlings were watered daily at 100% (200 ml) (W3), 50% (100 ml) (W2) and 25% (50 ml) (W1) of the field capacity.

Relative Height Growth (RHG) and Relative Diameter Growth (RDG)

In the study, height and diameter measurements of the seedlings were carried out before the start of biochar treatment (May 22, 2024) and after the measurements were made. Initially, relative height and diameter growth were calculated to minimize the height and diameter differences in the seedlings, and analyses were performed based on these calculations. Relative height and diameter growth were calculated as the ratio of the difference between the last measurement and the first measurement to the first measurement. These measurements were carried out on all seedlings.

Gas Exchange Measurement

In the study, photosynthesis parameters were measured in 5 seedlings from each treatment group of the experimental design on July 30, 2024, with the help of a Li-Cor device [(LI-6800, Lincoln, NE, USA) and a small light source (6800-02 – red, blue LEDs)]. Calibration of the device [Air flow rate (500 μmol s^{-1}), photosynthesis photon flux density (PPFD) (500 μmol s^{-1}), and reference CO2 (400 μmol mol^{-1} s^{-1})] was performed as recommended by the manufacturer. In the seedlings where the measurements were made, the leaves were selected from the mature leaves (3rd and 5th leaves) located below the apical bud.

In the study, net photosynthesis (assimilation) rate (Anet, μmol m^{-2} s^{-1}), transpiration amount (E, mmol m^{-2} s^{-1}), stomatal conductance (gs, μmol H_2O m^{-2} s^{-1}) were directly measured as photosynthesis parameters and the ratio of intercellular CO2 to ambient CO_2 (Ci/Ca), instantaneous water use efficiency (WUE=Anet/E) and internal water use efficiency (iWUE=Anet/gs) were calculated using the data.

Chlorophyll a, b, a+b, carotenoid amount

After photosynthesis measurement, chlorophyll a, b, total chlorophyll (a+b), and total carotenoid amount in leaves taken from 3 randomly selected seedlings were calculated according to Arnon (1949). 0.1 g of the samples were taken, homogenized with 80% acetone, and centrifuged at 5000 rpm. The obtained supernatant was placed in the spectrophotometer, and the readings were measured at 663, 645, and 450 nm, and the chlorophyll a, b, a+b, and carotenoid amounts were calculated using the formulas below.

Chl a = (ΔA663 x 12.7) – (ΔA645 x 2.69),

Chl b = (ΔA645 x 22.9) – (ΔA663 x 4.68),

Total chl = (20.2 X A645) + (8.02 X A663) ve

Total carotenoid = (ΔA450x4.07) - [(0.0435 x Kl-a) + (0.3367 x Kl-b)]

Leaf Relative Water Content (RWC)

After photosynthesis measurements (July 30, 2024), leaf samples of approximately the same size were taken from each of the seedlings in each treatment group. The leaf samples were placed in a cooling container and brought to the laboratory. On the same day, they were placed in Perti dishes with deionized water in the dark and allowed to enter the turgor state for 24 hours. At the end of the period, the samples were weighed again to determine their turgor weights and then dried in an oven at 70°C for 72 hours, and their dry weights were measured. The relative water contents of the samples in each treatment group were calculated using the following formula.

Relative water content (%) = [(Wet weight – Dry weight) / (Turgor weight – Dry weight)] x 100.

Statistical Analysis

This study was designed according to a completely randomized experimental design for hazelnut seedlings grown under 3 different irrigation and 3 different doses of biochar. 10 seedlings (considered as replication) were used in each treatment group, and 90 tube seedlings were used in 9 experimental groups. SAS 9.1 (SAS Institute Inc., Cary, NC, USA) statistical program was used for all statistical analyses. PROC UNIVARIATE function was used to determine whether the data showed normal distribution, and then the PROC MIXED function was used for variance analysis (ANOVA). Tukey test was used to separate the means of the groups for parameters showing statistically significant differences (alpha=0.05).

RESULTS

Relative Height Growth (RHG) and Relative Diameter Growth (RDG)

It was determined that irrigation, biochar, and their interaction had a statistically significant ($P\leq0.05$) effect on both RDG and RHG while biochar had no significant effect on RHG ($P>0.05$) (Table 2). RHG generally increased with increasing irrigation (W1<W2=W3), while it decreased with increasing biochar treatment (B0>B1=B2). Under the effect of both factors, the seedlings in the W2xB0 treatment had the highest RHG (0.32 mm/mm), while the lowest RHG (0.14 mm/mm) was obtained in the W1xBO treatment group.

The increased irrigation amount (W1<W3=W2) statistically increased RHG, and no significant difference was detected in RHG of the two highest irrigation amounts ($P>0.05$). No effect of biochar treatments on RHG was detected ($P>0.05$). Under the influence of both factors, the highest RHG (0.18 cm/cm) was obtained in the W2xB0 treatment, while the lowest RHG (0.11 cm/cm) was obtained in the W1xB2 treatment group.

Table 2. Degree of freedom (df) of the morphological and physiological parameters analyzed in the study, F and P values according to ANOVA results.

	Between subjects		Within subjects
Source of variation	Irrigation (W)	Biochar (B)	WxB
df	2	2	4
RDG	10.02***	30.12***	12.59***
RHG	13.55***	1.66ns	4.39**
Anet	24.80***	2.93ns	7.08**
gs	36.77**	2.85ns	6.03***
E	8.22***	1.99ns	2.43ns
iWUE	37.58***	0.87ns	1.69ns
WUE	9.87***	2.02ns	2.14ns
Ci/Ca	18.54***	1.34ns	1.16ns
RWC	9.45**	3.72ns	3.35*
Chl a	93.74***	169.65***	40.93***
Chl b	39.26***	104.08***	23.92***
Total chl	98.65***	197.59***	46.26***
Caratones	44.34***	157.66***	39.23***

*** = $P \leq 0.0001$; ** = $P < 0.001$; ** = $P < 0.05$. ns: not significant.

Gas Exchange Parameters at The Leaf Level

The variance analysis of photosynthesis parameters (E, gs, Anet, WUE, iWUE, Ci/Ca) between treatment groups and within groups is shown in Table 2. When photosynthesis parameters were examined, it was determined that irrigation was statistically significant (P<0.05) in all parameters, while biochar treatment was insignificant (P<0.05) (Table 2). Under the interaction of the combination of two factors (irrigation x biochar), only the Anet and gs parameters of hazelnut seedlings were statistically significant (P<0.05), and the others were insignificant (Table 2).

When photosynthesis data were examined, the Anet and gs values of seedlings growing under irrigation and the interaction of irrigation and biochar treatments were significant (P<0.05). In contrast, biochar treatment was insignificant (P<0.05) (Table 2). Increasing irrigation amounts increased Anet values statistically significantly. Under two factors, the highest Anet (8.69 µmol m^{-2} s^{-1}) was detected in the W3xB0 treatment group, while the lowest Anet (3.88 µmol m^{-2} s^{-1}) was detected in the W1xB0 group (Figure 1). Under increasing irrigation amount, gs values also increased, and the order was W3>W2=W1. Under two factors, the highest gs (0.20 µmol H_2O m^{-2} s^{-1}) was detected in the W1xB1 treatment group, while the lowest Anet (0.06 µmol m^{-2} s^{-1}) was detected in the W1xB0 group (Figure 2).

When the E, iWUE, WUE, and Ci/Ca values of hazelnut seedlings were examined, it was found that only irrigation had a statistically significant effect (P≤0.05) (Table 2). It was determined that the E amount of the over-irrigated seedlings (W3) was higher than the E amount of the medium (W2) and low-irrigated (W1) seedlings, and there was no statistical difference between the two low irrigations (W3>W2=W1). However, the increased irrigation amount statistically decreased the iWUE values of the hazelnut seedlings, and the order was as follows (W2=W1>W3). In WUE, this order was W2>W3=W1. The Ci/Ca values in the over-irrigated seedlings were statistically higher than those in the medium and low-irrigated seedlings (W3>W1=W2), and no statistical difference was found between the medium and low-irrigated seedlings.

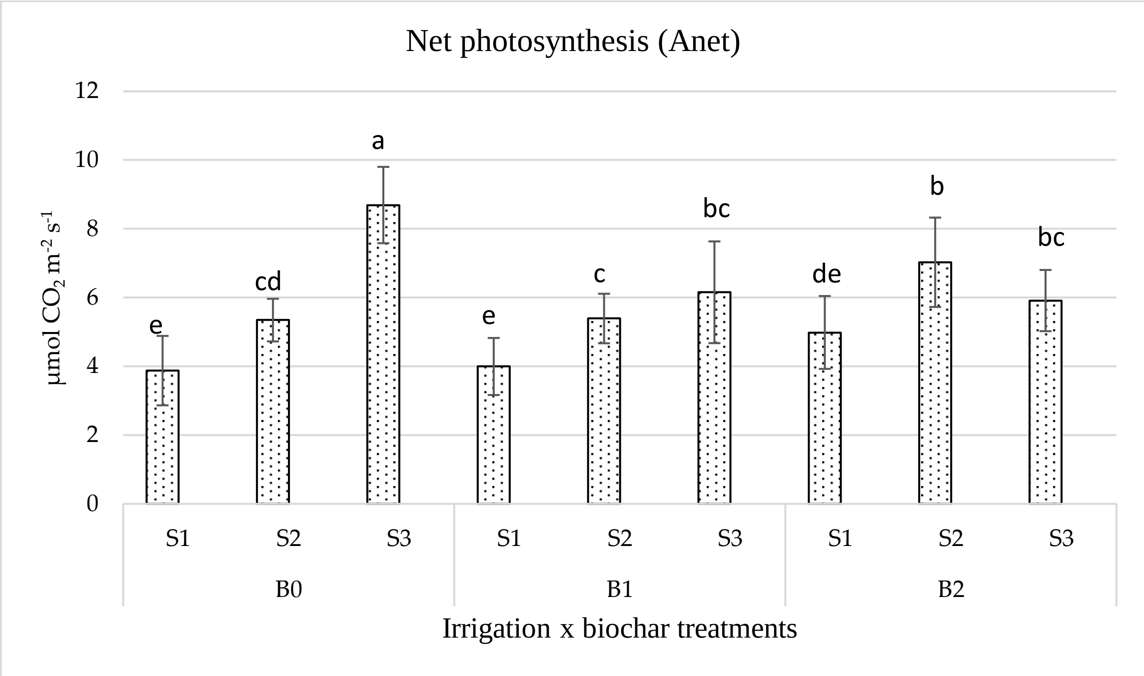

Figure 1. Net photosynthesis means [standard deviations (±SD)] and Duncan test results of Turkish hazelnut seedlings grown under different irrigation and biochar treatments.

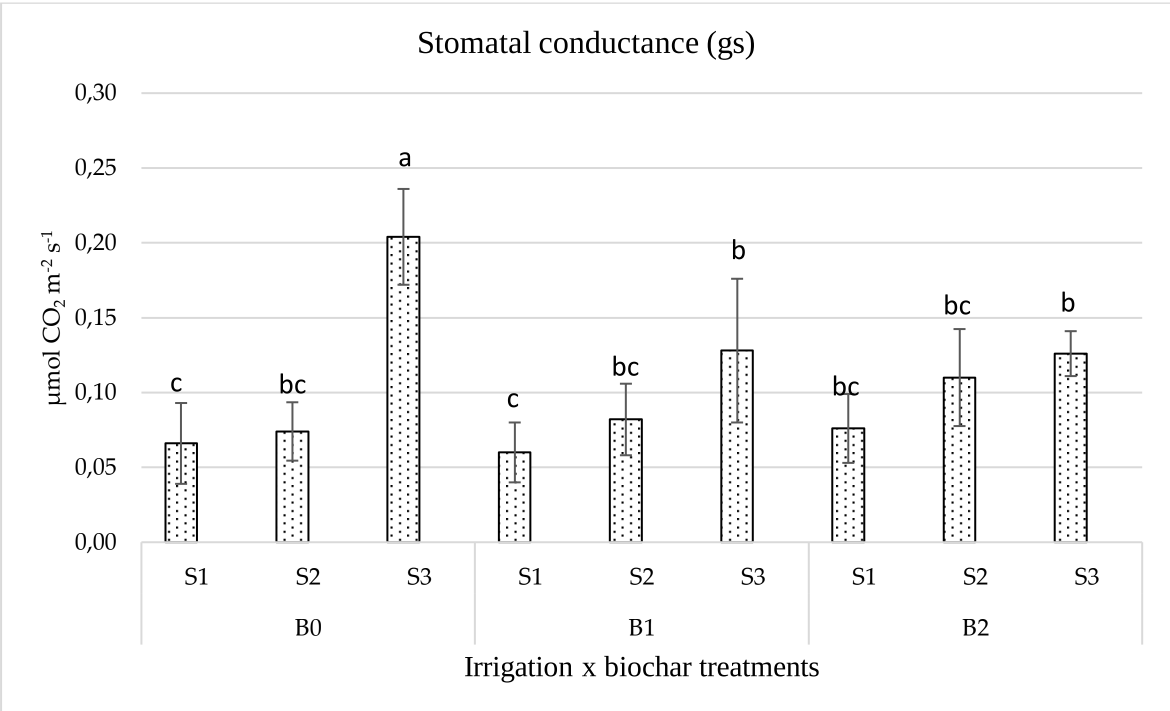

Figure 2. Stomatal conductance averages [standard deviations (±SD)] and Duncan test results of Turkish hazelnut seedlings grown under different irrigation and biochar treatments.

Chlorophyll a, b, a+b, carotenoid amount

When the analysis results on the leaf samples of hazelnut seedlings were examined, it was determined that irrigation, biochar, and the interaction of both factors had statistically significant ($P \leq 0.05$) effects on the amounts of chlorophyll a, b, total chlorophyll, and carotenoids (Table 2). When the results were evaluated, it was determined that the effect of irrigation on the amounts of chlorophyll a, b, total chlorophyll, and carotenoids was generally W2>W3>W1. In the biochar treatment, except for the amount of carotenoids (B0=B1>B2), the order was found to be B0>B1>B2 in the amounts of chlorophyll a, b, total chlorophyll.

When the effect of the interaction of irrigation and biochar on these parameters was examined, it was determined that the highest values were generally obtained in the W2xB0 group, and the lowest values were obtained in the seedlings in the W1xB1 and W1xB2 treatment groups (Figures 3, 4, 5, 6).

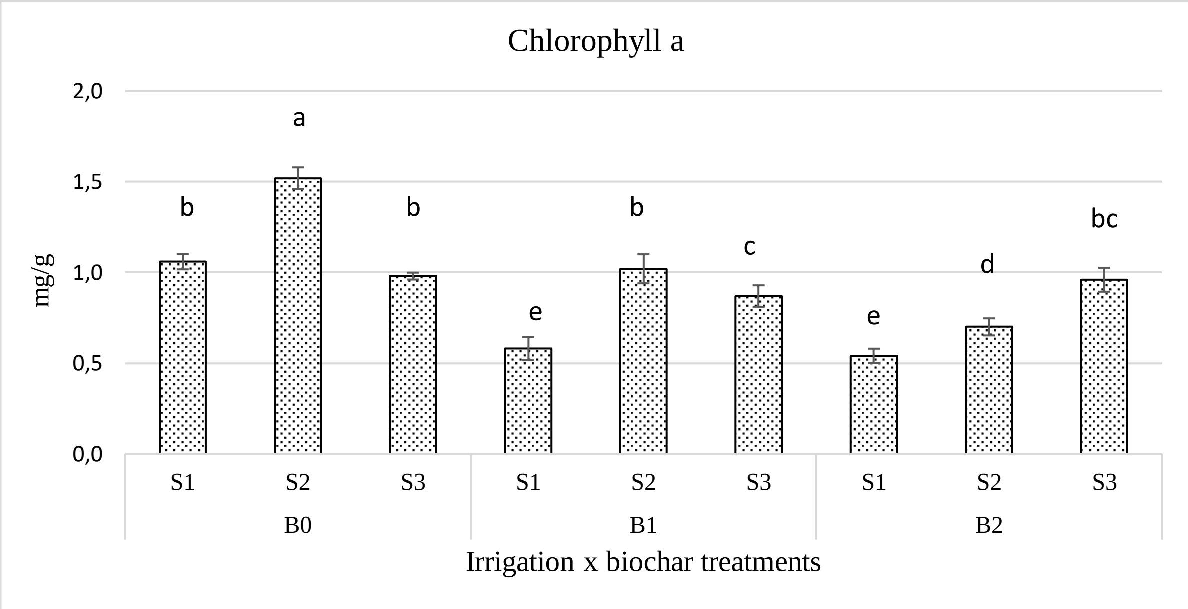

Figure 3. Chlorophyll a values in leaves of Turkish hazelnut seedlings grown under different irrigation and biochar treatments [standard deviations (±SD)] and Duncan test results.

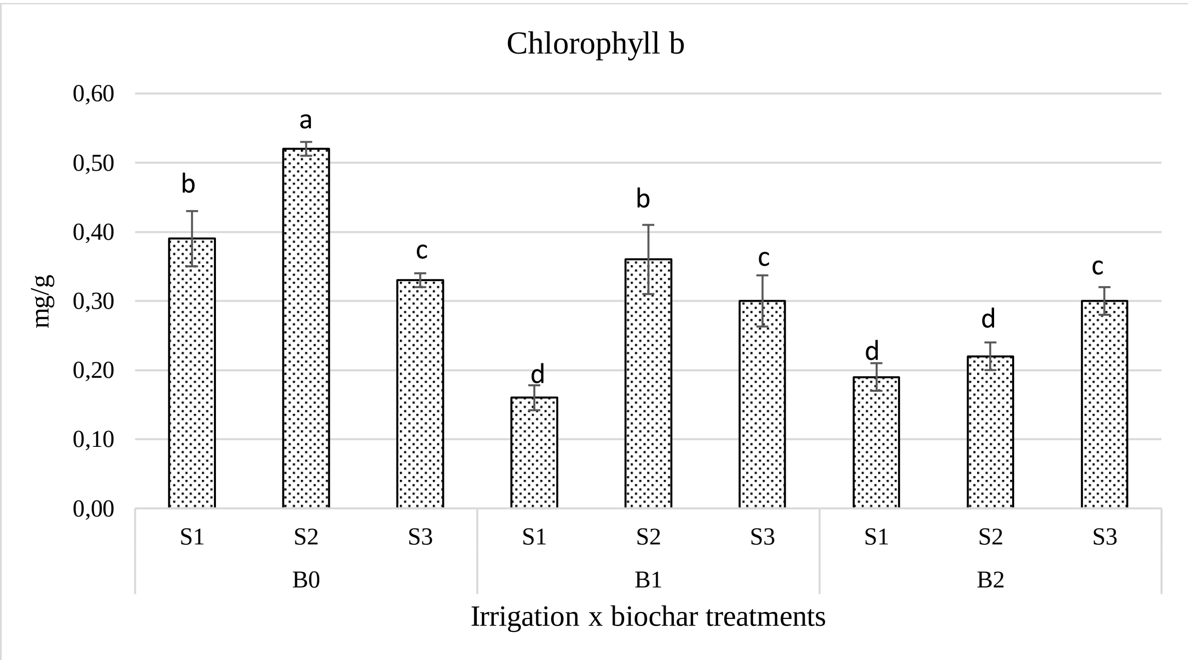

Figure 4. Chlorophyll b values in leaves of Turkish hazelnut seedlings grown under different irrigation and biochar treatments [standard deviations (±SD)] and Duncan test results.

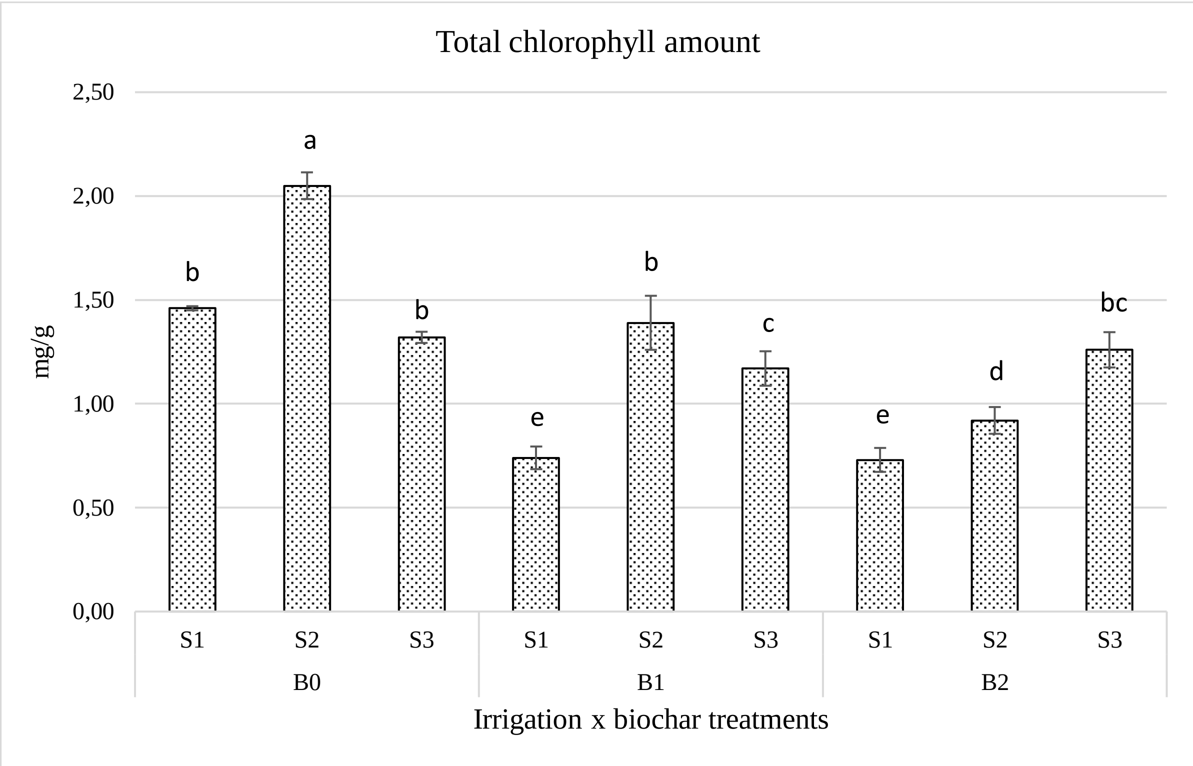

Figure 5. Total chlorophyll values in leaves of Turkish hazelnut seedlings grown under different irrigation and biochar treatments [standard deviations (±SD)] and Duncan test results.

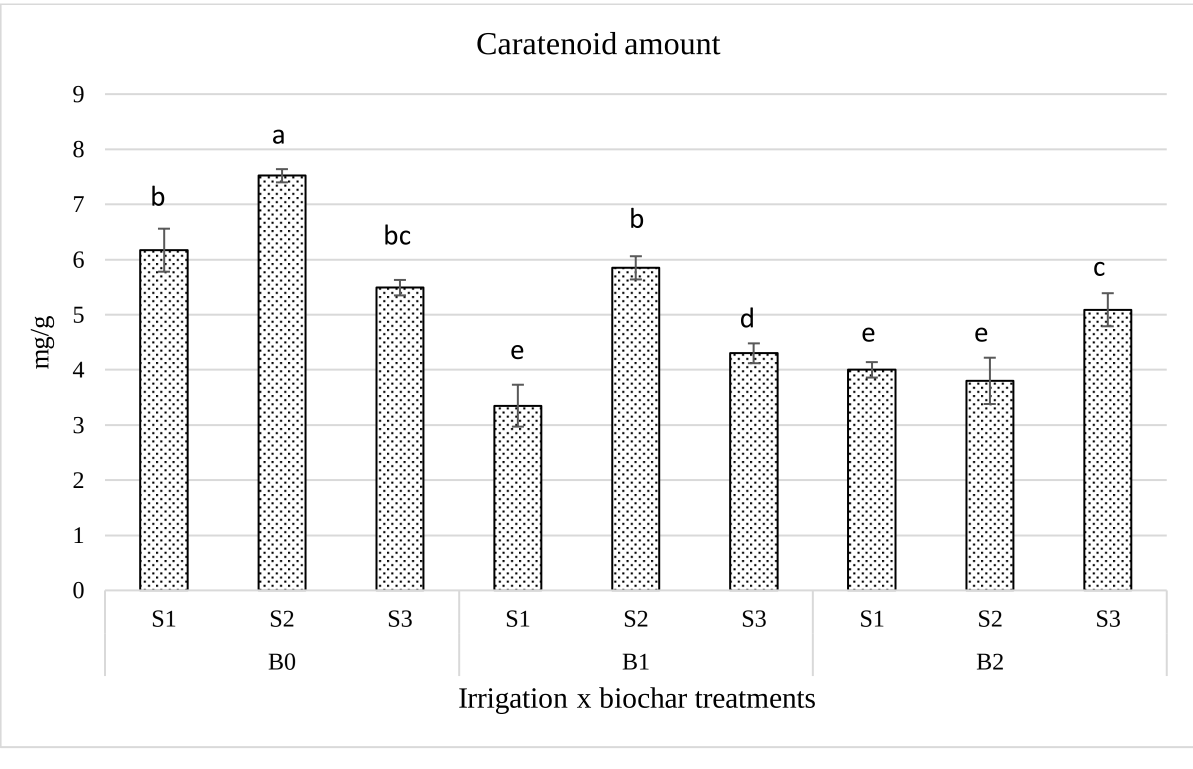

Figure 6. Carotenoid values in leaves of Turkish hazelnut seedlings grown under different irrigation and biochar treatments [standard deviations (±SD)] and Duncan test results.

Leaf Relative Water Content (RWC)

As a result, all treatment groups except biochar treatment (Irrigation, Irrigation x Biochar) have statistically significant ($P \leq 0.05$) RWC values on RWC. The RWC value of low-watered seedlings is lower than the RWC values of medium and high-watered seedlings. However, no statistical difference was observed between the RWC values of medium and high-watered seedlings ($P > 0.05$). In general, RWC increased with increasing irrigation. Under the interaction of the two factors, RWC in seedlings varied between approximately 64% and 48%, and the highest and lowest RWC values were obtained in the W3xB1 and W1xB0 treatment groups, respectively.

DISCUSSION

The Effect of Drought Stress and Biochar Treatments on Turkish Hazelnut Seedlings Morphological Features

The growth and development of plants and trees that do not receive enough water or are exposed to drought are restricted due to many protective mechanisms (resistance, alleviation, avoidance). These protective mechanisms allow plants to extend their roots and reach water, reduce their leaf areas, or close the stomata to minimize water loss through transpiration (Seleiman et al., 2021; Cantürk, 2023). It is known that due to the spongy and porous structure of biochar, more water is stored in the soils where biochar is applied, and thus, plants are less affected by drought conditions (Egamberdieva et al., 2017; Qiu et al., 2022). This study determined that the RHG and RDG of the seedlings exposed to drought grew less than those in the control group. It was determined that the biochar treatment did not affect RHG but negatively affected RDG. This result was interpreted as the nutrient element taken from the soil was first used for height growth. However, under the interaction of both factors, it has been determined that both RHG and RDG generally decrease with decreasing irrigation amount. Under drought conditions, the elongation of plant shoot and cambium cells decreases, which ultimately causes decreases in RHG and RDG (Koç, 2022b).

Drought Stress and Biochar Treatments Effect on Turkish Hazelnut Seedlings Physiological Features

Plant species are faced with many adverse abiotic stress conditions, perhaps the most dangerous of which is drought, and it has been revealed in many studies that drought has many negative effects on plants (Yiğit et al., 2016; Tekin et al., 2022; Seleiman et al., 2021). Plants are not only exposed to one environmental stress factor in their natural habitats; they are affected by multiple stress factors. Under these one or more stress factors, physiological and biochemical changes occur in plants, as well as morphological changes (Cantürk, 2023).

When the photosynthesis data (E, gs, Anet, WUE, iWUE, Ci/Ca) and RWC results were evaluated, it was determined that irrigation was affected based on treatments, but biochar had no effect. When the seedlings under the effect of both factors were evaluated, it was determined that the seedlings exposed to drought made less Anet and gs, and there was no statistical difference in other photosynthesis parameters (E, iWUE, WUE, Ci/Ca). This situation can be said that water has a greater effect on plant growth and development than biochar. The fact that the seedlings from the drought-exposed groups (W1) had lower RWC values indicates that these seedlings restrict their photosynthetic activities. As it is known, water is necessary for many physiological (photosynthesis and carbon assimilation) and biochemical activities as well as plant growth and development (Koç, 2022b; Cantürk, 2023). It has been shown in many studies that plants exposed to drought stress cannot take sufficient amounts of water and plant nutrients from the soil through their roots, thus decreasing the xylem pressure potential in their stems and, as a result, the stomata in the leaves close, reducing the water lost through transpiration, i.e., decreasing Anet and gs (Song et al., 2020; Hauer et al., 2021; Hsu et al., 2021; Seleiman et al., 2021).

Although biochar, which is known to have positive effects on the growth and development of field crops and their water retention capacity (Egamberdieva et al., 2017; Zhu et al., 2017; Li et al., 2020; Yang et al., 2020; Tüfenkçi and Yerli, 2023), has been found to have positive effects on photosynthetic activity and nutrient uptake in plants exposed to drought in various studies (Ali et al., 2017; Trupiano et al., 2017; Semida et al., 2019), it could not be determined in our study that it had a statistically positive effect on photosynthetic parameters in Turkish hazelnut seedlings, which is a perennial species. It is thought that this may be due to the limited study period (approximately 3 months) and the fact that biochar was applied from the soil surface of the seedlings in plastic tubes.

In this study, chlorophyll (Chl a, b, and total chl) and carotene amounts were generally lower at low irrigation rates. Similar results were also shown in a soybean study (Gullap et al., 2024). In the study, an increase in the biochar treatment dose caused a decrease in these values in seedlings. However, some studies have shown that biochar treatments alleviate the negative effects of chlorophyll parameters of plants exposed to drought stress (Youssef et al., 2018; Zhang et al., 2020). It is thought that the decrease in chlorophyll amounts and photosynthetic activity in seedlings is due to the effect of oxidative stress caused by drought stress (Anjum et al., 2011; Yildirim et al., 2021).

CONCLUSION

Water, vital for all living things, is important for plant growth, development, and physiological processes throughout their lives. Its importance has increased, especially under drought stress, which is one of the negative effects of climate change. Under drought stress, plants cannot get enough nutrients from the soil; thus, their growth and the physiological activities of their cells are limited. Biochar, obtained from plant wastes, fertilizes the soil and positively affects plant growth and development under drought, as well as the physiological activities of plants. In this study, the effects of different irrigation and biochar treatments on growth and gas exchange parameters in Turkish hazelnut seedlings were evaluated, and it was determined that irrigation was more important than biochar.

In conclusion, the application of biochar had no effect on RHG but had a negative impact on RDG in this study, whereas drought stress had a negative impact on both RHG and RDG of seedlings. Analyses of photosynthesis parameters and leaf RWC revealed that the amount of irrigation had a substantial impact on these parameters, whereas biochar had no tangible effect. Other photosynthetic parameters did not alter statistically under drought circumstances; however, Anet and gs values did. At low irrigation levels, the quantities of carotene and chlorophyll were reduced. However, considering that the biochar application period in this study was short and that the biochar was given to the plastic bags with seedlings from the topsoil, it is thought that similar studies carried out for a more extended period and mixing the biochar into the soil substrates before planting the seedlings will produce better results. Therefore, similar studies should be diversified, and the results should be examined.

COMPLIANCE WITH ETHICAL STANDARDS

a) Authors' Contributions

Each of the authors contributed 50%.

b) Conflict of Interest

The authors declare that there is no conflict of interest.

c) Statement of Human Rights

Work does not require a legal permit.

d) Statement of Human Rights

This study does not involve human participants.

e) Acknowledgement

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