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Physical and Physiological Properties and Mineral Content of Curly Lettuce Grown by Applying Different Rates of Biochar to the Soil with Varying Irrigation Water Levels

Değişen Sulama Suyu Seviyeleriyle Toprağa Farklı Oranlarda Biyoçar Uygulanarak Yetiştirilen Kıvırcık Marulun Fiziksel ve Fizyolojik Özellikleri ile Mineral Madde İçeriği

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Abstract: The crisis experienced from the water supply causes food production to be adversely affected in the agriculture sector, which is the biggest consumer of water. The deficit irrigation strategy ensures the continuity of food production as well as using water effectively. However, since the plant grown in this strategy is exposed to abiotic stress, it experiences significant yield and quality losses. For this reason, it is necessary to develop approaches to improve yield and quality losses of the plant grown with deficit irrigation. In this study, the physical and physiological properties and mineral content of curly lettuce (*Lactuca sativa* L. var. *Crispa*) grown by applying different rates of biochar to the soil (0%, 1%, 2%, 3%) with varying irrigation water levels (100%, 67%, 33%) researched. The study determined that decreasing irrigation water level decreased plant height, stem diameter, number of leaves, root wet and dry weights, plant weight, chlorophyll and leaf relative water contents, stomatal conductivity and N, P, K, Ca, Mg, Na, Fe, Cu, Mn and Zn contents of curly lettuce, while increasing the membrane damage index, but the physical and physiological properties and mineral content affecting the yield and quality of curly lettuce improved with increasing biochar rates. In the study, as a result of the emergence of the highest stress factor in irrigation at 33% level, it was observed that physical and physiological properties and mineral content of curly lettuce were affected at the highest level, and the dose of biochar, which managed the stress most effectively, was 3%. As a result, considering that biochar has an important potential to improve yield and quality losses of curly lettuce grown under deficit irrigation conditions, the use of biochar in the deficit irrigation regime were found to be recommendable.

Keywords: Biochar, curly lettuce, deficit irrigation, irrigation water level, mineral content

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Öz: Su arzından yaşanan kriz suyun en büyük tüketicisi olan tarım sektöründe gıda üretiminin olumsuz etkilenmesine neden olmaktadır. Kısıntılı sulama stratejisi suyu etkin kullanmanın yanı sıra gıda üretiminin sürekliliğini de sağlamaktadır. Ancak bu stratejide yetişen bitki abiyotik strese maruz kaldığı için önemli verim ve kalite kayıpları yaşamaktadır. Bu nedenle kısıntılı sulamayla yetiştirilen bitkinin verim ve kalite kayıplarını iyileştirmeye yönelik yaklaşımların geliştirilmesi gerekmektedir. Bu çalışmada değişen sulama suyu seviyeleriyle (% 100, % 67 ve % 33) toprağa farklı oranlarda biyoçar uygulanarak (% 0, % 1, % 2 ve % 3) kıvırcık marulun (*Lactuca sativa* L. var. *Crispa*) fiziksel ve fizyolojik özellikleri ile mineral madde içeriği araştırılmıştır. Çalışma azalan sulama suyu seviyesinin kıvırcık marulun bitki boyunu, gövde çapını, yaprak sayısını, kök yaş ve kuru ağırlıklarını ve bitki ağırlığını, klorofil ve yaprak bağıl su içeriklerini, stoma iletkenliğini ve N, P, K, Ca, Mg, Na, Fe, Cu, Mn ve Zn içeriklerini azaltırken membran zararlanma indeksini artırdığını ancak kıvırcık marulun verim ve kalitesini etkileyen fiziksel ve fizyolojik özellikleri ile mineral madde içeriğinin artan biyoçar oranlarıyla gelişim gösterdiğini belirlemiştir. Çalışmada % 33 seviyesinde sulamada en yüksek stres faktörünün ortaya çıkması sonucunda kıvırcık marulun fiziksel ve fizyolojik özellikleri ile mineral madde içeriğinin en yüksek seviyede etkilendiği ve stresi en etkili yöneten biyoçar dozunun ise % 3 oranında gerçekleştiği görülmüştür. Sonuç olarak kısıntılı sulama koşullarında yetiştirilen kıvırcık marulun verim ve kalite kayıplarını iyileştirmeye yönelik biyoçarın önemli bir potansiyelinin olduğu dikkate alınarak kısıntılı sulama rejiminde biyoçarın kullanımı önerilebilir olarak bulunmuştur.

Anahtar Kelimeler: Biyoçar, kıvırcık marul, kısıntılı sulama, sulama suyu seviyesi, mineral madde içeriği

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INTRODUCTION

Agriculture, which is the largest consumer of the world's freshwater use, is struggling to meet its food needs in the face of increasing population and global warming (Chai et al., 2016). While more food production is required to meet the demand of the increasing population, the increase in plant water consumption with the increasing severity of global warming reveals the need for more water. However, although water has a renewable character, it is actually a limited natural resource. While it is not possible to increase the amount of freshwater, the increasing population and global warming also lead to a significant reduction in the amount of existing freshwater resources by polluting them. It is predicted that the world population will increase by 30% in 2050 year (Godfray et al., 2010), and it is stated that water resources and agricultural areas should be increased by 53% and 38%, respectively, to meet the food demand of this increasing population (Mancosu et al., 2015). Currently, 2.5 billion people have problems accessing water of suitable water quality (Schiermeier, 2014), and it is estimated that more than 20% of the world's population may face water scarcity in the near future (Girones et al., 2010).

It is certain that the crisis in water supply has affected the agricultural sector on the largest scale. Imbalances in food production in the agricultural sector, which is affected by insufficient water resources, cause food security and food crisis risks to accelerate (Kang et al., 2017). For this reason, irrigation in agricultural production should be managed more effectively and food production should be continued with less water input. Deficit irrigation, in which less than the amount of water needed by the plant is supplied to the plant, ensures continuity in production, especially in regions where water resources are insufficient. In addition, deficit irrigation, which reveals the possibility of opening more areas to irrigation with the amount of water that is restricted from here, is considered as a food production model that provides significant water savings in agricultural production (Chai et al., 2014). However, it is inevitable that the cellular and physiological functions of the plant, which is experiencing water stress, are negatively affected by deficit irrigation, resulting in a decrease in yield and quality (Chai et al., 2016). For this reason, it is necessary to make improvements with practical approaches to compensate for the yield and quality losses in plants grown with the deficit irrigation regime.

The biochar material with a coaly structure, which is formed as a result of the thermal decomposition of the biomass by pyrolysis at high temperatures under limited oxygen conditions, is a good soil conditioner. Biochar, an environmentally friendly material, increases the carbon stocks in the soil with its rich organic carbon content, both regulating soil fertility and saving water by improving the water holding capacity of the soil (Yang et al., 2020). In addition, the porous structure and spongy nature of the biochar reveal the effective management of irrigation water by storing more water within it (Ahmad et al., 2014). Biochar makes important contributions to the improvement of soil fertility by providing nutrients to the soil and increasing the availability of nutrients (Zhu et al., 2017). Biochar, which increases the surface area of the soil and improves the cation exchange capacity, supports the improvement of plant yield and quality by retaining nutrients and water in the soil (Egamberdieva et al., 2017). Plants that face various biotic and abiotic stresses can overcome these stress conditions more easily with biochar (Semida et al., 2019). All these superior characteristics of biochar have brought it to the forefront as a practical organic material that regulates soil water and increases water use efficiency in arid conditions.

Since vegetables are very sensitive to drought stress, they experience significant decreases in yield and quality under water stress conditions, especially in arid and semi-arid regions. However, this decrease in yield and quality can be improved by mitigating the water stress experienced with biochar applied to the soil (Yildirim et al., 2021). To our best knowledge, although there were some studies in the literature investigating the effectiveness of biochar on the yield and quality of some vegetables grown under water deficit conditions, no studies were found examining the effects of biochar under drought stress conditions on curly lettuce, which has an important potential among leafy green vegetables and makes up about half (252 thousand tons) of the 562 thousand tons of lettuce produced in Turkey (TUIK, 2023). Therefore, this study focusing on the effects on the physical and physiological properties and mineral content of the plant when irrigated with varying irrigation water levels of curly lettuce grown in soil treated with biochar at different rates, hypothesized that increasing rates of biochar would reduce the adverse effects of curly lettuce exposed to drought stress.

MATERIAL AND METHOD

The experiment was carried out in a plastic covered greenhouse and during the experiment, daily mean temperature and humidity were 23±4°C and 48±6%. The experiment, which was created with a completely randomized design with 3 replications, was carried out by irrigating curly lettuce soil in which biochar was mixed on the basis of dry weight at 4 different rates [B0: 0% (no biochar), B1: 1%, B2: 2%, B3: 3% biochar] at 3 varying irrigation levels [I100: irrigation at 100% (full irrigation), I67: 67%, I33: 33% levels]. Thus, the total number of pots (volume: 4 liters, diameter: 19 cm, height: 18 cm) in the experiment was 36 (3 replications × 4 biochars × 3 irrigation water levels).

Before the experiment, the pH and EC of the soil and biochar were determined by pH meter and conductive meter (McLean, 1982; Corwin and Rhoades, 1984), while the organic matter and total N content were determined according to the Walkley-Black and Kjeldahl methods (Nelson and Sommers, 1982; Bremner and Mulvaney, 1982). According to the soil texture determined by the Bouyoucos hydrometer method (Gee and Bauder, 1986), pH, EC, organic matter and total N values of the sandy loam soil (sand: 66%, silt: 16%, clay: 18%) were 7.17, 0.62 dS m^{-1}, 0.81% and 0.04, respectively. The same values of biochar were 9.65, 4.26 dS m^{-1}, 56.11% and 1.80%, in the same order. In the experiment, pyrolyzed oak biochar material at 400°C was used as the biochar material.

The sieved and homogenized biochar was mixed with the sieved air-dried soil and transferred to pots. The seedlings of the Campania variety of curly lettuce (*Lactuca sativa* L. var. *Crispa*) obtained from a commercial company, planted in two per pot, were diluted in the next period and the experiment was continued with one seedling in each pot. After planting, the current soil moisture was completed to the field (pot) capacity by irrigating, and irrigations were continued at three-day intervals until the harvest period. After the seedlings were planted, the first three irrigations were carried out by weighing the weight of the current moisture in the control treatment that did not apply biochar [0% (no biochar)] and completing to the pot capacity according to this determined soil moisture, with full irrigation at the same level for all treatments. In subsequent irrigations, deficit irrigations were started and irrigations at varying irrigation water levels [irrigation at 100% (full irrigation), 67%, 33% levels] were continued until the harvest period, taking into account the weight of the current moisture in the control treatment.

At the end of approximately three month experiment, plant height was determined by measuring with the help of a ruler. The stem diameter was measured with a digital caliper. The number of leaves was obtained by counting the leaves of each plant by peeling them off. Root wet weight was determined by weighing the root sample after cleaning with distilled water, and then the same sample was dried in an oven at 65°C until it reached a constant weight and thus root dry weight was obtained. Plant weight was determined by weighing each harvested plant on a scale.

To determine the chlorophyll content, measurements were taken from ten different points of each plant with the SPAD-502 chlorophyllmeter device and the mean of these measurements was recorded. Leaf relative water content was calculated according to Smart and Barss (1973) by determining the weights of fresh leaf samples, leaf samples kept in distilled water for 4 hours and the same leaf samples kept in an oven at 65°C for 48 hours. Disc samples taken from leaves were kept in ionized water for 24 hours and their electrical conductivity was measured, and then the same samples were kept in a water bath at 95°C for 20 minutes and their electrical conductivity was measured again, and finally, the membrane damage index by using these two electrical conductivity values was determined by measuring the electrolyte coming out of the leaf cells (Jamei et al., 2009). To measure pore activity, stomatal conductivity was measured from five different points of each plant with the Decagon SC-1 diffusion leaf porometer device (Kiran et al., 2014; Camoglu and Demirel, 2015).

For the mineral content (N, P, K, Ca, Mg, Na, Fe, Cu, Mn, Zn) of plant samples, the samples were dried and ground and subjected to wet burning. While the Kjeldahl method was used for the N content of plant samples (AOAC, 2005), the other mineral content was obtained by readings with an Inductively Coupled Plasma spectrophotometer (Kalra, 1997).

SPSS program was used in the statistical evaluation of the obtained data. The significant means of the data evaluated with the General Linear Model were classified with the Duncan multiple range test at the 5% probability level.

RESULTS AND DISCUSSION

The physical properties of curly lettuce (plant height, stem diameter, number of leaves, root wet and dry weight, plant weight) were significantly ($p < 0.01$) affected by varying irrigation water levels and biochar treatments at different rates (Table 1). While the physical properties of curly lettuce decreased with decreasing irrigation water levels, these physical properties improved with increasing rates of biochar (Figure 1).

The decrease in the physical properties of curly lettuce with the decreasing irrigation water level can be explained by the decreasing moisture in the soil and the exposure of the plant to drought stress. The weakening of the plant's nutrient uptake from the soil due to the decrease in soil water storage with deficit irrigation can be expressed as the reason for lower physical development. The decrease in the mineral content of curly lettuce under the conditions of decreasing irrigation water level supports this situation (Figure 3). Lettuce is a plant that is highly dependent on water for its potential to improve its physical properties and increase its yield (Montenegro et al., 2011). There is a linear relationship between the physical properties affecting the lettuce yield and the water consumption of the lettuce (Karipcin and Satir, 2016). Water stress adversely affects the organs involved in cell functions and photosynthesis, and causes the plant's physical properties to weaken (Muller et al., 2011). Increasing drought stress reduces the chlorophyll content of lettuce (Figure 2), which is the reason why the plant displays a lower level of physical characteristics as a result of decreased metabolic functions (Yazgan et al., 2008). In line with the findings of this study, the results of different studies also stated that the decreasing irrigation water level reduces the physical properties of lettuce (Senyigit and Kaplan, 2013; Karipcin and Satir, 2016; Al-Bayati and Sahin, 2018).

The increase in the physical properties of curly lettuce with increasing biochar rates can be explained by the plant's more effective management of nutrients in the root profile under biochar conditions and the addition of nutrients to the soil by biochar. The increase in the mineral content of curly lettuce under the conditions of increasing biochar rates supports this situation (Figure 3). Depending on its porous structure and surface load holding capacity, biochar improves the nutrient holding capacity of the soil and increases the physical properties of the plant (Hossain et al., 2020). Biochar makes soil suitable for nutrient mobility as a nutrient pool and for increasing the bioavailability of nutrients (Gul and Whalen, 2016). The biochar creates a better environment for soil microorganisms also supports the conversion of nutrients into useful forms by plants and ensures the improvement of plant yield (Li et al., 2017). The fertilizer characteristic of biochar as a soil conditioner transforms the soil into an environment where the plant can increase productivity in terms of macro and micro nutrients (Purakayastha et al., 2019). In addition, biochar may have kept the soil water in its body for a longer period time and increased the use of soil moisture by the plant, resulting in the better physical development of the plant. Thanks to its porous structure, hydrophilic and large surface area, biochar can able to preserve the water in the soil for a longer period of time without being exposed to evaporation, so biochar uses soil moisture effectively, improves the conditions for plant growth and increases plant productivity (Razzaghi et al., 2020). The improvement of soil physical properties of biochar also contributes to more effective management of soil moisture. The decrease in the bulk density of the soil applied with biochar and the increase in its porosity provide the development of the soil water reservoir (Laghari et al., 2016). Mandal et al. (2021) reported that the water holding capacity of biochar treated sandy, loamy and clayey soils increased with the contribution of biochar. All these favorable conditions of the biochar improved soil provide a better development of the plant and increase the physical properties of the plant. Sabatino et al. (2020) stated that the improvement of the physical properties of curly lettuce grown in biochar treated soil is reflected in the yield of curly lettuce.

Table 1. The variance analysis results.
Çizelge 1. Varyans analizleri sonuçları.

Source	df	Mean square	F	P	Mean square	F	P
		Plant height			*Stem diameter*		
Irrigation	2	323.531	318.575	0.000	99.194	66.130	0.000
Biochar	3	16.472	16.220	0.000	18.324	12.216	0.000
Interaction	6	1.386	1.365	0.269	0.380	0.523	0.953
Error	24	1.016			1.500		
		Number of leaves			*Root wet weight*		
Irrigation	2	247.861	114.397	0.000	124.059	305.479	0.000
Biochar	3	27.778	12.821	0.000	14.541	35.806	0.000
Interaction	6	0.306	0.141	0.989	0.120	0.297	0.933
Error	24	2.167			0.406		
		Root dry weight			*Plant weight*		
Irrigation	2	4.751	42.651	0.000	102 747.250	433.889	0.000
Biochar	3	2.501	22.453	0.000	6 424.037	27.128	0.000
Interaction	6	0.008	0.074	0.998	93.843	0.396	0.874
Error	24	0.111			236.806		
		Chlorophyll			*Leaf relative water content*		
Irrigation	2	670.110	420.718	0.000	554.937	478.509	0.000
Biochar	3	30.799	19.337	0.000	63.670	54.901	0.000
Interaction	6	0.367	0.230	0.963	0.425	0.367	0.893
Error	24	1.593			1.160		
		Membrane damage index			*Stomatal conductivity*		
Irrigation	2	1 149.211	1 428.577	0.000	7 209.694	118.787	0.000
Biochar	3	28.453	35.370	0.000	1 168.769	19.257	0.000
Interaction	6	0.653	0.812	0.571	27.102	0.447	0.840
Error	24	0.804			60.694		
		N			*P*		
Irrigation	2	5.094	268.760	0.000	1.342	108.266	0.000
Biochar	3	1.371	72.351	0.000	0.475	38.340	0.000
Interaction	6	0.009	0.497	0.804	0.004	0.338	0.910
Error	24	0.019			0.012		
		K			*Ca*		
Irrigation	2	3.526	199.763	0.000	1.639	130.950	0.000
Biochar	3	0.339	19.211	0.000	0.243	19.448	0.000
Interaction	6	0.002	0.124	0.992	0.004	0.283	0.939
Error	24	0.018			0.013		
		Mg			*Na*		
Irrigation	2	0.331	224.303	0.000	1.065	128.913	0.000
Biochar	3	0.032	21.661	0.000	0.200	24.258	0.000
Interaction	6	0.000	0.323	0.919	0.002	0.184	0.979
Error	24	0.001			0.008		
		Fe			*Cu*		
Irrigation	2	34 435.845	615.425	0.000	87.879	3 193.657	0.000
Biochar	3	7 515.483	130.524	0.000	0.242	8.798	0.000
Interaction	6	155.450	2.700	0.038	0.002	0.074	0.998
Error	24	57.579			0.028		
		Mn			*Zn*		
Irrigation	2	12.593	1 707.539	0.000	235.436	357.000	0.000
Biochar	3	0.201	27.250	0.000	23.953	36.321	0.000
Interaction	6	0.005	0.637	0.699	0.648	0.983	0.458
Error	24	0.007			0.659		

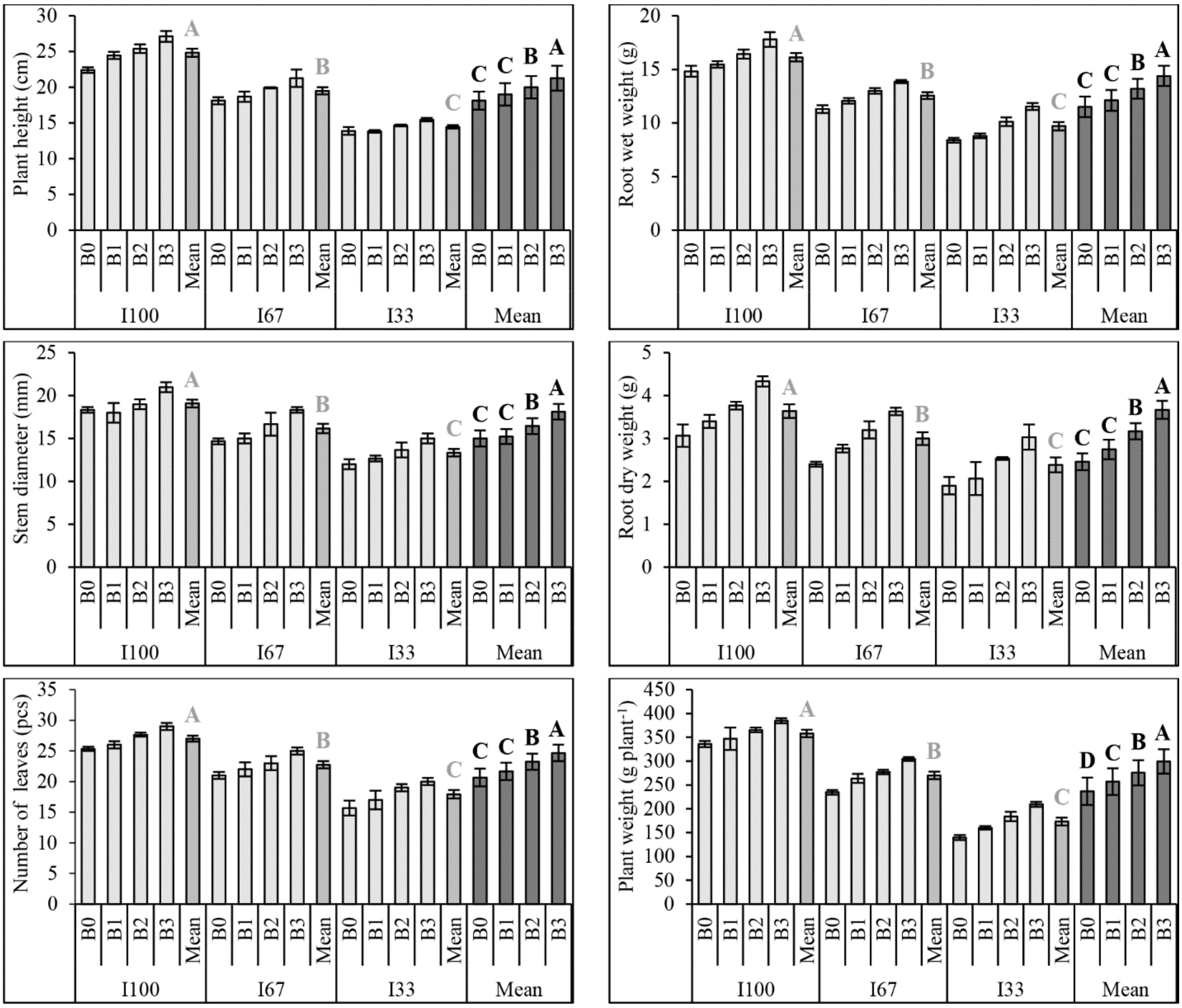

Figure 1. Physical properties of curly lettuce in varying irrigation water levels and biochar treatments at different rates.

Şekil 1. Değişen sulama suyu seviyelerinde ve farklı oranlarda biyokömür uygulamalarında kıvırcık marulun fiziksel özellikleri.

The physiological properties of curly lettuce (chlorophyll content, leaf relative water content, membrane damage index, stomatal conductivity) were significantly ($p < 0.01$) affected by varying irrigation water levels and biochar treatments at different rates (Table 1). While the chlorophyll content, leaf relative water content and stomatal conductivity of curly lettuce decreased and the membrane damage index increased with decreasing irrigation water levels, the chlorophyll content, leaf relative water content and stomatal conductivity of curly lettuce increased and membrane damage index decreased with increasing rates of biochar (Figure 2).

The decrease in the chlorophyll content of curly lettuce with the decreasing irrigation water level can be explained by insufficient soil moisture due to drought conditions. Chlorophyll, which is a clear indicator of water stress, decreases with the inhibition of chlorophyll functions in increasingly deficit irrigation conditions (Bauerle et al., 2004). The decrease in the water potential of the leaves of the plant exposed to drought with the decreasing irrigation water level can be expressed as the reason for the decreased leaf relative water content under deficit irrigation conditions. Since there is a linear relationship between plant water consumption and leaf relative water content, increased moisture conditions in the soil explain more leaf relative water content (Yazdic and Degirmenci, 2018). Insufficient soil moisture causes significant damage to membrane systems by negatively affecting the membrane structure of the cell (Yildirim et al., 2022). Increasing drought stress may cause damage to cell membrane systems by decreasing the leaf relative water content of lettuce (Figure 2) with increasing leaf temperature. In addition, decreasing chlorophyll content in arid conditions (Figure 2) may increase the damage to cell membrane systems as a result of damage to mesophyll cells (Marcińska et al., 2013). Thus, the increase in the membrane damage index of curly lettuce with the decreasing irrigation water level can be explained in this way. In addition, drought due to decreasing irrigation water levels also causes a decrease in the stomatal conductivity of the plant (Oukaltouma et al., 2022). In this study also, it was observed that the stomatal conductivity of curly lettuce decreased under increasing drought conditions. Similarly, Camoglu et al. (2019) also stated that increasing deficit irrigation significantly reduced the stomatal conductivity of tomatoes. While decreasing moisture in the soil decreases the chlorophyll content, the leaf relative water content and the stomatal conductivity of the plant, it causes an increase in the membrane damage index (Ors and Ekinci, 2015). With increasing drought stress, the decrease in stomatal conductivity and leaf relative water content, and then the closure of stomata and the decrease in chlorophyll content and the increase in membrane damage index as a result of increasing leaf temperature can be listed as the chain effects of decreasing soil moisture on plant physiology.

The increase in chlorophyll content of curly lettuce with increasing biochar rates can be explained that biochar increases the plant's nutrient uptake from the soil. The increase in the mineral content of curly lettuce under increasing biochar rates also supports this situation (Figure 3). While Fe is involved in chlorophyll formation and protein development (Pushnik et al., 1984), decreasing N weakens chlorophyll growth since N is a building block of chlorophyll (Bojović and Marković, 2009). In addition, the presence of micronutrients in the soil supports the formation of chlorophyll by being carried to the plant leaves, and this results in an increase in the chlorophyll content of the plant (Bolat and Kara, 2017). Qianqian et al. (2022) stated that biochar increased the chlorophyll content of lettuce. Considering the water retention supporting property of biochar in the soil (Ahmad et al., 2014), the reason for the increase in the leaf relative water content and the decrease in the membrane damage index of curly lettuce under increasing rates of biochar can be explained. Cornelissen et al. (2013) stated that improving the water holding capacity of the soil increases the water storage of the plant, while it was reported as a result of a different study that the leaf relative water content of the plant increased with this improvement provided by the biochar. Karabay et al. (2021) stated that the membrane damage index of peas decreased in conditions where increasing doses of biochar were applied to the soil compared to the control treatment, and they explained this decrease with the longer protective effect of biochar on soil moisture. In addition, the decrease in the membrane damage index of curly lettuce with increasing biochar rates can also be explained by the increase in the protective enzyme activity of biochar. Biochar treatment to the soil prevents the increase of membrane damage by improving the active oxygen capacity and membrane lipid peroxidation, as well as protective enzymes such as superoxide dismutase, catalase and guaiacol peroxidase (Lyu et al., 2016). Biochar reduces the membrane damage index by providing the processing of enzymes that improve the yield of the plant and increase the defense system (Yildirim et al., 2021). In addition, the effect of biochar on soil moisture retention also leads to an improvement in the stomatal conductivity of the plant (Tanure et al., 2019). In this study also, it was observed that the stomatal conductivity of curly lettuce increased with increasing biochar rates. Biochar manages soil moisture more effectively due to its special surface area and spongy structure (Ahmad et al. 2014) and increases the plant's use of soil water (Hossain et al., 2020). Thus, the stomatal conductivity of the plant that uses water more effectively is likely to increase. Similarly, Yıldırım et al. (2021) also stated that the stomatal conductivity of cabbage grown in biochar treated soil increased and this increase was due to the effect of biochar on soil moisture management and drought reducing effect.

The mineral content of curly lettuce (N, P, K, Ca, Mg, Na, Fe, Cu, Mn, Zn) was significantly ($p < 0.01$) affected by varying irrigation water levels and biochar treatments at different rates (Table 1). While the mineral content of curly lettuce decreased with decreasing irrigation water levels, mineral content other than Na in curly lettuce increased with increasing rates of biochar, but the increase in Cu was at a lower level and Na decreased (Figure 3).

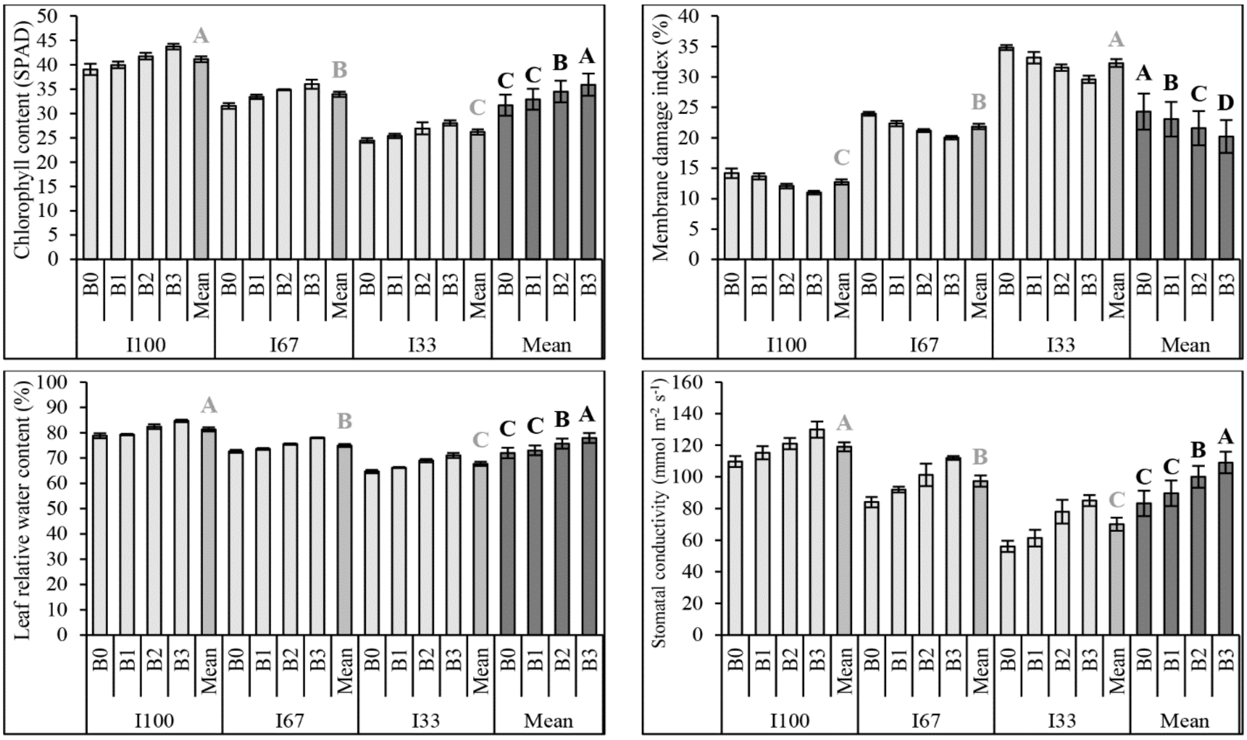

Figure 2. Physiological properties of curly lettuce in varying irrigation water levels and biochar treatments at different rates.

Şekil 2. Değişen sulama suyu seviyelerinde ve farklı oranlarda biyokömür uygulamalarında kıvırcık marulun fizyolojik özellikleri.

The decrease in the mineral content of curly lettuce with the decreasing irrigation water level can be explained by the limitation of nutrient intake as a result of the plant's limited water intake from the soil due to insufficient soil moisture. The plant performs less transpiration due to the decrease in soil water storage with deficit irrigation can be expressed as the reason for the decrease in the mineral content of curly lettuce in drought conditions. Similarly, Karipcin and Satir (2016) and Demir et al. (2022) also stated that the mineral content of lettuce decreased under deficit irrigation conditions and that the highest mineral content was obtained from full irrigation conditions.

The increase in the mineral matter content of curly lettuce with increasing biochar rates can be explained by the nutrient content of biochar to the soil and the increase of biochar's nutrient uptake by the plant. Biochar may have supported the plant's uptake of more nutrients from the soil by improving the nutrient holding capacity of the soil (Hossain et al., 2020) and increasing the nutrient content of the soil with its content (Purakayastha et al., 2019). Biochar absorbs and preserves soil nutrients, preventing their loss and increasing their uptake and use by plants (Nguyen et al., 2017). Thus, this situation can be expressed as the reason for the increase in the mineral content of curly lettuce with increasing rates of biochar. Yildirim et al. (2021) also stated that the mineral content of the plant increased with increasing rates of biochar due to the nutrient retaining and soil nutrient content increasing effects of biochar.

High accumulation of Na in the plant causes the plant to be exposed to toxicity by negatively affecting the osmotic balance of the plant and disrupting the nutrient distribution (Katerji et al., 2004). However, Na uptake of the plant grown in biochar treated soil is limited due to the increased demand for K, Ca and Mg from the plant (Chaganti et al., 2015). In particular, the competition between K and Na significantly affects the nutrient uptake of the plant through the roots. Biochar is an organic material that not only minimizes Na uptake by improving the K stock of the soil and increasing the K uptake of the plant, but also regulates the uptake of K and other nutrients from the soil (Akhtar et al., 2015). Thus, this situation explains the decrease in Na content of curly lettuce with increasing biochar rates. Similarly, Yue et al. (2016) also stated that biochar treatment increased the mineral matter uptake of the plant by reducing the Na uptake of the plant.

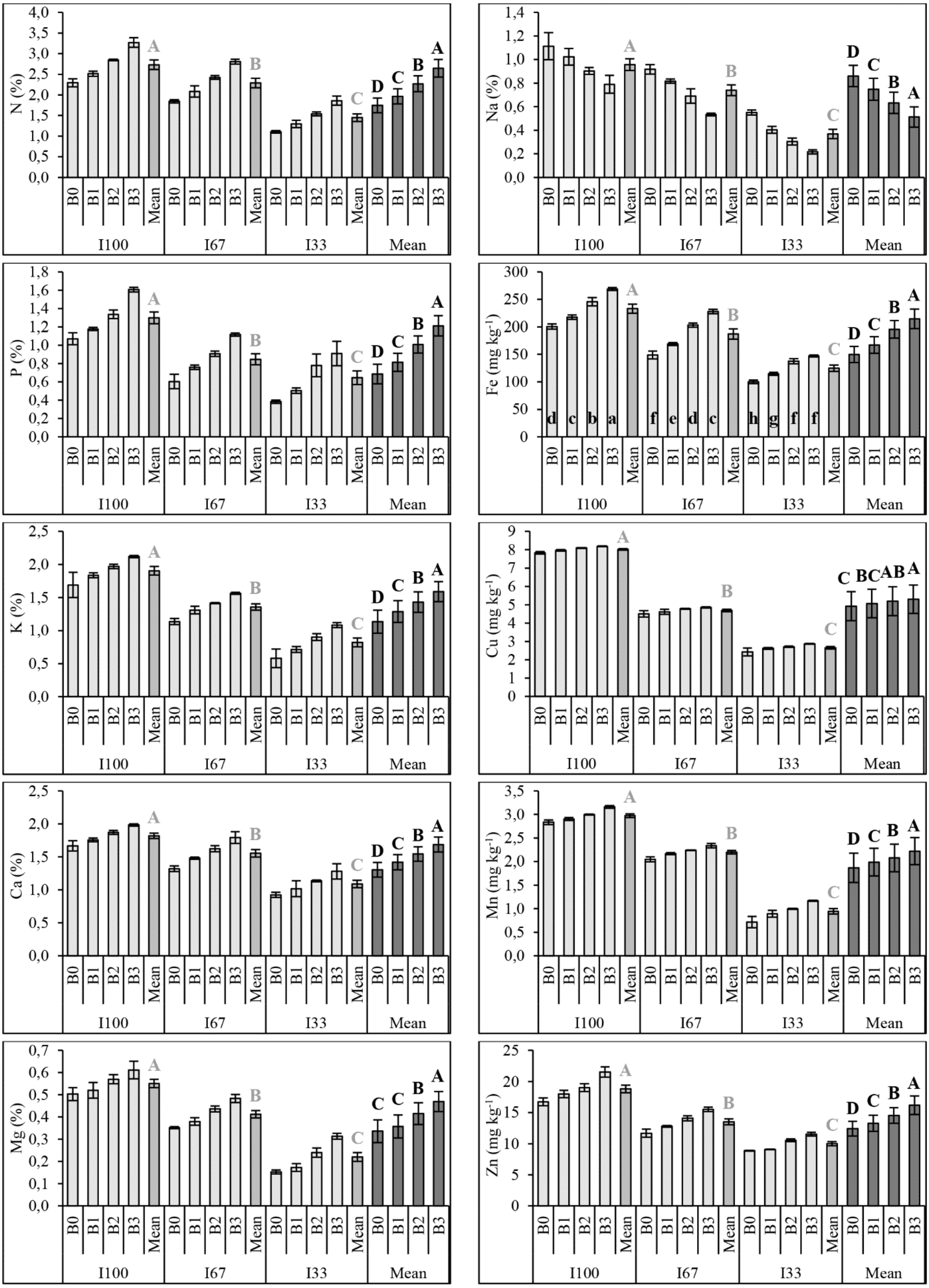

Figure 3. Mineral content of curly lettuce in varying irrigation water levels and biochar treatments at different rates.
Şekil 3. Değişen sulama suyu seviyelerinde ve farklı oranlarda biyokömür uygulamalarında kıvırcık marulun mineral madde içeriği.

CONCLUSION

This study, which examines the effects of irrigation with varying irrigation water levels of curly lettuce grown in soil treated with biochar at different rates on the physical and physiological properties and mineral content of the plant, determined that decreasing irrigation water level negatively affected the physical and physiological properties and mineral content of curly lettuce, but these negative effects that affect the yield and quality of curly lettuce improved with increasing biochar rates. In the study, the highest abiotic stress was obtained in the irrigation of curly lettuce at 33% level and the dose of biochar, which manages the stress most effectively, was 3%. As a result, considering the decrease in freshwater resources and the increase in drought in today's conditions, it was found that it can be suggested to use biochar to improve the physical and physiological properties and mineral content of curly lettuce irrigated with deficit irrigation, and to focus on integrated managements to improve yield in the deficit irrigation strategy for future studies.

CONFLICT OF INTEREST

The authors have declared no conflict of interest.

DECLARATION OF AUTHOR CONTRIBUTION

Şefik Tüfenkçi and Caner Yerli designed the study, participated in experiment, and drafted the manuscript.

REFERENCES

Ahmad, M., Rajapaksha, A. U., Lim, J. E., Zhang, M., Bolan, N., Mohan, D., Vithanage, M., Lee, S. S., & Ok, Y. S. (2014). Biochar as a sorbent for contaminant management in soil and water: a review. *Chemosphere, 99*, 19-33. https://doi.org/10.1016/j.chemosphere.2013.10.071.

Akhtar, S. S., Andersen, M. N., & Liu, F. (2015). Residual effects of biochar on improving growth, physiology and yield of wheat under salt stress. *Agricultural Water Management, 158*, 61-68. https://doi.org/10.1016/j.agwat.2015.04.010.

Al-Bayatı, Y. F. A., & Sahin, M. (2018). Determination of water-yield parameters of lettuce plantin Konya open field conditions. *Soil Water Journal, 7*(2), 38-45. https://doi.org/10.21657/topraksu.460725.

AOAC. (2005). Official methods of analysis of the association of official analytical chemists. Association of Official Analytical Chemists (AOAC).

Bauerle, W. L., Weston, D. J., Bowden, J. D., Dudley, J. B., & Toler, J. E. (2004). Leaf absorptance of photosynthetically active radiation in relation to chlorophyll meter estimates among woody plant species. *Scientia Horticulturae, 101*(1-2), 169-178. https://doi.org/10.1016/j.scienta.2003.09.010.

Bojović, B., & Marković, A. (2009). Correlation between nitrogen and chlorophyll content in wheat (*Triticum aestivum* L.). *Kragujevac Journal of Science, 31*(5827), 69-74.

Bolat, I., & Kara, O. (2017). Plant nutrients: sources, functions, deficiencies and redundancy. *Journal of Bartin Faculty of Forestry, 19*(1), 218-228. https://doi.org/10.24011/barofd.2513133.

Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen total 1. In: A. L. Page, M. H. Miller & D. R. Keeney (Eds.), *Methods of soil analysis* (pp. 903-948). America and Soil Science Society, Madison.

Camoglu, G., & Demirel, K. (2015). The effects on yield and some physio–morphological traits of different salinity and potassium treatments in lettuce. *COMU Journal of Agriculture Faculty, 3*(1), 89-97.

Camoglu, G., Demirel, K., Akcal, A., & Genc, L. (2019). The effects of water stress on the yield and physiological properties of table tomato. *Journal of Agricultural Faculty of Bursa Uludag University, 33*(1), 15-29.

Chaganti, V. N., Crohn, D. M., & Simunek, J. (2015). Leaching and reclamation of a biochar and compost amended saline-sodic soil with moderate SAR reclaimed water. *Agricultural Water Management, 158*, 255-265. https://doi.org/10.1016/j.agwat.2015.05.016.

Chai, Q., Gan, Y., Turner, N. C., Zhang, R. Z., Yang, C., Niu, Y., & Siddique, K. H. (2014). Water-saving innovations Chinese agriculture. *Advances in Agronomy, 126*, 149-201. https://doi.org/10.1016/B978-0-12-800132-5.00002-X.

Chai, Q., Gan, Y., Zhao, C., Xu, H. L., Waskom, R. M., Niu, Y., & Siddique, K. H. (2016). Regulated deficit irrigation for crop production under drought stress. A review. *Agronomy for Sustainable Development, 36*, 1-21. https://doi.org/10.1007/s13593-015-0338-6.

Cornelissen, G., Martinsen, V., Shitumbanuma, V., Alling, V., Breedveld, G. D., Rutherford, D. W., Sparrevik, M., Hale, S. E., Obia, A., & Mulder, J. (2013). Biochar effect on maize yield and soil characteristics in five conservation farming sites in Zambia. *Agronomy, 3*(2), 256-274. https://doi.org/10.3390/agronomy3020256.

Corwin, D. L., & Rhoades, J. D. (1984). Measurement of inverted electrical conductivity profiles using electromagnetic induction. *Soil Science Society of America Journal, 48*(2), 288-291. https://doi.org/10.2136/sssaj1984.03615995004800020011x.

Demir, H., Kaman, H., Sonmez, I., Mohamoud, S. S., Polat, E., & Ucok, Z. (2022). Yield, quality and plant nutrient contents of lettuce under different deficit irrigation conditions. *Acta Scientiarum Polonorum Hortorum Cultus*, *21*(1), 115-129. https://doi.org/10.24326/asphc.2022.1.10.

Egamberdieva, D., Reckling, M., & Wirth, S. (2017). Biochar-based Bradyrhizobium inoculum improves growth of lupin (*Lupinus angustifolius* L.) under drought stress. *European Journal of Soil Biology*, *78*, 38-42. https://doi.org/10.1016/j.ejsobi.2016.11.007.

Gee, G. W., & Bauder, J. W., (1986). Particle size analysis. In: A. L. Page, M. H. Miller & D. R. Keeney (Eds.), *Methods of soil analysis* (pp. 338-411). America and Soil Science Society, Madison.

Girones, R., Ferrús, M. A., Alonso, J. L., Rodriguez-Manzano, J., Calgua, B., de Abreu Corrêa, A., Hundesa, A., Carratala, A., & Bofill-Mas, S. (2010). Molecular detection of pathogens in water–the pros and cons of molecular techniques. *Water Research, 44*(15), 4325-4339. https://doi.org/10.1016/j.watres.2010.06.030.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science*, *327*(5967), 812-818. https://doi.org/10.1126/science.1185383.

Gul, S., & Whalen, J. K. (2016). Biochemical cycling of nitrogen and phosphorus in biochar-amended soils. *Soil Biology and Biochemistry*, *103*, 1-15. https://doi.org/10.1016/j.soilbio.2016.08.001.

Hossain, M. Z., Bahar, M. M., Sarkar, B., Donne, S. W., Ok, Y. S., Palansooriya, K. N., Kirkham, M. B., Chowdhury, S., & Bolan, N. (2020). Biochar and its importance on nutrient dynamics in soil and plant. *Biochar*, *2*, 379-420. https://doi.org/10.1007/s42773-020-00065-z.

Jamei, R., Heidari, R., Khara, J., & Zare, S. (2009). Hypoxia induced changes in the lipid peroxidation, membrane permeability, reactive oxygen species generation, and antioxidative response systems *Zea mays* leaves. *Turkish Journal of Biology*, *33*(1), 45-52. https://doi.org/10.3906/biy-0807-14.

Kalra, Y. (1997). Handbook of reference methods for plant analysis. CRC press.

Kang, S., Hao, X., Du, T., Tong, L., Su, X., Lu, H., Li, X., Huo, Z., Li, S., & Ding, R. (2017). Improving agricultural water productivity to ensure food security in China under changing environment: From research to practice. *Agricultural Water Management*, *179*, 5-17. https://doi.org/10.1016/j.agwat.2016.05.007.

Karabay, U., Toptas, A., Yanik, J., & Aktas, L. (2021). Does biochar alleviate salt stress impact on growth of salt-sensitive crop common bean. *Communications in Soil Science and Plant Analysis*, *52*(5), 456-469. https://doi.org/10.1080/00103624.2020.1862146.

Karipcin, M. Z., & Satir, N. Y. (2016). Effect of arbuscular mycorrhizal fungi (AMF) on growth and nutrient uptake of lettuce (*Lactuca sativa*) under water stress. *Yuzuncu Yil University Journal of Agricultural Sciences*, *26*(3), 406-413.

Katerji, N., Van Hoorn, J. W., Hamdy, A., & Mastrorilli, M. (2004). Comparison of corn yield response to plant water stress caused by salinity and by drought. *Agricultural Water Management*, *65*(2), 95-101. https://doi.org/10.1016/j.agwat.2003.08.001.

Kiran, S., Ozkay, F., Ellialtioglu, S., & Kusvuran, S. (2014). Studies on some physiological changes of drought stress applied melon genotypes. *Soil Water Journal*, *3*(1), 53-58. https://doi.org/10.21657/tsd.67125.

Laghari, M., Naidu, R., Xiao, B., Hu, Z., Mirjat, M. S., Hu, M., Kandhro, M. N., Chen, Z., Guo, D., Jogi, Q., Abudi, Z. N. & Fazal, S. (2016). Recent developments in biochar as an effective tool for agricultural soil management: a review. *Journal of the Science of Food and Agriculture*, *96*(15), 4840-4849. https://doi.org/10.1002/jsfa.7753.

Li, H., Dong, X., da Silva, E. B., de Oliveira, L. M., Chen, Y., & Ma, L. Q. (2017). Mechanisms of metal sorption by biochars: biochar characteristics and modifications. *Chemosphere*, *178*, 466-478. https://doi.org/10.1016/j.chemosphere.2017.03.072.

Lyu, S., Du, G., Liu, Z., Zhao, L., & Lyu, D. (2016). Effects of biochar on photosystem function and activities of protective enzymes in Pyrus ussuriensis Maxim. under drought stress. *Acta Physiologiae Plantarum*, *38*, 1-10. https://doi.org/10.1007/s11738-016-2236-1.

Mancosu, N., Snyder, R. L., Kyriakakıs, G., & Spano, D. (2015). Water scarcity and future challenges for food production. *Water*, *7*, 975-992. https://doi.org/10.3390/w7030975.

Mandal, S., Pu, S., Adhikari, S., Ma, H., Kim, D. H., Bai, Y., & Hou, D. (2021). Progress and future prospects in biochar composites: Application and reflection in the soil environment. *Critical Reviews Environmental Science and Technology*, *51*(3), 219-271. https://doi.org/10.1080/10643389.2020.1713030.

Marcińska, I., Czyczyło-Mysza, I., Skrzypek, E., Filek, M., Grzesiak, S., Grzesiak, M. T., Janowiak, F., Hura, T., Dziurka, M., Dziurka, K., Nowakowska, A., & Quarrie, S. A. (2013). Impact of osmotic stress on physiological and biochemical characteristics in drought-susceptible and drought-resistant wheat genotypes. *Acta Physiologiae Plantarum*, *35*, 451-461. https://doi.org/10.1007/s11738-012-1088-6.

McLean, E. O. (1982). Soil pH and lime requirement. In: A. L. Page, M. H. Miller & D. R. Keeney (Eds.), *Methods of soil analysis* (pp. 199-224). America and Soil Science Society, Madison.

Montenegro, M., Silva, A. Z., & Pedraza, R. O. (2011). Effect of water availability on physiological performance and lettuce crop yield (*Lactuca sativa*). *Ciencia E Investigación Agraria*, 38(1), 65-74.

Muller, B., Pantin, F., Génard, M., Turc, O., Freixes, S., Piques, M., & Gibon, Y. (2011). Water deficits uncouple growth from photosynthesis, increase C content, and modify the relationships between C and growth in sink organs. *Journal of Experimental Botany, 62*(6), 1715-1729. https://doi.org/10.1093/jxb/erq438.

Nelson, D. W., & Sommers, L. E. (1982). Total carbon, organic carbon, and organic matter. In: A. L. Page, M. H. Miller & D. R. Keeney (Eds.), *Methods of soil analysis* (pp. 539-577). America and Soil Science Society, Madison.

Nguyen, T. T. N., Xu, C. Y., Tahmasbian, I., Che, R., Xu, Z., Zhou, X., Wallace, H. M., & Bai, S. H. (2017). Effects of biochar on soil available inorganic nitrogen: a review and meta-analysis. *Geoderma, 288*, 79-96. https://doi.org/10.1016/j.geoderma.2016.11.004.

Ors, S., & Ekinci, M. (2015). Drought stress and plant physiology. *Derim, 32*(2), 237-250.

Oukaltouma, K., El Moukhtari, A., Lahrizi, Y., Makoudi, B., Mouradi, M., Farissi, M., Willems, A., Qaddoury, A., Bekkaoui, F., & Ghoulam, C. (2022). Physiological, biochemical and morphological tolerance mechanisms of faba bean (*Vicia faba* L.) to the combined stress of water deficit and phosphorus limitation. *Journal of Soil Science and Plant Nutrition*, 22(2), 1632-1646. https://doi.org/10.1007/s42729-022-00759-2.

Purakayastha, T. J., Bera, T., Bhaduri, D., Sarkar, B., Mandal, S., Wade, P., Kumari, S., Biswas, S., Menon, M., Pathak, H., & Tsang, D. C. (2019). A review on biochar modulated soil condition improvements and nutrient dynamics concerning crop yields: Pathways to climate change mitigation and global food security. *Chemosphere*, *227*, 345-365. https://doi.org/10.1016/j.chemosphere.2019.03.170.

Pushnik, J. C., Miller, G. W., & Manwaring, J. H. (1984). The role of iron in higher plant chlorophyll biosynthesis, maintenance and chloroplast biogenesis. *Journal of Plant Nutrition*, 7(1-5), 733-758. https://doi.org/10.1080/01904168409363238.

Qianqian, M., Haider, F. U., Farooq, M., Adeel, M., Shakoor, N., Jun, W., Jiaying X., Wang, X. W., Panjun, L., & Cai, L. (2022). Selenium treated Foliage and biochar treated soil for improved lettuce (*Lactuca sativa* L.) growth in Cd-polluted soil. *Journal of Cleaner Production, 335*, 130267. https://doi.org/10.1016/j.jclepro.2021.130267.

Razzaghi, F., Obour, P. B., & Arthur, E. (2020). Does biochar improve soil water retention? A systematic review and meta-analysis. *Geoderma, 361*, 114055. https://doi.org/10.1016/j.geoderma.2019.114055.

Sabatino, L., Iapichino, G., Mauro, R. P., Consentino, B. B., & De Pasquale, C. (2020). Poplar biochar as an alternative substrate for curly endive cultivated in a soilless system. *Applied Sciences, 10*(4), 1258. https://doi.org/10.3390/app10041258.

Schiermeier, Q. (2014). Water on tap. *Nature, 510*, 326-328. https://doi.org/10.1038/510326a.

Semida, W. M., Beheiry, H. R., Sétamou, M., Simpson, C. R., Abd El-Mageed, T. A., Rady, M. M., & Nelson, S. D. (2019). Biochar implications for sustainable agriculture and environment: A review. South African Journal of Botany, 127, 333-347. https://doi.org/10.1016/j.sajb.2019.11.015.

Senyigit, U., & Kaplan, D. (2013). Impact of different irrigation water levels on yield and some quality parameters of lettuce (*Lactuca sativa* L. *var*. Longifolia cv.) under unheated greenhouse condition. *Infrastructure and Ecology of Rural Areas*, *2*, 97-107.

Smart, R. E., & Barrs, H. D. (1973). The effect of environment and irrigation interval on leaf water potential of four horticultural species. *Agricultural Meteorology, 12*, 337-346. https://doi.org/10.1016/0002-1571(73)90030-7.

Tanure, M. M. C., da Costa, L. M., Huiz, H. A., Fernandes, R. B. A., Cecon, P. R., Junior, J. D. P., & da Luz, J. M. R. (2019). Soil water retention, physiological characteristics, and growth of maize plants in response to biochar application to soil. *Soil and Tillage Research, 192*, 164-173. https://doi.org/10.1016/j.still.2019.05.007.

TUIK. (2023). Agriculture Statistics. https://data.tuik.gov.tr/Kategori/GetKategori?p=tarim-111&dil=1 [Access date: February 5, 2023].

Yang, A., Akhtar, S. S., Li, L., Fu, Q., Li, Q., Naeem, M. A., He, X., Zhang, Z., & Jacobsen, S. E. (2020). Biochar mitigates combined effects of drought and salinity stress in quinoa. *Agronomy, 10*(6), 912. https://doi.org/10.3390/agronomy10060912.

Yazdic, M., & Degirmenci, H. (2018). Effect on leaf water potential and chlorophyll value of different irrigation levels in cotton. *KSU Journal of Agriculture and Nature, 21*(4), 511-519.

Yazgan, S., Ayas, S., Demirtas, C., Buyuukcangaz, H., & Candogan, B. N. (2008). Deficit irrigation effects on lettuce (*Lactuca sativa* var. *Olenka*) yield in unheated greenhouse condition. *Journal of Food Agriculture and Environment, 6*, 357-361.

Yildirim, E., Ekinci, M., & Turan, M. (2021). Impact of biochar in mitigating the negative effect of drought stress on cabbage seedlings. *Journal of Soil Science and Plant Nutrition*, *21*(3), 2297-2309. https://doi.org/10.1007/s42729-021-00522-z

Yildirim, E., Ekinci, M., Turan, M., Agar, G., Ors, S., Dursun, A., Kul, R., & Akgul, G. (2022). Physiological and biochemical changes of pepper cultivars under combined salt and drought stress. *Gesunde Pflanzen*, *74*(3), 675-683. https://doi.org/10.1007/s10343-022-00642-1.

Yue, Y., Guo, W. N., Lin, Q. M., Li, G. T., & Zhao, X. R. (2016). Improving salt leaching in a simulated saline soil column by three biochars derived from rice straw (*Oryza sativa* L.), sunflower straw (*Helianthus annuus*), and cow manure. *Journal of Soil and Water Conservation*, *71*(6), 467-475. https://doi.org/10.2489/jswc.71.6.467.

Zhu, X., Chen, B., Zhu, L., & Xing, B. (2017). Effects and mechanisms of biochar-microbe interactions in soil improvement and pollution remediation: a review. *Environmental Pollution*, *227*, 98-115. https://doi.org/10.1016/j.envpol.2017.04.032.