International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

Impact Of Biochar On Some Physical Traits Of Soil And Variation Of Irrigation And Biochar Levels On Growth And Yield Of Lettuce (Lactuca Sativa L.)

Huda F.S. ALsardar[1], Ahmed Khairuldeen Abdulsalam[2] and Fathel F.R. Ibraheem[3]
[1,2]Department Soil Science and Water Resource, College of Agriculture and Forestry, University of Mosul, Iraq
[3]Department Horticulture and Landscape Architecture, College of Agriculture and Forestry, University of Mosul, Iraq

Abstract. *The experimental design aimed to evaluate the effects and interactions among three factors that including drip irrigation regimes with three levels (50%, 75%, and 100%) of the soil's field capacity, Biochar incorporation at two levels (0% and 0.5% by weight), and two imported lettuce cultivars (Nader and Rama). Biochar was integrated into the soil during land preparation and was also used during the seedling establishment phase prior to transplanting. The factorial experiment comprised 12 treatment combinations derived from the three factors (3 × 2 × 2), and each treatment was replicated three times, yielding 36 experimental units in total. A randomized complete block design (RCBD) with a split-plot arrangement was employed. The main plots were allocated to the lettuce cultivars, while subplots received random combinations of irrigation levels and biochar treatments. The collected data were subjected to statistical analysis based on the adopted experimental layout.*
Results were summarized as follows: Addition of biochar at a rate of 0.5% to soil resulted in a significant decrease in bulk density, accompanied by increases in soil porosity and saturated hydraulic conductivity compared to the control treatment without biochar. Furthermore, biochar application led to significant improvements in productivity traits and overall yield,. The studied productivity parameters specifically head weight and total head yield showed significant enhancements under both 75% and 100% field capacity irrigation levels compared to the 50% field capacity treatment. Additionally, the Rama cultivar demonstrated a statistically superior performance over the Nader cultivar across all measured traits.
Key words: *Biochar, Cultivars, Field Capacity, Irrigation, Lactuca.*

INTRODUCTION

Lettuce (*Lactuca sativa* L.) is considered one of the most important leafy vegetable crops belonging to the Compositae family, also known as the sunflower family, scientifically referred to as *Asteraceae* (Hassan, 2003). This plant family is among the largest in the plant kingdom, encompassing nearly 800 genera and over 20,000 species, the majority of which are annual herbaceous plants. Lettuce is primarily cultivated for its tender leaves, which are consumed fresh (Kim et al., 2016).
Many factors affect lettuce growth and productivity; climactic as well as appropriate agricultural practices play a crucial role. With the growing global population, the demand for fresh food is increasing and the area of lettuce needs to be expanded by increasing the yield of lettuce per unit area. This must be done with some of modern agricultural strategies of maximization of quantity, quality of the production as well. One of the biggest

challenges now for agriculture is the increasing lack of water availability. Global decline in water availability–exacerbated by growing population, increasing competition for water and deteriorating water quality–has emerged as a major global issue (Cera, 2022, Karlsons and Osvalde, 2025).
Climate change exacerbates this double challenge through its negative effects on the sustainability of agricultural systems and development itself. Against this backdrop, the need for the adoption of modern irrigation methods and enhanced water use efficiency has taken on an urgent dimension. Deficit irrigation is a relatively new approach to ameliorate water limitations. This method is to provide crops with a limited supply of water that meets only the priority requirements of the crops as much as possible, so that the amount of irrigation water used reaches the minimum level of waste, and the crop growth and yield can be guaranteed to a certain extent (Farooq et al., 2019). This is even more so in regions with arid/semi-arid climates where food security relies on the improved and effective use of scarce fresh water resources (FAO, 2023).
Of all the irrigation systems, drip irrigation is one of the most efficient and accurate methods of providing water to crops. By promoting direct delivery of water to the root zone of plants, it minimizes losses from evaporation and surface runoff, thereby increasing water use efficiency (Howell, 2001). Well, scientists have also stressed the need for irrigation adjustments at particular field capacity levels. This approach can also optimize the trade-off between water savings and good crop performance (Fereres & Soriano, 2007). In addition, research such as that by Kang et al. (2017) Whereas the need to improve productivity of water used in agriculture has focused on institutional, effcient systems Jan et al. In addition to irrigation techniques, soil health has come to be recognized in sustainable agriculture as an equally important target of improvement. One stable, carbon-rich product obtained from the pyrolysis (the thermal decomposition of organic material at elevated temperatures in an inert atmosphere) process is biochar, a material that has been deployed for some time as a soil amendment for its beneficial physical and hydrological properties for soils. Reduces soil bulk density, increases porosity, and can increase retention and infiltration rates (Lehmann et al., 2011).
Biochar has also been shown to improve the plasticity and strength of soils through alteration of the Atterberg limits which further contributes to resistance to soil compaction and erosion (Mukherjee & Lal, 2013). In addition to that, it also aids in better soil aggregation as measured by the mean weight diameter of soil – an indicator for enhanced soil structure and health (Agegnehu et al., 2016). Related to plant performance the amendment of agricultural soils with biochar had promoted development and yield of lettuce (Lactuca sativa L.) (Wang et al., 2025 and Zhylina et al., 2025).
The reasons for these advantages are associated with nutrients retention, soil fertility improvement and moisture environment in root zone (Liu et al., 2013). Biochar, therefore, represents a potentially sustainable and low-cost high-efficiency technology for soil quality restoration and sustainable production. Cultivar selection is another key factor influencing yield potential. Genetic and environmental interactions resulting in a wide variation in productivity and adaptability of lettuce varieties. Most of the lettuce grown in Iraq belongs to the Cos (Romaine) group, which is known for long heads and agronomically desirable traits (Carini et al., 2020). Different varietal have been shown in many studies to greatly affect yield size, but also crop quality, mainly reflecting variability

in total genetic potentials for any cultivated response to the growing condition (Kumar, 2000).
Open-pollinated and hybrid cultivars with higher yield potential have been promoted in recent literature to optimize production efficiency. The genetic constitution of these cultivars is known to express its productivity at different stages of plant development (Ibraheem, 2007).
There are need to variable integration offers an exciting new strategy to improve the production of lettuce when water is limited and environmental conditions are variable. The overarching goal was to achieve an optimal balance between improving crop performance and enhancing soil physical quality, thereby promoting sustainable and efficient agricultural practices. As well as, to explore the role of biochar in enhancing key soil physical properties. Therefore, the current work aims to investigate effects of different levels of field capacity by drip irrigation, biochar soil amendments and cultivar types on the growth characteristics and yield of lettuce.

MATERIALS AND METHODS

This study was designed to evaluate the effects of three main factors: (1) Three levels of drip irrigation corresponding to 50%, 75%, and 100% of field capacity; (2) Two levels of biochar application (0% and 0.5% by weight); and (3) Two imported lettuce cultivars—*Nader* and *Rama*. Biochar was incorporated into the soil prior to transplanting, during field preparation. The experiment consisted of 12 treatment combinations (3 irrigation levels × 2 biochar levels × 2 cultivars), replicated three times, resulting in a total of 36 experimental units. A factorial experiment within a split-plot design was adopted, arranged in a randomized complete block design (RCBD). Cultivars were assigned to the main plots, while irrigation and biochar treatments were randomized within the sub-plots.
The field trial was conducted during the 2024–2025 growing season at the Agricultural and Forestry College experimental station, located in the Al-Ghabat (forest park) area of Mosul University. Prior to planting, soil samples were collected from the 0–30 cm surface layer for analysis of selected physical and chemical properties of the plastic-house soil. Land preparation involved plowing with a disk plow, followed by leveling and smoothing using a harrow. The experimental area was then divided into experimental units, each measuring 1.5 m^2 (1.5 m length × 1.0 m width), with three planting rows per bed. Rows were spaced 35 cm apart, and plants were spaced 30 cm apart within each row, resulting in 15 plants per unit and 45 plants per treatment. A 50 cm buffer was maintained between plots to prevent treatment interference.
A drip irrigation system was installed as the primary irrigation method for the experiment. Two lettuce cultivars were used in the study. The first, Rama, produced by Prims Seeds (Netherlands), had a stated purity of 99% and a germination rate of 95%, classified as Romaine lettuce. The second, Nader, from Enza Zaden (Netherlands), also had a purity of 99% and a germination rate of 85%, and was likewise identified as Romaine lettuce, according to packaging information.
Seeds were sown on December 14, 2024, in plastic seedling trays containing 50 cells each, using peat moss as the germination medium. Transplanting was conducted on January 11, 2025, when seedlings had developed three to four true leaves. Seedlings were carefully

transplanted with peat moss intact around the roots, ensuring adequate soil moisture at the time of planting.

All agronomic practices—such as fertilization, weeding, and pest and disease management were uniformly applied across all plots. Fertilizers included urea (46% N) at 200 kg ha^{-1}, potassium sulfate (50% K_2O) at 200 kg ha^{-1}, and triple superphosphate (P_2O_5) at 300 kg ha^{-1}. Fertilizers were applied one week after transplanting by digging shallow trenches alongside the planting rows, placing the fertilizers inside, and covering them with soil (Hassan, 2003). For disease prevention, *Speed 24 SC*, a systemic fungicide, was applied pre-planting at a rate of 3–5 kg ha^{-1} to control root and stem rots in vegetables and fruit trees. Additionally, *Amidal 20 SL* was used at a concentration of 1.5 ml L^{-1} as a protective foliar spray targeting soilborne fungi responsible for seedling wilt and root.

Statistical analysis was conducted using SAS software (version 2017), and treatment means were compared using Duncan's Multiple Range Test at a significance level of 0.05 (Rawari & Khalafallah, 2000). The following parameters were examined

1. Bulk density was determined using the core method as described by Blake & Hartge (1986).
2. Soil porosity was calculated based on bulk density and particle density values, following the method described by Danielson & Sutherland (1986).
3. Saturated hydraulic conductivity of the soil was measured using the falling head method, as described by Klute and Dirksen (1986).
4. Number of leaves (leaves $plant^{-1}$): The number of leaves per plant was recorded, excluding the very small leaves present at the apical growing point of the stem.
5. Head weight (g $head^{-1}$): Calculated by dividing the total weight of heads harvested from the experimental unit by the number of heads produced.
6. Total head yield (kg m^{-2}): Calculated by dividing the total weight of the harvest from the experimental unit by its area, then using proportional scaling to express the yield per square meter.

RESULTS AND DISCUSSION

Effect of Biochar Addition on Soil Bulk Density (g cm^{-3}): The data from Figure (1) showed that the application of biochar decreased the soil bulk density. The results indicate 1.55 g cm^{-3} as bulk density in the control treatment without biochar and 1.42 g cm^{-3} with the application in 0.5% of biochar meaning 8.39% reduction in bulk density (Table 5). The decrease in bulk density is essentially because the density of the particles of biochar is intrinsically lower than that of mineral soil particles and has a high porosity.

Biochar has contributed with the increase of the total volume of pores, which has consequently decreased the general specific mass of soil matrix when combining biochar with soil. Soil porosity measurements shown in Figure (2) also attest to these findings, displaying greater porosity for treatments that received biochar compared to the control treatment. Previous studies showed that biochar can decrease soil bulk density, which is consistent with our results (Table 5), including one of the first studies on biochar (Hu et al., 2025; Listyarini & Farni, 2025; Wang et al., 2025).

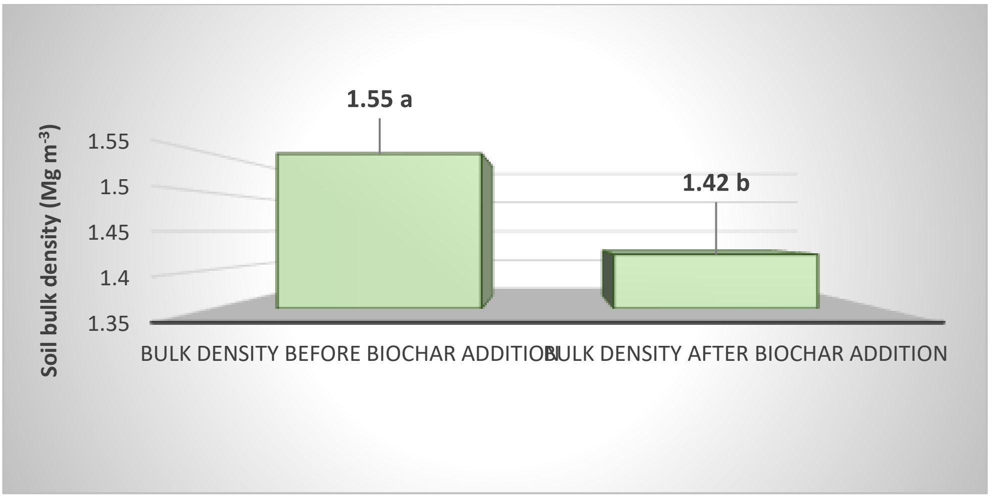

Figure 1. Effect of biochar addition on soil bulk density.

Effect of Biochar Addition on Soil Porosity (%): Porosity is a fundamental physical property that governs the movement of water and air within the soil and is closely linked to bulk density. Recent studies indicate that biochar application typically increases the total porosity of soil, a change associated with reduced bulk density and improved pore size distribution, especially when moderate levels of biochar are used. As shown in Figure (2), biochar addition raised soil porosity from 41.6% in the control treatment to 46.5% at a 0.5% biochar application rate, reflecting an increase of 11.78%.
Over the long term, biochar's effects on enhancing soil porosity are further promoted by biophysical interactions within the soil, such as root growth, microbial activity, and the restructuring of soil aggregates around biochar particles. Several studies have reported improvements in total porosity following biochar amendment, including those by Hu et al. (2025), Listyarini & Farni (2025), Chen et al. (2025), and Wang et al. (2025).

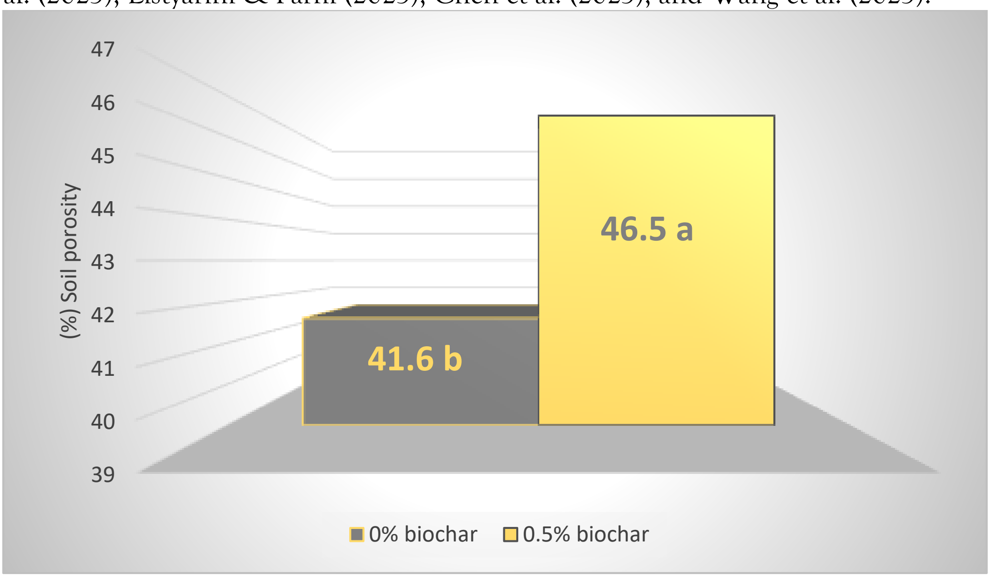

Figure 2. Effect of biochar addition on soil porosity.

Effect of Biochar Addition on Saturated Hydraulic Conductivity (cm hr^{-1}): The results presented in Figure (3) demonstrate that biochar application to the soil increased saturated hydraulic conductivity (Ks). Specifically, the Ks value before biochar addition was 0.626 cm hr^{-1}, whereas applying biochar at a rate of 0.5% raised this value to 0.843 cm hr^{-1}, representing an increase of 34.66%. This observed enhancement in saturated hydraulic conductivity is attributed to improvements in soil physical properties, primarily due to the modification of pore connectivity and structural changes induced by biochar incorporation.
Biochar is characterized by its porous nature, high surface area, and three-dimensional structural framework, which collectively contribute to increased soil saturated hydraulic conductivity upon amendment. These findings are consistent with previous studies conducted by Al-Mehmdy et al. (2025), Bagarello et al. (2025), and Thao et al. (2025).

Figure 3. The effect of biochar addition on saturated hydraulic conductivity

Number of Leaves (leaves $plant^{-1}$): Data from Table (1) indicate that the highest number of leaves per plant, 49.2083 leaves, was recorded at the 75% field capacity irrigation level, which was significantly greater only compared to the 100% field capacity treatment, where the lowest leaf number of 46.7917 leaves per plant was observed. Regarding the effect of biochar levels, the 0.5% biochar treatment significantly outperformed the 0% treatment in leaf number, with values of 49.500 and 46.389 leaves per plant, respectively.
As for cultivar effects, the *Rama* cultivar produced the highest leaf number of 49.278 leaves per plant, significantly surpassing the *Nader* cultivar, which had 46.611 leaves per plant. In terms of the interaction between irrigation levels and biochar application, the combination of 50% field capacity irrigation with 0.5% biochar yielded the highest leaf number at 50.917 leaves per plant. This value was significantly higher than the interaction treatments of 50% field capacity with 0% biochar and 100% field capacity with 0% biochar. The lowest leaf number, 44.583 leaves per plant, was recorded under the interaction treatment of 100% field capacity irrigation with no biochar application.

Regarding the interaction effects between irrigation levels and cultivars, the highest leaf number (49.333 leaves per plant) was observed under the combination of 75% field capacity irrigation with the *Rama* cultivar. This was significantly higher than the lowest leaf number (44.250 leaves per plant), recorded for the interaction between 100% field capacity irrigation and the *Nader* cultivar. No significant differences were noted among the other interaction treatments for both cultivars.

Concerning the interaction between biochar levels and cultivars, all combinations outperformed the treatment with no biochar applied to the *Nader* cultivar, which exhibited the lowest leaf number at 44.167 leaves per plant. The highest leaf number (49.944 leaves per plant) was recorded for the combination of 0.5% biochar with the *Rama* cultivar. Regarding the three-way interaction among irrigation levels, biochar levels, and cultivars, the data in the table show that the combination of 100% field capacity irrigation, 0.5% biochar, and the *Rama* cultivar produced the highest leaf number of 52.167 leaves per plant, significantly exceeding many other treatment combinations. Conversely, the lowest leaf number (42.167 leaves per plant) was observed under the interaction of 50% field capacity irrigation, 0% biochar, and the *Nader* cultivar.

Table 1. Levels of irrigation with biochar's and cultivars effects on leaves number.

Irrigation Levels	Biochar Levels	Cultivars: Nader	Cultivars: Rama	Irrigation Levels X Biochar Levels	Mean Effect of Irrigation Levels
50% FC	%0	42.167 f	47.333 b-d	44.750 b	47.8333 ab
	%0.5	50.833 a-c	51.000 ab	50.917 a	
75% FC	%0	47.667 b-d	52.000 a	49.833 a	49.2083 a
	%0.5	50.500 a-c	46.667 b-e	48.583 a	
100% FC	%0	42.667 ef	46.500 c-e	44.583 b	46.7917 b
	%0.5	45.833 d-f	52.167 a	49.000 ab	
Irrigation Levels X Cultivars	%50	46.500 ab	49.167 a	Mean Effect of Biochar	
	%75	49.083 a	49.333 a		
	%100	44.250 b	49.332 a		
Biochar Levels	% 0	44.167 b	48.611 a	46.389 b	

X Cultivars	%0.5	49.056 a	49.944 a	49.500 a
Mean Effect of Cultivars		46.611 b	49.278 a	

*According to the probability methodology of Dunkan at a larger level or equal to 5%, the averages that share a similar letter, there are no different statistical connotations between them.

Head Weight (g head⁻¹): Data presented in Table (2) indicate that plants grown under 75% and 100% field capacity irrigation levels exhibited a significant increase in head weight compared to those grown at 50% field capacity, with no significant difference observed between the two higher irrigation levels. The highest significant head weight of 817.50 g was recorded at 100% field capacity, while the lowest value of 730.42 g was observed in plants grown under 50% field capacity.

Additionally, biochar application at 0.5% significantly improved head weight compared to the control (no biochar), with respective values of 821.67 g and 733.89 g per head. The *Rama* cultivar also significantly outperformed the *Nader* cultivar in this trait, recording head weights of 825.56 g and 730.00 g, respectively.

Regarding the interaction between irrigation levels and biochar application, the combination of 100% field capacity with 0.5% biochar produced the highest significant head weight of 886.67 g, surpassing all other interaction treatments. However, the minimum head weights (625.83 g) were recorded when the irrigation levels were 50% field capacity with no biochar addition.

The interaction of irrigation levels and cultivars was significant for head weight so that Rama plants irrigated at 100% field capacity had the highest head weight (843.33 g) which was significantly higher than all other combinations. Conversely, the minimum value for this interaction—675.00 g—was observed in the Nader plants exposed to the 50% field capacity. In context of genotype × treatment interaction, the head weight of Rama plants was highest (856.67 g) treated with 0.5% biochar which was significantly higher than all other treatments. On the other hand, for this interaction, the minimum head weight was 673.33 g observed in Nader plants without biochar application.

The three-way interaction among irrigation levels, biochar application, and cultivars revealed that the highest head weight of 900.00 g was achieved by *Rama* plants grown under 100% field capacity with 0.5% biochar. This combination significantly exceeded many other treatment interactions. In contrast, *Nader* plants grown under 50% field capacity without biochar recorded the lowest head weight of 530.00 g.

Table 2. Levels of irrigation with biochar's and cultivars effects on weight of head.

Irrigation Levels	Biochar Levels	Cultivars		Irrigation Levels X Biochar Levels	Mean Effect of Irrigation Levels
		Nader	Rama		
50% FC	%0	530.00 f	721.67 c-e	625.83 c	730.42 b
	%0.5	820.00 a-c	850.00 ab	835.00 a	
75% FC	%0	780.00 b-d	875.00 ab	827.50 a	785.42 a

	%0.5	666.67 e	820.00 a-c	743.33 b	
100% FC	%0	710.00 de	786.67 b-d	748.33 b	817.50 a
	%0.5	873.33 ab	900.00 a	886.67 a	
Irrigation Levels X Cultivars	%50	675.00 c	785.83 ab	Mean Effect of Biochar	
	%75	723.33 bc	847.50 a		
	%100	791.67 a	843.33 a		
Biochar Levels X Cultivars	% 0	673.33 c	794.44 b	733.89 b	
	%0.5	786.67 b	856.67 a	821.67 a	
Mean Effect of Cultivars		730.00 b	825.56 a		

*According to the probability methodology of Dunkan at a larger level or equal to 5%, the averages that share a similar letter, there are no different statistical connotations between them.

Total Head Yield (kg m^{-2}): Data from Table (3) indicate that plants grown under 75% and 100% field capacity irrigation levels significantly outperformed those grown under 50% field capacity in total head yield, with no significant difference between the two higher irrigation levels. The highest yield value of 8.1750 kg m^{-2} was recorded at 100% field capacity, while the lowest value of 7.3042 kg m^{-2} was observed at 50% field capacity. Biochar application at 0.5% also significantly improved this trait compared to the control treatment without biochar, with yields of 8.2167 kg m^{-2} and 7.3389 kg m^{-2}, respectively. The *Rama* cultivar significantly exceeded the *Nader* cultivar in total yield, producing 8.2556 kg m^{-2} and 7.3000 kg m^{-2}, respectively.

Regarding the interaction between irrigation levels and biochar application, the combination of 100% field capacity with 0.5% biochar resulted in the highest significant yield of 8.8667 kg m^{-2}, outperforming 50% of other interaction treatments. The minimum total yield 6.2583 kg m^{-2} matrix with 50% field capacity without biochar.

An interaction of irrigation levels with cultivars showed that in 100% of field capacity, the highest seed yield (8.4333 kg m^{-2}) was obtained from Rama plants, which was associated with all other treatment combinations. Conversely, fields of Nader plants subjected to 50 percentage field capacity had the lowest yield in this interaction with (6.7500 kg m^{-2}).

The interaction between the biochar application and cultivar type was observed, with 0.5% biochar applied to Rama plants giving maximum yield followed by which was 8.5667 kg m^{-2} where other treatments were statistically different from this. Nader plants grown without biochar showed the lowest yield in this interaction, at 6.7333 kg m^{-2}.

In addition, the three-way interaction among irrigation level, biochar rate and cultivar indicated that the best results max yield 9.0000 kg m^{-2} were achieved in the case of Rama plants subjected to irrigation level of 100% field capacity and amended with 0.5% biochar.

On the other hand, the minimum yield of 5.3000 kg m^{-2} was found in plants of Nader grown at 50% field capacity without biochar addition.

Table 3. Levels of irrigation with biochar's and cultivars effects on total yield of heads.

Irrigation Levels	Biochar Levels	Cultivars		Irrigation Levels X Biochar Levels	Mean Effect of Irrigation Levels
		Nader	Rama		
50% FC	%0	5.3000 f	7.2167 c-e	6.2583 c	7.3042 b
	%0.5	8.2000 a-c	8.5000 ab	8.3500 a	
75% FC	%0	7.8000 b-d	8.7500 ab	8.2750 a	7.8542 a
	%0.5	6.6667 e	8.2000 a-c	7.4333 b	
100% FC	%0	7.1000 de	7.8667 b-d	7.4833 b	8.1750 a
	%0.5	8.7333 ab	9.0000 a	8.8667 a	
Irrigation Levels X Cultivars	%50	6.7500 c	7.8583 ab	Mean Effect of Biochar	
	%75	7.2333 bc	8.4750 a		
	%100	7.9167 a	8.4333 a		
Biochar Levels X Cultivars	% 0	6.7333 c	7.9444 b	7.3389 b	
	%0.5	7.8667 b	8.5667 a	8.2167 a	
Mean Effect of Cultivars		7.3000 b	8.2556 a		

*According to the probability methodology of Dunkan at a larger level or equal to 5%, the averages that share a similar letter, there are no different statistical connotations between them.

Yield related traits head weight and total head yield are shown in Tables 2 and 3 and indicate a significant increase up to irrigation levels of 75% and 100% field capacity compared to the 50% level. Likely, this improvement is ascribed to the enhanced water supply at these higher irrigation levels, which facilitates critical physiological functions such as active photosynthesis, nutrient acquisition and translocation, and the processes of biosynthesis of biomolecules including sugars and proteins. These physiological benefits evoke better vegetative growth along with increasing its yield, Keeping moisture in the soil near field capacity encourages continuous cell division and elongation while also delaying water stress, which results in stomata closure and reduced photosynthetic efficiency. In comparison, plants with 50% field capacity suffer significant water stress, inhibiting

vegetative growth and biomass production. In lettuce, this stress causes fewer and smaller leaves which reduces head weight and yield (Farooq et al., 2009)
According to Rashwan and Elsaied (2022), water deficiency inhibits physiological processes and absorption among plant species as well as facilitating the production of stress-related hormones, including abscisic acid (ABA). Higher levels of ABA, on association with ABA receptors available on guard cells lead to the closure of stoma and decrease in CO_2 availability for assimilation as a result, reducing the photosynthetic potential of the plant., as shown in study by Karam et al (2006) that efficient water consumption is positively related to plant growth and yield if the irrigation levels are raised. Considering that lettuce is sensitive to water stress, it seems reasonable to expect that irrigation management maintaining between 75% and 100% of field capacity plays a critical role in crop productivity, in order to find a balance between deficiency and excess moisture.
Moreover, as shown in Tables 1, 2 and 3, 0.5% biochar application enhanced leaf number, head weight and total head yield as compared to no biochar treatments. Such improvement is probably related to the ability of biochar to affect several soil characteristics (physical, chemical, and biological) even at low application rates. Due to its porous nature and high specific surface area biochar provides higher aeration, increased porosity and efficient water and air movement in the soil under the root zone (Lehmann et al., 2011). These alterations allow for better root development and minimize the impact of plant water stress. In addition, biochar also enhances the soil's water holding capacity, which increases the soil capacity to provide consistent supply of water to the root zone, which can contribute to increased growth and yield, especially in coarse textured or soils with low organic matter (Mukherjee et al., 2013).
Data further revealed that, in all traits measured, Rama cultivar was superior over Nader cultivar across the study (Tables 1, 2 and 3). This higher performance can be attributed to the genetic divergence among the cultivars25. Differences in the genetic makeup can have profound effects on growth potential, adaptability and physiological responses as specific cultivars of any species can perform better under certain environmental conditions (Kumar et al., 2018). Alternatively, this could be explained due to the genetic background of Rama cultivar being more attuned to optimum conditions as per the location of the experiment, resulting in higher overall productivity (Lambers et al., 2008). Moreover, favourable environmental conditions such as temperature, humidity and light may match more with the physiology of Rama cultivar, which could also contribute to the observed superiority (Taiz et al., 2015).

CONCLUSIONS

Adding biochar to soil at rate of 0.5% resulted in a decrease in the bulk density of the soil a significant increase in soil porosity andsaturated hydraulic conductivity. Also led to significant improvements in productivity traits and overall yield. Productivity traits head weight and total head yield showed significant enhancements under both 75% and 100% field capacity irrigation levels compared to the 50% field capacity treatment. Additionally, the Rama cultivar demonstrated a statistically superior performance over the *Nader* cultivar across all measured traits. Accordingly, this study recommends adding biochar to the soil because of its positive effects in improving the physical properties of the soil and plant yield. Using an irrigation level between 100 and 75% of field capacity and using *Nader* cultivars In the lettuce production fields in Mosul city**.**

ACKNOWLEDGEMENTS
The University of Mosul's especially the College of Agriculture and Forestry cooperation was much appreciated by the writers as it enabled the completion of this article.

REFERENCES
1. Agegnehu, G., Bass, A. M., Nelson, P. N., & Bird, M. I. (2016). Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Science of the Total Environment*, *543*, 295-306.
2. Al-Mehmdy, S. M., Al-Khateb, B. A., Al-Hadithi, M. Y., & Al-Darajy, A. L. (2025, February). The Role of Biochar and Water Level on Some Physical Soil Properties, Growth and Yield of Barley. In IOP Conference Series: Earth and Environmental Science (Vol. 1449, No. 1, p. 012094). IOP Publishing.1-16.
3. Al-Rawi, K. M., & Khalafallah, K. (2000). Design and analysis of agricultural experiments. Ministry of Higher Education and Scientific Research; House of Books for Printing and Publishing, Iraq.
4. Bagarello, V., Conte, P., Ferro, V., Iovino, M., Librici, C., Nicosia, A., & Zanna, F. (2025). How Rilling and Biochar Addition Affect Hydraulic Properties of a Clay-Loam Soil. European Journal of Soil Science, 76(1), 1-20.
5. Blake, G. R., & Hartge, K. H. (1986). Bulk density. In methods of soil analysis. part 1, physical and mineralogical method, 2nd ed. Edited by A. Klute. P. 363-375.
6. Cera, L. B. (2022). Growth and yield performance of lettuce (Lactuca Sativa L.) fertilized with varying levels of compost. International Journal of Advances in Social and Economics, 4(2), 50-56.
7. Carini, F., Filho, A. C., Kleinpaul, J. A., Neu, I. M. M., Silveira, D. L., Pacheco, M., & Andriolo, J. L. (2020). Agronomic performance of lettuce cultivars in different seasons and shading conditions. *IDESIA (Chile)*, *38*(1), 47-58.
8. Chen, Z., Intraravimonmata, C., Kamchoom, V., Chen, R., & Sinsamutpadung, N. (2025). Biochar Amendment as a Mitigation Against Freezing–Thawing Effects on Soil Hydraulic Properties. Agronomy, 15(1), 1-12.
9. Danielson, R. E., & Sutherland, P. L. (1986). Porosity. In methods of soil analysis. part 1, physical and mineralogical method, 2nd ed. Edited by A. Klute. P. 363-375.
10. FAO. (2023). The state of food and agriculture 2023. Overcoming water challenges in agriculture. Roma.
11. Farooq, M., Hussain, M., Ul-Allah, S., & Siddique, K. H. (2019). Physiological and agronomic approaches for improving water-use efficiency in crop plants. Agricultural Water Management, 219, 95-108.
12. Farooq, M., Wahid, A., Kobayashi, N. S. M. A., Fujita, D. B. S. M. A., & Basra, S. M. (2009). Plant drought stress: effects, mechanisms and management. In Sustainable agriculture (pp. 153-188). Dordrecht: Springer Netherlands.
13. Fereres, E., & Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. Journal of experimental botany, 58(2), 147-159.
14. Hassan, A. A. M. (2003). Production of composite, cucurbit, and colocasia vegetables. Dar Al-Bayda for Publishing and Printing.
15. Howell, T. A. (2001). Enhancing water use efficiency in irrigated agriculture. Agronomy journal, 93(2), 281-289.
16. Hu, J., Yang, S., Cornelis, W. M., Huang, Q., Qi, S., Jiang, Z., & Xu, Y. (2025). Biochar amendment mitigates negative effects of controlled irrigation on paddy soil structure: Insights from micro-pore network analysis. Agricultural Water Management, 1-14.
17. Ibraheem, F. F. R. (2007). Effect of planting dates and gibberellic acid spraying on growth and yield of two cauliflower cultivars (Brassica oleracea var. botrytis) (Master's thesis). College of Agriculture and Forestry, University of Mosul, Ministry of Higher Education and Scientific Research, Republic of Iraq.
18. Karam, F., Lahoud, R., Masaad, R., Daccache, A., Mounzer, O., & Rouphael, Y. (2006). Water use and lint yield response of drip irrigated cotton to the length of irrigation season. Agricultural Water Management, 85(3), 287-295.

19. Karlsons, A., & Osvalde, A. (2025). Effect of zeolite, clay and peat on salt stress tolerance of lettuce (Lactuca sativa L.). Agronomy Research, 23(S1), 73–85, 2025
20. Kang, S., Hao, X., Du, T., Tong, L., Su, X., Lu, H., ... & 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.
21. Kim, M. J., Moon, Y., Kopsell, D. A., Park, S., Tou, J. C., & Waterland, N. L. (2016). Nutritional value of crisphead 'Iceberg'and romaine lettuces (Lactuca sativa L.). Journal of Agricultural Science, 8(1), 37-45.
22. Klute, A., & Dirksen, C. (1986). Hydraulic conductivity and diffusivity laboratory method. In methods of soil analysis. part 1, physical and mineralogical method, 2nd ed. Edited by A. Klute. P. 637-732.
23. Kumar, A., Dahiya, M. S., & Bhutani, R. D. (2000). Performance of brinjal genotypes in different environments of spring-summer season. *Haryana Journal of Horticultural Sciences*, *29*(1/2), 82-83.
24. Kumar, P., Yadava, R. K., Gollen, B., Kumar, S., Verma, R. K., & Yadav, S. (2018). Genetic variability and diversity analysis in lettuce (Lactuca sativa L.). Journal of Horticultural Science and Biotechnology, 93(4), 341-349.
25. Lambers, H., Chapin III, F. S., & Pons, T. L. (2008). *Plant physiological ecology*. Springer Science & Business Media.
26. Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., & Crowley, D. (2011). Biochar effects on soil biota–a review. *Soil biology and biochemistry*, *43*(9), 1812-1836.
27. Listyarini, D., & Farni, Y. (2025). Improving Physical Properties of Ultisol and Maize Yield Using Coconut Shell biochar and Leucaena Compost. Journal of Degraded and Mining Lands Management, 12(2), 6991-6999.
28. Liu, X., Zhang, A., Ji, C., Joseph, S., Bian, R., Li, L., ... & Paz-Ferreiro, J. (2013). Biochar's effect on crop productivity and the dependence on experimental conditions—a meta-analysis of literature data. *Plant and soil*, *373*(1), 583-594.
29. Mukherjee, A., & Lal, R. (2013). Biochar impacts on soil physical properties and greenhouse gas emissions. *Agronomy*, *3*(2), 313-339.
30. Rashwan, B. R., & Elsaied, R. E. S. (2022). Response of Lettuce (Lactuca sativa L.) Plant to Bio-stimulants Under Various Irrigation Regimes in Reclaimed Sandy Soil. *Environment, Biodiversity and Soil Security*, *6*(2022), 103-115.
31. SAS. 2017. SAS Users Guide, Personal Computers. Inst. Inc. Cary. N.C. USA.
32. Taiz, L., Zeiger, E., Moller, I. M., & Murphy, A. (2015). *Plant physiology and development. Sinauer Associates.*
33. Thao, T., Lopez, V. D., Gonzales, M., Berhe, A. A., Diaz, G., & Ghezzehei, T. A. (2025). Impact of Almond Shell Biochar Properties and Application Rate on Soil Physical and Hydraulic Characteristics. Sustainable Environment, 11(1),1-19.
34. Wang, J., Shi, D., Wang, R., Zhai, B., Liu, C., & Feng, S. (2025). Improving soil properties and maize yield under fertilizer reduction using bio-organic matter combined with biochar. International Journal of Agricultural and Biological Engineering, 18(2), 179-188.
35. Zhylina, M., Karnozhytskyi, P. P., Miroshnichenko, D., Konohrai, V., Sterna, V., & Ozolins, J. (2025). The effect of growth stimulants based on humic acids from Ukrainian lignite and biochar from agricultural residues on the growth and development of lettuce (Lactuca sativa). Agronomy Research, 23(1), 571-584.