Radish plant growth as affected by irrigation and biochar application in sandy soil under water stress conditions

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ABSTRACT: The present study was carried out to evaluate the effect of corncob waste-derived biochar (locally produced via slow pyrolysis at 500°C) in limited oxygen on improving the sandy soil properties and radish growth.
The pot experiment was carried out as a Randomized Complete Block Design (RCBD), with three replications in the open greenhouse of the Faculty of Agriculture, Saba Basha, Alexandria University. There were three studied factors. The main factor is the irrigation regime (five treatments, 20, 40, 60, 80, and 100% of potential evapotranspiration (ET_0). The sub-factor is two types of biochar (soft and hard biochar). The sub-sub factor is biochar rates of 0.0, 1, 3, and 5% (w/w) treatments.
The study revealed that the higher values of biochar application rates up to 5%, increase vegetative growth parameters such as shoot weight, leaf area, No. of leaves, fresh weight, and dry weight and root measurements.
The study also showed a significant effects of irrigation regimes on vegetative growth parameters, including biomass weight, shoot fresh weight, shoot dry weight, shoot area, number of leaves, shoot height, and shoot water content in Radish.
The study shows that biochar application rates significantly affect root growth parameters, with higher rates leading to increased protein content, total fresh weight, dry weight, root length, root diameter, total fresh weight, and total dry weight compared to the control treatment. The data collected reveal that different irrigation regimes significantly impact radish root growth parameters, with increases of 303.27%, 76.38, 79.25, 75.68, 76.07, 75.60, and 74.09%, respectively, indicating a dramatic increase in root growth with an increasing irrigation rate.
Therefore, further research must be performed on biochar applications to soil and include the following:
i. Long-term effects of biochar application on soil physicochemical properties and crop yield, ii. Effects of biochar type, pyrolysis temperature, and application rate on other soil types, and iii. Factors that influence farmers' use of biochar application technologies.

Keywords: *biochar, soil-biochar mixture, radish plant, soil fertility*

INTRODUCTION

Biochar is a carbon-rich residue like corncob residues, leaves, etc. that was heated under high temperature (in this study, 500 °C) to reach the pyrolysis stage in low oxygen conditions inside especial furnace, made particularly for this purpose. **(Lehmann and Joseph, 2009).** Biochar is a dark porous substance with high carbon content, a developed pore structure, strong stability, a high surface area, and rich functional groups. **(Tenenbaum, 2009).** Biochar is produced and applied to soil to improve soil properties, increase soil productivity, and sequester carbon (C).

Numerous earlier studies have demonstrated that adding biochar to soil increases its organic carbon content and modifies its physicochemical characteristics, such as the distribution of soil pores ***(Fu et al., 2019; Głąb et al., 2016)*** and the stability of soil aggregates ***(***Baiamonte ***et al., 2019)***, which are connected to the soil's ability to retain water and preserve fertilizers ***(Ouyang and Zhang, 2013)***.

Biochar may also reduce the bulk density of the majority of soils. ***(Verheijen et al., 2014),*** Biochar does not significantly increase total nitrogen concentrations, as compost and biochar have similar concentrations. CEC increases with biochar addition, but not as significantly as compost **(Liu et al., 2012).** So, this may be reflected in improving agricultural production **(Verheijen et al., 2019).**

The second material in this experiment is sandy soil, which may be found in large areas in arid and semi-arid locations like the Sahara, Saudi Arabia, Turkey, northwest China, and Western Australia **(Huang and Hartemink, 2020).** Sandy soils have over 68% sand and less than 18% clay in the first 100 centimeters of the soil surface **(Bruand et al., 2005)** and are classified in Reference Soil Groups **(FAO, 2006)**.

Sandy soils occur in arid to humid and cold to hot climates, they are excessively drained, highly leached, low in organic matter, and have poor fertility. Satisfactory crop yields may be obtained from sandy soils if some general management rules are adopted (**Osman, 2018).**

Both small radish and radish are important root vegetables that are necessary for a healthy diet and have economic importance, where immature shoots, seedlings, roots, and leaves are utilized for human consumption.

It is worth noting that small radish and radish are employed as additional therapeutic agents in the diet of patients with diabetes, several cancer types, cardiovascular illnesses, liver and respiratory disorders, and other conditions. **(Luo et al., 2018; Ghosh and Konishi, 2007).** Radish is grown all over the world, especially in China, Japan, and Korea **(FAO, 2019; Nishio and Sakamoto, 2017).**

As a result of its great nutritional and therapeutic benefits, every part of the radish plant is edible from the root to the green leafy tops. In addition to being edible, the radish's green, leafy tops are higher in calcium, protein, and vitamin C than the root. More importance should be placed on the green tips than the roots since they are extremely nutrient and mineral-rich. Juicing radishes together with their green stalks makes a great cleansing beverage. It can purify the body as a whole and calm the digestive system**. (Swe et al., 2022).**

The objective of the present study is to evaluate the radish plant growth in the amended sandy soil by corncob-biochar under water stress conditions.

III. MATERIALS and METHODS

III.1. Biochar sample

The biochar used in this study was obtained from the Biochar Production Project Unit of the **"Development of Biochar Technology Production from Agricultural Residues and its Application to Solve some Existing Environmental Problems in Egyptian Community",** Central Laboratory for Agricultural Climate, Albossaly site, financially supported by the Academy of Scientific Research and Technology, Egypt.

The biochar was produced from soft and hard parts of corncob by pyrolysis at a high temperature (500 °C) under limited oxygen conditions using the fabricated stove for this purpose (**Gerges et. al., 2023).** The biochar was subjected to chemical analysis, according to **Carter and Gregorich (2008**), The chemical properties of soft and hard Biochar are presented in Table (1).

Table (1). Chemical analysis of soft and hard corncob Biochar

Parameters	Soft Biochar	Hard Biochar
EC (1:10, water extract), dS/m	2.556	2.985
pH (1:10, water suspension)	7.50	8.10
Organic carbon, %	37.00	41.00
Cation Exchange Capacity (CEC), me/100 g soil	10.39	19.69
Soluble nutrients, %		
N	0.044	0.085
P	0.017	0.710
K	0.403	0.680
Ca	0.160	0.385
Mg	0.115	0.077
Total Elements, %		
N	0.945	1.272
P	0.980	1.079
K	1.350	1.750
Ca	1.340	1.450
Mg	1.360	0.780
Na	0.800	1.200

III.2. Biochar characteristics

The biochar (soft and hard) was analyzed with SEM, and the surfaces of BC were imaged with many hollow channels in diameters of around 29 and 95 nanometers for soft biochar and from 27 to 89 nm for hard biochar. The structural difference may reflect the specific surface area and the adsorption capacity of water **(Gerges, et al., 2023).**

The functional groups identified from the FTIR spectra for the soft and hard biochar samples are reported. The spectra of soft biochar demonstrated many bands such as amides group, aromatic group, carboxyl group, nitro group, thiocarbonyl, and alkyl group (**Gerges, et al., 2023).**

III.3. Soil sample

The soil sample used in this study was taken from El-Shagaa Village in the Nubaria district of the Behiera Governorate's surface layer (0–30 cm). After being air-dried, the soil was sieved using a 2.0 mm sieve. Table (2) shows some chemical and physical characteristics. The procedures described by **Carter and Gregorich (2008)** were followed while analyzing the properties of the soil.

Table (2). Physical and chemical analysis of soil used in the present study

Parameters	Values
Particle-size distribution (%)	
Sand	94.00
Silt	5.00
Clay	1.00
Textural class	Sand
EC, dS/m (1:1, water extract)	0.477
pH (1:1, water suspension)	7.67
Organic carbon (%)	1.38
$CaCO_3$ (%)	2.50
Soluble cations (me/l)	
Ca^{2+}	1.753
Mg^{2+}	1.550
Na^+	0.803
K^+	0.351
Soluble anions (me/l)	
$CO_3^{=}+HCO_3^-$	0.352
Cl^-	2.533
$SO_4^{=}$	1.863
Available Nutrients (mg/kg)	
N	52.1
P	15.08
K	351.67

III.4. Soil-Biochar mixture preparation

The rates of biochar being mixed with sandy soil have been at 0, 1, 3, and 5% (w/w), and then the mixtures were incubated for 30 days at room temperature (25±2 °C) with the rewetted soil-biochar mixture at field capacity every 7 days. After incubating the soil mixture, it was air dried and passed through a 2.0 mm sieve, which was consequently retained until the analysis.

III.5. Pot Experiment setup

The pot experiment was carried out in the open greenhouse at the Faculty of Agriculture, Saba Basha, Alexandria University, using a Randomized Complete Block design (RCBD), with three replications.

The pot experiment was designed to study three factors. The main factor was the irrigation regime, which was five treatments: 20, 40, 60, 80, and 100% of potential evapotranspiration, ET_o. The sub-factor was biochar which was two types (soft and hard biochar), while the sub-sub factor was biochar rates of 0.0, 1, 3, and 5% (w/w) treatments.

There were 120 pots with a capacity of 5 kg (16 cm in diameter and 16 cm in height). The radish seeds (*Raphanus sativus*, L.) white balady radish variety was sown in pots (2 seeds per pot) on Dec 30, 2020. Irrigation rates are calculated according to the crop evapotranspiration calculated with the Penman-Monteith equation **(Allen et al., 1998).** The irrigation was applied every two days. At harvesting time on Feb 13, 2021, the plants were collected manually. Harvested plants from each pot were separated into roots and shoots and they were weighed separately.

III.6. Plant parameters

III.6.1. Vegetative growth parameters

Shoot height (cm), leaf area (cm^2), number of leaves per plant, shoot fresh weight (g), shoot dry weight (g) and shoot water content (%).

III.6.2. Root measurements

Root fresh weight (g), root dry weight (g), total fresh weight (g), total dray weight (g), root water content (%), root diameter. RD (cm), root length RL (cm) and protein content (%)

III.6.3. Soil available nutrients

Soil-available macronutrients (N, P, and K)

Soil available nitrogen content (mg/kg) was determined in the soil extract using the micro-Kjeldahl method described by **Peach, and Tracey(1956).**

Soil available phosphorus content (mg/kg) was extracted according to **Olsen et al. (1954),** and determined according to **Jackson (1973).**

Soil available potassium content (mg/kg) was extracted according to **Jackson (1973).**

Soil-available micronutrients (Fe, Mn, Cu, and Zn)

DTPA-extractable micronutrients: (Fe, Mn, Cu, and Zn) were measured by atomic absorption spectrophotometer according to **Linsay and Norvell (1978)**

III.6.4. Soil chemical characteristics

Electrical conductivity (EC) in the soil water extract (1:1, w/v) was measured using a conductivity meter according to **(Jackson 1973)**.

Soil pH was measured using a pH meter in the 1:1 soil-water solution **(Jackson, 1973).**

Soil organic carbon (SOC) was determined using the modified Walkley-Blacks titration method (**Carter and Gregorich, 2008**). The soil organic matter content (SOM) was computed using the appropriate constant (1.724).

Soluble cations (meq/l) were determined using the EDTA titer titrimetry technique, following the guidelines provided by **Carter and Gregorich (2008).** Flame photometry was used to calculate Na and K using the procedures described in **(Jackson 1973).**

Soluble anions (meq/l): Soluble HCO_3, Cl, and SO_4 were determined according to the methods outlined in **(Carter and Gregorich 2008).**

Total calcium carbonates (%) were determined according to the methods outlined in **(Carter and Gregorich, 2008)**

III.6.5. Laboratory plant analysis

At the harvesting time, after 46 days from sowing seeds, the root plant sample was cut into small pieces, rinsed with distilled and tap water, air-dried, and then dried in an electric oven for 48 hours at 70°C. The dried samples were ground in a plant mill. The crushed powder was digested using sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) according to **Lowther (1980).** Root nutrient contents were determined by Inductively Coupled Plasma Emission Spectrometry, ICP (Ultima 2 JY Plasma), whereby N, P, K, Ca, and Mg as % and Fe, Mn, Cu, and Zn as mg/kg (dry matter) were recorded as **Iveillo et al. (2008).** To determine the protein content (%), N content was multiplied by 5.75.

III.6.6. Statistical analysis

The data were analyzed using STATISTIX 10 **(Statistix, 2019)**. Means were separated using the Least Significant Difference Test (LSD) at a 5% probability level of significance (**Snedecor and Cochran, 1991)**.

IV. RESULTS and DISCUSSION

IV.1. Radish Vegetative Growth

IV.1.1. Effect of irrigation regime

The impact of the irrigation regime on vegetative growth parameters is illustrated in Table 3. All vegetative growth, such as shoot height, leaf area, No. of leaves, shoot fresh weight, shoot dry weight, and shoot water content, are highly significantly affected by irrigation regimes. The vegetative parameters of Radish increased as the irrigation regime rates (% of ET_0) were increased. The increments of (100% of ET_0) over the lowest rate of irrigation (20% of ET_0) were 15.08, 70.95, 23.05, 76.82, 69.23, 0.68, 86.69, and 0.68%, respectively.

Hardie et al. (2014) reported that biochar has a limited influence on plant water availability, particularly in low-irrigation rates. However, some studies suggest that the benefits of biochar for soil water availability and retention can endure for several years, especially if high-quality biochar is used. Biochar has the potential to improve soil water retention and reduce evaporation-related water loss. Biochar behaves like a sponge, retaining water and nutrients in the soil, which is beneficial to plant growth and agricultural production. The type of biochar, soil texture, and climate all influence how biochar impacts soil water status.

The research suggests that biochar can enhance soil infiltration, water availability, and prevent soil erosion. It offers numerous benefits for agricultural and urban systems. Future studies should focus on optimizing biochar management strategies for specific soil and environmental conditions.

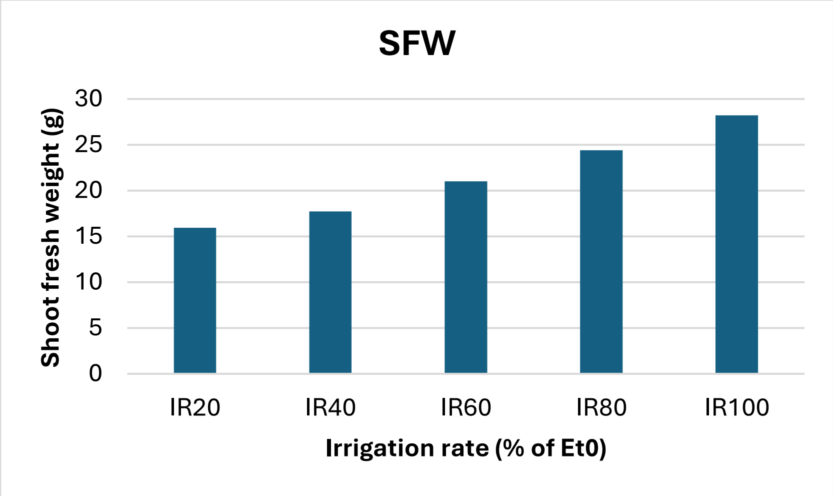

Figure (1). Effect of irrigation rate on shoot fresh weight (g)

IV.1.2. Effect of Biochar Type

Both soft and hard biochar types have a significant effect on leaf area and shoot water content, while other vegetative parameters were not affected but generally enhanced the vegetative growth parameters.

IV.1.3. Effect of Biochar Rate

Application of biochar rates, i.e., 0, 1, 3, and 5%, have highly significant effects on radish vegetative growth. A high application rate, i.e., 5%, has higher values of vegetative growth. The increments over the control treatment (i.e., 0%) were 17.14, 28.14, 7.20, 35.24, 26.18, and 0.85% for shoot height, leaf area, No. of leaves, shoot fresh weight, shoot dry weight, and shoot water content, respectively (Table 3).

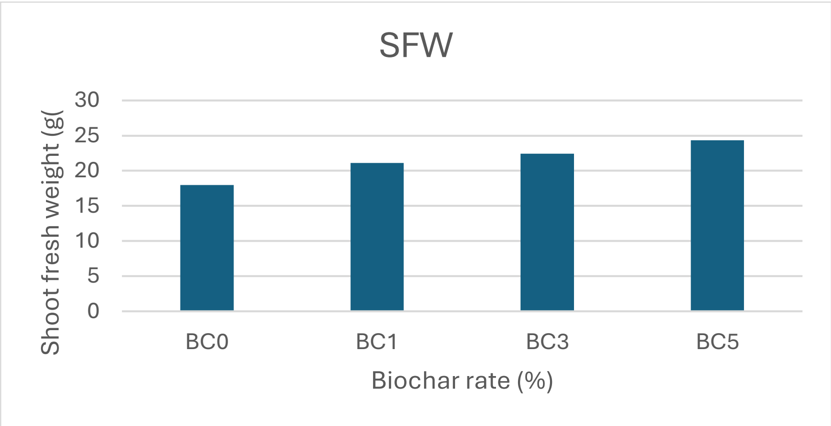

Figure (2). Effect of biochar rate (%) on shoot fresh weight (g)

Table (3). Mean effects of vegetative growth parameters as affected by irrigation regimes, biochar type, and biochar rates of Radish.

Treatments	Shoot height (h) cm	Leaf area (LA) cm^2	No. of leaves per plant	Shoot fresh weight (g)	Shoot dry weight (g)	Shoot water content (%)
The main effect of the Irrigation regime, IRR (% of ET_0)						
20	9.15	232.88	8.46	15.96	1.69	89.41
40	9.26	256.21	9.26	17.74	1.88	89.40
60	9.85	299.66	9.75	21.03	2.13	89.87
80	10.16	342.86	10.00	24.39	2.44	90.00
100	10.53	398.10	10.41	28.22	2.86	89.87
LSD (0.05)	0.31**	26.28**	0.63**	1.96**	0.21**	0.13**
The main effect of Biochar type						
Soft	9.72	298.62	9.36	20.97	2.21	89.46
Hard	9.86	313.26	9.78	21.97	2.19	90.03
LSD (0.05)	ns	14.87*	ns	ns	ns	0.42*
the main effect of Biochar Rate, Rate (%)						
0	8.87	266.39	9.17	17.99	1.91	89.38
1	9.80	300.27	9.56	21.11	2.19	89.63
3	10.09	315.75	9.73	22.44	2.29	89.80
5	10.39	341.36	9.83	24.33	2.41	90.09
LSD (0.05)	0.46**	18.76**	0.46*	1.60**	0.14**	0.24**
Interaction effects (LSD 0.05)						
IRR X type	**	**	ns	ns	**	ns
IRR X Rate	ns	ns	ns	ns	ns	*
Type X Rate	**	ns	ns	ns	*	*
IRR X Type X rate	ns	ns	ns	ns	ns	ns

IV.1.4. Interaction's effects

The interaction between the treatments, i.e., irrigation regimes, biochar type, and biochar application rates varied between significant effect and no effect but generally enhanced the vegetative growth parameters.

The effects of biochar on plant growth are likely the most researched, with much research demonstrating a significant boost in plant growth, particularly in places with nutrient-deficient soils. Biochar has been demonstrated to boost plant development by improving nutrient intake, decreasing soil acidity, and increasing soil water retention. While the specific mechanisms by which biochar works are still being debated. **(Lehmann, et al. 2006; Jeffery, 2011).**

The mechanism by which biochar influences plant growth is currently being debated. According to much research, biochar enhances soil quality by increasing soil organic carbon content, nutrient availability, and soil water-holding capacity, boosting plant development. Others claim that biochar has a direct effect on plants, boosting plant nutrition and encouraging development.

IV.2. Radish Root Growth

IV.2.1. Effect of irrigation regime

The data presented in Table (4) illustrate the effect of the irrigation regime on radish root growth. Irrigation regimes (i.e. 20, 40, 60, 80, and 100% of ET_0) have highly significant effects on root growth parameters (root fresh weight, root dry weight, root water content, total fresh weight, total dry weight, root diameter, root length, and protein content). The increments over the low irrigation regime (20% of ET0) were 75.60, 79.25, -0.31, 76.38, 74.09, 76.06, 75.68, and 303.27%, respectively. Increasing irrigation rate significantly increased the root growth parameters.

The results indicated that water stress negatively impacts plant and root growth, resulting in reduced biomass and altered root architecture. The study also highlights the importance of understanding the underlying physiological and molecular mechanisms to develop strategies for improving plant tolerance to water stress **(Smith, et al 2010a).**

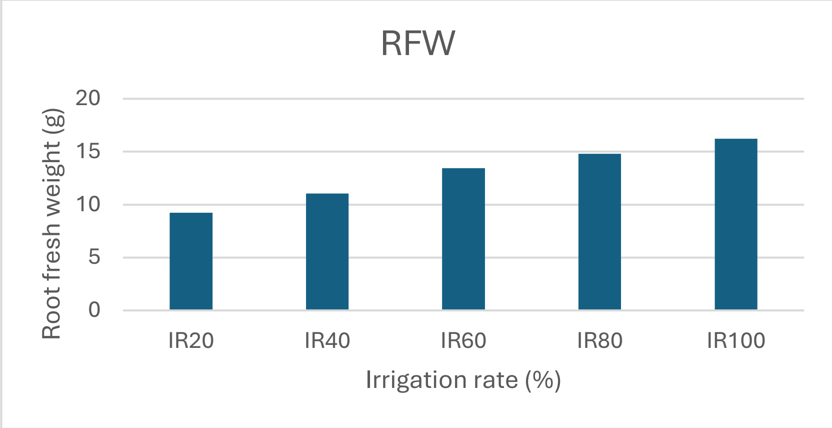

Figure (3). Effect of irrigation rate on root fresh weight (g)

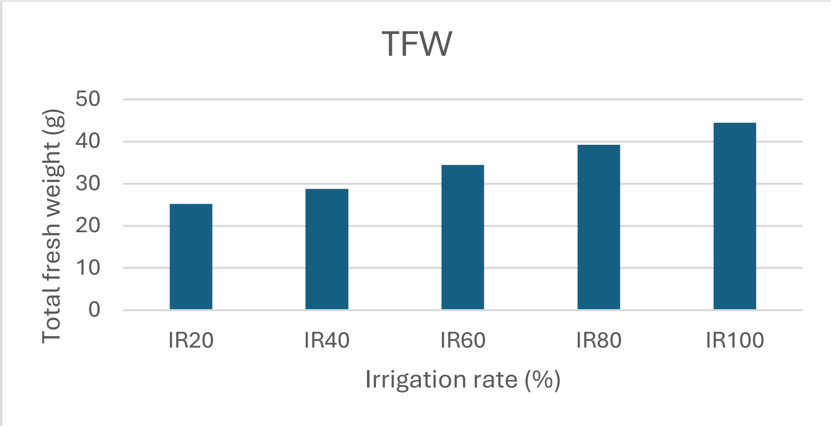

Figure (4). Effect of irrigation rate on total fresh weight (g)

IV.2.2. Effect of biochar type

The biochar type has a significant effect on root water content and total fresh weight. In which hard biochar exceeds the soft biochar. Other root growth parameters were not affected.

IV.2.3. Effect of biochar rates

The application rates of biochar have a significant effect on root growth parameters. The data illustrated in Table (4) revealed that increasing the application rate of biochar increased all the root growth parameters (root fresh weight, root dry weight, root water content, total fresh weight, total dry weight, root diameter, root length, and protein content). The increments over the control treatment were 23.82, 25.76, -0.39, 30.80, 25.96, 23.65, 23.84 and 37.53%, respectively.

IV.2.4. Interaction effects:

The interaction between the treatments i.e., irrigation regimes, biochar type, and biochar application rates varied between significant effect and no effect, but generally enhanced the root growth parameters (Table 4).

Studies show promising effects of corncob-biochar treatment on radish growth and productivity in sandy soil, but further investigation is needed to understand the processes influencing soil attributes and crop yield. **(Liu et al., 2012)**

In the current study, Biochar application increased root yield by an average of 23.82%. Also, root quality (root diameter and root length) was improved by 23.65 and 23.84%, respectively. The effectiveness of biochar application is influenced by factors such as soil type, biochar properties, and application rate (**Jeffery, 2011**).

Table (4). Mean effects of root growth parameters as affected by irrigation regimes, biochar type, and biochar rates of Radish.

Treatments	Root fresh weight (g)	Root dry weight (g)	Root water content(%)	Total fresh weight (g)	Total Dry weight (g)	Root diameter RD (cm)	Root length RL (cm)	Protein content (%)
The main effect of the Irrigation regime, IRR (% of ET_0)								
20	9.232	1.59	82.65	25.19	3.28	1.63	8.51	2.14
40	11.045	1.84	83.49	28.79	3.72	1.96	10.18	2.97
60	13.450	2.40	82.26	34.48	4.53	2.38	12.40	4.46
80	14.810	2.62	82.24	39.20	5.06	2.62	13.66	6.09
100	16.211	2.85	82.39	44.43	5.71	2.87	14.95	8.63
LSD (0.05)	1.11**	0.18**	0.87*	3.07**	0.39**	0.19**	1.02**	0.22**
The main effect of Biochar Type, Type								
Soft	12.83	2.30	82.02	33.80	4.51	2.27	11.83	4.77
Hard	13.07	2.22	83.19	35.04	4.41	2.31	12.05	4.94
LSD (0.05)	ns	ns	0.82*	1.85**	ns	ns	ns	ns
The main effect of Biochar Rate, Rate (%)								
0	11.46	1.98	82.80	29.45	3.89	2.03	10.57	4.21
1	12.78	2.25	82.47	33.89	4.44	2.26	11.79	4.54
3	13.36	2.33	82.67	35.80	4.62	2.36	12.32	4.89
5	14.19	2.49	82.48	38.52	4.90	2.51	13.09	5.79
LSD (0.05)	0.91**	0.17*	ns	2.51**	0.31**	0.16**	0.84**	0.08**
Interaction effects (LSD 0.05)								
IRR X type	ns	*	*	**	**	ns	ns	**
IRR X Rate	ns	ns	ns	ns	ns	ns	ns	**
Type X Rate	ns	*	ns	ns	ns	*	ns	**
IRR X Type X rate	ns	ns	ns	ns	ns	ns	ns	**

IV.3. Radish root nutrient contents

The root nutrient contents that are affected by irrigation regimes, biochar type, and biochar rates and their interaction are illustrated in Table (5).

IV.3.1. Effect of irrigation regimes

The root nutrient content is highly significantly affected by irrigation regimes. Increasing the irrigation regimes led to high values of both macro- and micronutrient contents. Increasing the irrigation regime enhanced the nutrient uptake by radish roots. The increments of nutrient contents were 280.90, 33.95, 281.84, 158.15, and 151.89% for N, P, K, Ca, and Mg, respectively over the check treatment (20% of ET_0). The increase in micronutrient content was 155.95, 166.07, 309.68, and 80.06% for Fe, Mn, Cu, and Zn, respectively over the check treatment (20% of ET_0).

Studies highlight the importance of efficient irrigation strategies for optimal nutrient availability and uptake, emphasizing the need for farmers to reduce fertilizer leaching and increase nitrogen retention in the root zone. **(Smith et al., 2010b).** Irrigation timing is crucial for promoting root growth, as early-season watering boosts root development, increases water and nutrient uptake, and enhances plant drought resistance. Controlled water stress during growth stages, like deficit watering, enhances plant and root growth while conserving water, emphasizing the importance of accurate irrigation systems for crop yield. **(Johnson et al., 2018).**

Further research is needed to explore advanced irrigation methods, improve water efficiency, and understand the intricate connections between crop stages, ultimately enhancing farmers' long-term food security and promoting sustainability.

IV.3.2. Effect of Biochar type

Both biochar types, soft and hard corncob biochar have a highly significant effect on the root nutrient contents. The effects varied between the nutrients, but hard biochar was less effective.

IV.3.3. Effect of Biochar Rate

The biochar application rate has a highly significant effect on root nutrient content. Increasing the biochar application rate increased the root nutrient content. The highest values were attended at the highest rate. The increments over the control treatment (0%) were 36.72, 51.56, 26.73, 26.22, and 26.67% for N, P, K, Ca, and Mg, respectively. The increase in micronutrient content was 42.51, 23.71, 38.12 and 15.59% for Fe, Mn, Cu, and Zn, respectively over the control treatment (0%).

IV.3.4. Interaction effects

The interaction between irrigation regimes, biochar type, and application rates significantly affects root nutrient contents. Biochar reduces nutrient loss, improves soil qualities, and prevents nutrient leaching, minimizing environmental effects of excessive fertilizer use. **(Smith et al., 2010b).**

Biochar treatment in sandy soil can improve plant fertility and nutrient availability. This is due to biochar's high carbon content, which works as a soil conditioner, encouraging beneficial microbial activity and decreasing nutrient loss. There is also evidence that biochar can boost agricultural output in sandy soils. However, the mechanisms by which biochar affects soil fertility and the best application methods are yet unknown **(Sohi et al., 2010).**

The current research focuses on how biochar application can improve soil nutrient retention. Biochar can adsorb nutrients including nitrogen, phosphorus, and potassium, minimizing leaching and increasing nutrient availability for plant uptake. On the other hand, the effect of biochar on nutrient retention is controlled by biochar qualities and soil parameters.

Lehmann et al. (2006) found that biochar improves plant nutrient uptake, increasing crop growth and yield, but responses vary due to soil type, biochar characteristics, and crop requirements.

In addition, **Jeffery et al. (2011)** concluded that biochar application can greatly boost agricultural productivity, with a yield increase of 10-20% on average. Biochar's beneficial effects are related to increased nutrient availability and soil water retention. According to the findings of **Laird et al. (2010),** biochar amendments can improve soil quality by increasing pH, improving nutrient retention, and boosting microbial activity. The effectiveness of biochar, on the other hand, it varies depending on the application rate and feedstock type.

In general, research on biochar application and soil nutrient accessibility holds significant economic and environmental importance. It increases agricultural productivity, improves soil quality, mitigates climate change, and promotes environmental stewardship, all of which promote sustainable farming practices worldwide

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Table (5). Mean effects of root nutrient contents as affected by irrigation regimes, biochar type, and biochar rate of Radish.

Treatments	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
			%				mg/kg		
The main effect of the Irrigation regime (% of ET_0)									
20	0.466	0.483	1.338	0.325	0.212	0.227	25.770	9.589	60.220
40	0.647	0.453	1.957	0.393	0.263	0.301	34.275	11.111	67.480
60	0.939	0.569	2.405	0.538	0.346	0.357	38.712	12.480	74.120
80	1.261	0.518	3.796	0.648	0.405	0.413	50.916	14.451	85.190
100	1.775	0.647	5.109	0.839	0.534	0.581	68.565	39.284	108.430
LSD (0.05)	0.040**	0.058**	0.301**	0.046**	0.018**	1.325*	2.408**	0.685**	1.236**
The main effect of Biochar type									
Soft	0.831	0.476	3.433	0.759	0.469	0.319	47.664	22.435	95.237
Hard	1.204	0.592	2.409	0.338	0.234	0.432	39.631	12.332	62.940
LSD (0.05)	0.046**	0.036**	0.258**	0.059**	0.038**	ns	2.385**	0.504**	1.815**
The main effect of Biochar rate (%)									
0	0.884	0.415	2.559	0.492	0.315	0.327	38.888	14.072	72.606
1	0.952	0.522	2.825	0.523	0.332	0.348	42.198	17.389	78.889
3	1.027	0.569	3.057	0.558	0.362	0.363	45.395	18.636	80.934
5	1.2087	0.629	3.243	0.621	0.399	0.466	48.110	19.436	83.927
LSD (0.05)	0.016**	0.077**	0.076**	0.014**	0.012**	1.108**	1.921**	0.343**	0.713**
Interaction effects									
IRR X type	*	*	**	**	*	ns	**	**	**
IRR X Rate	**	**	**	**	**	ns	**	**	**
Type X Rate	**	**	**	**	**	ns	**	**	**
IRR X Type X rate	**	*	**	**	**	ns	**	**	**

IV.4. Soil-available nutrients

The effects of irrigation regimes, biochar type, and biochar application rates on soil available nutrients are illustrated in Table (6).

IV.4.1. Effect of irrigation regimes

Irrigation regimes have a highly significant effect on soil available nutrient content. Increasing irrigation regimes from 20 to 100% of ET_0 increased the soil available nutrients and the higher values were attained at a high irrigation level (100% of ET_0). The increase in soil available nutrient contents was 175.23, 639.38, 257.34, 94.34, 180.05, 68.86, and 67.92% for N. P, K, Fe, Mn, Cu, and Zn, respectively (Table 5 and Figures (5, 6, and 7).

Table (6). Mean effects of soil available nutrient contents as affected by irrigation regimes, biochar type, and biochar rate of Radish.

Treatments	N	P	K	Fe	Mn	Cu	Zn
				mg/kg			
The main effect of the Irrigation regime (% of ET0)							
20	89.43	7.39	210.35	5.967	1.985	0.456	0.957
40	114.69	21.18	309.17	7.670	3.227	0.536	1.079
60	145.78	32.42	452.71	9.113	4.070	0.583	1.195
80	182.22	40.79	596.25	10.390	4.635	0.641	1.299
100	246.14	54.64	751.67	11.596	5.559	0.770	1.607
LSD (0.05)	8.54**	1.40**	11.40**	0.112**	0.080**	0.029**	0.050**
The main effect of Biochar type							
Soft	108.07	28.24	457.56	6.091	3.315	0.537	1.160
Hard	203.23	34.33	470.50	11.804	4.476	0.657	1.295
LSD (0.05)	6.26**	1.33**	8.96**	0.148**	0.094**	0.04**	0.049**
The main effect of Biochar rate (%)							
0	139.90	26.25	410.61	8.339	3.539	0.553	1.155
1	147.06	29.67	446.67	8.744	3.743	0.589	1.208
3	156.79	32.67	482.67	9.131	4.002	0.606	1.242
5	178.85	36.56	516.17	9.575	4.297	0.641	1.303
LSD (0.05)	4.86**	0.94**	5.78**	0.132**	0.072**	0.017**	0.029**
Interaction effects (LSD 0.05)							
IRR X type	**	**	**	**	**	**	**
IRR X Rate	**	**	**	**	**	**	**
Type X Rate	**	**	**	**	**	**	**
IRR X Type X rate	**	**	**	**	**	**	**

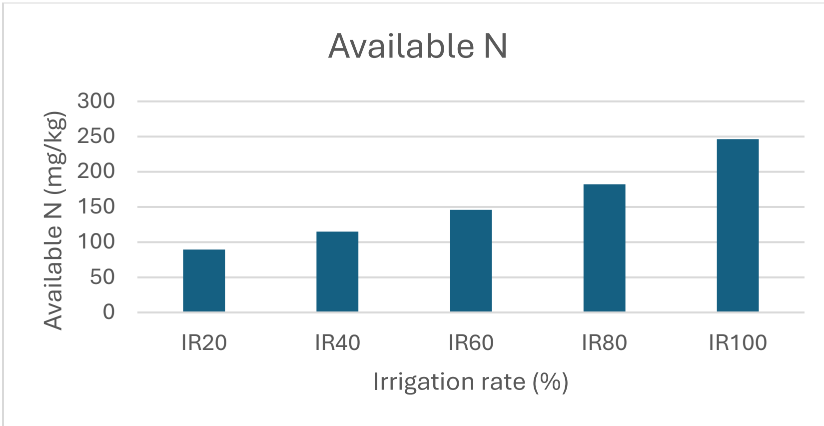

Figure (5). Effect of irrigation rate on soil available N

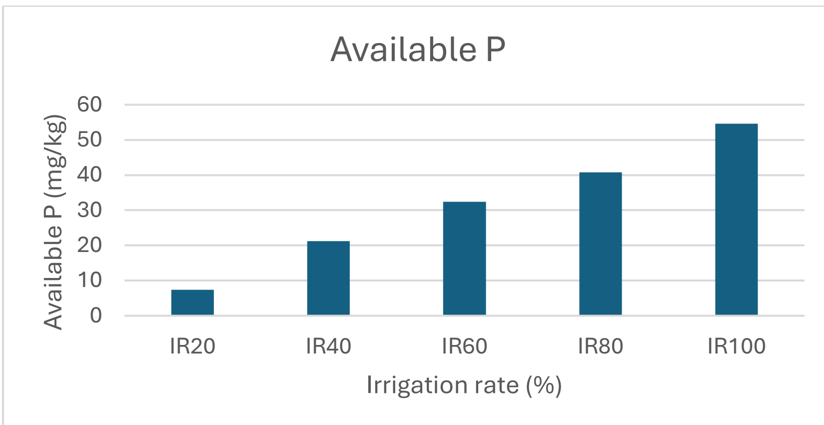

Figure (6). Effect of irrigation rate on soil available P

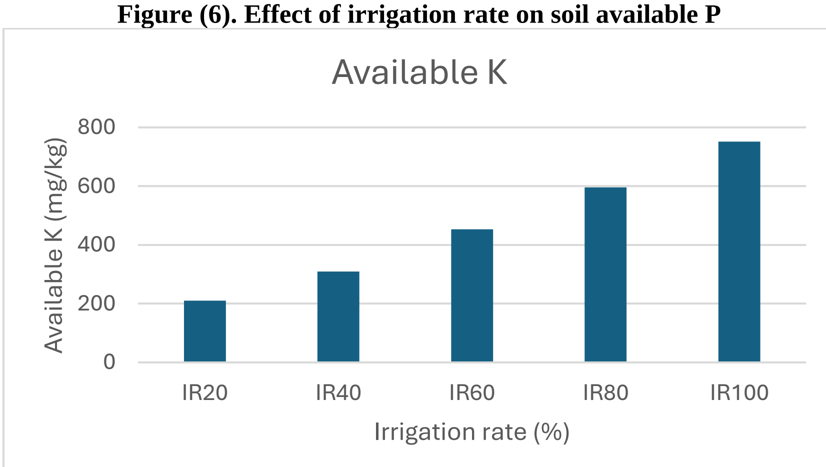

Figure (7). Effect of irrigation rate on soil available K

IV.4.2. Effect of biochar type

Both biochar types, soft and hard corncob biochar have highly significant effect on soil available nutrients. The hard biochar has more effect than the soft biochar.

IV.4.3. Effect of biochar application rate

The biochar application rate has a highly significant effect on soil available nutrient content. Increasing the biochar application rate significantly increased the soil's available nutrient content. The highest values were attended at the highest biochar rate. The increments over the control treatment (0%) were 27.84, 39.28, 25.71, 14.82, 21.42, 15.91 and 12.85% for N, P, K, Fe, Mn, Cu, and Zn, respectively (Table 6 and Figures 8, 9, and 10)

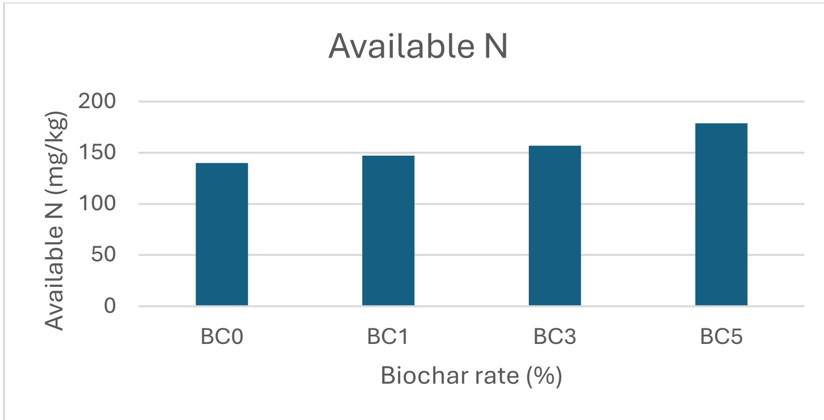

Figure (8). Effect of biochar rate on soil available N (mg/kg)

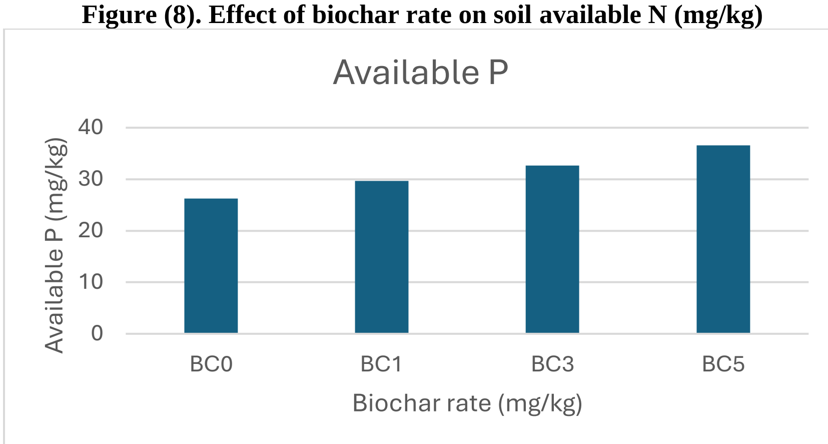

Figure (9). Effect of biochar rate on soil available P (mg/kg)

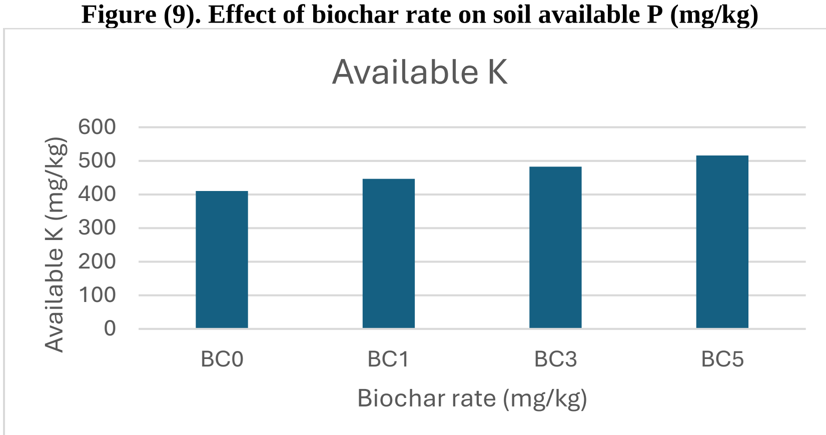

Figure (10). Effect of biochar rate on soil available K (mg/kg)

IV.4.4. Interaction effects

The interaction between irrigation regimes, biochar type, and biochar application rates was highly significant on root nutrient contents. Generally, the interaction effects of all treatments enhanced the nutrient contents. **Smith et al. (2010a)** demonstrated that applying biochar enhanced the availability of important nutrients like nitrogen, phosphorus, and potassium in the soil. Furthermore, the study showed that biochar addition increased soil fertility and nutrient retention capacity**.**

According to **Johnson et al. (2012),** biochar application improves soil nutrient dynamics by increasing nutrient availability, improving nutrient retention, and decreasing nutrient leaching. As reported by **Brown et al. (2015),** biochar application improves soil nutrient availability, particularly for critical nutrients, and has a favorable impact on crop productivity by improving yields in many agricultural settings. Biochar treatment has the potential to improve soil fertility and nutrient availability, according to **Gupta et al. (2018),** but its effectiveness is influenced by correct nutrient management methods. Integrating biochar with appropriate nutrient management measures can help to ensure long-term agricultural sustainability.

IV.5. Soil chemical analysis

Table (7) illustrates the effects of irrigation regimes, biochar type, and biochar application rate on chemical analysis of soil cultivated with Radish.

IV.5.1. Effect of irrigation regimes

The irrigation regimes have highly significant effects on chemical analysis of soil cultivated with Radish. Increasing irrigation regimes increased the pH, EC, SOC, and soluble cations (Ca, Mg, Na, and K) as shown in Table (7), due to the high concentration of soluble cations of the biochar architecture itself. The high irrigation regime (100% of ET_0) has the highest value. The increments were 14.57, 469.69, 14.62, 245.27, 461, 51, 732.40, and 609.89% for pH, EC, SOC, Ca, Mg, Na, and K, respectively, comparing to (20% of ET_0).

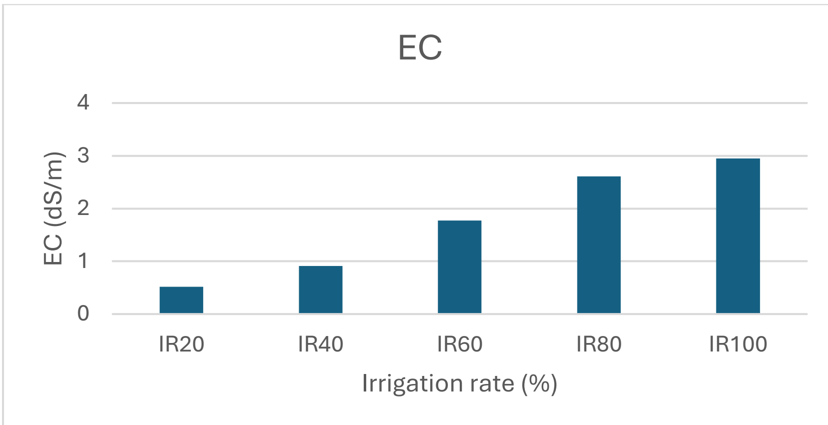

Figure (11). Effect of irrigation rate on soil electrical conductivity

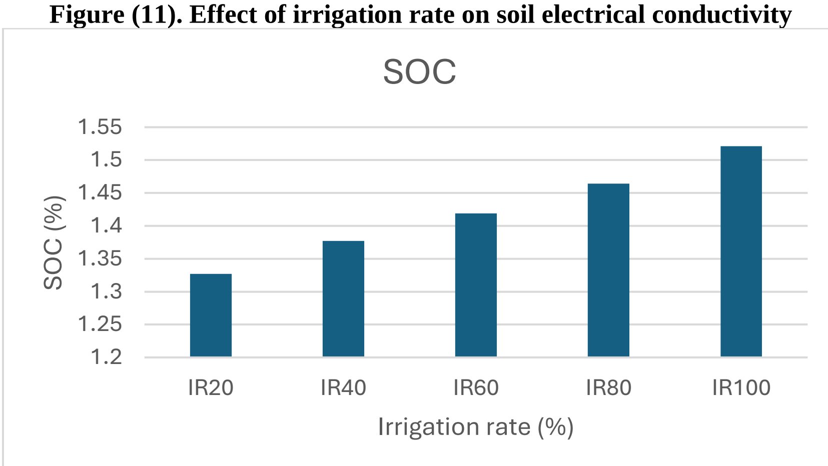

Figure (12). Effect of irrigation rate on soil organic carbon

IV.5.2. Effect of biochar type

Both biochar types, soft and hard corncob biochar have highly significant effect on soil chemical properties. The hard biochar has more effect than the soft biochar.

IV.5.3. Effect of biochar application rate

Increasing the biochar application rate significantly increased the soil chemical analysis (Table 7). The highest values were attained with the highest application rate. The increments over the control treatment were 2.83, 134.23, 38.30, 29.00, 32.74, 69.79, and 75.98% for pH, EC, SOC, Ca, Mg, Na, and K, respectively.

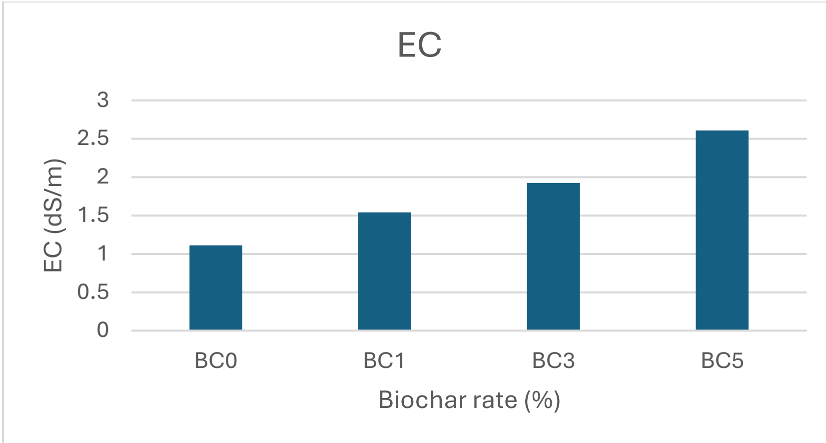

Figure (13). Effect of biochar rate on soil electrical Conductivity

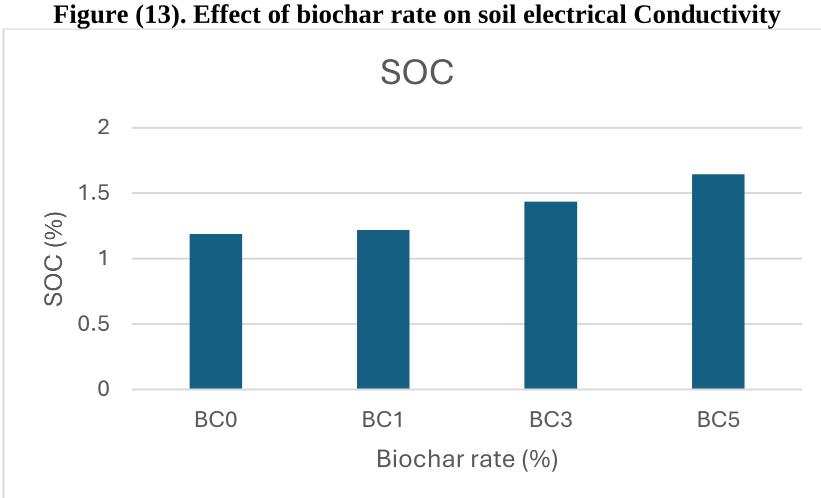

Figure (14). Effect of biochar rate on soil organic carbon

Table (7). Mean effects of soil chemical analysis as affected by irrigation regimes, biochar type, and biochar rate of Radish.`

Treatments	pH	EC dS/m	SOC %	SOM %	Ca	Mg	Na	K
					meq/l			
The main effect of the Irrigation regime (% of ET_0)								
20	7.07	0.518	1.327	2.286	1.939	1.397	1.126	0.719
40	7.26	0.914	1.377	2.371	3.118	3.023	1.814	1.085
60	7.50	1.772	1.419	2.445	5.450	5.620	4.661	1.888
80	7.69	2.607	1.464	2.525	6.010	6.801	7.316	3.942
100	8.10	2.951	1.521	2.623	6.694	7.844	9.370	5.102
LSD (0.05)	0.06**	0.040**	0.015**	0.026**	0.095**	0.116**	0.794**	0.267**
The main effect of Biochar type								
Soft	7.46	1.430	1.395	2.404	5.519	4.077	2.752	1.593
Hard	7.59	2.164	1.448	2.496	3.283	5.225	5.932	2.584
LSD (0.05)	0.07**	0.059**	0.045*	0.076*	ns	0.107**	0.447**	0.121**
The main effect of Biochar rate (%)								
0	7.43	1.113	1.188	2.048	3.862	4.022	3.290	1.574
1	7.48	1.543	1.219	2.102	4.142	4.377	3.959	1.774
3	7.55	1.925	1.436	2.476	4.618	4.866	4.734	2.236
5	7.64	2.607	1.643	2.833	4.982	5.339	5.586	2.770
LSD (0.05)	0.03**	0.031**	0.019**	0.033*	0.069**	0.090*	0.561**	0.173**
Interaction effects (LSD 0.05)								
IRR X type	*	**	ns	ns	*	*	**	**
IRR X Rate	**	**	*	ns	*	*	**	**
Type X Rate	**	**	ns	ns	ns	*	ns	ns
IRR X Type X rate	**	**	*	ns	*	*	ns	*

The current findings were consistent with those published by Smith et al. (2010a), Johnson et al. (2017), Brown et al. (2018), and Anderson et al. (2019), indicating that biochar application can successfully elevate soil pH, depending on the kind and application rate of biochar. It underlines the importance of carefully considering biochar qualities and soil properties to optimize its application in regulating soil acidity. Lehmann, et al. (2006) also stated that biochar can retain carbon in terrestrial ecosystems, improve soil fertility, improve nutrient cycling, and reduce greenhouse gas emissions.

According to Laird et al. (2010), biochar amendments can improve soil quality in agricultural soils by increasing pH, improving nutrient retention, and increasing soil fertility. These findings imply that the use of biochar has the potential to increase agricultural output. As stated by Jeffery et al. (2011) and Spokas et al. (2012), biochar application can boost crop yield, particularly in nutrient-poor soils, by increasing nutrient availability and soil moisture retention. However, biochar's effectiveness is determined by many parameters, including feedstock type, application rate, and soil conditions. According to Laird et al. (2010), biochar amendments can improve soil quality in agricultural soils by increasing pH, improving nutrient retention, and increasing soil fertility. These findings imply that the use of biochar has the potential to increase agricultural output.

V. Conclusion

As a result of the present study, the following recommendations are made:

i. Large-scale research should be emphasizing on biochar by interested researchers on all soil types all over the agricultural regions. The results of such research will enable the recommendation of biochar sources, and application rates for each soil type in the Agri-ecological zones.
ii. Farmers in the study area should use corncob biochar as an amendment to improve soil properties and fertility and then increase crop yield. corncob biochar application develops the soil's physical characteristics making the soil more efficient in supporting and retaining water and nutrients.
iii. Biochar should be seen as an alternative to organic waste. Organic waste management is a major problem. Incorrect management of organic waste has public health implications that can affect the quality of life of the people living in such an environment, particularly concerning environmental pollution.

Therefore, furthermore, research must be performed on the effects of biochar applications on soil properties and include the following:

i. Long-term effects of biochar addition on physicochemical properties of soil and crop yield.
ii. Effects of biochar types, application rates, and pyrolysis temperature on soil properties.
iii. Factors that influence the ways of biochar application technologies by farmers.

In general, biochar application increases soil pH, organic matter, available nitrogen, available phosphorus, and available potassium contents while decreasing soil bulk density. The biomass, root growth, and shoot yields of radish were enhanced as the rate of biochar treatment was raised. As a result, it can be inferred that adding biochar to soil would be quite beneficial in terms of increasing soil fertility and radish output. Thus, biochar application provides a unique technique for dealing with surplus organic waste to trap carbon and perhaps improve soil and plant production, resulting in sustainable soil management.

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الملخص العربي

نمو نبات الفجل تحت تأثير الرى وإضافة الفحم الحيوي في التربة الرملية تحت ظروف الإجهاد المائي

جورج وهبة مرقص جرجس – جمال عبد الناصر خليل – عادل حسين احمد حسين

قسم الاراضي والكيمياء الزراعية – كلية الزراعة سابا باشا – جامعة الاسكندرية

تم إجراء الدراسة الحالية لتقييم تأثير الفحم الحيوي المشتق من قوالح الذرة (المنتج محلياً من خلال التحليل الحراري عند 500 درجة مئوية) في ظروف أكسجين محدودة على تحسين خصائص التربة الرملية ونمو نبات الفجل تم خلط التربة الرملية مع الفحم الحيوي بنسب تبلغ 0 و1 و3 و5٪ (وزنا) ثم تم ترطيب الخليط حتى السعة الحقلية كما تم تحضينه في درجة حرارة الغرفة (25±2 مئوية) لمدة شهر مع إعادة الترطيب كل 7 أيام.

تم إجراء التجربة في أواني بلاستيك بتصميم القطاعات كاملة العشوائية (RCBD) مع ثلاث مكررات في الصوبة المفتوح بكلية زراعة سابا باشا جامعة الإسكندرية. كانت هناك ثلاثة عوامل تمت دراستها, العامل الرئيسي هو نظام الري وبه خمس معاملات 20 و 40 و 60 و 80 و 100٪ من قيمة البخر- نتح المرجعي (ET0) العامل الفرعي هو نوعاًن من الفحم الحيوي (الناعم والخشن). العامل تحت الفرعي هو نسب الفحم الحيوي وهى 0.0 و1 و3 و5٪ (وزنا) لقد كان هناك 120 وعاء بسعة 5 كجم (قطر= 16 سم وارتفاع= 16 سم). زُرعت بذور الفجل (Raphanus sativus) من صنف الفجل الأبيض البلدي في الأواني (2 بذور لكل وعاء) في 30 ديسمبر 2020. تم تطبيق الممارسات الزراعية كما هو موصى به. تم تطبيق عملية الري كل يومين وفقًا للبخر- نتح من النبات المحسوب باستخدام معادلة بينمان- منتيث. في وقت الحصاد، في 13 فبراير 2021 تم جمع النباتات يدوياً ثم تم فصل النباتات المحصودة من كل وعاء إلى جذور وسيقان وتم وزنها بشكل منفصل.

تمت أجراء قياسات النمو الخضري وقياسات الجذور على عينات النبات في وقت الحصاد حيث تم تقطيع عينات الجذور النباتية إلى قطع صغيرة ثم غسلها تجفيفها هوائيا ومن ثم تجفيفها عند 70 درجة مئوية لمدة 48 ساعة. تم طحن المواد الجافة في مطحنة النبات وهضمها. تم تقدير العناصر الغذائية فى ناتج الهضم.

تبين أن اضافة البيوتشار تؤثر بشكل كبير على معايير نمو الفجل مثل ارتفاع الساق ومساحة الورقة و عدد الأوراق و الوزن الطازج والوزن الجاف حيث أظهرت تحسن في بعض المعايير. اضافة البيوتشار يؤثر بشكل كبير على نمو االنبات في الفجل وقد تلاحظ وجود قيم أعلى عند تطبيق معدلات 5% من البيوتشار. تم ملاحظة زيادات في وزن الساق , مساحة الورقة , عدد الأوراق , الوزن الطازج والوزن الجاف.

تكشف الدراسة عن تأثيرات كبيرة لأنظمة الري على معايير نمو النبات بما في ذلك وزن الكتلة الحيوية , وزن الساق الطازج , وزن الساق الجاف , مساحة الورقة , عدد الأوراق , ارتفاع الساق ومحتوى الماء في الساق. كما تظهر الدراسة أن معدلات اضافة البيوتشار تؤثر بشكل كبير على معايير نمو الجذور مع قيم أعلى إلى تؤدي إلى زيادة في محتوى البروتين , الوزن الطازج الإجمالي ,الوزن الجاف , طول الجذر , وقطر الجذر مقارنة بمعاملة الكنترول. تكشف البيانات المجمعة أن أنظمة الري المختلفة تؤثر بشكل كبير على معايير نمو جذور الفجل مع زيادات تبلغ 303.27%، 79.25، 76.38، 76.06، 75.68، 75.60، و74.09%، على التوالي مما يدل على زيادة كبيرة في نمو الجذور مع زيادة معدلات الري.

لذلك، يجب إجراء مزيد من الأبحاث على تطبيقات البيوتشار على التربة وتتضمن الآتي:

1) التأثيرات طويلة الأمد لاضافة البيوتشار على الخصائص الفيزيائية والكيميائية للتربة وعائد المحاصيل.

2) تأثيرات نوع البيوتشار ودرجة حرارة الانحلال الحراري ومعدل الاضافة على أنواع تربة أخرى.

3) العوامل التي تؤثر على استخدام تقنيات اضافة البيوتشار من قبل المزارعين