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Improvement of Soil, Physiological Characteristics and Productivity of Rice Using Biostimulants under Water Stress

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WATER stress detrimentally affects soil quality and crop development. The coupled of biochar and compost tea could be a promising strategy for improving soil quality, crop development as well as the productivity of rice plants. Our investigation was performed in split block design to appraise the impact of coupling addition of biochar with compost tea for mitigating the increasing of irrigation intervals (6 days (I_1), 9 days (I_2), and 12 days (I_3)) in rice (*Oryza sativa* L. Giza 179) during 2022 and 2023 seasons. It was found that the coupled addition of biochar and Compost tea further improved exchangeable sodium percentage and soil enzymes than sole application. In addition, no difference significance was found between irrigation periods every 6 days (I_1) and 9 days (I_2) and coupled treatment. Consequently, the coupled application enhanced physiological attributes (relative water content and stomatal conductance) while decrement proline content due to the increased activity of antioxidant enzymes (catalase, Ascorbate peroxidase (, and peroxidase). Accordingly, the greatest findings were obtained with the integrative use of biochar and compost tea. In conclusion, the integrated application of biochar and compost tea might be promising efforts for reinforcing soil, physiological characteristics and productivity of rice under environmental stressors conditions.

Keywords: Irrigation intervals, biochar, Rice, compost tea, soil enzymes, antioxidant enzymes.

1. Introduction

Most of the world's population lives on using Rice (*Oryza sativa* L.) as the primary meal in their food (Seck et al. 2012). Therefore, scientists should exert efforts to increase crop productivity to meet the steady increase in the population, especially those who live in arid and semi-arid areas where production is noticeably low, especially in Egypt. In Egypt, rice is cultivated roughly in 0.7 m ha, with productivity expected at 7 million tons based on (FAOSTAT, 2022). Global warming causes a main menace to crop productivity due to exposure of plants to environmental stressors such as water stress which negatively influences on plant growth and production (Kumar et al. 2020). Therefore with increasing the harmful impact of drought and increasing population, we need to focus on improving soil quality and increasing the potential of plants to escape from abiotic stress during the vegetative and reproductive growth of rice (Hafez et al. 2019). Rice is highly vulnerable to water stress during various growth stages, leading to a lessening in productivity by 70% owing to environmental stressors (Kheir et al. 2019). Water stress is one of the most common natural disasters that negatively influence normal morphological, physical, and biochemical processes (Hafez et al. 2021a). Water stress triggers a decrease in the absorption of elements necessary for plant growth, as well as a decrease in the amount of water absorbed by the plant roots (Helmy and El-

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Sherpiny 2022), which causes damage to tissues, including a decrease in plant growth (Osman et al. 2021). Water stress had hindered influence on leaf expansion and stomatal conductance resulting in declined photosynthesis rate and physiological functions Abd-El-Aty et al. 2023). Soil amendment and improvement its quality under conditions of lack available water for the rice crop is very necessary to maintain the appropriate amount of water suitable for absorption by plant roots to help the plant growth and development under harsh conditions (Omara et al. 2022). It turns out that the most important recent technology used to improve soil quality is the application of biochar to the soil before planting. Biochar is a soil amendment using from burn plant residues under low oxygen conditions (El-Shamy et al. 2022). Biochar addition led to improvement in the ability to retain moisture around the roots, the cation exchange capacity, reducing the exchangeable sodium ratio, and thus improving soil fertility (Abou Hussien et al. 2020), increasing the absorption of nutrients dissolved in the ground solution by plant roots, and enhancing microbial activity in the soil (Alharbi et al. 2022). Biochar application increased plant water relations which positively reflected on physiological parameters and productivity (Bassouny and Abbas, 2019; Hafez et al. 2021b). There is another approach to reducing transpiration from the surfaces of plant leaves increasing the ability of plants to retain water within plant tissues and increasing stomatal conductance, and that is through foliar spraying with Compost tea (Hafez et al. 2021c). Compost tea is sprayed and applied as a plant growth regulator which contains all macro and micro nutrients. Many reports proved that silicon application could mitigate oxidative stress under water stress conditions (Hafez and Gharib 2016). Compost tea is considered as imperative for alleviating the damage impacts of abiotic stress, including water stress. Compost tea application could enhance metabolism activity, and water retention (Nehela et al. 2021). However, the application of compost tea helps transfer the products of the metabolic process inside the plant leaves to the flowers and seed formation (Abou Hussien et al. 2021). It also helps the transfer of water and nutrients absorbed by the root from the soil to the other plant parts (Abdelrasheed et al. 2021). Compost tea can help in protein synthesis, cell division, growth, osmotic adjustment and enhance physiological processes, seed size, and quality. So, compost tea could enhance yield attributes, grain yield. Little researches about the coupled application of biochar and compost tea, under soil water deficiency (Seleiman and Hafez 2021). In this investigation, we are assumed to assess the coupled application of biochar and compost tea for alleviating water deficiency in rice (Rashwan et al. 2024). It is supposed that the paper's results will be useful for improving growth and rice productivity under water deficiency.

Materials and Methods

Investigational Design and Treatments

The current investigation was executed at Sakha Agricultural Research Center, Kafr El-sheik Governorate, Egypt on May 15th, 2022, and May 14th in 2023 summer seasons to estimate the application of biochar as soil application and compost tea as spraying on soil properties, physiological attributes, yield parameters, productivity and quality under irrigation intervals as (each 6 (I_1), 9 (I_2) and 12 (I_3) days following transplanting) on rice (*Oryza sativa* L., cv. Giza 179). The layout was split-block set with four replications. Irrigation intervals were distributed in horizontal plots while soil and foliar applications were allocated in vertical plots. Rice seeds (Giza 179 cv.) were soaked for a night and repeated for a night. The seeding amount was 118 kg ha^{-1} which was allocated on the nursery land for 30 days. Then, the plants were cultivated at 5 seedlings $hill^{-1}$ and distancing 25 x 25 cm and rows in 20 m^2 (4.0 m × 5.0 m). Recommended fertilizer rates have been applied such as N fertilization was added at 150 kg N ha^{-1} as sulphate ammonium (20.5%) and applied three times, also before sowing has been applied calcium super phosphate (15.5% P_2O_5) was applied at 120 kg P_2O_5 ha^{-1}.

Biochar characteristics

Biochar was produced using plant residues at 400 °C under hypoxia. Biochar at rate 10 t ha^{-1} was added on the soil surface before the tillage process (Danapriatna et al. 2023).

Table 1. Soil analysis in 2022 and 2023 summer seasons.

Character	2022	2023
Soil organic matter (g kg^{-1})	10.8	10.9
Particle size distribution (%)		
Sand	27.22	27.17
Silt	25.23	25.55
Clay	47.55	47.28
Texture grade	clayey	clayey
Soluble cations (cmolc kg^{-1} soil)		
Ca^{++}	7.54	9.29
Mg^{++}	5.76	6.23
Na^{+}	26.75	22.63
K^{+}	0.33	0.39
Soluble anions (cmolc kg^{-1} soil)		
HCO_3^{-}	4.61	3.34
Cl^{-}	24.56	18.21
SO_4^{--}	15.13	11.15
pH (1:2.5, soil: water suspension)	8.02	8.07
Electrical conductivity (ECe, dS m^{-1})	5.01	5.04
ESP (%)	22.01	21.05

Table 2. The physicochemical analysis of the biochar is as follows:

Parameter	value
N (g kg^{-1})	25.21
P (g kg^{-1})	7.45
K (g kg^{-1})	13.21
$CaCO_3$ (%)	1.4
pH	7.60
Electrical conductivity (EC, dS m^{-1})	0.7
Moisture content (g kg^{-1})	33
Water holding capacity (g kg^{-1})	954
Bulk density (g cm^{-3})	0.2
Specific surface area (m^2 g^{-1})	37

Compost tea characteristics

Rice plants were sprayed with Compost tea as foliar spraying application with 300 mg L^{-1} at the rate of 250 L ha^{-1} at 20, 35, and 50 days from transplanting. It was purchased from Department of microbiology in Sakha station, ARC**,** Egypt**.**

Measurements

Physicochemical properties in soil

It was taken after harvesting a randomized soil sample at a deepness of 25 cm which was desiccated and passed through a strainer for exchangeable sodium percentage (ESP) measurement by an Atomic Absorption Spectrophotometer (AAS, Perkin Elmer 3300) with a detection limit of 100 ppb was measured Na^+, K^+, Ca^{2+}, and Mg^{2+} ions. ESP was calculated by formula (1) as stated by (Seilsepour et al. 2009). ESP = 1.95 + 1.03 × SAR (R2 = 0.92) where SAR (Sodium adsorption ratio) was measured by formula (2) as stated by (Richards, 1954):

$$SAR = [Na^+] / \sqrt{\frac{([Ca^{2+}] + [Mg^{2+}])}{2}}$$

Enzyme activities in soil

At 65 days after transplanting, urease activity was estimated and calculated as NH_3-N g^{-1} h^{-1} at 37 °C and determined based on **Kandeler and Gerber (1988)** using a spectrophotometer (RIGOL, USA). Dehydrogenase activity was also estimated as µg TTC g^{-1} h^{-1} and assessed by **Öhlinger and Von Mersi (1996),** using a spectrophotometer (RIGOL, USA).

Physiological characteristics in plant leaves

Relative water content (RWC, %) in plant leaves

At 65 days after transplanting, in ten plant leaves randomly from each experimental unit, RWC was measured according to **Barrs and Weatherley (1962)** the formula: $\mathrm{RWC}\,(\%) = [(\mathrm{FW} - \mathrm{DW}) / (\mathrm{TW} - \mathrm{DW})] \times 100$

Stomatal conductance (gs) in plant leaves

At 65 days after transplanting, in ten plant leaves randomly from each experimental unit, stomatal conductance (g_s) was estimated by a dynamic diffusion porometer using the next formula: Total leaf conductance (rl) is $1/rl = 1/ra + 1/rb$.

Free proline content (Pro) in plant leaves

At 65 days after transplanting, in ten plant leaves randomly from each experimental unit, proline content was measured using a spectrophotometer (RIGOL, USA) according to **(Bates, 1973)** the method of mortar and pestle.

Antioxidant enzymes activity in plant leaves

At 65 days after transplanting, in ten plant leaves randomly from each experimental unit, catalase (CAT, unit mg^{-1} protein) was assessed by spectrophotometer at 240 nm by **Aebi (1984)**. Ascorbate peroxide (APX, unit mg^{-1} protein) activity was measured by spectrophotometer at 290 nm using the method of **Kumar (2022).** While, peroxidase (POD, unit mg^{-1} protein) was measured by spectrophotometer at 430 nm by **Vetter *et al.* (1998)**

Yield and its components

At end of the investigation, in ten plant leaves randomly from each experimental unit, number of spikelets per panicle and the number of spikes m^{-2} were measured then threshed the spikes to get 1000-grain weight (g).After harvesting, the plot was harvested and collected to air-dried for 48 h. to measure grain and straw yields (kg ha^{-1}).

Harvest index (HI) was measured as next formula:

$$\text{Harvest index } (\%) = \frac{\text{Grain yield } (\text{kg ha}^{-1})}{\text{Biological yield } (\text{kg ha}^{-1})} \times 100$$

Nutrient Uptake

At end of the investigation, 10 panicles were selected from each experimental unit to get 50 grains and digested with HNO_3-H_2O_2 solution (2:1) to measure N, P, K and Si contents (g kg^{-1}). Nitrogen content was measured by the Kjeldahl method using (A.O.A.C. 2005). Phosphorus content was calorimetrically assessed by the method of (Sparks, *et al.* 1996). Potassium content was measured by AAS (Perkin Elmer 3300) using the method of (Sparks, *et al.* 1996).

Statistical Analyses

The results attained were analysed by an F-test **(Gomez and Gomez 1984)**. Duncan's test was applied to explain the variance between the averages.

2. Results

ESP, urease and dehydrogenase enzymes activity

The exchangeable sodium percentage (ESP) in soil was estimated after harvesting (Table 3). The ESP is affected by different irrigation intervals and soil and foliar (SF) treatments. Our results displayed that the addition of a single biochar or compost tea lowered ESP compared to untreated plots (control). However, ESP was further lessened when biochar was applied compared to compost tea in two growing seasons. The co-application had a lower than individual application for ESP. In addition, for different irrigation periods (I_1, I_2, and I_3), the highest decline in ESP was observed in I1 (every 6 days) was slightly different from I2 (every 9 days) while I3 (every 12 days) and was higher than I1 and I2 in both seasons (Table 3).

Activity Urease and Dehydrogenase (as of soil enzymes were estimated as indicated in our results as shown in Table 3. Our results displayed that the addition of a single biochar or compost tea augmented the activity of urease and dehydrogenase compared to untreated plots (control). However, the activity of urease and dehydrogenase was further higher when biochar was applied compared to compost tea in two growing seasons. The co-application had further increased than individual application. In addition, for different irrigation periods, the maximum increase in activity of urease and dehydrogenase was observed in I_1 (every 6 days) and I_2 (every 9 days) compared to I_3 (every 12 days) in both seasons (Table 3). The interaction between various irrigation intervals and soil and foliar (SF) treatments was significant in both seasons.

Table 3. Impact of compost tea and biochar applications on soil exchangeable sodium percentage (ESP) and the activity of soil enzymes (urease and dehydrogenase) in rice grown under irrigation intervals (I_1, I_2 and I_3) during 2022 and 2023.

Treatments	ESP		Urease (mg N-NH_4^+ g^{-1} soil h^{-1})		Dehydrogenase (mg TPF g^{-1} soil d^{-1})	
	2022	2023	2022	2023	2022	2023
Irrigation intervals (I)						
I_1	15. 98b	16.27b	175.27a	188.77a	115.01a	111.10a
I_2	16.46b	16.79b	156.39ab	165.39ab	100.26ab	107.31ab
I_3	19.02a	19.61a	114.05b	125.48b	67.33b	80.92b
F-Test	**	**	**	**	**	**
SF treatments						
Control	19.50a	19.56a	102.2 de	110.4 d	52.1 g	55.7 f
Biochar	16.02c	16.23c	154.2 b	171.2 b	103.1 c	107.7 c
Compost tea	17.32b	17.78b	136.2 c	146.8 c	83.1 d	87.5 d
Combination	15.80d	15.56d	201.7 a	211.2 a	138.5 a	148.2 a
F-Test	**	**	**	**	**	**
Interaction (I×SF)	**	**	**	**	**	**

Means in the same column followed by different letters are significant according to the Tukey's test ($P \leq 0.05$). SF treatments (soil application with biochar and foliar spraying with compost tea), I_1, I_2 and I_3 are meaning the irrigation interval every 6,9 and 12 days, respectively.

RWC, gs and Pr

WC, gs, and Pr express the physiological state that the plant is in under conditions of water shortage and the effect of applying biochar as a soil amendment and foliar spraying with compost tea as shown in Table 4. Our data showed that a single application of biochar or compost tea increased RWC and gs while declining Pr relative to control. However, relative water content (RWC) and stomatal conductance (gs) were further higher when compost tea was sprayed compared to biochar in two growing seasons while proline content further declined under the same treatment. The co-application had further augmented than the sole application. In addition, for different irrigation periods, the highest increase in RWC and gs while proline content minimum decreased were remarked in I_1 (every 6 days) on par with I_2 (every 9 days) compared to I_3 (every 12 days) in two years (Table 4). While plants irrigated with I_3 declined physiological parameters compared to I_1 and I_2 in both seasons. The interaction irrigation intervals and soil and foliar (SF) addition was significant in both years.

Table 4. Physiological characteristics of rice leaves as influenced by compost tea and biochar under various irrigation intervals in 2022 and 2023 years.

Treatments	Relative water content (RWC; %)		Stomatal conductance (gs; mmol H_2O m^{-2} s^{-1})		Proline content (pro; μ g^{-1} FW)	
	2022	2023	2022	2023	2022	2023
Irrigation intervals (I)						
I_1	92.90a	94.07a	55.05a	55.57a	10.48b	9.73b
I_2	91.00a	91.99a	52.96a	55.04a	10.59b	10.09b
I_3	82.72b	85.02b	47.17b	47.98b	12.68a	12.24a
F-Test	**	**	**	**	**	**
SF treatments						
Control	82.70d	84.76d	45.96d	46.85d	14.85a	13.86a
Biochar	87.32c	89.43c	50.09c	51.89c	12.03b	11.24b
Compost tea	90.52b	92.98b	54.08b	54.52b	9.94c	9.45c
Combination	95.00a	95.76a	56.74a	58.22a	8.21d	8.08d
F-Test	**	**	**	**	**	**
Interaction (I×SF)	**	**	**	**	**	**

Means in the same column followed by different letters are significant according to the Tukey's test ($P \leq 0.05$). SF treatments (soil application with biochar and foliar spraying with compost tea) I_1, I_2 and I_3 are meaning the irrigation interval every 6,9 and 12 days, respectively.

Catalase (CAT), ascorbate peroxide (APX) and peroxidase (POD)

CAT, APX, and POD express the activity of antioxidant enzymes and their potential to scavenge ROS that the plant is in under conditions of water shortage and the effect of applying biochar and foliar spraying with Compost tea as shown in Table 5. Our data showed that a single application of biochar or Compost tea declined CAT, APX, and POD compared to untreated plots (control). However, CAT, APX, and POD were further decreased with the co-application of biochar and compost teain the two years. A same findings was remarked with I_1 (each 6 days) on par with I_2 (each 9 days) compared to I_3 (each 12 days) in the two years. The integration of biochar or compost tea application caused declined CAT, APX, and POD with irrigation each 6 days (I_1) that did not vary greatly with the irrigation each 9 days (I_2) in growing years (Table 5). The interaction between various irrigation intervals and soil and foliar (SF) treatments was significant in both seasons.

Table 5. Antioxidant enzymes (CAT, APX and POD) of rice leaves as affected by compost tea and biochar under various irrigation intervals in 2022 and 2023 seasons.

Treatments	CAT (Unit mg^{-1} protein)		APX (Unit mg^{-1} protein)		POD (Unit mg^{-1} protein)	
	2022	2023	2022	2023	2022	2023
Irrigation intervals (I)						
I_1	0.05bc	0.07bc	0.09bc	0.11bc	15.83bc	15.48bc
I_2	0.07b	0.9b	0.11b	0.12b	18.01b	17.98b
I_3	0.13a	0.18a	0.18a	0.19a	26.54a	25.48a
F-Test	**	**	**	**	**	**
SF treatments						
Control	0.14a	0.18a	0.18a	0.20a	25.29a	24.82a
Biochar	0.08b	0.15b	0.14b	0.16b	19.55b	19.36b
Compost tea	0.07b	0.11b	0.12b	0.15b	17.47b	16.95b
Combination	0.05c	0.08c	0.07c	0.09c	11.24c	11.72c
F-Test	**	**	**	**	**	**
Interaction (I×SF)	**	**	**	**	**	**

Means in the same column followed by different letters are significant according to the Tukey's test ($P \leq 0.05$). SF treatments (soil application with biochar and foliar spraying with compost tea) I_1, I_2 and I_3 are meaning the irrigation interval every 6,9 and 12 days, respectively.

Yield-related traits (1000-grain weight (g), number of grains panicle^{-1} and Number of panicles m^{-2})

1000-grain weight (g), number of grains panicle^{-1}, and Number of panicles m^{-2} are indicators reflecting the effect of physiological and biochemical conditions for plants under water shortage through the positive effect of applying biochar and foliar spraying with compost tea as shown in Table 6. Our data showed that a single application of biochar or Compost tea increased yield components compared to untreated plots (control). However, yield components were further increased when compost tea was sprayed compared to biochar in two growing seasons. The co-application had further augmented than the sole application. In addition, for different irrigation intervals, the maximum increase in yield components were remarked in I_1 (every 6 days) on par with I_2 (every 9 days) compared to I3 (every 12 days) in the two years (Table 6). While plants irrigated with I_3 declined yield-related traits relative to I_1 and I_2 in the two years. The interaction between various irrigation intervals and soil and foliar (SF) treatments was significant in both seasons.

Crop Yield

Grain yield (t ha^{-1}), straw yield (t ha^{-1}) and harvest index (%) are indicators that reflect the effect of physiological, and biochemical conditions along with yield components for plants under water shortage through the positive effect of applying and foliar spraying with compost tea as shown in Table 7. Our data showed that a single application of biochar or Compost tea increased crop yield parameters compared to untreated plots (control). However, Crop yield were further increased when compost teawas sprayed compared to biochar in two growing seasons. The co-application had further augmented than the sole application. In addition, for different irrigation intervals, the highest increase in Grain yield (t ha^{-1}), straw yield (t ha^{-1}), and harvest index (%) were observed in I1 (every 6 days) on par with I_2 (every 9 days) compared to I_3 (every 12 days) in the two years (Table 7). While plants irrigated with I3 declined yield compared to I1 and I2 in both seasons. The interaction between various irrigation intervals and soil and foliar (SF) treatments was significant in both years.

Table 6. Yield components of rice as influenced by compost tea and biochar under various irrigation intervals in 2022 and 2023 seasons.

Treatments	1000-grain weight (g)		number of grains panicle^{-1}		Number of panicles m^{-2}	
	2022	2023	2022	2023	2022	2023
Irrigation intervals (I)						
I_1	29.64a	30.83a	133.88a	135.43a	441.75a	446.05a
I_2	27.75a	28.77a	130.07a	132.75a	437.53a	443.94a
I_3	21.44b	23.65b	120.72b	122.09b	429.97b	433.64b
F-Test	**	**	**	**	**	**
SF treatments						
Control	20.53d	22.16d	120.54d	123.24d	421.44d	425.86d
Biochar	24.34c	26.66c	126.35c	128.48c	436.32c	439.75c
Compost tea	29.17b	29.54b	131.25b	131.95b	440.65b	443.47b
Combination	30.04a	32.44a	135.95a	138.29a	445.55a	456.04a
F-Test	**	**	**	**	**	**
Interaction (I×SF)	**	**	**	**	**	**

Means in the same column followed by different letters are significant according to the Tukey's test ($P \leq 0.05$). SF treatments (soil application with biochar and foliar spraying with compost tea) I_1, I_2 and I_3 are meaning the irrigation interval every 6,9 and 12 days, respectively.

Table 7. Productivity of rice as influenced by compost tea and biochar under various irrigation intervals in 2022 and 2023 seasons.

Treatments	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		HI (%)	
	2022	2023	2022	2023	2022	2023
Irrigation intervals (I)						
I_1	8.98a	8.77a	13.31a	13.61a	37.55a	36.50a
I_2	8.69a	8.48a	13.12a	13.27a	37.04a	36.20a
I_3	7.76b	7.38b	12.49b	12.49b	35.43b	34.25b
F-Test	**	**	**	**	**	**
SF treatments						
Control	7.78d	7.38d	12.27d	12.48d	35.29d	34.27d
Biochar	8.28c	8.06c	12.78c	13.00c	36.52c	35.53c
Compost tea	8.68b	8.48b	13.20b	13.31b	36.97b	36.14b
Combination	9.17a	8.95a	13.75a	13.71a	37.61a	36.86a
F-Test	**	**	**	**	**	**
Interaction (I×SF)	**	**	**	**	**	**

Means in the same column followed by different letters are significant according to the Tukey's test ($P \leq 0.05$). SF treatments (soil application with biochar and foliar spraying with compost tea) I_1, I_2 and I_3 are meaning the irrigation interval every 6,9 and 12 days, respectively.

N, P and K contents in rice grains

Nutrient elements contents in rice grains are influenced by water shortage and the effect of applying biochar and compost tea as shown in Figure 1. Our data showed that a single application of biochar or compost tea increased grain nitrogen (N), phosphorus (P), and potassium (K) contents compared to untreated plots (control). However, Nutrient elements contents were further boosted when compost tea was sprayed compared to biochar in two growing seasons. The co-application had further augmented than the sole application. In addition, for different irrigation intervals, the maximum increase in nutrient elements contents in grains was observed in I_1 (every 6 days) on par with I_2 (every 9 days) compared to I_3 (every 12 days) in the two years (Figure 1). While plants irrigated with I_3 declined nutrient contents in rice grains relative to I_1 and I_2 in both seasons. The interaction between different irrigation intervals and soil and foliar (SF) treatments was significant in both seasons.

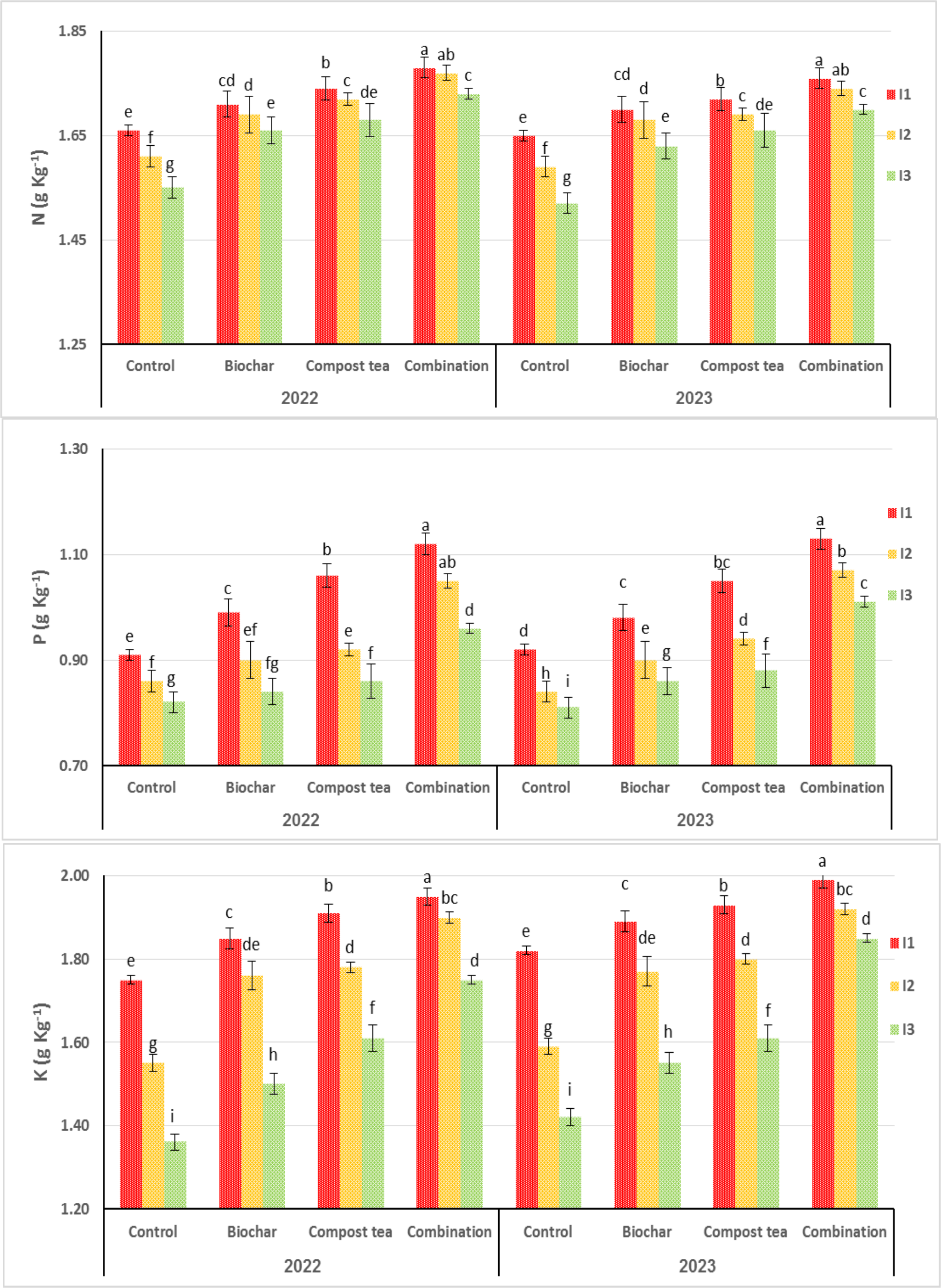

Fig. 1. Nutrient elements contents (N, P and K) in rice grains as influenced by compost tea and biochar under various irrigation intervals in 2022 and 2023 years. Soil application with biochar and foliar spraying with compost tea. I_1, I_2 and I_3 are meaning the irrigation interval every 6,9 and 12 days, respectively.

4. Discussion

This field experiment demonstrated no doubt the positive influence of biochar on improving soil quality and increasing the absorption of nutrients necessary and water uptake for plant growth. Protective spraying with compost tea also came to emphasize the pivotal role which they play as growth stimulants and improving productivity under conditions of water shortage. The percentage of exchangeable sodium in the soil decreased with the soil addition of biochar, and the positive effect was on improving the availability of necessary elements such as potassium, magnesium, and calcium, while it caused the sodium element to be adsorbed onto the soil particles, which led to a noticeable improvement in the soil properties **(Naeem *et al*. 2017).** It was found from our field experiment that when adding biochar with an increase in the irrigation interval helped to significantly improve the quality of the soil due to the ability of biochar to accumulate soil moisture and preserve it around the roots of plants because it also has properties such as: biochar's porous structure and high water holding **(Ouyang *et al.* 2013).** While applying compost tea alone slightly improved the properties and quality of the soil, while applying it as a spray in the presence of biochar improved more than applying biochar alone, because foliar spraying contains important elements, which are characterized by their positive role in improving the health condition of the soil and the available nutrients **(Chintala *et al.* 2014).** What also indicates an improvement in the health condition of the soil is the activity of the enzymes urease and hydrogenase, which were shown to increase under conditions of lack of irrigation water when adding biochar to the soil resulting in augment cell division and elongation **(Akhtar *et al*. 2014) in addition to improvement in ESP.** This is due to the promotion of growth hormones auxin and cytokinin which accelerate the water transportation as well as activating the metabolic system **(Haider *et al.* 2016).** While applying Compost tea alone slightly improved enzymes urease and hydrogenase, while applying it as a spray in the presence of biochar improved more than applying biochar alone, because foliar spraying contains important elements, which are characterized by their positive role in improvement enzymes urease and hydrogenase **(Kammann *et al.* 2011).**

Applying biochar also had an impact on improving the physiological condition of the plant, such as increasing stomatal conductance, increasing the relative water content, plus reducing the proline content of the plant leaves, which reflects a strong indication of the plant's ability to tolerate increased intervals of irrigation by growing under these conditions compared to the experimental plots to which biochar was not added **(Liu *et al*. 2017).** The positive impact of biochar on the growth was due to stimulating the meristematic activity, IAA-producing bacteria **(Egamberdieva *et al.* 2017).** However, application of compost tea as foliar spraying resulted in a further significant increase in the absorption of nutrients through stomata and hormone-like compounds, moreover, its pivotal role in osmoregulation and influencing hydraulic conductivity as well as improving the biosynthesis and the permeability of the plasma membrane **(Gomaa *et al.* 2021).** While applying it as a spray in the presence of biochar gave the highest values in physiological attributes than sole application. This proves the complementary role of foliar application alongside soil application on physiological attributes such as (increasing the relative water content plus reducing the proline content of the plant leaves) **(Rodrigues *et al.* 2009)**

Applying biochar led to a noticeable improvement in antioxidant enzymes (CAT, APX and POD) under conditions of increased irrigation intervals. CAT, APX and POD activities could convert H_2O_2 into non-toxic compounds such as (H_2O and O_2) **(Liang *et al.* 2003).** However, application of compost tea as foliar spraying gave the same trend under conditions of increased irrigation intervals and showed a noticeable improvement (CAT, APX and POD) which proved that no significant difference between both soil and foliar application under different irrigation intervals **(Yaghubi *et al*. 2016).** Compost tea has a pivotal role in improvement membrane stability and detoxifies the negative effects of ROS mitigating oxidative stress **(Hasanuzzaman *et al.* 2018).** This proves the complementary role of foliar application alongside soil application on (CAT, APX and POD) which positively reflect on the biosynthesis of phytohormones, the activity of 1-aminocyclopropane-1-carboxylate (ACC) deaminase, and osmolyte production **(Ahmad et al. 2016).**

Applying biochar also had an impact on improving the yield components and rice productivity, that reflects a strong indication on crop yield under increased intervals of irrigation compared to the experimental plots to which biochar was not added **(Nehela *et al*. 2021)**. The promising impact of biochar on yield related traits and rice productivity was due to uptake and translocation of the nutrition materials from leaves into grains **(Abdelrasheed *et al.* 2021).** Moreover, biochar might enhance the ovary, and thus may lead to an increase grain yield. However, application of compost tea as foliar spraying resulted in a further significant increase in the absorption of nutrients through stomata and hormone-like compounds, which reflect on yield related traits and productivity that can increase its panicle fertility **(Liang *et al.* 2007).** This proves the complementary role of foliar application alongside soil application on yield components and yield productivity under increasing of irrigation intervals. The high efficiency of coupling application could be due to its ability to decrease osmotic damage, augment potassium absorption and translocation from sources to sink **(Gomaa *et al*. 2021).**

Applying of biochar improved soil nutrient content which became available to absorb by the roots. All biochar characteristics increase holding of nutrients and water around the plant roots which positively reflecting on N, P, and K contents in grains under water shortage **(Hafez and Gharib 2016).** While, foliar-applied compost tea improved leaf area, cell division as well as physiological attributes. Foliar-applied compost tea increased uptake and translocate nutrients from leaves to grains by potassium ions which improved leaf water content. Foliar-applied compost tea increased the transport of nutrient elements in grains **(Seleiman and Hafez 2021).** This proves the complementary role of foliar application alongside soil application grain nutrient content under increasing of irrigation intervals.

Conclusion

It was clear from the coupled application of biochar as a soil application, as well as foliar spraying with compost tea, played a pivotal role in maintaining the nutritional and water content in the soil around the roots of rice plants. This was shown by measuring the exchangeable sodium percentage, which led to an increase the soil quality which was reflected positively in the increase (CAT, APX and POD), which reduced the oxidative stress, and in turn reflected positively on the physiological characteristics of the plant and ultimately the rice productivity and nutrient elements contents in rice grains. Biochar and compost tea are considered a very promising strategy for enhancing rice growth and productivity under water stress. Nevertheless, further research experiments are required to affirm the findings attained on a large scale.

Conflicts of interest

The authors have declared that no competing interests exist.

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References

A.O.A.C. (2005). Official Methods of Analysis of AOAC International, 18th ed., Association of Official Analytical Chemists: Washengton, D.C., USA.

Abd-El-Aty, M. S., Kamara, M. M., Elgamal, W. H., Mesbah, M. I., Behiryc S. I., Abo-Marzoka,S.A. (2023). Influence of Foliar Application of Some Biostimulants on Physiological, Agronomic Characters and Crop Water Productivity of Rice under Water Deficit and Normal Conditions. Egypt. J. Soil Sci. Vol. 63, No. 4, pp: 455-464.Abdelrasheed, K.G., Mazrou, Y., Omara, A.E.-D., Osman, H.S., Nehela, Y., Hafez, E.M., Rady, A.M.S., El-Moneim, D.A., Alowaiesh, B.F., Gowayed, S.M. (2021). Soil amendment using biochar and application of K-humate enhance the growth, productivity, and nutritional value of onion (Allium cepa L.) under deficit irrigation conditions. Plants, 10, 2598.

Abou Hussien, E. A., Ahmed, B. M., Elbaalawy, A. M. (2020). Efficiency of Azolla and Biochar Application on Rice (Oryza sativa L.) Productivity in Salt-Affected Soil. Egypt. J. Soil. Sci. Vol. 60, No. 3, pp. 277-288.

Abou Hussien, E. A., Nada, W. M., Hany M. (2021). Improving Chemical and Microbial Properties of Calcareous Soil and Its Productivity of Faba Bean (Vicia faba L.) Plants by Using Compost Tea Enriched with Humic Acid and Azolla. Egypt. J. Soil. Sci. Vol. 61, No. 1, pp. 27-44.

Aebi, H. (1984). Catalase in vitro. Methods Enzym. 105, 121–126.

Ahmad, P., Abdel Latef, A.A.,Abd_Allah, E.F., Hashem, A., Sarwat, M., Anjum, N.A., Gucel, S. (2016). Calcium and potassium supplementation enhanced growth, osmolyte secondary metabolite production, and enzymatic antioxidant machinery in cadmium-exposed chickpea (Cicer arietinum L.). Frontiers in Plant Science, 7, 513.

Akhtar, S.S., Li, G., Andersen, M.N., Liu, F. (2014). Biochar enhances yield and Quality of tomato under reduced irrigation. Agricultural Water Management, 138:37–44.

Alharbi, K., Rashwan, E., Mohamed, H.H., Awadalla, A., Omara, A.E.-D., Hafez, E.M., Alshaal, T. (2022). Application of Silica Nanoparticles in Combination with Two Bacterial Strains Improves the Growth, Antioxidant Capacity and Production of Barley Irrigated with Saline Water in Salt-Affected Soil. Plants, 11, 2026.

Barrs, H.. Weatherley, P. A. (1962). Re-Examination of the Relative Turgidity Technique for Estimating Water Deficits in Leaves. Australian Journal of Biological Sciences,15, 413.

Bassouny,M. A. and Abbas, M. H.H.(2019). Role of Biochar in Managing The Irrigation Water Requirements of Maize Plants: The Pyramid Model Signifying the Soil Hydrophysical and Environmental Markers. Egypt. J. Soil. Sci. Vol. 59, No. 2, pp. 99-115.

Bates, L.S., Waldren, R.P., Teare, I.D. (1973). Rapid determination of free proline for water-stress studies. Plant and Soil 39, 205–207.

Chintala, R., Mollinedo, J., Schumacher, T.E., Malo, D.D., Julson, J.L. (2014). Effect of biochar on chemical properties of acidic soil. Archive of Agronomy and Soil Sciences, 60,393–404.

Danapriatna, N., Ismarani I., Dede, M. (2023). Application of biochar and biological fertilizer to improve soil quality and *Oryza sativa* L. productivity, Cogent Food & Agriculture, 9:1, 2207416.

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.

El-Shamy, M.A., Alshaal, T., Mohamed, H.H., Rady, A.M.S., Hafez, E.M., Alsohim, A.S., Abd El-Moneim, D. (2022). Quinoa Response to Application of Phosphogypsum and Plant Growth-Promoting Rhizobacteria under Water Stress Associated with Salt-Affected Soil. Plants, 11, 872.

FAOSTAT. (2022). Food and agriculture organization of the United Nations statistics division. Available at: http://faost at.fao.org/site/567/Deskt opDef ault.aspx. Accessed 10 Dec, 2022.

Gomaa, M.A., Kandil, E.E., El-Dein, A.A.M.Z., Abou-Donia, M.E.M., Ali, H.M., Abdelsalam, N.R. (2021). Increase maize productivity and water use efficiency through application of Compost teaunder water stress. Scientific Reports, 11, 224–224.

Gomez, K.A., Gomez, A. (1984). Statistical procedure for agricultural research—hand book. New York: Wiley.

Hafez, E., Gharib, H. (2016). Effect of exogenous application of ascorbic acid on physiological and biochemical characteristics of wheat under water stress. International Journal of Plant Production, 10, 579-596.

Hafez, E.M., Alsohim, A.S., Farig, M., Omara, A.E.-D., Rashwan, E., Kamara, M.M. (2019). Synergistic effect of biochar and plant growth promoting rhizobacteria on alleviation of water deficit in rice plants under salt-affected soil. Agronomy, 9, 847.

Hafez, E.M., Gowayed, S.M., Nehela, Y., Sakran, R.M., Rady, A.M.S., Awadalla, A., Omara, A.E.-D., Alowaiesh, B.F. (2021a). Incorporated biochar-based soil amendment and exogenous glycine betaine foliar application ameliorate rice (*Oryza sativa* L.) tolerance and resilience to osmotic stress. Plants, 10, 1930.

Hafez, E.M., Osman, H.S., El-Razek, U.A.A., Elbagory, M., Omara, A.E.-D., Eid, M.A., Gowayed, S.M. (2021b). Foliar-applied Compost tea coupled with plant growth-promoting rhizobacteria improves growth, physiology, nutrient uptake and productivity of faba bean (Vicia faba L.) irrigated with saline water in salt-affected soil. Plants, 10, 894.

Hafez, E.M., Osman, H.S., Gowayed, S.M., Okasha, S.A., Omara, A.E.-D., Sami, R., Abd El-Monem, A.M., Abd El-Razek, U.A. (2021c). Minimizing the adversely impacts of water deficit and soil salinity on maize growth and productivity in response to the application of plant growth-promoting rhizobacteria and silica nanoparticles. Agronomy, 11, 676,

Haider, G., Steffens, D., Moser, G., Müller, C., Kammann, C.I. (2016). Biochar reduced nitrate leaching and improved soil moisture content without yield improvements in a four-year field study. Agriculture, Ecosystems & Environment, 237:80–94.

Hasanuzzaman, M., Bhuyan, M.H.M.B., Nahar, K., Hossain, S., Al Mahmud, J., Hossen, S., Masud, A.A.C., Moumita, M., Fujita, M. (2018). Potassium: A vital regulator of plant responses and tolerance to abiotic stresses. Agronomy, 8, 31.

Helmya, A. A., El-Sherpiny, M. A. (2022). Response of Maize Plants to Compost and Melatonin under Terraces and Alternate Furrow Irrigation Techniques. Egypt. J. Soil Sci. Vol. 62, No. 4, pp: 383 – 394.

Kammann, C.I., Linsel, S., Gößling, J.W., Koyro, H.W. (2011). Influence of biochar on drought tolerance of Chenopodium quinoa Willd and on soil–plant relations. Plant and Soil, 345:195–210.

Kandeler, E., Gerber, H. (1988). Short-term assay of soil urease activity using colorimetric determination of ammonium. Biology and Fertility of Soils, 6, 68-72.

Kheir, A.M.S., Abouelsoud, H.M., Hafez, E.M., Ali, O.A.M. (2019). Integrated effect of nano-Zn, nano-Si, and drainage using crop straw–filled ditches on saline sodic soil properties and rice productivity. Arabian Journal of Geosciences, 12, 471.

Kumar P. (2022). Measurement of Ascorbate Peroxidase Activity in Sorghum. Bio Protoc. Oct 20,12(20):e4531. doi: 10.21769/BioProtoc.4531. PMID: 36353717, PMCID: PMC9606448.

Kumar, S., Dwivedi, S.K., Basu, S., Kumar, G., Mishra, J.S., Koley, T.K., Rao, K.K., Choudhary, A.K., Mondal, S., Kumar, S., et al. (2020). Anatomical, agro-morphological and physiological changes in rice under cumulative and stage specific drought conditions prevailed in eastern region of India. Field of Crop Research, 245, 107658.

Liang, Y., Chen, Q.i.n., Liu, Q., Zhang, W., Ding, R. (2003). Exogenous silicon (Si) increases antioxidant enzyme activity and reduces lipid peroxidation in roots of salt-stressed barley (*Hordeum vulgare* L.). Journal of Plant Physiology, 160, 1157–1164.

Liang, Y., Sun, W., Zhu, Y.-G., Christie, P. (2007). Mechanisms of silicon-mediated alleviation of abiotic stresses in higher plants: A review. Environmental Pollution, 147, 422–428,

Liu, C., Liu, F., Ravnskov, S., Rubæk, G.H., Sun, Z., Andersen, M.N. (**2017).** Impact of wood biochar and its interactions with mycorrhizal fungi, phosphorus fertilization and irrigation strategies on potato growth. *J. Agron.* Crop Science, 203,131–145.

Naeem, M.A., Khalid, M., Aon, M., Abbas, G., Tahir, M., Amjad, M., Murtaza, B., Yang, A., Akhtar, S.S. (**2017).** Effect of wheat and rice straw biochar produced at different temperatures on maize growth and nutrient dynamics of a calcareous soil. Archive of Agronomy and Soil Science, *63*,2048–2061.

Nehela, Y., Mazrou, Y.S.A., Alshaal, T., Rady, A.M.S., El-Sherif, A.M.A., Omara, A.E.-D., Abd El-Monem, A.M., Hafez, E.M. (**2021).** The integrated amendment of sodic-saline soils using biochar and plant growth-promoting rhizobacteria enhances maize (*Zea mays* L.) resilience to water salinity. Plants, *10*, 1960,

Öhlinger, H., Von Mersi, W. (1996). Enzymes Involved in Intracellular Metabolism. In Methods in Soil Biology, Schinner, F., Öhlinger, R., Kandeler, E., Margesin, R., Eds., Springer Berlin Heidelberg: Berlin, Heidelberg, , pp. 235-245.

Omara, A.E.-D., Hafez, E.M., Osman, H.S., Rashwan, E., El-Said, M.A.A., Alharbi, K., Abd El-Moneim, D., Gowayed, S.M. (**2022).** Collaborative impact of compost and beneficial rhizobacteria on soil properties, physiological attributes, and productivity of wheat subjected to deficit irrigation in salt affected soil. Plants, 11, 877.

Osman, H.S., Gowayed, S.M., Elbagory, M., Omara, A.E., El-Monem, A.M.A., Abd El-Razek, U.A., Hafez, E.M. (**2021).** Interactive impacts of beneficial microbes and Si-Zn nanocomposite on growth and productivity of soybean subjected to water deficit under salt-affected soil conditions. Plants, 10, 1396,

Ouyang, L., Wang, F., Tang, J., Yu, L., Zhang, R. (**2013).** Effects of biochar amendment on soil aggregates and hydraulic properties. Journal of Soil Science and Plant Nutrition, 13, 991–1002.

Rashwan, B. R.A., El-Azazy, H. M., Mahmoud, R. E. (2024). Effect of Cultivation Methods and Fertilization by Effective Microorganisms and/or Compost on Productivity and Water Use Efficiency of Wheat (Triticum aestivum L.). Egypt. J. Soil Sci. Vol. 64, No. 1, pp: 83-98.

Richards, L.A. *(*1954). Diagnosis and Improvement of Saline and Alkali Soils (Agriculture Handbook No. 60), Richards, L.A., Ed., United States Department Of Agriculture: Washington D. C.

Rodrigues, F.A., Duarte, H.S.S., Domiciano, G.P., Souza, C.A., Korndörfer, G.H., Zambolim, L. (**2009).** Foliar application of Compost tea reduces the intensity of soybean rust. Australasian Plant Pathology, 38, 366–372.

Seck, P.A., Diagne, A., Mohanty, S., Wopereis, M.C.S. (2012). Crops that feed the world 7: Rice. Food Security, 4, 7–24.

Seilsepour, M., Rashidi, M., Khabbaz, B.G. (**2009).** Prediction of soil exchangeable sodium percentage based on soil sodium adsorption ratio. . American-Eurasian Journal of Agricultural & Environmental Sciences, 5, 1–4.

Seleiman, M.F., Hafez, E.M. (2021). Optimizing Inputs Management for Sustainable Agricultural Development. In Mitigating Environmental Stresses for Agricultural Sustainability in Egypt, Awaad, H., Abu-hashim, M., Negm, A., Eds., Springer International Publishing: Cham, pp. 487-507.

Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., (1996). Sumner, M.E. *Methods of Soil* Analysis: Part 3 Chemical Methods, Soil Science Society of America, Inc., American Society of Agronomy, Inc.: Madison, Wisconsin, USA,

Vetter, J.L., Steinberg, M.P., Nelson, A.I. (**1958).** Enzyme assay, quantitative determination of peroxidase in sweet corn. Journal of Agricultural and Food Chemistry, 6, 39-41.

Yaghubi, K., Ghaderi, N., Vafaee, Y., Javadi, T. (**2016**). Compost teaalleviates deleterious effects of salinity on two strawberry cultivars grown under soilless pot culture. Scientia Horticulturae*,* *213,* 87–95.