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Effect of Biochar and Process Water Derived from the Co-Processed Sewage Sludge and Food Waste on Garden Cress' Growth and Quality

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Abstract: Very little is known about how products derived from the hydrothermal carbonization (HTC) of municipal waste affect the availability and uptake of nitrogen in plant nutrition. This study examined the effects of 60% sewage sludge and 40% food waste HTC products, i.e., biochar (BC) and process water (PW), as nitrogen sources on garden cress growth and quality. A fertilization program using four nitrogen doses [(control), 9, 12, and 15 kg da^{-1} N] and BC, PW, chemical nitrogen (CN), and their combinations were used in a pot experiment conducted under greenhouse conditions. The highest nitrogen dose often produced better results in terms of plant growth and quality. Additionally, fertilization with PW+CN and BC+CN at the highest nitrogen dose significantly improved plant height, plant fresh and dry weight, and root dry weight parameters of garden cress over the previous treatments. The highest stem diameter, number of leaves, and plant area values were obtained in the 15 kg da^{-1} N dose PW+BC application. The vitamin C content in cress decreased with the increasing levels of CN. The highest vitamin C content was obtained with 15 kg N da^{-1} PW fertilization. BC+PW and CN fertilization applications improved chlorophyll a, b, and the total contents of garden cress leaves. Moreover, the nitrate (NO_3) concentration of cress increased with CN doses while it decreased in all BC and PW administrations. The 9, 12, and 15 kg N da^{-1} doses of PW+CN and the 15 kg N da^{-1} dose of BC+CN yielded the highest agricultural nitrogen utilization efficiency (ANUE) values. Plant nutrient content was positively affected in all fertilization applications, except for Na and Cl. However, it was determined that BC+CN fertilizer application improved plant nutrient uptake. Surprisingly, PW+CN treatment at the lowest nitrogen dosage resulted in the highest soil organic matter and total nitrogen content. In conclusion, it has been determined that biochar and process water have a synergistic effect with CN to increase plant growth by improving nitrogen efficiency, but their application alone without CN is insufficient to meet the nitrogen requirement.

Keywords: biochar; process water; nitrogen; synergic effect; *Lepidium sativum* L.; nitrogen use efficiency; plant growth; quality

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1. Introduction

Garden cress (*Lepidium sativum* L.), an annual herb of the Brassicaceae family, is rich in health-promoting phytochemical components. Additionally, cress has lately emerged as a new leafy vegetable for fresh produce due to demand from consumers, growers, and processors [1]. Its leaves are rich in calcium, magnesium, phosphorus, potassium, copper, and manganese. It is an excellent source of fiber, flavonoids, selenium, s-methyl cysteine, sulfoxide, and glucosinolate [2,3]. In addition to the vitamins, minerals, and several anti-carcinogenic components, its seeds and green parts have been used as a remedy for asthma, cough, skin disorders, and other maladies since ancient times [4,5]. It has the advantage of reducing constipation due to its high magnesium and calcium content while its higher iodine level helps to strengthen bones [3].

It is well known that nitrogen is one of the most crucial nutrients for plant growth and yield. However, crops can only absorb about 30–40% of the nitrogenous fertilizer used, resulting in low utilization efficiency and nitrogen losses that harm the environment [6,7]. In comparison to cereal production, the greenhouse vegetable system always employs more intensive crop rotations, more frequent watering, and significantly higher nutrient input [8]. Even though the nitrogen use efficiency of intensive vegetable soil was very poor, annual nitrogen fertilizer inputs in the greenhouse vegetable system were 3–4 times higher than those in the non-vegetable system [9]. Therefore, developing effective strategies to reduce nitrogen losses in vegetable cultivation and increase nitrogen utilization efficiency is imperative.

It is more important than ever to address the growing global concern about the inappropriate treatment of municipal solid waste. Around 3 billion tons of food is wasted annually, with an estimated 1.3 billion tons rotting in consumer and retail bins as a result of improper handling and harvesting techniques [10]. Food wastes (FW) are organic and rich in nutrients such as nitrogen, phosphate, and potassium. Composting is a common strategy to create biofertilizers and lessen FW [11,12]. However, composting has drawbacks with long processing durations, uneven passive air dispersion, and high odor potential, whereas anaerobic digestion has concerns with sluggish hydrolysis, foaming, and the safe disposal of the digested products. It is essential to use processing technologies that can address the aforementioned problems and open doors for more efficient resource recovery. However, sewage sludge (SS) output has dramatically expanded over the past few decades due to rapid urbanization and population growth, reaching over 45 million dry tons globally [13,14]. Approximately 80% of SS is comprised of water, and it could contain dangerous substances (such as pathogens, personal care products, heavy metals, pharmaceuticals, and other micropollutants) that pose an environmental risk. Given the rising output of SS and its potential impact, the quest for alternative processing technologies has recently caught the interest of researchers [15]. Agricultural application of SS is already limited and will be subject to more stringent regulation in the future due to its pathogen and heavy metal content. It is thought that the conversion of these wastes into carbonaceous material to improve the soil will have a considerable positive impact on both the economy and ecology [16]. Therefore, the efficacy of nutrient management based on the circular economy of nutrients can be improved by employing waste for nutrient recovery and reuse in agriculture [17]. Numerous studies on the subject have revealed that agricultural products and renewable energy can be produced by processing waste, including biomass, in different ways [18–20].

Thermochemical technology is currently the most remarkable method among the existing waste conversion technologies for digesting waste biomass [21]. Of these technologies, hydrothermal carbonization (HTC) is considered an effective method for converting organic waste into useful products [22]. HTC is a thermochemical procedure that improves the properties of raw biomass for future usage, in subcritical water under a moderate temperature (ranging from 180–360 °C) and 2–20 MPa pressure [23,24]. Due to the elimination of the pre-dehydration phase, HTC has recently become an extensively used method for SS processing [25]. In this technique, water acts as a catalyst for the degradation and conversion of biomass. This allows the biomass to be processed in an aqueous form without the need for drying. Additionally, products processed under high pressure and temperatures are sterilized, eliminating pathogens [26–28]. Through the HTC process, biomass is transformed into carbonaceous biochar (also known as hydrochar), gas (mostly CO_2), and process water rich in organic and inorganic compounds [29]. Process water (PW) accounts for about 90% of HTC products [30].

Biochar (BC) can increase soil fertility by providing and/or retaining nutrients for crop production [31–33]. However, little study on the usage of PW has been conducted. Only a few studies examining the possibility of using PW as a fertilizer have evaluated the impact on plant growth by mixing the liquid fraction with BC or other organic substrates [34,35]. Mau et al. [36] revealed that HTC process water from poultry litter can effectively improve

lettuce growth in the last phases of development. Two recent studies have demonstrated the potential of employing BC and PW produced by HTC of agricultural wastes and SS instead of chemical fertilizers [37,38]. According to these investigations, plant reactions to inorganic substrates (such as silica or quartz sand) can either inhibit or stimulate, depending on the raw material and dilution dose of the process filtration fluid used [36,39]. The findings imply that HTC filtrate can be used as a liquid fertilizer for crops to replenish nutrients. In addition, there are reports that BC can be employed in research as a nutrient-rich soil conditioner [40]. Biochar also can boost plant growth by enhancing the chemical composition of the soil [41]. Moreover, by preserving the plant's nutrients in its body, it can improve the food's usability. As per previous research, it has been found that BC has significant impacts on enhancing plant growth after being mixed into the soil [42–44]. It has been stated that the amount of fertilizer needed can be reduced by up to 10% by applying biochar to the soil. The retention of readily available nutrients in the soil (NPK), an increase in carbon mineralization, a balance in nitrogen fixation, a 50% increase in cation exchange capacity, and an increase in soil permeability are the long-term effects that it may have on physical, chemical, and biological properties [44,45]. The use of HTC BC derived from SS as a growth media component in horticulture has also been suggested [46]. Previous research has stated that adding BC may reduce gaseous nitrogen losses caused by denitrification following high nitrogen treatments [47]. It was also demonstrated that nutrients in usable forms were still present following the hydrothermal process [16]. On the other hand, trace element content is reported to accumulate and immobilize in hydrothermal sewage biochar, posing a negligible environmental concern [48,49]. The majority of studies on the carbonization of SS for agricultural use focus on BC, which has been shown to increase soil nutrients and soil fertility indicators [45,50–52], improve plant growth [53–55], and possibly replace mineral fertilizers (nitrogen, phosphorus, and micronutrients] for plant production [56]. The conversion of waste biomass into hydrothermal products for use in agriculture is seen as an ecologically sustainable alternative and potential supplement to mineral fertilizers. However, to the best of our knowledge, there is no study investigating the use of process water and solid phase from the treatment of SS with FW with HTC instead of chemical nitrogen in plant growth. This study aimed to reduce the use of chemical fertilizers in cress production, improve nitrogen usage efficiency, evaluate the use potential of BC and PW obtained from SS and FW as organic fertilizers, and improve cress development and quality.

2. Materials and Methods

The study was carried out as a pot experiment in the controlled greenhouses at The Plant Production, Application and Research Centre of Atatürk University, Erzurum (39°57′ N and 41°10′ E), Turkey, in October 2021. The plant material for the experiment was *Lepidium sativum* L. cv. Zeybek. A 2:1 sand and garden soil (*v*/*v*) mixture was utilized as a growing medium. Table 1 presents the properties of this medium.

Table 1. Physical and chemical properties of the starting soils.

Properties	Unit	Value	Properties	Unit	Value
Sand	%	36.87	K	cmolc kg^{-1} dw	2.68
Silt	%	32.85	Ca	cmolc kg^{-1} dw	15.12
Clay	%	40.68	Mg	cmolc kg^{-1} dw	1.34
pH	1:2.5 w s^{-1}	8.05	Na	cmolc kg^{-1} dw	0.21
EC	micromhos cm^{-1}	126.79	B	mg kg^{-1} dw	0.07
$CaCO_3$	%	3.09	Cu	mg kg^{-1} dw	0.84
Organic matter	mg kg^{-1} dw	1.06	Fe	mg kg^{-1} dw	6.87
NH_4-N	mg kg^{-1} dw	1.88	Zn	mg kg^{-1} dw	0.18
NO_3-N	mg kg^{-1} dw	0.98	Mn	mg kg^{-1} dw	0.32
P	mg kg^{-1} dw	3.53			

Commercially available urea ammonium sulfate was used as chemical nitrogen, while Synpet Company provided the biochar and process water. The company used a modified HTC method (referred to as the thermal conversion process) as the waste treatment technology. In this process, all organic wastes containing carbon are converted into ecologically acceptable specific products like biochar and process water (high nutrient-containing liquid fertilizer) under the influence of temperature, pressure, and the high reactivity of water. Following is a summary of the steps and phases of this process (https://www.synpet.com/, accessed on 13 October 2022).

1st stage reactor (Depolymerization): To ensure the separation of inorganic and organic polymers, 60% SS and 40% FW are held at 150 °C under 5–8 bar pressure for a defined period as they reach the 1st stage reactor from the feeding and mixing tank. At this stage, physical separation is achieved with the effect of temperature and pressure.

2nd stage reactor (Hydrolysis): By adding some more water to the wet stock material that comes to this stage, the reactive property of water at moderate temperature (250 °C) and pressure (50 bar) is used. In this way, molecular fragmentation and plant nutrients such as N, S, and P, which are bound in solid matter, are decomposed and passed into the liquid phase. The condensation process is carried out on the liquid intermediate product brought to the evaporator after filtering the separated solid and liquid phases. The concentrated product that was obtained from this source was used as PW (liquid fertilizer with high nutrient content) in our study. The chemical characteristics of the PW are presented in Table 2.

Table 2. Some chemical properties of PW.

Analyzed Parameters	Unit	Analysis Results	Analyzed Parameters	Unit	Analysis Results
pH	-	2.2	Water Soluble CaO	%	0.1
Density	g cm^{-1}	1.16	Total MgO	%	0.14
EC	dS m^{-1}	24.3	Water Soluble MgO	%	0.12
Organic matter	%	33.2	Total SO_3	%	10.6
Humic acid	%	1.7	Water Soluble SO_3	%	11.3
Fulvic Acid	%	3.8	Pb	mg kg^{-1}	0.3
Organic Nitrogen	%	0.7	Cd	mg kg^{-1}	0.1
Total N	%	4.1	Cu	mg kg^{-1}	0.3
NO_3-N	%	0.8	Ni	mg kg^{-1}	9.8
NH_4-N	%	2.6	Zn	mg kg^{-1}	81
NH_2-N	%	>0.5	Cr	mg kg^{-1}	18.5
Total P_2O_5	%	1.2	Mn	mg kg^{-1}	114
Water Soluble P_2O_5	%	1.1	K	mg kg^{-1}	4456
Water Soluble K_2O	%	0.46	Ca	mg kg^{-1}	3060
Total CaO	%	0.1	Fe	mg kg^{-1}	4165

3rd reactor (Cracker): The low-water solid intermediate transported to this reactor is broken down into short hydrocarbon chains at a high temperature (550 °C), from which a solid ultimate product with a large surface area and high C content is obtained. The ultimate product was used in the study as BC. The chemical characteristics of the BC are presented in Table 3.

Table 3. Some chemical properties of BC.

Analyzed Parameters	Unit	Analysis Results
pH	-	7.8
EC	dS m^{-1}	0.38
Total (humic + fulvic)	%	4.9
Organic nitrogen	%	1.6
C	%	21.54
H	%	1.26
N	%	1.38
O	%	2.1
Pb	mg kg^{-1}	162
Cd	mg kg^{-1}	10
Cu	mg kg^{-1}	393
Ni	mg kg^{-1}	310
Zn	mg kg^{-1}	1187
Cr	mg kg^{-1}	449
Mn	mg kg^{-1}	549
K	mg kg^{-1}	10.290
P	mg kg^{-1}	22.980
Mg	mg kg^{-1}	7372
Ca	mg kg^{-1}	57.500
Fe	mg kg^{-1}	25.680

2.1. Experiment Setup

A completely randomized factorial design was used to conduct the experiment, which included 4 doses (0, 9, 12, and 15 kg da^{-1} N), 3 replications (3 pots each replication), and 6 treatments (BC: biochar, PW: process water, CN: chemical nitrogen, BC+PW: biochar and process water combination, BC+CN: biochar and chemical nitrogen combination, PW+CN: process water and chemical nitrogen combination) for a total of 171 pots. All doses of chemical fertilizer and biochar were weighed and thoroughly mixed with the growing media before being put into the pots. While calculating the fertilizer amounts according to the application doses, the total nitrogen content of the fertilizer was taken into account. In combination applications, half of the calculated amounts of each fertilizer were applied to keep the doses constant. The pots were watered until they reached the field capacity, and when the soil was tempered, the seeds were planted. At a depth of 2 cm, about 10 cress seeds were sown, and the surface of the soil was pressed by hand. Up to emergence, irrigation was applied twice daily in the form of a spray. After seedlings emerged, the soil was irrigated by pouring tap water, and during the experiment, care was made to preserve soil moisture at a level close to the field's capacity. When the cotyledon leaves became parallel to the ground, five plants were left in each pot. Immediately after plant emergence, the process water was poured into the pots using a graduated cylinder. Based on the nitrogen content and density of the process water, it was diluted with tap water. All maintenance procedures were carried out without a hiccup, from sowing to harvest. The plants were grown in natural light with daily temperatures of about 25° and a relative humidity of about 50%.

2.2. Harvest, Growth Properties, Measurements

In the study, morphological parameters such as plant height, root collar diameter, number of leaves, leaf area, shoot fresh and dry weight, and root fresh and dry weight of garden cress were measured 55 days after sowing. The plant height was measured in "cm" with a ruler, taking into account the longest leaf. The stem diameter was recorded in "mm" using a digital caliper (±0.01 mm margin of error). The average leaf area of a plant was measured as "cm^2" using a portable leaf area meter (CID-202 Portable Laser Leaf Area Meter by CID Bio-Science, Inc. 1554 NE 3rd Avenue, Camas, WA, USA). The number of leaves "per/plant" was calculated by counting leaves larger than 1 cm and dividing by the number of plants. Plants in treatments were harvested to determine the fresh weight of the plant and the root, and the weight of the shoots and roots was recorded as "g" by promptly weighting on precision scales. The weighed samples were dried in an oven at 68 °C until their weight remained constant, and their dry weight was then determined as "g" by weighing the samples once again on a precision balance. The ratio of plant and root dry matter was calculated as the ratio of dry matter in fresh weight to 100. Water soluble dry matter (WSDM) was directly determined by measuring the water coming out from pressed garden cress leaves with a portable (±0.01) precision digital refractometer. The vitamin C content of the plants was recorded as "mg L^{-1}" by reading the Merck Reflex device with the help of ascorbic acid test kits. The amount of chlorophyll in plant leaves was measured one day before harvest using a handheld SPA-502 (Konica Minolta Sensing, Inc.,Tokyo, Japan) chlorophyll meter and recorded as the "SPAD value". According to the methods given by Lichtenthaler and Buschmann [57], the concentrations of chlorophyll a, chlorophyll b, total chlorophyll, and total carotenoid were read spectrophotometrically at 450 nm, 645 nm, and 663 nm using a spectrophotometer (Thermo Scientific, Waltham, MA, USA). In the method, the fresh leaves of garden cress were ground with liquid nitrogen and then centrifuged by homogenizing in 80% acetone as part of the process of analyzing the extracts. The following equations were utilized to calculate the chlorophyll a, b, total chlorophyll, and total carotenoid contents of cress leaves as "mg g^{-1} FW" in fresh weight. In the equations, V represents the final volume of 80% acetone, and W represents the fresh weight of the extracted tissue expressed in grams.

$$\text{Chlorophyll a (mg g}^{-1}\text{ FW)} = (12.7 * 663\text{ nm}) - (2.69 * 645\text{ nm}) * (V/W * 10{,}000)$$

$$\text{Chlorophyll b (mg g}^{-1}\text{ FW)} = (22.91 * 645\text{ nm}) - (4.68 * 663\text{ nm}) * (V/W * 10{,}000)$$

$$\text{Total Chlorophyll (mg g}^{-1}\text{ FW)} = [(20.2 * 645\text{ nm}) + (8.02 * 663\text{ nm})] * (V/W * 10{,}000)$$

$$\text{Total carotenoid (mg g}^{-1}\text{ FW)} = 4.07 * 450\text{ nm} - (0.0435 * \text{Chll an amount} + 0.367 * \text{Chll b amount})$$

Agricultural nitrogen use efficiency (ANUE) was calculated from the "kg" nitrogen dose application as "g" plant fresh weight increase over the control, according to the following formula [58].

$$\text{ANUE} = (\text{FW} - \text{FW0})/\text{F}$$

FW = Plant fresh weight in the amount of fertilizer applied (g)
FW0 = Plant fresh weight in control (g)
F = Amount of fertilizer applied (kg)

For mineral analysis, dried shoot samples were ground up to pass through a 1 mm mesh screen. The Kjeldahl method was applied to determine the total nitrogen content in leaf samples using a Vapodest 10 Rapid Kjeldahl Distillation Unit (Gerhardt, Konigswinter, Germany) [59]. An inductively coupled plasma spectrophotometer (Optima 2100 DV; PerkinElmer, Shelton, CT, USA) was used to analyze the mineral concentrations of leaf samples (P, K, Ca, Mg, S, Na, Mn, Fe, Cu, Cl, and B) by Mertens' methodology [60,61]. The nitrate content of the leaf samples was assessed using Bremner and Mulvaney [62] techniques: nitrate analysis was carried out on plant extracts for fast nitrate-N determination.

Salicylic acid is nitrated at extremely acidic conditions to form a compound, which absorbs most effectively in basic (pH > 12) solutions at 410 nm.

Soil samples were air-dried, ground up, and passed through a 2 mm filter, before being analyzed physically and chemically. The Kjeldahl method [59] was used to calculate the total nitrogen content. Electrical conductivity (EC) was assessed in saturated extracts, according to Rhoades [63]. Soil pH was determined in a 1:2 soil/water suspension according to McLean [64]. Organic matter (OM) of soil was analyzed by the Smith-Weldon method according to Nelson and Sommers [65].

Data preparation was carried out with Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) and all data were expressed as a treatment mean ± standard error. Statistical analysis was performed using SPSS 25 (IBM, Armonk, NY, USA). Data were subjected to a two-way analysis of variance (ANOVA) to evaluate the single or interactive effects of independent variables (fertilizer and dose) on the parameters. Using Duncan's multiple-range test, the means of applications were separated at the 0.05 level of significance. Significant differences were denoted by distinct letters.

3. Results

3.1. Growth Characteristics

In the study, the effect of fertilizer ($p < 0.001$), dose ($p < 0.001$), and fertilizer x dose interaction ($p < 0.001$) was statistically significant in all measured plant growth parameters. The growth features of garden cress were significantly impacted by different nitrogen (N) levels of the chemical nitrogen (CN), biochar (BC), and process water (PW) applied either as a sole or combination (Figures 1 and 2). In comparison to the control, nitrogen application considerably increased growth parameters such as plant height, stem diameter, leaf number, leaf area, plant fresh and dry weight, and root fresh and dry weight. Maximum results were often recorded when a 15 kg da^{-1} N dose of PW+CN was applied. At different nitrogen levels, aside from plant area, alternative applications often produced better outcomes than a single chemical nitrogen application. The applications of PW+CN and BC+CN at a 15 kg da^{-1} N dose resulted in the tallest plants, exhibiting height increases of 112.08% and 107.42% over the control, respectively. While the highest stem diameter was obtained at 9 kg da^{-1} N dose of BC+CN application and 15 kg da^{-1} N dose of PW+CN application, these applications increased the stem diameter by 115.81% and 110.31%, respectively, compared to the control. With a rise of 76.52%, the 15 kg da^{-1} N of PW+CN application resulted in the highest increase in the number of leaves per plant relative to the control. Similar to other results, the 15 kg da^{-1} N application of PW+BC, which represented an increase of 372.76% from the control, produced the best results in the mean plant area. PW+CN and BC+CN applications played the most important role in increasing the plant fresh weight by 825.12% and 808.72% over control, respectively. The same applications also dramatically increased the plant's dry weight by 615.94% and 655.60% respectively, compared to the control. Additionally, the highest control-based increase was produced by 15 kg da^{-1} N BC+CN application with 451.81% in root fresh weight, while in root dry weight produced by 15 kg da^{-1} N BC+CN and 15 kg da^{-1} N PW+CN applications with 462.78% and 448.12%, respectively.

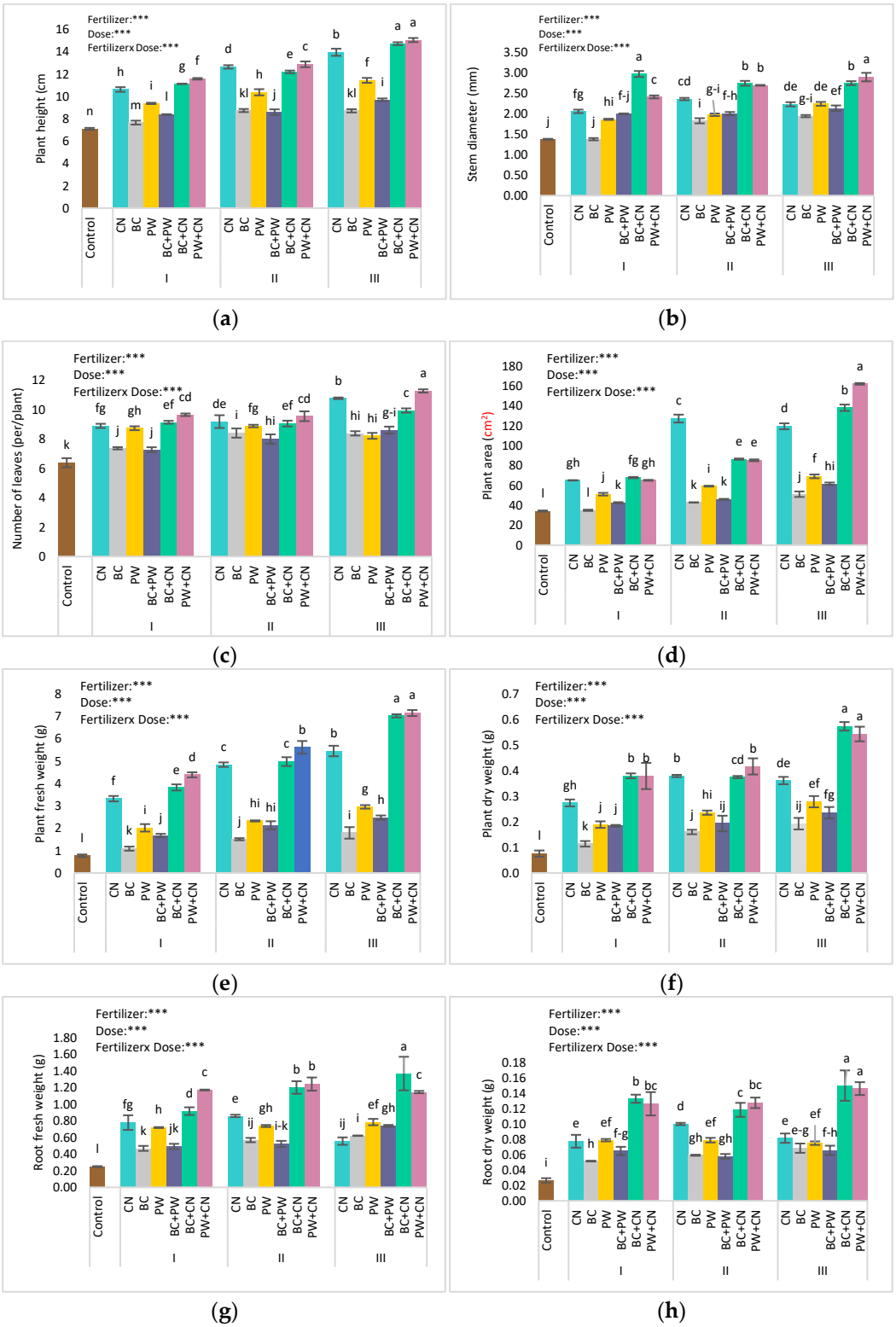
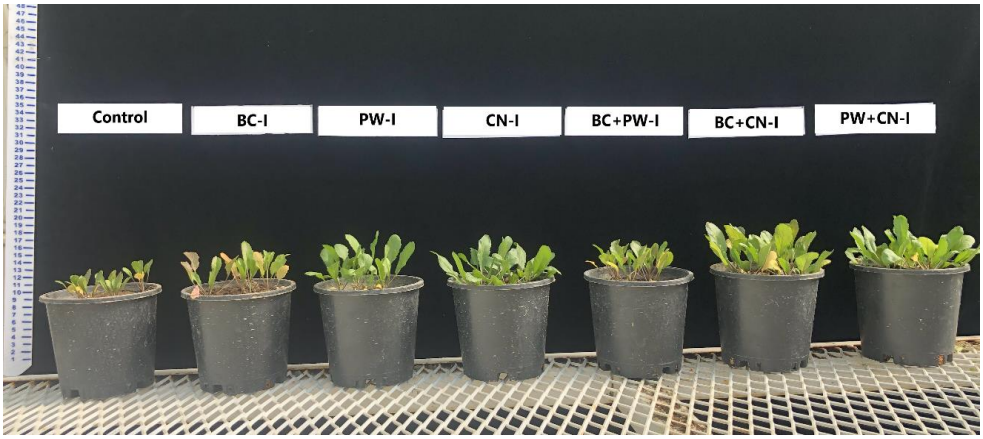
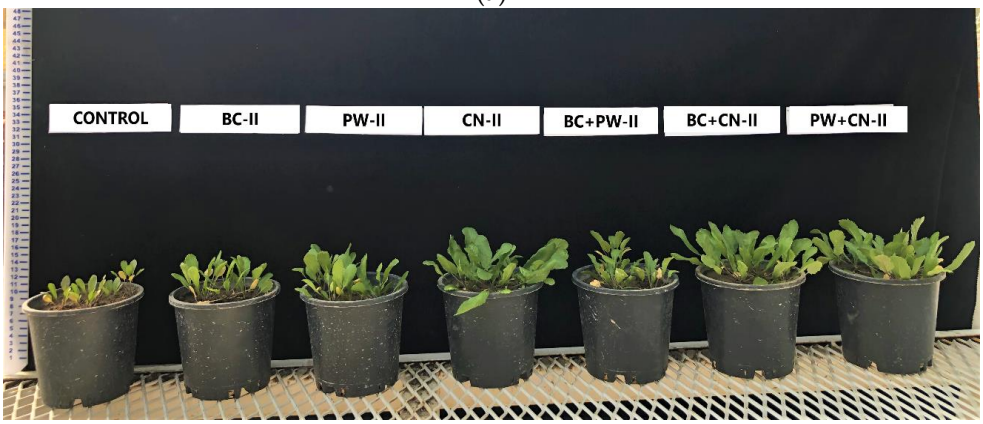


Figure 1. The impact of varying fertilizer and nitrogen concentrations on the garden cress (**a**) plant's height, (**b**) stem diameter, (**c**) number of leaves, (**d**) area, and (**e–h**) both plant, and root fresh and dry weight. Control: 0 kg da^{-1} N non-fertilizer); I: 9 kg da^{-1} N, II: 12 kg da^{-1} N, III: 15 kg da^{-1} N; BC: biochar, PW: process water, CN: chemical nitrogen, BC+PW: biochar and process water combination, BC+CN: biochar and chemical nitrogen combination, PW+CN: process water and chemical nitrogen combination. *** Means followed by a different letter are significantly different according to Duncan's multiple range test ($p \leq 0.001$).



(**a**)



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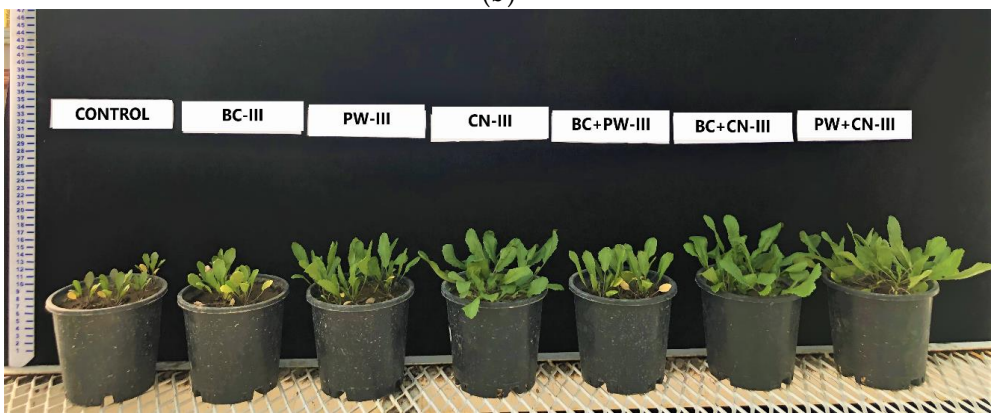


(**c**)

Figure 2. Effects of varying nitrogen dosages and fertilizers on the growth of garden cress. Control: 0 kg da^{-1} N (non-fertilizer), I: 9 kg da^{-1} N, II: 12 kg da^{-1} N, III: 15 kg da^{-1} N; BC: biochar, PW: process water, CN: chemical nitrogen, BC+PW: biochar and process water combination, BC+CN: biochar and chemical nitrogen combination, PW+CN: process water and chemical nitrogen combination. (**a**–**c**): Effects of varying nitrogen dosages and fertilizers on the growth of garden cress.

3.2. Quality Characteristics

In the study, fertilizer ($p < 0.001$), dose ($p < 0.001$), and fertilizer x dose interaction ($p < 0.001$) had a statistically significant impact on the qualitative characteristics of cress, including plant dry matter, WSDM, vitamin C, chlorophyll a, chlorophyll b, total chlorophyll, total carotenoid, etc. However, the effect of fertilizer x dose interaction on the dry matter content of the plant was found to be significant at the $p < 0.05$ level (Figure 3). Varying nitrogen doses resulted in different fertilizer application effects on quality parameters.

The dose of 9 kg da^{-1} N of BC+PW (13.02%) resulted in the highest increase in plant dry weight, whereas the dose of 12 kg da^{-1} N of PW+CN (40.83%) and 9 kg da^{-1} N of BC+PW (36.67%) showed the maximum increase in WSDM content relative to control. The lowest vitamin C concentrations were produced by CN single doses and decreased as the nitrogen dose increased. The concentration of vitamin C increased by the maximum amount of 29.66% over the control, with the 15 kg da^{-1} N PW application. The 15 kg da^{-1} N PW (28.81%) treatment provided the highest increase in SPAD over the control, while the 15 kg da^{-1} N BC application had the lowest SPAD value. Applications of 15 kg da^{-1} N BC+PW and 15 kg da^{-1} N CN resulted in the maximum increase in chlorophyll a, b, and total chlorophyll content when compared to the control, with respective increases of 1252.06%, 1345.29%, 1344.54%, and 1359.83%, 1281.65%, and 1351.23%. However, the 15 kg da^{-1} N CN application resulted in the highest increase in carotenoid content, which was 338.95% over the control.

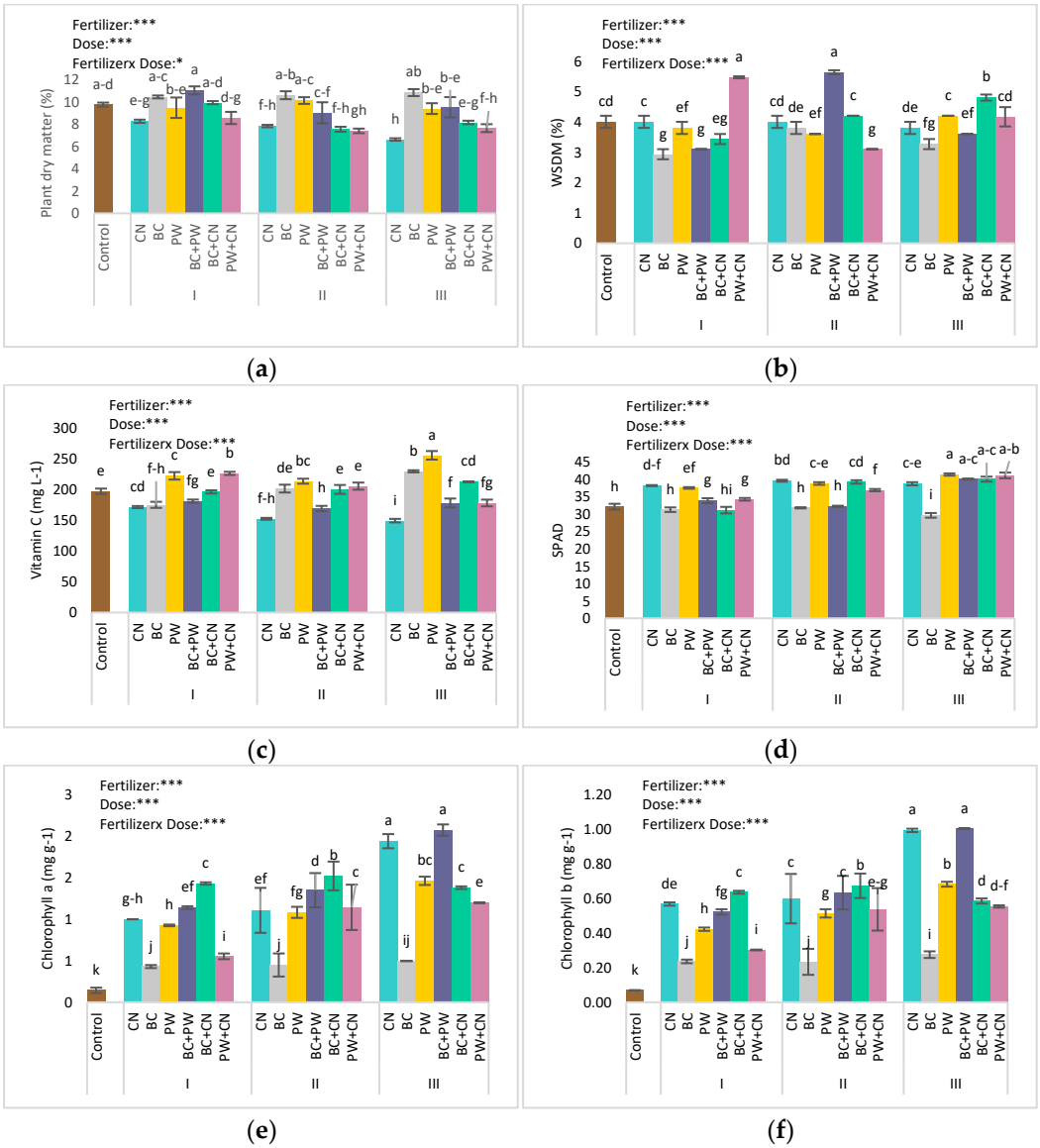
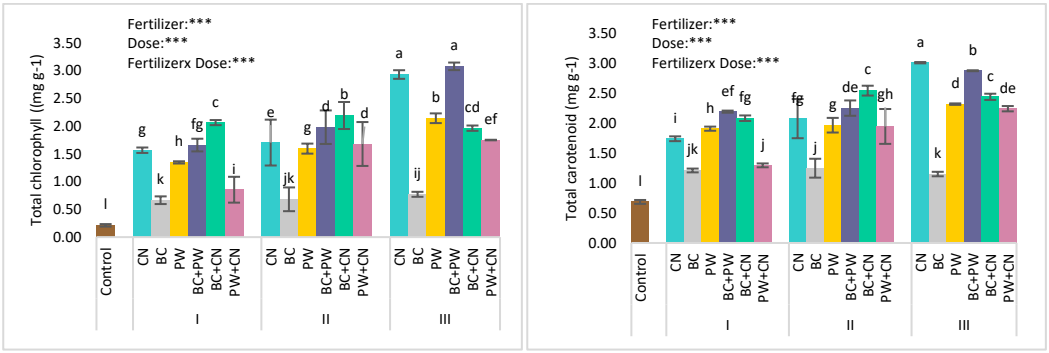


Figure 3. *Cont.*



(**g**) (**h**)

Figure 3. The effect of the varying fertilizer and nitrogen doses on plant and root dry matter, (**a**) plant's height, (**b**) stem diameter, (**c**) number of leaves, (**d**) area, and (**e**–**h**) both plant, and root fresh and dry weight. WSDM, Vitamin C, SPAD, chlorophyll a, b, total chlorophyll, and total carotenoid of garden cress. Means followed by a different letter are significantly different according to Duncan's multiple range test ($p \leq 0.001$). Control: 0 kg da^{-1} N (non-fertilizer), I: 9 kg da^{-1} N, II: 12 kg da^{-1} N, III: 15 kg da^{-1} N; BC: biochar, PW: process water, CN: chemical nitrogen, BC+PW: biochar and process water combination, BC+CN: biochar and chemical nitrogen combination, PW+CN: process water and chemical nitrogen combination. Means followed by a different letter are significantly different according to Duncan's multiple range test ***: $p \leq 0.001$, *: $p \leq 0.05$.

3.3. Agricultural Nitrogen Use Efficiency (ANUE)

ANUE was impacted at a significant level ($p < 0.001$) by the sources responsible for variation (fertilizer, dose, and fertilizer x dose interaction). According to other treatments, the nitrogen utilization efficiency was rather high at all nitrogen doses of the PW+CN combination and the 15 kg da^{-1} N BC+CN application. As each dose was independently evaluated, in comparison to solo CN treatments, nitrogen utilization efficiency increased in PW+CN combinations in 9, 12, and 15 kg da^{-1} N by 36.66%, 23.53%, and 31.98%, respectively. Similarly, the 15 kg da^{-1} N BC+CN combination increased ANUE by 29.91% compared to the same dose of single CN administration. The results indicated that chemical fertilizer combinations with process water and biochar were much more effective in ANUE of garden cress than chemical nitrogen alone (Figure 4).

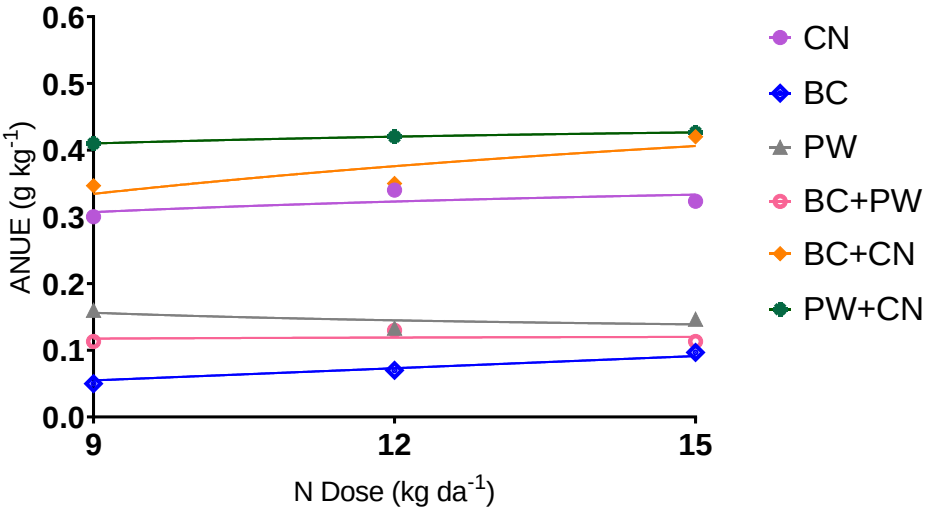


Figure 4. The effect of varying fertilizers and nitrogen doses on the efficiency of garden cress agricultural nitrogen use (ANUE). I: 9 kg da^{-1} N, II: 12 kg da^{-1} N, III: 15 kg da^{-1} N; BC: biochar, PW: process water, CN: chemical nitrogen, BC+PW: biochar and process water combination, BC+CN: biochar and chemical nitrogen combination, PW+CN: process water and chemical nitrogen combination.

3.4. Plant Nutrient Element Contents

The effect of fertilizer, dose, and fertilizer x dose interaction on the nutrient content of garden cress was presented in Tables 4–6. The findings showed that, aside from Na and Cl content, all treatments promoted nutritional content in garden cress shoots when compared to the control. The highest amount of nitrogen was observed in the 15 kg da^{-1} N BC+CN application with a 3.05% content, but the maximum amounts of NO_3 and NH_4 were observed in 15 kg da^{-1} N CN application with concentrations of 943.33 g mL^{-1} and 559.33 g mL^{-1}, respectively. Moreover, the highest nutritional values were found to be 0.28% in a 9 kg da^{-1} N CN application for P, 2.3% and 2.4%, respectively, in 9 kg da^{-1} N and 15 kg da^{-1} N of BC+CN applications for K, 1.12% in a 15 kg da^{-1} N of BC+CN application for Ca, 0.26% and 0.27%, respectively, in a 12 kg da^{-1} N CN and 9 kg da^{-1} N BC+CN applications for Mg, and 0.29% in a 9 kg da^{-1} N BC+CN for S. Maximum Mn, Fe, Zn, B, Cl, and Na contents were also reported in treatments with 9 kg da^{-1} N BC+CN, 15 kg da^{-1} N BC+CN 9 kg da^{-1} N BC+CN, control, and 12 kg da^{-1} N CN, in that order. These nutritional contents' respective values were 22.68 mg g^{-1}, 53.19 mg g^{-1}, 21.15 mg g^{-1}, 7.7 mg g^{-1}, and 1.81 mg g^{-1}, 188.39 mg g^{-1}. The measurement values usually fell within the critical ranges of the plant nutrient concentrations.

Table 4. Effects of varying nitrogen doses and fertilizers on the elements N, NO_3, NH_4, P, and K in shoots of garden cress. Means followed by a different letter are significantly different according to Duncan's multiple range test ($p \leq 0.001$). Control: 0 kg da^{-1} N (non-fertilizer), I: 9 kg da^{-1} N, II: 12 kg da^{-1} N, III: 15 kg da^{-1} N; BC: biochar, PW: process water, CN: chemical nitrogen, BC+PW: biochar and process water combination, BC+CN: biochar and chemical nitrogen combination, PW+CN: process water and chemical nitrogen combination.

Dose	Fertilizers	Total N (%)	NO_3 (µg mL^{-1})	NH_4 (µg mL^{-1})	P (%)	K (%)
Control		0.96 ± 0.16 l	22.33 ± 2.08 i	48.33 ± 6.51 l	0.1 ± 0.01 k	0.59 ± 0.06 i
I	**CN**	1.95 ± 0.04 hi	286.33 ± 8.51 e	371 ± 16.52 d	0.24 ± 0 c–e	1.18 ± 0.06 c–g
	BC	1.78 ± 0.1 ij	31.67 ± 1.53 i	58.33 ± 3.51 kl	0.2 ± 0.02 g–i	1.07 ± 0.06 e–h
	PW	1.62 ± 0.08 j	39 ± 1.5 i	79.67 ± 2.08 jk	0.19 ± 0 hi	1.02 ± 0.08 gh
	BC+PW	2.15 ± 0.01 e–h	28 ± 1.00 i	155.67 ± 12.01 h	0.26 ± 0.03 bc	1.38 ± 0.07 c–e
	BC+CN	2.8 ± 0.04 ab	155 ± 11 g	395.67 ± 22.28 cd	0.27 ± 0.01 ab	2.04 ± 0.1 b
	PW+CN	2.43 ± 0.03 d–f	287.67 ± 7.51	307 ± 15.72 e	0.19 ± 0.01 i	1.42 ± 0.06 cd
II	**CN**	2.42 ± 0.04 d–g	370.67 ± 22.94 d	458 ± 27.62 b	0.28 ± 0.01 a	1.45 ± 0.07 cd
	BC	1.99 ± 0.02 f–i	28 ± 1.00 i	80.67 ± 11.02 jk	0.23 ± 0.01 d–f	1.21 ± 0.04 c–g
	PW	1.29 ± 0.12 k	49.5 ± 6.00 i	93.33 ± 6.66 k	0.16 ± 0.01 j	0.78 ± 0.08 hi
	BC+PW	2.06 ± 0.04 f–i	34.33 ± 1.53 i	185.33 ± 7.02 g	0.21 ± 0.01 f–h	1.09 ± 0.06 e–g
	BC+CN	2.26 ± 0.14 d–f	223 ± 12.53 f	474.67 ± 17.9 b	0.22 ± 0.01 e–g	2.33 ± 0.07 a
	PW+CN	2.49 ± 0.22 c–d	349.67 ± 42.19 d	385.33 ± 8.33 d	0.2 ± 0.01 f–i	1.31 ± 0.09 c–g
III	**CN**	2.25 ± 0.04 d–g	943.33 ± 30.55 a	559.33 ± 35.23 a	0.25 ± 0.01 bc	1.47 ± 0.02 c
	BC	1.81 ± 0.09 ij	24.33 ± 0.58 i	126 ± 33.72 i	0.21 ± 0.01 f–h	1.18 ± 0.06 c–g
	PW	1.96 ± 0.05 g–i	100.5 ± 27.37 h	108 ± 7.21 ij	0.18 ± 0.01 i	1.06 ± 0.06 f–h
	BC+PW	2.21 ± 0.1 d–h	42 ± 2.00 i	201 ± 11.53 f	0.24 ± 0.01 cd	1.34 ± 0.11 c–f
	BC+CN	3.05 ± 0.42 a	430.33 ± 14.57 c	584 ± 25.16 a	0.25 ± 0.03 b–d	2.42 ± 0.64 a
	PW+CN	2.67 ± 0.37 bc	569.33 ± 19.01 b	417 ± 12 c	0.22 ± 0.02 fg	1.15 ± 0.1 d–g
Fertilizer		***	***	***	***	***
Dose		***	***	***	ns	ns
Fertilizer*Dose		***	***	***	***	**

Means followed by a different letter are significantly different according to Duncan's multiple range test ***: $p \leq 0.001$, **: $p \leq 0.01$, ns: non significant.

Table 5. Effects of varying nitrogen doses and fertilizers on the elements Ca, Mg, S, Mn, and Fe in shoots of garden cress. Means followed by a different letter are significantly different according to Duncan's multiple range test ($p \leq 0.001$). Control: 0 kg da^{-1} N (non-fertilizer), I: 9 kg da^{-1} N, II: 12 kg da^{-1} N, III: 15 kg da^{-1} N; BC: biochar, PW: process water, CN: chemical nitrogen, BC+PW: biochar and process water combination, BC+CN: biochar and chemical nitrogen combination, PW+CN: process water and chemical nitrogen combination.

Dose	Fertilizers	Ca (%)	Mg (%)	S (%)	Mn (mg g^{-1})	Fe (mg g^{-1})
Control		0.24 ± 0.01 g	0.06 ± 0.00 i	0.06 ± 0.00 k	5.1 ± 0.59 i	12.67 ± 1.02 i
I	**CN**	0.61 ± 0.02 c–e	0.19 ± 0.01 e–g	0.14 ± 0.01 g–i	16.21 ± 0.97 e–g	37.49 ± 1.46 d–g
	BC	0.52 ± 0.09 c–f	0.21 ± 0.04 b–e	0.16 ± 0.03 e–g	16.56 ± 1.88 d–g	39.4 ± 7.08 d–g
	PW	0.53 ± 0.05 c–f	0.15 ± 0.01 g–h	0.12 ± 0.01 ij	13.96 ± 1.11 g	34.27 ± 1.5 fg
	BC+PW	0.61 ± 0.02 c–e	0.2 ± 0.03 c–e	0.15 ± 0.00 gh	19.35 ± 1.92 b–d	39.89 ± 1.65 d–f
	BC+CN	0.71 ± 0.03 bc	0.26 ± 0.03 a	0.29 ± 0.02 a	22.68 ± 1.20 a	48.97 ± 4.25 ab
	PW+CN	0.48 ± 0.02 d–f	0.2 ± 0.01 d–f	0.2 ± 0.01 bc	16.07 ± 1.14 e–g	37.6 ± 2.36 d–g
II	**CN**	0.65 ± 0.03 cd	0.27 ± 0.02 a	0.19 ± 0.01 cd	20.84 ± 1.31 ab	47.95 ± 0.75 a–c
	BC	0.54 ± 0.01 c–f	0.22 ± 0.02 b–e	0.16 ± 0.01 fg	17.43 ± 1.28 c–f	41.21 ± 2.58 c–f
	PW	0.40 ± 0.04 fg	0.12 ± 0.01 h	0.1 ± 0.01 j	10.66 ± 1.12 h	26.17 ± 1.83 h
	BC+PW	0.56 ± 0.04 c–f	0.15 ± 0.01 gh	0.13 ± 0.01 h–j	14.88 ± 0.93 fg	34.4 ± 1.48 fg
	BC+CN	0.84 ± 0.04 b	0.24 ± 0.02 a–c	0.21 ± 0.02 b	20.5 ± 1.39 a–c	49.74 ± 0.64 ab
	PW+CN	0.44 ± 0.03 ef	0.25 ± 0.04 ab	0.18 ± 0.01 c–e	18.01 ± 2.12 b–e	50.06 ± 1.15 ab
III	**CN**	0.65 ± 0.03 cd	0.22 ± 0.02 b–e	0.16 ± 0.01 fg	20.66 ± 1.90 ab	42.59 ± 1.08 b–e
	BC	0.52 ± 0.02 c–f	0.18 ± 0.03 e–g	0.13 ± 0.00 h–j	16.58 ± 1.36 d–g	35.67 ± 1.01 e–g
	PW	0.47 ± 0.03 d–f	0.16 ± 0.02 f–g	0.11 ± 0.00 ij	14.8 ± 0.68 fg	31.92 ± 1.99 gh
	BC+PW	0.60 ± 0.02 c–e	0.23 ± 0.02 a–d	0.17 ± 0.02 d–f	19.32 ± 1.03 b–d	44.51 ± 2.22 b–d
	BC+CN	1.12 ± 0.41 a	0.23 ± 0.02 a–d	0.22 ± 0.02 b	19.89 ± 3.86 ac	53.19 ± 14.06 a
	PW+CN	0.45 ± 0.02 ef	0.2 ± 0.01 c–e	0.2 ± 0.03 b–d	17.88 ± 1.97 b–f	48.09 ± 1.91 a–c
Fertilizer		***	***	***	***	***
Dose		ns	ns	*	ns	ns
Fertilizer*Dose		**	***	***	***	***

Means followed by a different letter are significantly different according to Duncan's multiple range test ***: $p \leq 0.001$, **: $p \leq 0.01$, *: $p \leq 0.05$, ns: non significant.

Table 6. Effects of varying nitrogen doses and fertilizers on the elements Zn, B, Cl, and Na in shoots of garden cress. Means followed by a different letter are significantly different according to Duncan's multiple range test ($p \leq 0.001$). Control: 0 kg da^{-1} N (non-fertilizer), I: 9 kg da^{-1} N, II: 12 kg da^{-1} N, III: 15 kg da^{-1} N; BC: biochar, PW: process water, CN: chemical nitrogen, BC+PW: biochar and process water combination, BC+CN: biochar and chemical nitrogen combination, PW+CN: process water and chemical nitrogen combination.

Dose	Fertilizers	Zn (mg g^{-1})	B (mg g^{-1})	Cl (mg g^{-1})	Na (mg g^{-1})
Control		5.07 ± 0.78 f	1.54 ± 0.35 j	1.81 ± 0.06 a	168.08 ± 11.6 a–c
I	**CN**	9.56 ± 1.14 c–f	3.08 ± 0.39 e–j	1.01 ± 0.51 b–e	144.93 ± 3.16 d–f
	BC	7.15 ± 0.37 e–g	4.49 ± 1.26 c–f	1.13 ± 0.64 b–e	109.46 ± 10.77 hi
	PW	6.61 ± 0.25 e–g	2.45 ± 0.3 h–j	0.55 ± 0.04 e	116.87 ± 3.39 gh
	BC+PW	11.26 ± 0.95 cd	3.6 ± 0.11 d–i	1.24 ± 0.45 a–d	152.09 ± 5.16 c–e
	BC+CN	19.03 ± 3.2 ab	7.7 ± 0.76 a	0.98 ± 0.11 b–e	109.85 ± 12.91 hi
	PW+CN	15.95 ± 1.72 b	4.27 ± 0.73 c–g	1.06 ± 0.22 b–e	70.89 ± 5.43 k
II	**CN**	11.46 ± 0.57 c	5.56 ± 0.79 bc	1.85 ± 0.47 a	188.39 ± 18.98 a
	BC	8.65 ± 0.87 c–g	4.51 ± 0.72 c–e	1.49 ± 0.3 a–c	157.32 ± 12.04 b–d
	PW	5.67 ± 0.28 f	2.03 ± 0.36 ij	0.67 ± 0.37 de	159.68 ± 33.79 b–d
	BC+PW	10.32 ± 1.23 c–e	2.46 ± 0.29 h–j	0.8 ± 0.40 de	132.99 ± 4.12 e–g
	BC+CN	19.42 ± 2.21 ab	6.71 ± 0.42 ab	0.93 ± 0.06 c–e	93.69 ± 2.84 ij
	PW+CN	20.77 ± 2.01 a	3.33 ± 0.06 d–i	0.98 ± 0.06 b–e	90.42 ± 2.54 I–k

Table 6. *Cont.*

Dose	Fertilizers	Zn (mg g^{-1})	B (mg g^{-1})	Cl (mg g^{-1})	Na (mg g^{-1})
III	**CN**	10.43 ± 0.88 c–e	3.85 ± 0.22 d–h	1.33 ± 0.5 a–d	162.49 ± 7.71 b–d
	BC	7.63 ± 0.65 d–g	3.22 ± 0.08 e–i	1.11 ± 0.41 b–e	130.46 ± 3.46 e–g
	PW	6.29 ± 0.22 fg	2.77 ± 0.12 g–j	0.95 ± 0.34 c–e	124.75 ± 6.5 f–h
	BC+PW	12.38 ± 0.62 c	4.88 ± 0.75 cd	1.62 ± 0.35 ab	174.87 ± 18.78 ab
	BC+CN	21.15 ± 6.94 a	6.48 ± 2.67 ab	0.89 ± 0.12 c–e	92.58 ± 11.37 i–k
	PW+CN	18.28 ± 0.67 ab	2.9 ± 0.92 f–j	0.88 ± 0.01 c–e	86.47 ± 4.79 jk
Fertilizer		***	***	***	***
Dose		ns	ns	ns	***
Fertilizer*Dose		ns	***	*	***

Means followed by a different letter are significantly different according to Duncan's multiple range test **: $p \leq 0.01$, *: $p \leq 0.05$, ns: non significant.

3.5. Soil Properties

The study examined the effects of various fertilizers and application doses on the pH, EC, organic matter (OM), and total nitrogen content (Total N) of the soil. The effect of fertilizer, dose, and fertilizer x dose interaction on these properties is given in Table 7. The results showed that 9 kg da^{-1} N PW, 9 kg da^{-1} N C, N, and 12 kg da^{-1} N BC applications reduced the pH value of the soil relative to the control, while the highest soil pH was measured at doses of 12 kg da^{-1} N and 9 kg da^{-1} N of BC+CN combination with 7.96 and 7.92, respectively. On the other hand, all applications significantly raised the levels of OM and Total N in comparison to the control. However, fertilizer treatments significantly decreased the EC of the soil relative to the control. On the other hand, all applications drastically increased the content of OM and Total N over the control. The application of 9 kg da^{-1} N PW+CN produced the highest soil OM, with 2.68%, while 9 kg da^{-1} N CN and 9 kg da^{-1} N PW+CN produced the highest total N content with 0.1023% and 0.079%, respectively.

Table 7. Effects of varying nitrogen dosages and fertilizers on the soil properties. Means followed by a different letter are significantly different according to Duncan's multiple range test ($p \leq 0.001$). Control: 0 kg da^{-1} N (non-fertilizer), I: 9 kg da^{-1} N, II: 12 kg da^{-1} N, III: 15 kg da^{-1} N; BC: biochar, PW: process water, CN: chemical nitrogen, BC+PW: biochar and process water combination, BC+CN: biochar and chemical nitrogen combination, PW+CN: process water and chemical nitrogen combination.

Dose	Fertilizer	pH (1:2.5 w s^{-1})	EC (mS cm^{-1})	OM (%)	Total N (%)
Control		6.86 ± 0.32 d–e	117.32 ± 5.31 a	0.11 ± 0.01 h	0.0034 ± 0.0002 e
I	**CN**	6.80 ± 0.00 e	92.19 ± 7.03 bc	1.48 ± 0.31 f	0.1023 ± 0.0111 a
	BC	6.97 ± 0.21 b–e	97.13 ± 16.42 bc	1.80± 0.28 ef	0.0530 ± 0.0082 a–e
	PW	6.77 ± 0.06 e	89.6 ± 2.57 b–d	0.48 ± 0.21 gh	0.0141 ± 0.0062 de
	BC+PW	7.23 ± 0.05 bc	88.39 ± 4.65 b–d	2.55 ± 0.05 a–c	0.0751 ± 0.0014 ab
	BC+CN	7.92 ± 0.04 a	67.64 ± 18.64 fg	1.90 ± 1.07 d–f	0.0560 ± 0.0032 a–d
	PW+CN	7.27 ± 0.15 b	64.47 ± 7.80 fg	2.68 ± 0.07 a	0.0790 ± 0.002 a
II	**CN**	6.87 ± 0.40 de	87.63 ± 11.42 b–e	0.87 ± 0.10 g	0.0256 ± 0.0029 b–e
	BC	6.77 ± 0.25 e	104.7 ± 18.2 b	2.17 ± 0.10 a–e	0.0640 ± 0.0029 a–d
	PW	7.21 ± 0.04 bc	86.96 ± 0.6 b–e	0.67 ± 0.03 g	0.0198 ± 0.0009 c–e
	BC+PW	7.12 ± 0.07 b–d	62.96 ± 3.30 g	2.05 ± 0.03 b–e	0.0604 ± 0.001 a–d
	BC+CN	7.96 ± 0.12 a	81.99 ± 11.8 c–f	2.48 ± 0.03 a–c	0.0730 ± 0.0009 ab
	PW+CN	7.13 ± 0.21 b–d	69.1 ± 3.60 fg	2.28 ± 0.28 a–e	0.0670 ± 0.0081 a–c

Table 7. *Cont.*

Dose	Fertilizer	pH (1:2.5 w s^{-1})	EC (mS cm^{-1})	OM (%)	Total N (%)
III	CN	7.07 ± 0.15 b–e	100.57 ± 6.03 b	0.89 ± 0.08 g	0.0262 ± 0.0022 b–e
	BC	6.93 ± 0.15 c–e	101.2 ± 3.59 b	2.41 ± 0.35 a–d	0.0710 ± 0.0102 a–c
	PW	7.27 ± 0.07 b	89.69 ± 3.29 b–d	0.64 ± 0.01 g	0.0187 ± 0.0003 c–e
	BC+PW	7.22 ± 0.02 bc	70.8 ± 12.39 e–g	2.60 ± 0.07 ab	0.0764 ± 0.002 ab
	BC+CN	7.21 ± 0.06 bc	64.49 ± 1.69 fg	2.12 ± 0.09 b–e	0.0624 ± 0.0025 a–d
	PW+CN	6.98 ± 0.13 b–e	72.7 ± 6.6 d–g	2.00 ± 0.09 c–f	0.0588 ± 0.0026 a–d
Fertilizer		***	**	***	***
Dose		ns	ns	ns	ns
Fertilizer*Dose		***	*	***	ns

Means followed by a different letter are significantly different according to Duncan's multiple range test ***: $p \leq 0.001$, **: $p \leq 0.01$, *: $p \leq 0.05$, ns: non significant.

4. Discussion

In the current study, it was observed that varying doses of different fertilizer sources and combinations significantly increased the growth of garden cress. Even though all nitrogen doses improved plant growth relative to the control and in accordance with the growth parameters examined, the 15 kg da^{-1} N dose was reported to be the most effective. Additionally, the PW+CN and BC+CN combination showed more significant results in improving plant growth than other single and combined applications. Inorganic fertilizers, particularly nitrogen fertilizers, must be utilized to stimulate plant vegetative development. The most often used nutrient element in vegetable cultivation is nitrogen, which is the main component of protein and nucleic acids, the building blocks of all living things. When nitrogen levels are low, vegetable yield and quality suffer [66]. Studies have shown that nitrogen treatments severely impacted the quality and productivity of lettuce and spinach, and also that plant growth and yield generally increased with increasing the nitrogen dose to a specific threshold [67]. Although most HTC biochar, specifically the one made from plant biomass, has little nutritional value and cannot be used as a fertilizer on its own, it can be utilized in the soil to increase the value of fertilizer by reducing the amount of fertilizer lost through surface run-off [68,69]. Researchers are interested in sewage sludge HTC biochar because of its usefulness in improving soil quality, reducing heavy metal uptake, and potential benefits in nourishing soil in agricultural areas [70]. A study reported that differently modified sewage sludge hydrochars inhibited ammonia evaporation and enhanced soil nitrogen retention, rice nitrogen uptake, and rice yield [71]. The effectiveness of HTC biochar as a substitute or addition to mineral fertilizers in plant studies is being confirmed by very significant investigations. A study on the common bean using four HTC biochar application rates was carried out. Results showed that applications boosted both plant nutrient concentrations and soil fertility. Previous research indicated that the best time for HTC biochar amendment is three months before sowing when there is a maximum of dry matter [72]. A study on the impacts of biochar and the HTC process' liquid phase on the germination efficiency of spring barley and garden cress investigated the phytotoxic effects of the liquid phase and the adverse effects of numerous organic compounds on the germination and growth of cress seedlings. The findings demonstrated that HTC biochar had no phytotoxic effects, although it is always advisable to verify the use of carbonized products in agriculture [73]. In pot trials on common beans and barley, HTC biochar has been shown to have a positive effect on plant development; this effect is likely related to the increase in soil pH. However, the use of hydrochar did not benefit leek cultivation; as a result, a species-specific approach should be preferred [68]. On the other hand, Shan et al. [37] examined the use potential of the aqueous phase produced from co-HTC of sewage sludge and agricultural wastes (rice husk and wheat straw) and HTC only of sewage sludge rather than chemical fertilizers in the hydroponic cultivation of pakchoi. According to the study, the only fertilizers that can substitute chemical fertilizers are sewage sludge HTC aqueous phase 20% and co-HTC aqueous phase 60%. In a similar

study, it was found that the biomass of pakchoi grew by 25.7–40.9% in the liquid phase produced by co-HTC of sewage sludge and leftover mushroom compost, while the nitrogen recovery was reported to be 62.03–64.65% [38].

The findings of our study showed that CN fertilization had a detrimental impact on cress's vitamin C content. High doses of **nitrogen** application are reported to reduce the vitamin C content in vegetable crops [74]. The effects of commercial fertilization with ammonium nitrate at doses of 50 kg/ha N, 100 kg/ha N, and 150 kg/ha N on the growth and quality of cress were evaluated in a parallel study (Control), and it was observed that high nitrogen dosages led to poor vitamin C content [75]. Other research supports the finding that some crops lose vitamin C content when nitrogen fertilization is increased [76–79]. In the analysis of vitamin C in cress, Zhan et al. [80] reported 33.52 mg 100 g $^{-1}$ FW; in a study by Tuncay et al. [80] the total vitamin C content was reported to range from 66.9 to 89.2 mg 100 g^{-1} in 2002, and from 66.4 and 87.9 mg 100 g^{-1} in 2003. Our results were found to be quite high compared to those obtained in these studies.

Both single and combined applications of process water were found to boost the chlorophyll content of plants in the study. Contrarily, biochar only increased chlorophyll concentrations in combination applications. This may be because biochar limits the release of nutrients from the soil by absorbing them. However, it was found that adding biochar to process water significantly enhanced the chlorophyll contents of cress. Tuncay et al. [81] stated that the leaf color of cress with mineral nitrogen fertilization is darker than that of organic nitrogen sources. Leaf nitrogen concentration is directly related to leaf chlorophyll content, hence leaf greenness [82]. Numerous studies measure or analyze chlorophyll to estimate crop nitrogen status [83–86]. Contrary to the results of our work, Celletti et al. [87] claimed that phytotoxic compounds in the liquid process filtrate produced by hydrothermal carbonization of cow manure impeded plant growth. Low concentrations, however, led to nutritional deficiencies and reduced photosynthesis, which resulted in chlorosis and leaf yellowing. However, the researchers pointed out that liquid fertilizer can be used with treatments that remove phytotoxic substances and the effects of elements such as Na.

Our study determined that cress gained a significant increase in agricultural nitrogen use efficiency (ANUE) under PW and CN combination (PW+CN) and BC and CN combination (BC+CN) treatments, compared to single CN treatment. Fertilizer management has a direct impact on sustainable nutrient management, which demands both efficiency and effectiveness. The sustainability of fertilizer management systems is determined by nutrient use efficiency (NUE) [76]. The harvested yield and plant nitrogen uptake are closely related and mostly have a linear relationship. It was also observed that the growth traits and the findings for nitrogen usage efficiency were parallel. Hydrothermal biochar showed a higher rate of biodegradation and nitrogen availability than pyrolysis biochar, even in the second harvest of *Lolium perenne* grass, according to pot tests [88]. A recent study reported that biochar mixed with urea, leguminous residues and azocompost increased N-efficiency as well as reduced nitrogen loss through leaching, as nitrogen is retained on the large specific surface of the biochar [44].

The nitrogen fertilizers used in the current study were found to considerably boost the nutritional content of garden cress. The most effective outcomes came from combining PW and BC, which are frequently used with CN. It was discovered that the highest nitrogen dose (15 kg da^{-1} N) resulted in the maximum outcomes for the nitrate content. The application of CN was found to increase plant nitrate content in comparison to other applications, while the combination of CN with BC and PW was found to reduce it by almost half. As opposed to single CN applications, combined CN applications with BC and PW usually raised the organic matter and total nitrogen content in the soil. Similarly, Inne et al. [75] reported that a commercial nitrogen application of 150 kg/ha significantly raised the NO_3 level of garden cress. There is evidence that the NO_3 level in the leaf increases with increasing nitrogen dose in spinach and lettuce, which is consistent with our findings [89,90]. Nitrogen (N) and phosphorus (P) are extremely well retained in HTC biochar, suggesting that the resulting solid has the potential to serve as a source of nutrition [91]. Zhang et al. [92] highlighted

that nitrogen-rich HTC biochar has the potential to be utilized as a soil conditioner by regulating nitrogen content and stimulating plant growth. Up to 70% of nitrogen and potassium were carried into the liquid phase by the PW from the sewage sludge HTC process, which has proven to be rich in fertilizing components [93]. According to Sousa and Figueiredo [51], the quantity of total nitrogen, organic carbon, readily available potassium, and phosphorus in the soil increased after adding sewage sludge biochar to it. According to the study, adding sewage sludge biochar to the soil boosted nutrients such as P, N, Ca, and Mg, which improved soil fertility and radish yield. Researchers stated that a significant increase in foliar nutrients also improved plant height, dry weight, and leaf number. Yue et al. [55] observed significant increases in total soil nitrogen (1.5 times), black carbon (4.5 times), organic carbon (1.9 times), potassium (0.4 times), and available phosphorus (5.6 times) after applying sewage biochar to urban soil and growing turf grass in pots. Grass dry matter increased proportionally with increasing amounts of applied biochar due to improved plant mineral nutrition. SS biochar was also reported to retain nutrients, especially nitrogen (N) in permeable soil in wet conditions due to its nutrient affinity [94].

5. Conclusions

The study revealed that PW and BC applications alone were insufficient for growing garden cress, however, when combined with CN, they were very effective at reducing the nitrogen dose and improving agricultural nitrogen use efficiency. Additionally, PW and BC treatments together with CN enhanced the soil's nitrogen and organic matter content and boosted the plant nutrient intake. Consequently, the implementation of BC and PW to increase the utility of CN while lowering its dose is a very hopeful approach for the advancement of sustainable agriculture practices and systems. However, these findings are generally applicable to horticultural applications that use pots, and must be considered for short-term responses even in field conditions. Future research will provide more precise information regarding the practical usage of PW and BC derived from SS and FW as fertilizer, through extensive field trials that take into account the soil microbial population.

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