Research Article

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A brief investigation on the prospective of co-composted biochar as a fertilizer for Zucchini plants cultivated in arid sandy soil

https://doi.org/10.1515/opag-2022-0322
received April 18, 2024; accepted June 19, 2024

Abstract: Compost is commonly utilized to improve properties of infertile sandy soils, despite its high biodegradability which may increase greenhouse gases emissions. It is possible to combine compost with biochar, which degrades at a slower rate, forming a "co-composted biochar" product. This mixture could enhance plant growth parameters beyond those attained for using each component, individually. To investigate this assumption, zucchini was selected as a test plant to be grown, under greenhouse conditions, on a sandy soil that received biochar, compost or co-composted biochar (from rice straw or sugarcane bagasse (SB)) for a duration of 15 days. This timeframe was deemed sufficient to achieve a relatively stable degradation rate for compost. Application of organic materials increased both fresh and dry weights of zucchini plants, particularly when co-composted biochar of SB was used. Specifically, plant fresh weights increased by 1.24–1.71 folds when using this additive versus the control group. Additionally, availability of nitrogen, phosphorus, and potassium in soil and their uptake by plants significantly increased owing to application of all additives, with superiority for the co-composted biochar of SB. Enhancements in plant fresh weights were strongly correlated with increasing availability and uptake of phosphorus by plants. In conclusion, organic amendments have a substantial positive impact on enhancing the nutritional status and growth of zucchini, even during the early vegetative growth stage (within the first 15 days after planting). The greatest improvements were observed when co-composted biochar of SB was used and this confirm the main hypothesis of the study.

Keywords: biochar, compost, co-composted biochar, zucchini, NPK availability, NPK uptake, fresh weight

1 Introduction

In many regions across the globe, inorganic fertilizers are widely used to enhance crop production [1] in order to

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meet the escalating global food demands [2]. However, inappropriate application of these fertilizers adversely impacts soil health [3]. Minerals present in these fertilizers can reach and contaminate water bodies through leaching, soil erosion, and runoff [4], leading to significant environmental hazards [5]. Additionally, the costs of fertilizers are continuously rising [6]. Therefore, recycling agricultural waste in soil [7] through the circular economy approach may offer a secure alternative to substitute partially inorganic fertilizers [8]; hence reduce fertilizer expenses.

Organic additives have emerged as viable alternatives for improving soil health and sustaining soil productivity [9,10]. Utilization of these additives can significantly contribute in ensuring food security [11]. In the present investigation, two distinct types of organic additives were considered. The first one is biochar, which enhances various soil properties and, at the same time, sequesters effectively soil carbon [12]. Its production takes place via the pyrolysis of organic waste materials under limited aeration conditions [13–15]. Once being applied to soils, biochar persists thereon for extended periods, ranging from years [16] to potentially decades [17,18]. Consequently, its positive implications on soil productivity are noticeable within both the short [19,20] and long-terms [21]. Furthermore, biochar serves as a valuable source of nutrients for plant growth [22]. Additionally, it forms soluble complexes with immobile nutrients, thereby facilitating their uptake by plants [23].

Compost is the second organic product in this investigation. Such amendment undergoes rapid degradation in soil once being applied, and reaches to an almost constant degradation rate within only 2–3 days in arid soils [24]. This process broadly enriches soils with nutrients in available forms to meet the needs of plants [25]. Besides, it reduces soil pH, which further increases the availability of nutrients thereon [26]. Nevertheless, it increases CO_2 emissions that increase the global warming threats [24]. Also, some of the released nutrients, during compost decomposition, may become fixed under the alkaline conditions of arid soils [27]. It is then thought that a combination between biochar and compost, forming a product known as "co-composted biochar" may help to overcome the abovementioned problems [24]. This combination increases soil fertility and plant growth [28], particularly low-fertile ones [29], via increasing nutrient availability [30] and uptake by plants [22], while reducing greenhouse gas emissions [31].

A short-term experiment was therefore conducted to explore the implications of amending a poor fertile sandy soil with organic amendments, such as compost, biochar, and co-composted biochar derived from various organic sources for increasing the availability of NPK in soil, enhancing their uptake by plants, and consequently their outcomes on plant growth, i.e. fresh and dry weights. Our main hypothesis was that plants need high concentrations of nutrients after the germination period (first 15 days of plant growth) to initiate the vegetative growth stage; thus there would be significant variations in nutrient uptake and plant growth owing to application of different organic additives. In this concern, the mixed-type amendment (co-composted biochar) could enhance crop growth beyond the effects observed for each amendment when applied individually. The findings of this study are expected to contribute to our understanding of the short-term benefits of organic amendments in improving plant nutrition and growth.

2 Materials and methods

To test the hypothesis of the study, a 15-day greenhouse investigation was carried out on zucchini (*Cucurbita pepo*). This is an important summer vegetable crop in Egypt [32], of short life cycle [33], which can thrive in low-fertile soils, if provided with sufficient amounts of organic amendments [34].

The duration of this experiment (15 days) was chosen based on previous research, indicating that the degradation rate of compost decreases significantly to reach a nearly constant rate after the first week of application [24].

2.1 Soil sampling

A soil sample from the surface layer (0–30 cm) was obtained from the experimental farm located at the Research and Production Station, EL-Nobaria, Behara governorate, Egypt, which is affiliated with the National Research Centre. Physical and chemical properties of the soil were analyzed following the methods described by Klute [35] and Sparks et al. [36]. The findings of this analysis are found in Table S1.

Rice straw (RS) and sugarcane bagasse (SB) were utilized for production of composts, biochars, and co-compost biochars. Production of biochar occurred in New Borg El Arab City (SRTA-City, 21934), Alexandria, Egypt, through pyrolysis of the abovementioned organic residues at a temperature of 500°C under limited aeration conditions. This process lasted for 5 h to prepare rice straw biochar (RSB) while needed only 2 h for preparation of sugarcane bagasse biochar (SBB).

Compost production took place at the National Research Centre, Dokki, Giza, following the methodology described by Tolba et al. [37]. The compost was organized in form of layering piles, in which the first layer consisted of organic residues of thickness 15 cm which were mixed with 15% farmyard manure. The second layer included a thin layer (≈3 cm) of mineral fertilizers, i.e. 15 kg of NH_4SO_4 (with a nitrogen content of 20.6 g N kg^{-1}), 3 kg of CaH_2PO_4 (with a phosphorus content of 6.7 g P kg^{-1}) and 15 kg of calcium carbonate ($CaCO_3$). Then, additional organic and mineral layers were added in a similar manner to create a cone-shaped structure of approximately 1 meter high. Compost piles were then periodically watered to maintain its moisture content close to 50% of its weight, and left to mature for 145 days. Maturity of compost was determined by the development of a dark and crumbly texture, accompanied by an earthy odor. To enhance aeration and homogeneity, compost piles were turned upside down twice a month.

For preparation of co-composted biochar, extra 15% of biochar portions (on weight basis, made from the same organic substrate) were added while composting organic residues to produce rice straw co-composted biochar (RSCB) and sugarcane bagasse co-composted biochar (SBCB). This is typically considered an optimum percentage (10–15%) of biochar during feedstock composting, as outlined by Antonangelo et al. [38].

2.2 A greenhouse experiments

Soil samples were uniformly packed into plastic pots with a diameter of 15 cm and a depth of 5 cm. Each treatment consisted of ten pots, which were categorized as follows: (1) RSB, (2) SBB, (3) rice straw compost (RSC), (4) sugarcane bagasse compost (SBC), (5) rice straw composted biochar (RSCB), and (6) sugarcane composted biochar (SBCB). All organic materials were applied at a rate of 4.2 g kg^{-1}, which is equivalent to 10 Mg ha^{-1} on a weight basis. This dosage is considered economically viable for crop production, as suggested by Galinato et al. [39]. Additionally, a control treatment was included, where no organic materials were applied to the soil. Pots were then arranged in a randomized complete block design

Each pot was planted with three seeds of zucchini (*Cucurbite pepo* cultivar Jamila F1). The pots were then placed under greenhouse conditions for a period of 15 days, with a temperature range of 25–28°C, a 12-h light/dark cycle, and a humidity level of 30–35%. After this period, three pots per treatment containing fully germinated plants were selected for further investigation (determination of zucchini growth parameters and nutrient contents within plant tissues). Entire plants, at the early vegetative growth stage, were harvested to determine their fresh and dry weights. Plants were oven-dried at 70°C for 48 h. Also, soil samples were collected from the rhizosphere of each pot.

2.3 Soil, organic amendments and plant analyses

Plant materials and organic amendments were subjected to digestion using acid mixtures of H_2SO_4–$HClO_4$ (4:1) according to the protocol described by Gotteni et al. [39]. Determination of total phosphorus in the digests was carried out using the molybdate-ascorbic acid method [36] with the aid of a Spectro-UV-Vis Double Beam instrument UVD-3500 (Labomed Inc., Los Angeles, CA, USA) at a wavelength of 720 nm. The quantification of total P was performed using a flame photometer. The concentration of total nitrogen was measured in the plant digests using the macro-Kjeldahl method, while in the organic amendments, it was determined using the dry combustion technique with an elemental analyzer (Thermo-Fisher Scientific Inc., FLASH 2000 CHNS/O Analyzers, Waltham, MA, USA).

Other portions of the plant samples were digested using HNO_3 (69%) and H_2O_2 (30%) in a microwave oven digestion apparatus (Milestone Inc., model MLS 1200 Mega, Shelton, CT, USA), and their contents of micronutrients were determined using inductivity-coupled plasma (Thermo Fisher Scientific Inc., TM iCAPTM 7000 Plus Series ICP-OES, Waltham, MA, USA). Generally, determination of available NPK in soil samples followed the procedures outlined by Sparks et al. [36]. Specifically, the available N content was extracted using K_2SO_4 (1%) then measured using a micro Kjeldahl apparatus in the presence of MgO and Devarda alloy. Available P content was extracted with $NaHCO_3$ (0.5 N, pH 8.5) and quantified photometrically using the molybdate-ascorbic acid method with the assistance of a Spectro-UV-Vis Double Beam (UVD3500) instrument. Lastly, the available K content was extracted using ammonium acetate (1 N, pH 7) and measured using a flame photometer (model Jenway PFP7).

2.4 Statistical analysis

Data analyses were performed utilizing ANOVA and Duncan's Multiple Range through CoStat (Version 6.303, CoHort, USA, 1998–2004). Additionally, Pearson's coefficients were computed using the same software program. Graphs were generated using SigmaPlot 10. To calculate nutrient uptake by zucchini: we multiply nutrient concentrations within plant tissues by plant dry weights.

3 Results

3.1 Nutritive elements concentrations in the investigated organic residues

Table S2 provides information on the chemical properties of the investigated organic materials. Comparable pH values were observed among RS as a feedstock, its compost and composted biochar. However, its biochar was alkaline. On the other hand, the pH of SB was acidic, but increased upon either composting or, pyrolysis to form biochar, and also for composted biochar. The electrical conductivity (EC) values of all the investigated amendments were higher than those of the feedstock. Additionally, total nitrogen content increased in all amendments (except for SBC) compared to their respective feedstock. The carbon-to-nitrogen (C/N) ratios of compost and co-composted biochar were narrower than those of biochar or the feedstock.

Values of macro- and micro-nutrients in feedstock, biochars, composts, and co-composted biochars are presented in Figure 1 and Table S2. Results reveal that N, K, Mg, and Mn were generally higher in RS than in SB residues, while the latter exhibited higher Zn concentrations than the former. Biochars, produced from either RS or SC, exhibited significantly higher contents of most nutritive elements than their feedstock. Concerning compost, comparable or slightly higher nutrient concentrations were detected in such amendments versus the corresponding ones in co-composted biochar. Though, both organics recorded higher P, Ca, Mg, Fe. Mn and Cu than biochar. A point to note is that Zn content in SB residues was higher than its content in biochar, compost, and composted biochar.

3.2 Effect of organic additives on zucchini germination and growth

All organic additives significantly raised the germination percentage of Zucchini (Figure 2). This percentage was only 73% in the non-amended control soil, while increased up to 93–100% in organic amended soils. The highest increases were recorded for both RSC and SBCB treatments; nevertheless variations among all additives seemed to be insignificant.

Likewise, all organic applications significantly boosted zucchini dry weights (Figure 3), with superiority for SB products. The highest increases in plant dry weights were recorded for SBCB treatment, which was 1.6 fold higher than the control. On the other hand, comparable increases in fresh and dry weights of zucchini plants were noticeable owing to application of RC organic products.

3.3 Soil NPK availabile contents and their concentrations within zucchini plants

Organic additives significantly upraised available nitrogen (N) content in soil, with superiority for SBCB, RSBC and SBC treatments (Figure 4). In spite of that, slight and insignificant increases occurred in N concentrations within plant tissues, except for the application of RSC treatment which recorded the highest increases in this concern. Also, the uptake of N by plants (multiplication product of nutrient concentration within plant tissues by their dry weights) did not vary significantly among organic treatments at this growth stage, except when plants received RSCB (Table 1). In this concern, N-uptake by plants was approximately 1.7 fold higher than the control.

In case of K, all organic treatments (except RSB) showed significant increases in available K contents in soil. Though, all organic additives raised K content and uptake by zucchini plants. The highest K-uptake values were noted for SBC and SBCB, with no significant variations between these two treatments.

Only RSB and RSCB treatments showed significant increases in P available content in soil; however the concurrent increases in P concentrations within plant tissues were significant for application of all organic additives versus the control (Figure 4). Overall, insignificant variations in P uptake by zucchini plants were detectable owing to application of all organic additives; yet these values were still higher than the control.

3.4 Correlations among zucchini fresh weights, NPK available contents in soil, their concentrations within plant tissues and their contents in the applied organic additives

Available N content in soil was significantly correlated with its content in the investigated organic additives (Table 2). On the other hand, no significant correlations were detectable among P and K available contents in soil in relation to their

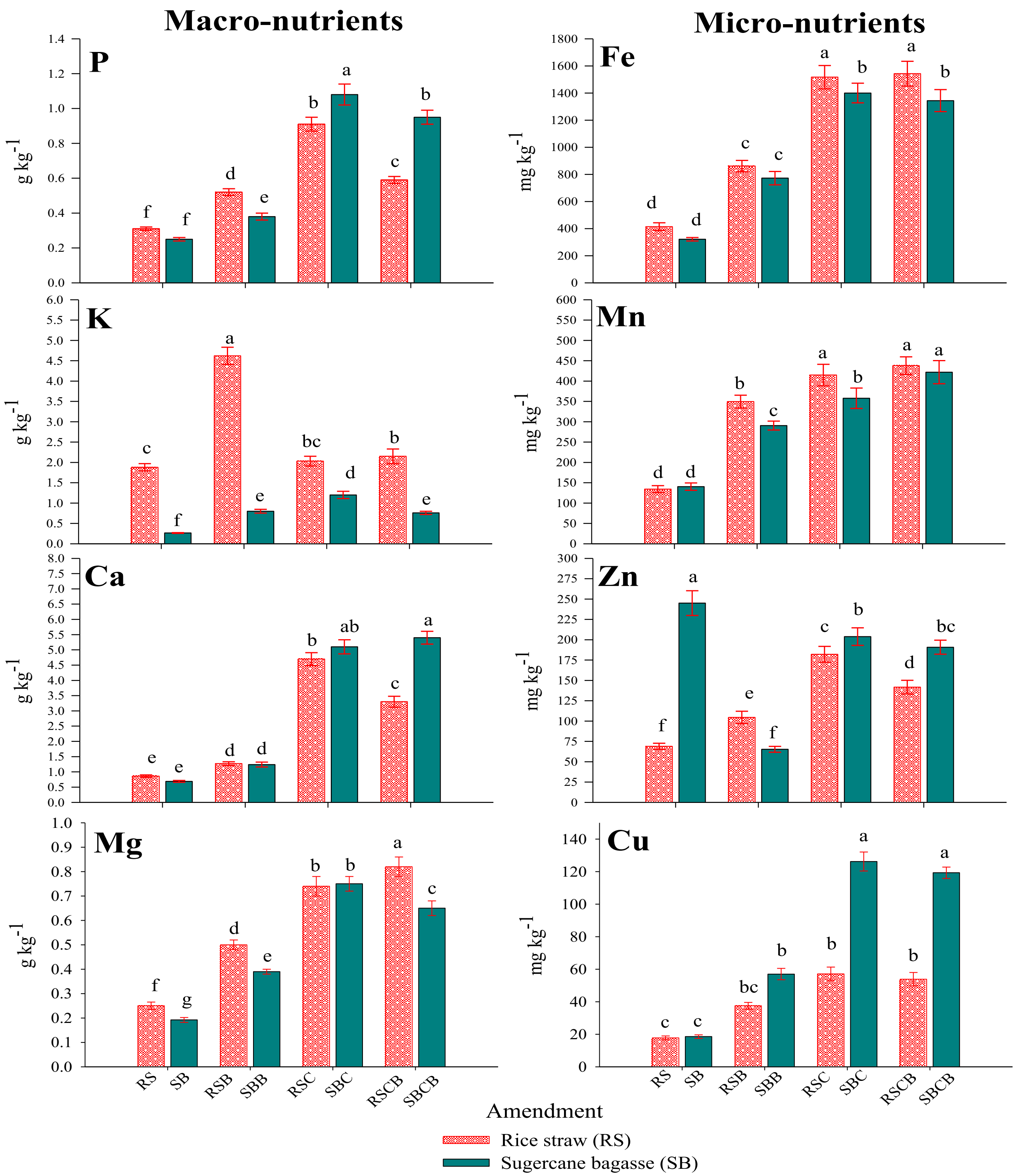

Figure 1: Concentrations of nutrients in organic amendments under investigation (calculated on dry weight bases): RS: rice straw, SB: SB, RSB, SBB, RSC, SBC, RSCB and SBCB. Similar letters indicate no significant variations among treatments.

contents in applied organic products. Nitrogen content in plant tissues was also significantly correlated with the available N content in soil. This N was mostly found in the form of nitrates in soil, because P availability in soil was negatively correlated with the -available N-content. Moreover, there was a significant correlation between K and N contents within plant tissues.

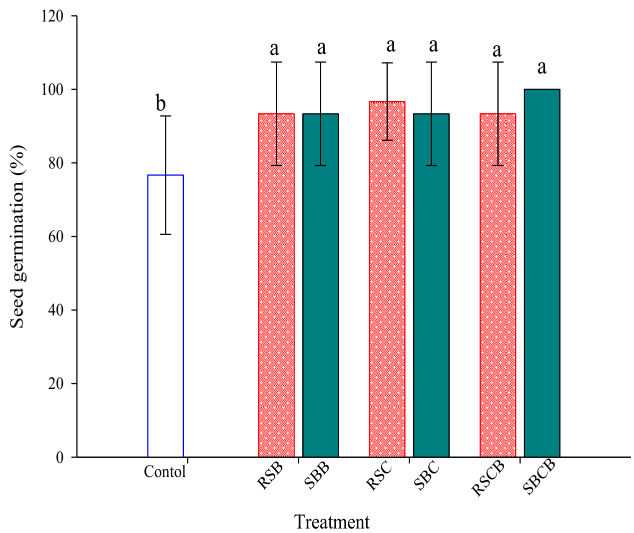

Figure 2: Seed germination percentage as affected by application of the organic amendments under investigation: see footnotes of Figure 1. Note: the three replicates of SBCB exhibited 100% seed germination. Similar letters indicate no significant variations among treatments.

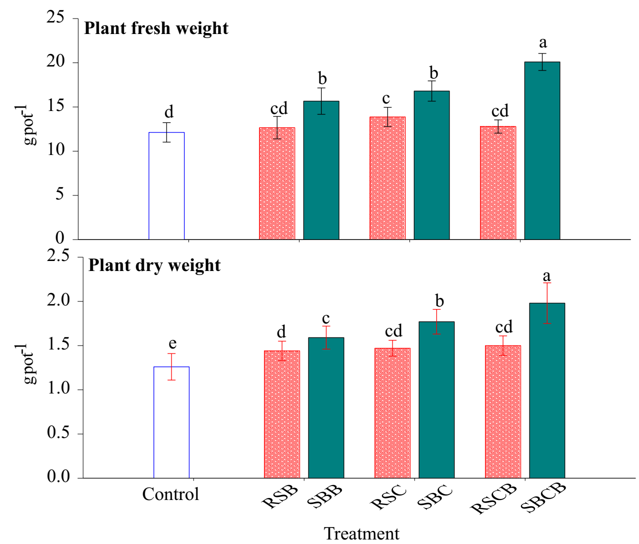

Figure 3: Plant fresh and dry weights (g plant^{-1}) as affected by application of the organic amendments under investigation: see footnotes of Figure 1. Similar letters indicate no significant variations among treatments.

Zucchini biomass was significantly correlated significantly with each of P contents in the organic additives, soil available P and P-uptake by plants. This result signifies the importance of P nutrition for zucchini plants during this growth stage. Likewise, zucchini biomass was significantly correlated with K in organic additives; however, the

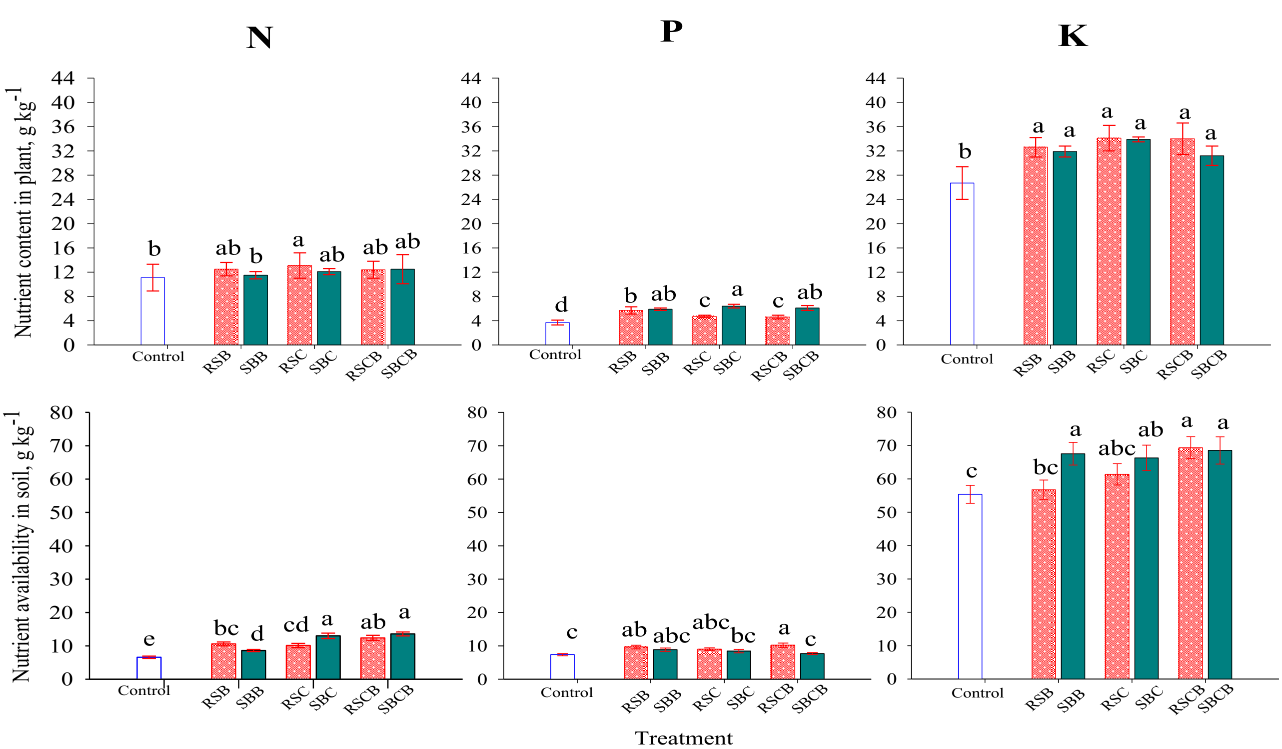

Figure 4: Available N, P and K contents (mg kg^{-1}) in soil and their corresponding concentrations within zucchini tissues (on dry weight basis) at 15 days after planting as affected by application of the different organics: see footnotes of Figure 1. Similar letters indicate no significant variations among treatments.

Table 1: Uptake of NPK by zucchini plants (mg pot^{-1}) owing to application of the different organic additives

Treatment	N	P	K
Con.	14.20 ± 3.98c	4.70 ± 0.68b	34.20 ± 0.94d
RSB	18.80 ± 2.58a–c	8.60 ± 0.64a	49.20 ± 1.42bc
SBB	16.80 ± 1.41bc	8.61 ± 0.23a	46.60 ± 0.47c
RSC	23.10 ± 1.30ab	8.31 ± 1.20a	60.40 ± 8.58ab
SBC	17.80 ± 0.53a-c	9.50 ± 0.75a	50.20 ± 2.91bc
RSCB	24.60 ± 5.70a	9.10 ± 1.76a	67.30 ± 11.22a
SBCB	20.10 ± 6.99a–c	9.80 ± 1.82a	50.20 ± 9.30bc

See footnotes of Figure 1. Similar letters indicate no significant variations among treatments.

relation between N-content in the additives and plant fresh weights was not significant. This result probably indicates the indirect roles of N-nutrition for enhancing the uptake of P and K.

Based on the above results, the efficiency of P on plant growth was estimated as a ratio between plant growth biomass (in grams) versus the applied dose of organic P per pot and the results are presented in Figure 5. Generally, the highest P utilization efficiency was recorded for the control treatment within this short-time investigation while P-use efficiency decreased when adding organics. Probably plants suffer from P deficiency utilize P more efficiently.

4 Discussion

4.1 Nutritive elements concentrations in the investigated organic residues

Biochars derived from either RS or SC exhibited significantly higher concentrations of most nutritive elements compared to the original feedstock, specifically NPK. Such increases may be attributed to the substantial loss of carbon (C) during the pyrolysis process [14]. On the other hand, biochar had relatively lower nutritive content compared to the other two amendments. In particular, compost had similar or slightly higher nutrient concentrations than co-composted biochar. These findings contradict the results reported by Jindo et al. [40], Khan et al. [41], and El-Gamal et al. [42], who observed no significant differences in nutrient content between co-compost biochar and biochar. It is hypothesized that composting enhances concentrations of NPK contents in the organic product [43] while reducing nutrient losses through volatilization compared to biochars [44].

Table 2: Coefficient of determination "r^2" values calculated for the relationships between/among zucchini biomass, NPK available contents, and the corresponding concentrations of these nutrients in plant and organic amendments

	Nutrient contents in organic additives			Available nutrient contents in soil			Total nutrient content in plant			Plant fresh weight
	N	P	K	N	P	K	N	P	K	
N content in the organic additive										
P content in the organic additive	**0.798****									
K content in the organic additive	−0.104	−0.338								
N available content in soil	**0.632****	0.244	−0.428							
P available content in soil	−0.295	0.146	−0.405	−0.224						
K available content in soil	**0.588***	0.275	0.391	0.429	−0.089					
N concentration in plants	**0.679****	0.412	0.323	0.434	−0.056	**0.814****				
P concentration in plants	−0.346	0.249	−0.264	**−0.563***	**0.802****	−0.254	−0.244			
K concentration in plants	0.451	0.253	0.190	0.321	−0.357	0.336	**0.657****	0.387		
Plant fresh weight	0.261	**0.501***	**0.569***	0.298	**0.628****	0.327	0.073	**0.500***	−0.255	

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

RS residues exhibited higher zinc (Zn) content than its processed products, i.e. biochar (RSB), compost (RSC), or composted biochar (RSCB). This disparity in Zn content suggests that significant losses of Zn might occur during the production of these organic additives, such as the pyrolysis process for production of biochar [45] and composting [46]. However, this pattern does not hold true for SB residues, as their Zn content in the feedstock was notably lower than the corresponding contents within all its products, i.e. biochar, compost, or co-composted biochar. The organic source likely contributes to this contradictory observation.

4.2 Effect of organic additives on zucchini germination

Seed germination was found to be significantly high when organic additives were used, surpassing the germination rate of the control group. Among the different organic treatments, no significant variations were observed in this context. These findings provide further evidence supporting the efficacy of organic amendments in enhancing seed germination, potentially through the preservation of soil moisture [20], which in turn promotes a higher rate of seed germination [47]. Similar results have been reported for various plant species, including *Zea mays, Phaseolus vulgaris* and *Abelmoschus esculentus* [48], *Solanum lycopersicum* [49], *Abelmoschus esculentus* L. [50].

4.3 Effect of organic additives on zucchini growth

All zucchini fresh and dry weights significantly increased with application of organic treatments, as depicted in Figure 3. The SBC and SBCB treatments exhibited the highest increases in plant fresh weights, which were 1.24 and 1.71 times greater than the control, respectively. In a similar study, Abd El-Mageed et al. [51] observed that co-composted biochar was more advantageous for crop production than biochar alone. This preference can be attributed to the fact that co-composted biochar not only stimulated the activities of beneficial soil biota but also increased the levels of dissolved organic carbon in the soil, as reported by Wang et al. [52].

Increases in zucchini fresh weights were comparable when soil was supplemented with either compost or biochar. The degradation rate of compost was found to be high in light-textured soil [24], resulting in the enrichment of soil with nutrients [23]. Conversely, biochar has a longer lifespan in soil [17] and forms soluble complexes with these nutrients [23], thereby prolonging availability of soil nutrients. Consequently, neither biochar nor compost alone can guarantee superiority in enhancing plant growth in the short term. However, the combination of these amendments may have remarkable impacts on plants. To validate our findings, a long-term investigation incorporating these amendments is also necessary.

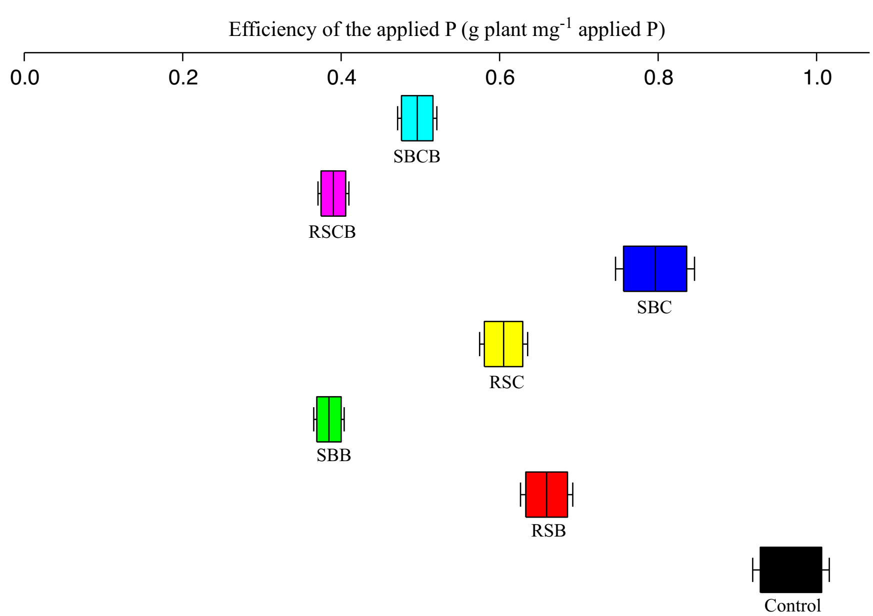

Figure 5: P-use efficiency by zucchini plants owing to application of the different organic additives. See footnotes of Figure 1. Similar letters indicate no significant variations among treatments.

4.4 Soil NPK availabile contents and their concentrations in zucchini plants

Available N content increased significantly in soil owing to addition of any of the organic products, especially SBS, RSBC and RSCT. These amendments enriched the studied soil with nutrients in available forms [23,53,54]. In particular, light-textured soils exhibited the highest degradation rate of compost [24], which in turn, raises available nutrient contents in soil [23], while biochar persists longer in soil [17]. Despite this, it ensures the long-term availability of soil nutrients.

To some extent, the results of soil K-available contents were comparable to the aforementioned N results, with all organic treatments (except RSB), which exhibited significant increases in K-available contents in soil compared to the control. Variations in soil-P availability were less pronounced among treatments, and only RSB and RSCB treatments recorded significant increases in P-available content in soil. These findings are in partial agreement with Berihun et al. [55], who observed that biochar applications led to an increase in P and K availability in soil.

The uptake of NK by zucchini plants significantly increased in the soil that was supplemented with the investigated organic additives. Specifically, the application of RS organics resulted in a greater increase in NK uptake compared to the use of SB organics. Among the different organic additives, RSC and RSBC were found to be effective in enhancing NK uptake by plants. These findings align with the research conducted by Abd El-Mageed et al. [51], which suggested that co-composted biochar is more advantageous than biochar in promoting plant growth. However, when it comes to P-uptake, no significant differences were observed among the various organic additives under investigation. Despite this, all the treatments exhibited higher increases in P-uptake compared to the control group.

4.5 Correlation coefficients for the relationships between zucchini biomass, NPK available contents in soil and the corresponding concentrations in plant and organic amendments

Both the availability of nitrogen in soil and nitrogen content in plant tissues exhibited significant correlations with the nitrogen content in the organic amendments under investigation. However, there was no significant correlation observed between the availability of nitrogen in the soil and the nitrogen content in the plants. This observation suggests that organic amendments contribute to enrich soils with nutrients, including N. Nevertheless, other factors, such as soil biota, might lessen nitrogen availability in soil, potentially leading to its temporary immobilization [56].

Potassium (K) content in plants exhibited a significant correlation with N content in soil. This discrepancy could be attributed to the oxidation of released N–NH_4^+ resulting in the formation of nitrate [57], and this in turn enhances the uptake of K by plants [58]. Conversely, the presence of nitrate ions may hinder the uptake of phosphorus (P) by plants [59], and this may explain the negative correlation between P-uptake and available N-soil. It is important to note that the potassium requirements of plants may be relatively low during this particular growth stage, and/or the soil may have had a sufficiently high available K content prior to plant cultivation (Table S1). Consequently, the K-content in plants did not exhibit a significant correlation with the availability of K in the soil.

Based on the aforementioned findings, P nutrition is critical during the beginning of the growth stage in zucchini. Thus, estimation of P's impact on plant growth efficiency was conducted by comparing the biomass of plant growth (measured in grams) with the dosage of organic P applied per pot. The outcomes of this analysis reveal that the efficiency declined with adding organic applications. This suggests that plants may experience inefficiency in P absorption and subsequently utilize P in a more efficient manner.

5 Conclusions

RS residues contained higher levels of many macro- and micro-nutrients than SB residues. When both residues were subjected to either composting or pyrolysis, NPK contents became more concentration. In this aspect, nutrient losses were reduced in composting the residues versus the pyrolysis process to produce biochar. A combination between biochar and compost, known as "co-composted biochar" was also considered in our investigation. Generally, all organic additives increased seed germination rates. They also increased N and K available contents in soil, and to some extent raised soil available P. This, in turn, raised their uptake by plants, especially P and K. Organic amendments, including co-composted biochar, have been found to have a significant positive effect on the growth of zucchini during the initial 15 days of plant growth. A noticeable significant correlation was noticeable, indicating that zucchini biomass was significantly influenced by each of P contents in organic additives, soil available P and P-uptake by plants. This indicates that P is a very important nutrient for zucchini plants during this growth stage. In this concern, plants grown on soils of low P inputs utilize P efficiently, yet further applications of P in organic forms lessened significantly the efficiency of utilizing this nutrient. Probably, P is needed for DNA replications, which proceed mitotic division needed for enhancing plant growth. The best organic additives to be applied during this growth stage were the co-composted biochar of sugarcane bagasse (SBCB) then SBC. These two additives contained the highest levels of P, which led to the utmost increases in P uptake by plants.

Acknowledgments: The authors express their gratitude to the following workplaces: Soils and Water Department, Faculty of Agriculture, Benha University, Egypt. Plant Nutrition Department, National Research Center, Dokki, Giza, Egypt. Department of Soils and Water, Faculty of Agriculture, New Valley University, Egypt. Botany Department, Faculty of Science, Suez Canal University, Ismailia, Egypt. Scuola di Scienze Agrarie, Forestali, Alimentari ed Ambientali (SAFE), Università degli Studi della Basilicata, Italy - Division of Environmental Studies and Land Use, National Authority for Remote Sensing and Space Sciences (NARSS), Cairo 1564, Egypt.

Funding information: Authors state no funding involved.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and consented to its submission to the journal, reviewed all the results and approved the final version of the manuscript. Conceptualization, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; MAEA; and MAB; methodology, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; AS; MD; MAEA; and MAB; software, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; MAEA; and MAB; validation, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; MAEA; and MAB; formal analysis, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; MAEA; and MAB; investigation, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; AS; MD; MAEA; and MAB; resources, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; AS; MD; MAEA; and MAB; data curation, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; AS; MD; MAEA; and MAB; writing-original draft preparation, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; AS; MD; MAEA; and MAB; writing-review and editing, IM; IMF; HSS, MHHA; MT; SAM; HHA; A.; AE; AS; MD;MAEA; and MAB; visualization, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; AS; MD; MAEA; and MAB; supervision, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; AS; MD; MAEA; and MAB; project administration, IM; IMF; HSS, MHHA; MT; SAM; HHA; A; AE; AS; MD; MAEA; and MAB; funding acquisition, IM; IMF; HSS, MHHA; MT; SAM; HHA; AAA; AE; AS; MD; MAEA; and MAB.

Conflict of interest: Authors state no conflict of interest.

Data availability statement: Data will be available upon reasonable request from the corresponding authors.

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