Cogent Food & Agriculture

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oafa20

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To cite this article: Nana Danapriatna, Ismarani Ismarani & Moh. Dede (2023) Application of biochar and biological fertilizer to improve soil quality and *Oryza sativa* L. productivity, Cogent Food & Agriculture, 9:1, 2207416, DOI: 10.1080/23311932.2023.2207416

To link to this article: https://doi.org/10.1080/23311932.2023.2207416

Published online: 01 May 2023.

Danapriatna et al., *Cogent Food & Agriculture* (2023), 9: 2207416
https://doi.org/10.1080/23311932.2023.2207416

cogent food & agriculture

Received: 06 February 2023
Accepted: 22 April 2023

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SOIL & CROP SCIENCES | RESEARCH ARTICLE

Application of biochar and biological fertilizer to improve soil quality and *Oryza sativa* L. productivity

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Abstract: Rice husk is an agricultural waste that can be processed into biochar as the main ameliorant to improve soil quality and crop productivity. Biochar has the potential to be combined with biological fertilizers for intensive paddy farming. This study aimed at assessing the potential of biochar and biological fertilizers to

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ABOUT THE AUTHORS

Nana Danapriatna has been a lecturer and researcher at the Faculty of Agriculture, Universitas Islam 45 Bekasi (Unisma Bekasi), Indonesia since 1988. Nana holds Ph.D. in agricultural sciences from Universitas Padjadjaran University. He is concerned about land quality restoration through fertilizers biological, agricultural wastes and bioremediation. Currently, Nana has received several grants from Unisma Bekasi to study the effect of straw and husk charcoal to improve land quality as well as rice productivity.

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PUBLIC INTEREST STATEMENT

Our study has demonstrated the potential of using biochar and biological fertilizers to improve soil quality and crop productivity in lowland paddy rice. Rice husk, an agricultural waste, can be converted into biochar, which can then be combined with biological fertilizers containing N-fixing and P-solvent microorganisms. The optimal combination was found to be 10 grams of biochar and three-time spraying of biological fertilizer (10BC+BF). We found that this treatment significantly affected N, P, and K in the soil, resulting in increased paddy clumps and yield. Our research presents a promising sustainable solution to improve soil quality and crop productivity, especially in tropical area.

improve soil quality and lowland paddy rice (Oryza sativa L.). This study used an experimental approach and the treatment of rice plants was carried out in a greenhouse. Rice plants were given biochar and biological fertilizer containing N-fixing and P-solvent microorganisms. The completely randomized experimental design involved four replications with six treatment combinations. The effect of this treatment was analyzed using analysis of variant (ANOVA) and least significant difference (LSD) with a 95% confidence level (α 0.05). We found that the optimal combination is 10 grams of biochar with three times of fertilizer (10BC+BF) on all parts of the plant. This research showed that the combination of biochar with biological fertilizers was able to significantly affect N, P and K in the soil. Only N in rice plants was also significantly affected by the treatment. The combination capable to increase the rice productivity according to paddy clumps and yield.

Subjects: Agriculture and Food; Agriculture

Keywords: endophyte microorganism; paddy; rice husk; soil fertility; yield production

1. Introduction

Strategies to increase agricultural productivity rely heavily on the use of inorganic fertilizers. In Indonesia, government policies that support the use of inorganic fertilizers by farmers are met through subsidies (Hoffmann et al., 2020). This subsidy policy budget for inorganic fertilizers costs between IDR 25–40 trillion per year (Fahmid et al., 2022). However, this policy is still ineffective because it has not been able to guarantee the availability of adequate fertilizer with rational price —according to the highest retail price (HRP) set by the Indonesian central government (Sahim et al., 2018). Another problem for this agrarian country is the large number of agricultural lands that have been converted into built-up areas for settlements, industries, and infrastructure (Dede et al., 2022; Susiati et al., 2022). Agricultural land also faces other threats, such as erosion and decreasing soil fertility, these affect the topsoil is carried away by rainwater and causing environmental problems for aquatic ecosystem (Sunardi et al., 2022).

Soil degradation is a real threat to farmers because it affects agricultural business and land productivity. Rice's field continues to decrease in harvest area, even per farmer family only has arable land between 0.1–0.4 hectare, which is accompanied by low professional regeneration for this occupation (Harini et al., 2012). It requires farmers and stakeholders to develop appropriate agricultural technology innovations by utilizing local resources, cheap and abundant organic materials. Paddy farming produces residues such as rice husk, straw and chaff. For rice husk, it is well known for its ability to restore soil quality and increase nutrient holding (Varela-Milla et al., 2013). Commercial rice farming requires 5–10 tonnes of organic substances per hectare (Kantikowati et al., 2022; Walianggen, 2022). Rice husk can be processed into biochar and used as a soil amendment to increase organic matter content, stabilize pH, and gain harvested production of various crops (Karam et al., 2021). Rice productivity after being given biochar can increase up to 55% depending on agroecosystem conditions and crop varieties. Biochar is a high-carbon organic compound up to 40–60%, it comes from the pyrolysis process of rice husk and is resistant to weathering through contact water, atmosphere, and organisms for decades in the soil (Uchimiya et al., 2017). Despite containing carbon, biochar from rice husk has ash (around 50%) with small amounts of N, P, K, Ca, Mg, Na, Al, and Fe (Ammal et al., 2020). Several studies have shown that the use of biochar affected soil characteristics in terms of water-holding capacity, pH, and activity of microorganisms (Glaser et al., 2015). Shetty and Prakash (2020) observed an increase in nutrient uptake by paddy after application of rice husk biochar. Application biochar on agricultural land increased its ability to store water and nutrients, reduce evaporation, and suppress the development of pests and plant diseases originating from the soil (Bakhat et al., 2021). Research has demonstrated that under certain conditions, biochar does not have a significant effect on soil, plant nutrition, and biomass production. This condition is caused by small doses of biochar, those agricultural activities are done in short periods of treatment (under one year) and without considering environmental factors such as climate, soil characteristics and paddy varieties (Major et al., 2010). The potential problem occurred when biochar is applied to intensive rice farming without proper experiments and consideration.

For commercial and intensive agricultural purposes, biochar is still unable to add significant soil nutrients. To tackle this problem, combination of biochar and N fertilizer able to reduce soil bulk density, increase water holding capacity and soil chemical status (Oladele et al., 2019). Although inorganic fertilizers could be a solution, rice farming requires an eco-friendly solution through the usage of biological fertilizers to achieve sustainable agriculture. Biochar and compost have been proven to increase rice growth, the combination was able to change soil characteristics—soil organic carbon and microbial biomass. Based on this phenomenon, biochar has the potential to be combined with biological fertilizers for rice plantations. (Rajput et al., 2019). Biological fertilizer could be made from a combination of *Pseudomonas mallei* and *Penicillium sp*. which have been shown to increase crop yields by up to 20% and reduce 25% the dose of phosphate fertilization (Fitriatin et al., 2009).

Biological fertilizers are inoculants with active ingredients from living organisms that function to bind certain nutrients and facilitate the availability of various nutrients in the soil for plants (Carvajal-Muño & Carmona-Garcia, 2012; Kumar et al., 2021). Biological fertilizers, apart from being abundant in microorganisms, also contain N-fixers and P-solvents. This combination could improve soil quality, and increase fertilization efficiency as well as rice productivity. The use of biochar and biological fertilizers will encourage farmers' income toward supporting sustainable agriculture. Therefore, this study aimed to determine the effect of biochar and biological fertilizers to improve soil quality and rice productivity.

2. Materials and Methods

2.1. Description of the Study Area

This greenhouse experiment was carried out at the Faculty of Agriculture, Universitas Islam 45 (Unisma) Bekasi using Ciherang's rice variety as test crop. The Unisma's greenhouse is located at 6° 15' 27.86" S and 107° 00' 23.79 E in Bekasi City, West Java, Indonesia with an elevation of 7 meters from the sea level. The study adopted a completely randomized design with four replications. Soil and rice received 6 (six) treatment combinations, including 0 gram of biochar without fertilizer (0BC); 0 gram of biochar with fertilizer (0BC+BF); 10 grams of biochar without fertilizer (10BC); 10 grams of biochar with fertilizer (10BC+BF); 25 grams of biochar without fertilizer (25BC); and 25 grams of biochar with biofertilizer (25BC+BF). Biochar was mixed in the soil one day before the rice was planted. The rice plant sample was 24 pots with the layout and treatment scheme as presented in Figure 1.

Biochar was obtained from rice husks by a combustion process in the pyrolysis machine at temperatures between 250–3500 °C for one hour. For the biological fertilizer, this study consisted of two N-fixing endogenous bacteria (*Bacillus sp.* 1×10^7, *Azospirillum sp.* 1×10^7) and one phosphate-solubilizing bacteria (*Pseudomonas sp.* 1×10^7) as a consortium. Every 30 grams of the biological fertilizer should be dissolved in 320 ml of water, biochar and the biological fertilizers also their contents showed in Figure 2 and Table 1. Rice seeds were placed in each 12 liters bucket that had previously been filled with 10 liters of agricultural soil (entisols) from Karawang Regency, Indonesia (Table 2). The area has annual temperature of 27°C with rainfall reach 1,500–3,000 mm. Karawang Regency is a center for national rice production, hence rice farming has made it a leading economic sector (Dede et al. 2018).

A concentrated solution of fertilizer must be added with 20 liters of water. Fertilization was sprayed whole part of the rice plant on days 7, 14 and 28. Each plant is also given inorganic fertilizer according to the Indonesian Ministry of Agriculture's dose for rice fields in Karawang

1	2	3	4	5	6	7	8
(0BC) 2	(10BC) 2	(25BC) 3	(0BC) 4	(10BC) 3	(10BC+BF) 3	(0BC+BF) 2	(25BC+BF) 3
(10BC+BF) 2	(0BC) 3	(25BC+BF) 4	(25BC) 2	(10BC) 1	(0BC+BF) 1	(0BC) 3	(25BC) 4
(0BC) 1	(10BC) 4	(25BC) 1	(10BC+BF) 4	(10BC,+BF) 1	(25BC+BF) 2	(0BC+BF) 4	(25BC+BF) 1

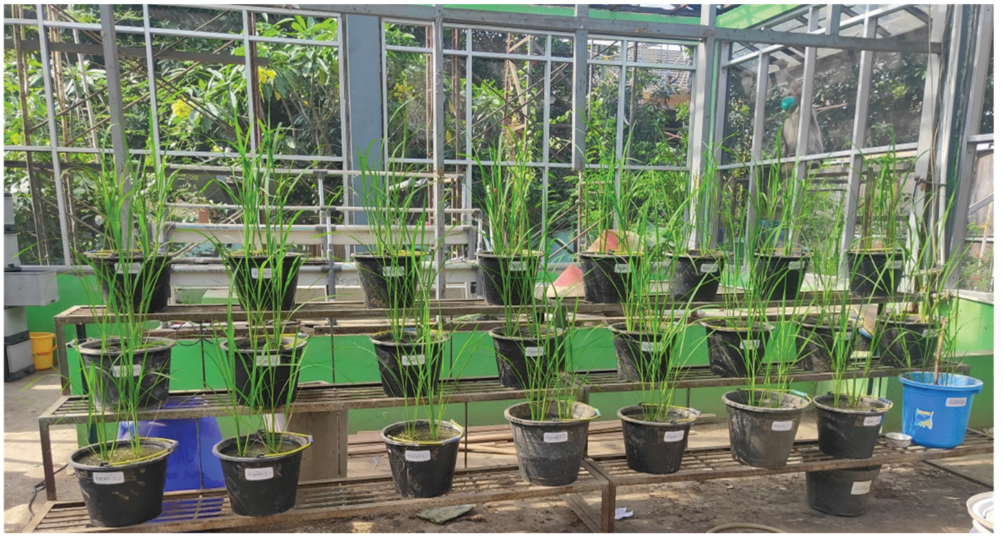


Figure 1. Layout for the experiment in the greenhouse.

Figure 2. Biochar and biological fertilizer for rice's treatments.

Table 1. Properties of biochar and biological fertilizer

Properties	Biochar	Biological fertilizer
Moisture (%)	5.52	Not available
Volatile matter (%)	23.74	Not available
Ash (%)	35.51	Not available
C (%)	34.45	1.36
N (%)	0.32	0.08
P (%)	0.15	2.41
K (%)	0.31	2.96

Table 2. Soil characteristic for the experiment

Parameter	Technique	Detail	Status
Soil texture	Peptizing	Sand (10.20%), silt (60.50%) and clay (28.30%)	Silty clay loam
pH	Potentiometric	H_2O (7.05) and KCl (6.10)	Neutral

(Rafiuddin et al., 2016). Paddy needs inorganic fertilizers such as 3.75 grams of Urea (equivalent to 70% the recommendation), one gram of super-phosphate (SP-36), and 0.625 grams of KCl. These inorganic fertilizers aim to adapt to real conditions and avoid biological adaptation failure (Fang et al., 2021). Paddy was observed every week, whereas the productivity and whole crops were analyzed to understand the different effects of treatments.

2.2. Data Analysis

Different treatments of soils were observed in nutrient content (N, P, K, C). Effects on rice plants were observed by nutrient (N, P, K), panicle number and yield productivity. This study used Analysis of Variant (ANOVA) and Least Significant Difference (LSD) (**Equation 1–2**). ANOVA compares the means of two or more data groups, while LSD can measure treatment differences and serves as a post hoc test (Ismail et al., 2022; Nurbayani & Dede, 2022; Q. Zhang et al., 2022). LSD required the mean squared error (MSE) and degrees of freedom for error (dfE) from ANOVA (Frene et al., 2022). These analyses were performed in Microsoft Excel and PSPP by 95% confidence level with a significance limit (p-value) less than 0.05.

$$F = \frac{MST}{MSE} \tag{1}$$

$$LSD_{\alpha} = t_{(\alpha,\mathrm{dfE})}\sqrt{\frac{2MSE}{r}} \tag{2}$$

where F is the F-statistical value, MST known as the mean square of treatments, MSE for the mean square error, α indicates the significance value, and r is the Pearson's correlation.

3. Results and discussion

3.1. Effect on Soil Quality

Biological fertilizers in the growing media can increase the K content to more than 150 parts per million (ppm), even in a number of samples that do not use biochar from rice husks. The use of at least 10 grams of biochar has increased the P content to above 30 ppm. The application of one of them, biochar and biological fertilizers, has been shown to increase the N content in the soil. The results of ANOVA in Table 3 show that the soil groups with these treatments proved to have a significant effect on chemical component, except for C-organic. Even though the N content was increased, the non-dynamic carbon content caused the C/N ratio to remain unchanged (Pérez & Torres-Bazurto, 2020; Y. Ye et al., 2014). In biochar the use of biochar with or without biological fertilizers can increase the N content between 1.36–1.81%. This result is strengthened by the significant test of biochar's treatment (p-value less than 0.05 with 95% confidence level). biochar results prove that biochar can increase the absorption of the main nutrients of plants. However, the combination should be able to improve soil quality and rice productivity.

The usage of biochar with biological fertilizers has been, significantly, increase N, P, and K in the soil. This indicates that microorganisms present in biological fertilizers (*Bacillus sp*., *Azospirillum sp*., and *Pseudomonas sp*.) play an active role in fixing N and dissolving P. Based on LSD test, these treatments were not able to significantly affect changes in C-organic and C/N in the soil (Table 4). The highest N and P were in the sample that received 25 grams of biochar with biological fertilizer. These combinations affect the nutrients, including microorganisms and soil physical properties—

Table 3. Effects of biochar and biological fertilizers on soils and paddy

Variable	Parameter	F	df	p-value	SEM	SED	CV (%)	LSD
Soil quality	N	4.12	23(5)	0.01	0.00	0.01	3.30	0.01
	P	5.01	23(5)	0.00	1.70	2.40	10.40	5.04
	K	7.13	23(5)	0.00	7.90	11.18	10.23	23.48
	C-organic	2.17	23(5)	0.10	0.02	0.03	2.16	0.07
Paddy crops	N	3.92	23(5)	0.01	0.13	0.18	17.39	0.37
	P	1.68	23(5)	0.19	0.01	0.02	12.61	0.04
	K	1.09	23(5)	0.40	0.30	0.42	14.49	0.88

Note: NPK stands for nitrogen, phosphorus, and potassium; C is the carbon; df is the degree of freedom; SEM is the standard error of mean; standard error of difference; CV is the coefficient of variation; LSD is the least significant difference.

Table 4. Effects of biochar and biofertilizer application on selected soil properties

Treatment	N (%)	P (ppm)	K (ppm)	C-org (%)	C/N ratio
0BC	0.19 a	26.97 a	129.65 a	2.04 a	10.90 a
0BC+BF	0.20 b	31.45 abc	152.95 ab	2.07 a	10.49 a
10BC	0.20 b	30.17 ab	139.38 a	2.05 a	10.42 a
10BC+BF	0.20 bc	35.35 cd	167.53 bc	2.09 a	10.47 a
25BC	0.20 bc	34.42 bcd	148.50 ab	2.09 a	10.33 a
25BC+BF	0.21 c	37.32 d	188.73c	2.13 a	10.29 a
LSD	0.01	5.04	23.48	0.09	0.58

The same letter in one column indicates no significant difference; ppm is parts per million.

Table 5. Various combinations of biochar and biological fertilizers on rice plants

Treatment	N (%)	P (ppm)	K (ppm)
0BC	1.28 a	0.23 a	3.93 a
0BC+BF	1.14 a	0.21 a	3.92 a
10BC	1.36 ab	0.21 a	3.72 a
10BC+BF	1.81 c	0.24 a	4.23 a
25BC	1.42 ab	0.24 a	4.10 a
25BC+BF	1.66 bc	0.26 a	4.61 a
LSD	0.37	0.04	0.88

Note: The same letter in one column indicates no significant difference; ppm is parts per million.

density, porosity, water content (Masulili et al., 2010). Meanwhile in rice plants, this treatment only had a significant impact on increasing N content. From LSD test, it was found that these treatments were not able to increase P and K content in the plant, because the changes were very minor (Table 5). A highest N was found in the treatment of 10 grams of biochar with biological fertilizer (10BC+BF). These results were confirmed by Chen et al. (2022), the use of biochar and organic fertilizers had positive effects on soil pH and organic carbon.

3.2. Effect on Rice Productivity

The combination of biochar and biological fertilizers not only has a positive effect on improving soil quality and plant content, but also has the potential to increase productivity as seen from the number of clumps of rice and dry grain harvested. LSD test showed that the combination treatment of 10 grams of biochar and biological fertilizer (10BC+BF) was the most optimal, efficient, and significant increase in rice productivity as shown in Table 6. This treatment increased the number

Table 6. Various combinations of biochar and biological fertilizers on rice productivity

Treatment	∑ clumps	Dry grain per pot (gram)
0BC	16 a	31.14 a
0BC+BF	19 ab	40.15 ab
10BC	17 a	51.55 bc
10BC+BF	21 bc	61.87 c
25BC	20 bc	53.26 bc
25BC+BF	22 c	62.44 c
LSD	3	15.562

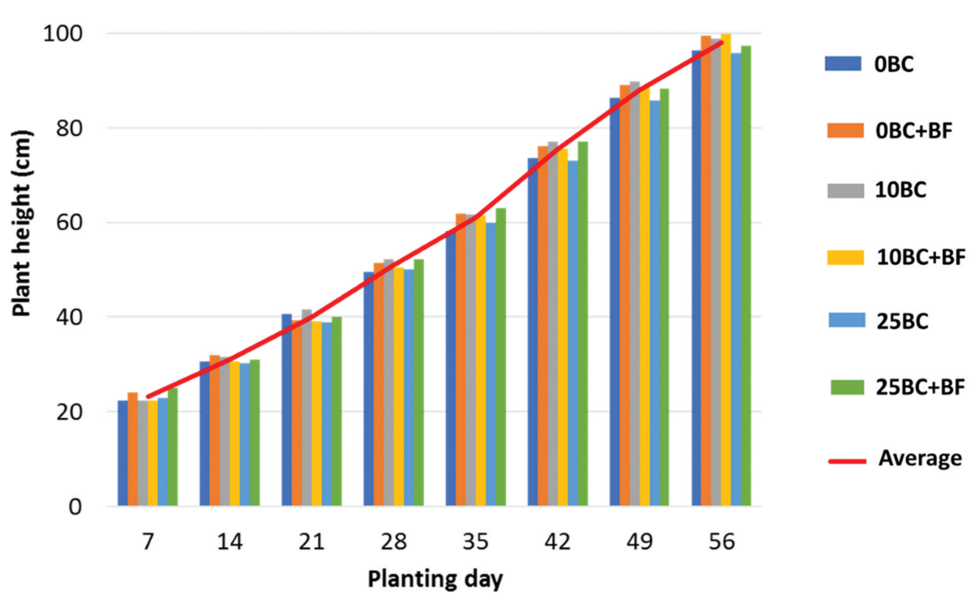
Note: The same letter in one column indicates no significant difference.

of clumps by 25%, and the dry grain harvest almost doubled. It further proves that the combination does not only have a positive effect on clumps, but also on body size and dry rice grains. Improving soil quality ensures that essential nutrients (N, P, and K) can be absorbed by plants, resulting in optimal growth and more abundant rice yields (Budiono et al., 2019; Paiman et al., 2021; T. Ye et al., 2019). The biochar maintains nutrients in planting media from water solution and the top layer is not eroded by runoff. Improving carbon content in the soil brought benefits to the cereals family's root system (Imran, 2021).

Biochar from rice husk is proven to be able to improve soil characteristics and increase fertilization efficiency, thus nutrient is more absorbed by plants. The application of 10 grams of biochar has increased the content of macro nutrients in the soil. Biochar not only contain carbon, but other ingredients such as 50% cellulose, 25–30% lignin, 15–20% silica, and 10–15% moisture (Hossain et al., 2020; Singh, 2018). On the other hand, biochar influences the nutrient cycle and keeps them longer in the soil (H. Zhang et al., 2022; Petrus et al., 2020). The effect of biochar is better when soil and plant are exposed to biological fertilizers from spraying. Microorganisms contained in the fertilizer increase the nutrients in the soil by fixing and releasing nitrogen, phosphate, and potassium compounds. Biochar is an ideal habitat for various soil-fertilizing bacteria (Ebe et al., 2019). This study confirmed that biological fertilizers have improved soil quality better than only used synthetic fertilizers. Biological fertilizers restore the soil ecosystem and do not disturb macroorganisms on agricultural lands (Escobar & Solarte, 2015; Pellejero et al., 2021). The application of biochar with biological fertilizers should consider soil types, rocks, climatological factors, rice varieties, and local community culture to increase agricultural productivity.

The use of biochar and biological fertilizers should be in a right dose. We recommend using 10 grams of biochar per pot along with the biological fertilizer (10BC+BF). This treatment is effective and efficient to improve soil quality as well as rice productivity as shown by the LSD test. Excess biochar only adds biomass and reduces agricultural productivity (Ullah et al., 2020; Yu et al., 2018). The biochar dose of 10 grams per pot should be adjusted in the field's scale and prevent harm to rice plants (Figure 3). Awad et al. (2018) stated that biochar had toxicity potential under redox conditions due to land flooding and poor drainage. Although it was a pragmatic solution, excessive biochar would detrimental to farmers with weak socio-economic status without receiving subsidies from the government (Mohammadi et al., 2020). For biological fertilizers, the dosage for each hectare is 300 grams for three applications in 7–14 days interval. Excess in biological fertilizers causes an imbalance of soil

Figure 3. Comparison of the rice's growth in 56 days in six different treatments (bottom) after planting day.



microorganisms and changes to pathogens. An abundance of Bacillus sp. in agricultural ecosystems causes diarrhea and food contamination associated with vegetables, rice, ready-to-eat food, milk and egg (Haque et al., 2021). Overpopulation of *Pseudomonas sp*. would harmful to the ecosystem of *Pseudomonal pneumonia* (Public Health Agency of Canada, 2011).

Rice husk biochar for paddy cultivation must be used efficiently by considering its effectiveness to increase productivity. This study showed that very high doses of biochar did not give optimal results, even though the clumps paddy was abundant. The right dose is able to improve aeration and soil function, resulting in an increase in soil physicochemical properties, which results in better health, structure, and soil fertility for paddy crops (Sy et al., 2021). The biochar effect can actually be significant when combined with biological fertilizers, it triggers increasing biomass in the soil and ultimately has a positive impact on paddy productivity (Hadiawati et al., 2019). However, in salt-affected soil, the combination of biochar and biological fertilizers was less than optimal where P and exchangeable K concentrations did not change significantly, hence the paddy productivity was not gained (Nguyen et al., 2018). Therefore, it is very important to pay more attention to soil and its agroecosystem before applying biochar and biological fertilizers.

4. Conclussion

Application of biochar with biological fertilizer had significant effects on soil N, P, and K, but this treatment was not significant to increase C-organic and C/N. For paddy, biochar and biological fertilizer increase N in the whole part of plants. This treatment stimulates paddy to grow faster and produces dry yields higher than conventional treatments. The best combination for lowland rice is 10 grams of biochar with 3 times fertilizing (10BC+BF) on all parts of the plant. The right doses would avoid adverse effects on plants, animals, and humans. Further research in extensive paddy field trials is required to know these effects on a massive scale. In addition, the treatment of crops with biochar and biofertilizers should be considered due to the rice varieties that exist among farmers.

Acknowledgments

The authors thank to famers who support in the field experiment, also to Millary Agung Widiawaty (BATAN-BRIN) for all support in this manuscript preparation. This research was funded by Universitas Islam 45 Bekasi through 'Hibah LPPM Unisma' (123/LPPM.UNISMA/1.1.I/II/2021) to the first author.

Funding

The work was supported by the Universitas Islam 45 Bekasi [123/LPPM.UNISMA/1.1.I/II/2021].

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Authors' contributions

ND: Conceptualization, Methodology, Software, Investigation, Funding, Writing—Original Draft; **II**: Conceptualization, Methodology, Resources, Supervision; **MD**: Formal analysis, Validation, Writing—Review and Editing.

Disclosure statement

No potential conflict of interest was reported by the authors.

Citation information

Cite this article as: Application of biochar and biological fertilizer to improve soil quality and *Oryza sativa* L. productivity, Nana Danapriatna, Ismarani Ismarani & Moh. Dede, *Cogent Food & Agriculture* (2023), 9: 2207416.

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