

Residual effects of biochar and application of biofilm biofertilizer on Alfisols physical properties and rice yield

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Abstract. Long-term and intensive use of chemical fertilizer reduce soil physical properties even plants yield. Especially on Alfisols with poor soil physical properties making it difficult for plant roots to penetrate and low water holding capacity. It is important to use biochar as environmentally-friendly soil conditioner and biofilm biofertilizer to reduce the use of chemical fertilizer and climate changes. This study examines the residual effect of coconut shell biochar in second season and the use of biofilm biofertilizer (BiO₂) to increase soil physical properties and rice yield on Alfisol. This was pot experiment conducted at green house used a split-split plot design, with the main plot was biofilm biofertilizer (BiO₂) concentration (0 and 100%), a sub-plot of biochar application method (mixed evenly with soil and spread on the soil surface), and a sub-sub-plot of biochar dosages (dose 0, 15 and 30 ton/ha). The results show that the K₁C₂D₂ treatment combination (the residual effect of 30 ton/ha biochar applied by evenly mixed it with the soil a year before, combined with the used of BiO₂) has the highest value in reducing soil bulk density (28%) and particle density (18.86%), and increasing soil porosity (36.78%), plant dry weight (261.51%) and rice yield (231.32%) than the control treatment.

1 Introduction

The demand for rice as the main staple food of Indonesia has increased every year. Thus, efforts to increase national rice production are carried out through extensification and intensification. However, the intensive and continuous use of chemical fertilizers will reduce the physical properties of soils and decrease plant productivity. Therefore, it is necessary to

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look for other alternatives, such as organic materials and biological fertilizers which are more environmentally friendly. Apart from intensification, the extensification of agricultural land using Alfisol soil can also be carried out as an effort to increase rice production. However, Alfisol has poor soil physical properties, due to the accumulation of clay from the horizons above and causing high soil compaction making it difficult for plant roots to penetrate, and has low aeration pores and water holding capacity [1].

Various attempts have been made to solve the problem of Alfisol soils, one of which is the use of biochar which is difficult to decompose in the soil. Biochar remains for a long time in the soil, thus improving the physico-chemical properties of the soil and act as carbon storage so it will enhance an effort to reduce climate change by the prolong of carbon sequestration as biochar-carbon. Biochar is a resistant material to biological decomposition due to its lignin content. High lignin content biochar (wood, coconut shell) is not easily decomposed like other materials (plant straw) and the lower the mineralization rate [2].

Coconut shell biochar was chosen because it can increase the water content in the soil by 21.55% when applied [3]. The use of biochar as a soil conditioner can improve soil physical properties, thus improving the rice growth and yield. Biochar pore structure provides a potential microhabitat for soil microorganisms of biofilm biofertilizer (BiO₂).

Biofilm biofertilizer (BiO₂) is a biological fertilizer technology which microbial inoculums are able to forms a thin layer of microbial biofilms when it is applied. Biofilms are complex group of various types of microbes attached to solid or semi solid substances and surrounded by a matrix of exopolysaccharide (EPS). BiO₂ is more resistant to environmental stress, predators, and antagonists, and can increase crop yields compared to conventional biofertilizers [4]. The application of BiO₂ can improve soil quality by increasing soil C-Organic status due to the increased storage of root exudates by BiO₂ microorganism components that form biofilms [5]. According to Sunil e al. [6], treatment with biofertilizer can increase 25.7 to 27.1 % grain yield compared to treatment without biofertilizer on Alfisol soil. The research aims were to study the residual effect of coconut shell biochar and the application of BiO₂ to soil physical properties and rice yields on Alfisol soils in second season (year). This result can be used as a reference for the use of biochar to improve soil physical properties and the effectiveness of biofilm biofertilizer (BiO₂) in increasing second-planting season rice yields on Alfisol soils.

2 Materials and Methods

This was second-year research (2022) with soil used in previous year (2021). The research was carried out from June 2022 - November 2022 in the green house of Faculty of Agriculture, Sebelas Maret University, Surakarta, Central Jawa, Indonesia. Analysis of soil physical properties was carried out at The Soil Physics and Conservation Laboratory, Faculty of Agriculture, Sebelas Maret University, Surakarta.

The study used a split-split plot experimental design, with the main plot was biofilm biofertilizer (BiO₂) concentration (concentration of 0% (K₀) and 100% (K₁)), sub-plot was coconut shell biochar application method (spread on the soil surface (C₁) and mixed evenly with the soil (C₂)), and sub-sub-plots was biochar doses (0 tons/ha (D₀), 15 tons/ha (D₁), and 30 tons/ha (D₂)) as has been done in first-year research. There were 12 treatment combinations, and control treatment, and local farmer treatment (fertilized with recommendation dose of nitrogen, phosphorus, kalium (NPK) fertilizer in the form of 250 kg/ha urea, 150 kg/ha SP-36, 100 kg/ha KCl) with three replications. The rice variety of IR 32 was used. The BiO₂ biofertilizer was taken from [4]. All treatment combinations were fertilized with organic fertilizer (2,5 tons/ha) while control and local farmer treatment were

not. Plastic pot with 50 cm diameter and 30 cm height was filled with fine soil (pass to 2 mm sieve) then flooded with water as high as 5 cm and incubated for 3 days. Three tillers of IR 32 rice approximately 14 days old were planted in each pot. The water height maintained and spraying BiO₂ as much as 5 ml two times in a week for the K₁ treatment. The observed variables include plant height, plant wet and dry weight as well as rice yield and soil bulk density, particle density and porosity. Data analysis using the analysis of variance at the 95% level of confidence, followed by the Duncan's Multiple Range Test (DMRT) if any significance. The best combination treatment compares to control treatment and local farmer treatment by T-test.

3. Results and Discussions

3.1. Soil characteristic used for experiment

The characteristics of the Alfisol soil used in this study are presented in the Table 1.

Table 1. Alfisol Soil Characteristic used for the experiment

| No. | Soil physical properties | Unit | Value | Classification |
|-----|--------------------------|-------------------|---------------------------------|----------------|
| 1 | Bulk density | g/cm ³ | 1.25 | - |
| 2 | Particle density | g/cm ³ | 2.47 | - |
| 3 | Porosity | % | 40.32 | |
| 4 | Texture | % | Silt 35% Clay 56% Sand 9% | Clay*) |

*) According to ICALRD [7]

As showed in the Table 1 that the Alfisol soil of Jumantono has the bulk density of 1.25 g/cm³ in accordance to the mineral soil criteria, which ranges from 0.6 to 1.4 g/cm³, while the particle density obtained at 2.47 g/cm³, and the soil porosity is 40.32. The Alfisol soil texture used in the study was clay with a dominance of 56% clay. According to this study this Alfisol soil has clay texture characteristics, medium to high bulk density, and low to moderate permeability.

3.2. The Effect of Treatment Factors on Soil Physical Properties and Rice Yields

The study result showed that the use of BiO₂ did not significantly decrease of soil bulk density but it did to the particle density and soil porosity variables. Treatment K₁ gave better average results than K₀ on bulk density, and particle density (Table 2). The use of biological fertilizers can cause the soil to become loose and crumbly due to the activity of microorganisms in biological fertilizers. The loose soil has a good porosity and water content to fulfill plant needs.

Table 2. Effect of Treatment Factors on Soil Physical Properties and Rice Yield^{*)}.

| Variable | BiO ₂ | | Biochar | | Biochar dosage | | |
|-------------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| | Concentration | | Application | | (D) | | |
| | (K) | (K) | Method | (C) | | | |
| | K0 | K1 | C1 | C2 | D0 | D1 | D2 |
| Bulk density, g/cm ³ | 1.10 ^a | 1.08 ^a | 1.10 ^a | 1.08 ^a | 1.14 ^a | 1.16 ^a | 0.98 ^b |
| Particle density, g/cm ³ | 2.26 ^a | 2.10 ^b | 2.19 ^a | 2.18 ^a | 2.26 ^a | 2.21 ^b | 2.09 ^c |
| Porosity, % | 51.27 ^a | 51.03 ^a | 49.53 ^b | 50.29 ^a | 49.39 ^b | 47.07 ^c | 53.26 ^a |
| Plant dry weight, g/pot | 21.17 ^b | 26.71 ^a | 22.34 ^b | 25.54 ^a | 23.22 ^b | 20.25 ^b | 28.34 ^a |
| Grain dry weight, g/pot | 4.05 ^b | 4.69 ^a | 4.13 ^b | 4.61 ^a | 3.99 ^c | 4.24 ^b | 4.89 ^a |

^{*)} Number followed by same alphabet in the same treatment factor was not significant different by DMRT at 5% level confident

Applying biochar by spreading it on the surface (C₁) has significantly different effect from applying it by mixing evenly in the soil (C₂) in terms of soil porosity. However, C₁ and C₂ were not significantly different in terms of bulk density, and particle density maybe because in the second season part of the biochar was mixed with the soil by water during plant maintenance period. In the second season, the effect of biochar dosages and application method were still significant on soil physical properties which in turn will enhance rice growth and increase rice yield. Treatment C₂ gave a better average yield than C₁ on bulk density, particle density and porosity (Table 2) which indicated the residual effect of biochar application method. The biochar dose of 30 tons/ha (D₂) was significantly different from the biochar dose of 0 tons/ha (D₀) and the biochar dose of 15 tons/ha (D₁) in terms of bulk density, particle density, and porosity. Treatment D₂ gave the best average results compared to D₀ and D₁ on bulk density, particle density, and soil porosity (Table 2). The coconut shell biochar that was given in the first-year experiment still had a significant effect on reducing the bulk density and soil density in second year experiment do to it resistance to microbial decomposition so it has long time persistence in the soil. Biochar has porous properties which can increase the pore space in the soil when applied, thereby reducing the bulk density of the soil. Reducing the bulk density can simultaneously increase the porosity of the soil, improve soil aeration, enhance root growth, penetration and nutrients absorption, which in turn will increase growth and rice yield.

The concentration of BiO₂ 0% (K₀) was significantly different from the concentration of 100% (K₁) BiO₂ on the dry weight and the dry grain weight. Treatment K₁ gave a better average yield than K₀ on plant dry weight and grain dry weight (Table 2). The application of BiO₂ is capable on increasing plant growth and yield by suppressing competition for nutrients, promoting plant growth, and controlling pests and diseases. The addition of biofilm biofertilizer increases the weight of filled grain and total plant weight [8]. The microbial activity of biological fertilizers can increase the availability of nutrients for plants. BiO₂ contains phosphate-solubilizing bacteria (PSB) which can increase the availability of P in the soil. Nutrient P has a role to accelerate flowering and grain ripening. The use of biological fertilizers in a sustainable manner will not cause environmental pollution. Biological fertilizers that applied with organic fertilizers are also able to reduce costs incurred by farmers when they do not buy them, but they do integrated farming system.

Applying biochar by spreading it on the soil surface (C₁) give significantly different effect compared to applying biochar by mixed evenly in the soil (C₂) on the dry weight and the dry grain weight. Treatment C₂ gave a better average yield than C₁ on the dry weight and the dry grain weight (Table 2). The biochar dose of 30 ton/ha (D₂) was significantly different from

the biochar dose of 0 ton/ha (D_0) and the biochar dose of 15 ton/ha (D_1) for the dry weight and the dry grain weight. Treatment D_2 gave the best average yield compared to D_0 and D_1 on the dry weight and the dry grain weight (Table 2). The right dose of biochar affects the yield of rice plants. According to Nurida *et al* [9] applying biochar at a dose of 15 ton/ha has a consistent effect on rice crop yields for three growing seasons. It means that biochar at this dose can support rice growth and yield for three growing seasons. The higher the dose of biochar given, the higher the quality of soil properties compared to the control treatment (0 ton/ha biochar), such as the content of nutrients N, P, and K which are beneficial for plant growth.

3.2.1. Effect of Treatment Combinations on physical Soil properties - Bulk density

The anova showed that biochar dosages, biochar application method and the interaction among treatments and were significantly affect the soil bulk density, while BiO_2 concentration was not. Highest bulk density value was taken at the $K_0C_1D_0$ and $K_0C_2D_0$ treatments (1.22 g/cm^3), while the lowest bulk density value was shown by the $K_1C_2D_2$ treatment (0.90 g/cm^3) (Fig. 1). The combination treatment of 100% BiO_2 and 30 tons/ha biochar mixed evenly in the soil showed the best results among the other treatment combinations. The value of soil bulk density usually higher in no-tillage soil while soil porosity values will be higher in perfectly tillage.

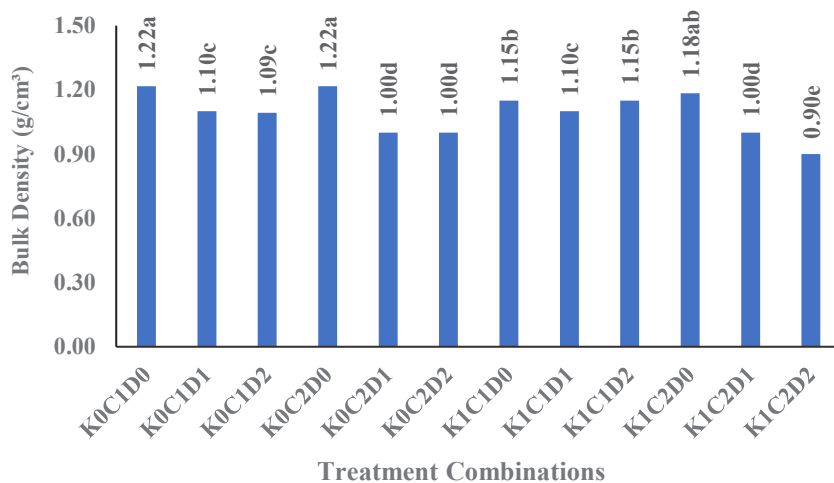


Fig. 1. The Effect of Treatment Combinations on Bulk Density

The T-test result showed that the $K_1C_2D_2$ treatment combination showed a decrease in bulk density compared to the control treatment (28%) and fertilizer (farmer treatment) (27%). Bulk density values for the $K_1C_2D_2$ treatment (0.90 g/cm^3), the farmer treatment (1.24 g/cm^3), and the control treatment (1.25 g/cm^3). The bulk density value of mineral soil ranges from $0.6 - 1.4 \text{ g/cm}^3$. The reduction in bulk density from the control treatment with $K_1C_2D_2$ or from 1.25 g/cm^3 to 0.90 g/cm^3 occurred due to the addition of biochar. The $K_1C_2D_2$ treatment combination had the best results. Biochar has a bulk density ($<0.6 \text{ g/cm}^3$) lower than the average bulk density of soil (1.25 g/cm^3) so when biochar is added, a decrease in soil bulk density will occur. Increasing organic carbon with the application of biochar can increase biological activity, soil aggregation, and increase soil pores thereby reducing soil density [10].

3.2.2. Effect of Treatment Combinations on physical Soil properties – particle density

Biochar dosages and interaction among treatment factors were influence significantly the soil particle density with the highest value was shown by the $K_0C_2D_0$ treatment (2.42 g/cm^3). and the lowest was $K_1C_2D_2$ treatment (2.01 g/cm^3) (Figure 2). Particle density decreased with increasing dose of biochar given. This is in line with the research result conducted by Rasoulzadeh and Yaghoubi [11] which the particle density of the soil decreased significantly with the application of 30 and 60 tons/ha dose of biochar which was caused by an increase in organic matter in the soil.

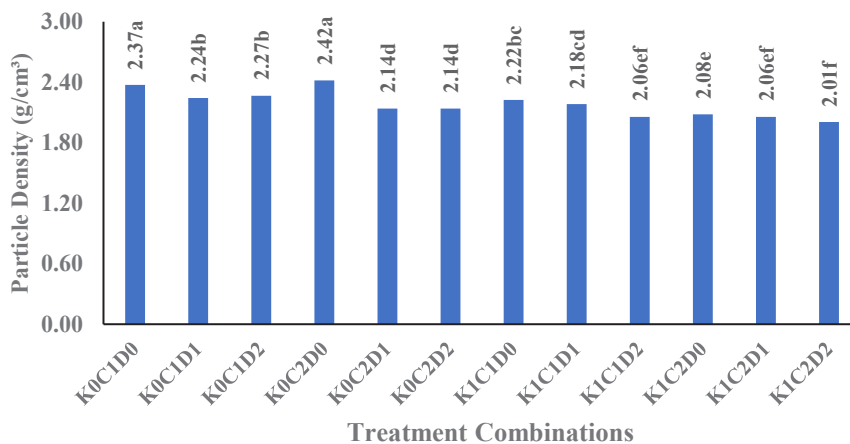


Figure 2. Effect of Treatment Combination on Particle Density

The T-test result showed that the $K_1C_2D_2$ treatment combination showed a decrease in particle density compared to the control (18.86%) and fertilizer (farmer treatment) (9.42%). Particle density values for the combination of the $K_1C_2D_2$ treatment (2.01 g/cm^3), the farmer treatment (2.23 g/cm^3), and the control treatment (2.47 g/cm^3). This shows that the combination of $K_1C_2D_2$ treatment can reduce the particle density than the control treatment, which is directly proportional to the decrease in soil bulk density. The higher the dose of biochar given the particle density will also decrease. The addition of biochar increases soil organic matter contain with a lower particle density (usually less than 1.0 g/cm^3) therefore decrease the particle density of the soil [12].

3.2.2. Effect of Treatment Combinations on physical Soil properties – porosity

The value of soil porosity can be increased by adding organic matter. The study result showed that both biochar dosages and the interaction among treatment factors were significantly affect soil porosity, while biochar application method and BiO_2 concentration were not. The highest porosity value was shown by the $K_1C_2D_2$ treatment (55.15%) (Figure 3). The porosity value of the $K_1C_2D_2$ treatment is considered high. According to Maysarah et al.[13] the soil porosity value of 50.02% - 77.81% was a high value. Soils with high porosity values have a crumbly soil structure, while low porosity soils have a massive structure. The lowest porosity value was shown by the $K_1C_2D_0$ treatment (48.10%) (Figure 3). The denser the soil can be seen from the lower the porosity value. The use of biochar at 30 tons/ha (D_2) increase soil porosity and decrease bulk density of Alfisol soils.

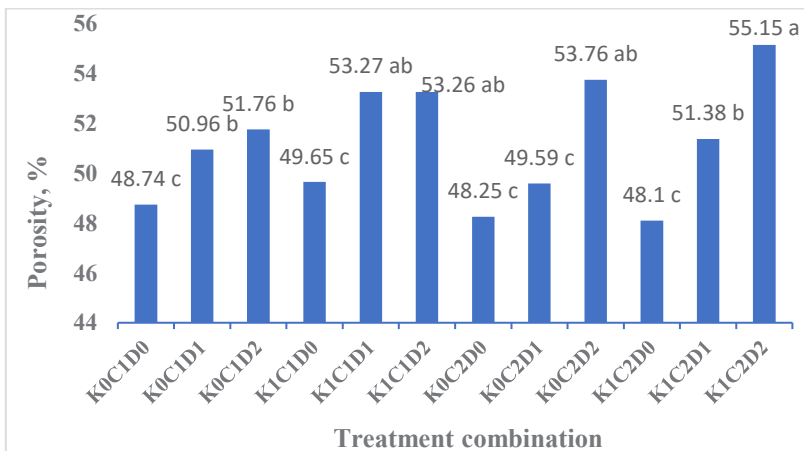


Fig. 3. Effect of Treatment Combination on Porosity

The T-test result showed that the best combination treatment ($K_1C_2D_2$) increases 37% of the porosity value than control treatment (40.32%) and 26% than NPK fertilizer treatment (farmer treatment) (43.81%). This shows that the combination between concentrations of 100% of BiO_2 and biochar at a dose of 30 tons/ha mixed evenly in the soil can increase the porosity of soil, which is also marked by a decrease of the bulk and particle density of the soil. The large number of soil aggregate formed can increase the porosity of the soil and accelerate the entry of water into the soil.

3.2.3. The effect of treatment combinations on rice yields

The result showed that there was a significant effect of the treatment combinations of BiO_2 concentration, and residual effect of biochar application method, and dosage of biochar on the rice yields (Table 3).

Table 3. The effect of treatment combinations on rice yield^{*)}

| Treatment | Plant dry weight (gr/pot) | Grain dry weight (gr/pot) |
|----------------------------------------------|---------------------------|---------------------------|
| K ₀ C ₁ D ₀ | 9.848 ^c | 3.31 ^g |
| K ₀ C ₁ D ₁ | 28.451 ^{ab} | 4.30 ^d |
| K ₀ C ₁ D ₂ | 17.868 ^{cd} | 4.24 ^d |
| K ₀ C ₂ D ₀ | 17.701 ^{cd} | 3.34 ^g |
| K ₀ C ₂ D ₁ | 24.135 ^{bc} | 3.90 ^{ef} |
| K ₀ C ₂ D ₂ | 29.025 ^{ab} | 5.23 ^b |
| K ₁ C ₁ D ₀ | 27.047 ^{ab} | 5.01 ^c |
| K ₁ C ₁ D ₁ | 27.538 ^{ab} | 3.84 ^f |
| K ₁ C ₁ D ₂ | 28.860 ^{ab} | 4.05 ^e |
| K ₁ C ₂ D ₀ | 23.730 ^d | 4.27 ^d |
| K ₁ C ₂ D ₁ | 26.286 ^b | 4.92 ^c |
| K ₁ C ₂ D ₂ | 33.911 ^a | 6.03 ^a |

^{*)}Number followed by same alphabet and same column was not significantly different by DMRT at 5% level confident.

The study result showed that the treatment combination with the best results in increasing the dry weight and dry grain weight was the $K_1C_2D_2$ treatment or the treatment with a combination of 100% BiO_2 concentration. the method of biochar application was mixed evenly in the soil. and the dose of biochar was 30 tons/ha (Table 3). The addition of biochar at a dose of 30 tons/ha can increase the productivity of rice plants. The presence of BiO_2 as a biological-fertilizers affects the increase of rice growth and yield such as the amount of grain and grain filled significantly [8]. Rhizobacteria can enhance growth of plant by various activities such as to increase nutrients availability as well as to increase it's tolerance to environmental stress like drought stress [14].

The yield was very low (3.31 – 6.03 g/pot) maybe due to the low of soil fertility of Alfisols used in the experiment as indicated by it soil physical (Table 1) and chemical (Table 4) properties. The soil has low soil fertility may because of high acidity, low organic carbon, low cation exchange capacity (CEC) and low of base saturation and heavy soil texture (high clay particle content). However, the biochar residues affect rice growth and increase yield 231.32% then control treatment in the second planting season.

Table 4. Chemical characteristic Alfisol soil used for the experiment

| No | Chemical properties | Value | Unit | Classification |
|----|---------------------|-------|-----------------------|----------------|
| 1 | pH H_2O | 4,98 | - | Acid |
| 2 | Organic-C | 0,723 | % | Low |
| 3 | CEC | 9,17 | cmol.kg ⁻¹ | Low |
| 4 | Base saturation | 19,09 | cmol.kg ⁻¹ | Low |

The results of the T-test showed that the $K_1C_2D_2$ treatment combination experienced an increase in the dry weight and dry grain weight from the control and farmers' treatment (Table 5). The use of chemical fertilizers for a long time can reduce soil fertility. So, the application of BiO_2 is an effort to reduce the use of chemical fertilizers of N, P, and K in agriculture system. Biochar residue in the $K_1C_2D_2$ treatment at a dose of 30 tons/ha can improve soil conditions and increase the availability of nutrients for plants. Adequate and available nutrients for plants will expedite the vegetative and generative processes of plants. This The use of biochar as a soil conditioner in the first season can improve soil physical properties in the second season which directly gives positive effect for rice growth and yield.

Table 5. Comparison of the best combination. control and NPK treatment on rice yield

| Treatment | Plant dry weight (gr/pot) | Grain dry weight (gr/pot) |
|-------------|------------------------------|------------------------------|
| $K_1C_2D_2$ | 33.91 ^a | 6.03 ^a |
| Control | 9.38 ^c | 1.82 ^b |
| Fertilizer | 12.55 ^b | 4.57 ^a |

^a) Number followed by same alphabet and same column was not significantly different by DMRT at 5% level confident

4 Conclusion

The residual effect of biochar dosages and application methods, biofilm biofertilizer (BiO_2) concentration and their interactions were significantly affected soil physical properties and

rice yields on Alfisol soils in the second-year growing season. The combination treatment of $K_1C_2D_2$ treatment (100% concentration of BiO_2 + applied of 30 tonha^{-1} biochar mix thoroughly to the soil a year before) reduced the soil bulk density by 28% and particle density by 19%, and increased porosity by 37% compared to the control treatment. The $K_1C_2D_2$ treatment also gives the highest plant dry weight (33.91 g) which increases by 262% to the control treatment and by 170% than the farmer treatment and the highest dry grain weight (6.03 g) which increases by 231% than the control treatment and by 32% than farmer treatment in the second growing season. The biochar mixes thoroughly to the soil give higher effect on soil physical properties than applied by spread it on the soil surface. Biochar improve Alfisols fertility by improving it porosity and reducing soil bulk and soil particle density so the rice grows better and give higher yield. Besides, biochar increases carbon sequestration by its long-time persistence in the soil so it supports climate change mitigation and sustainable agriculture. Based on the results can be suggested to apply biochar by mix it thoroughly to the soil with the dosage lower than if it is spread to the soil surface, maybe every 2 years or more.

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