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Effect of Soil Amendments Derived from Agricultural Biomass on Rice Yield and Soil Fertility in a Paddy Field of South Korea †

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Abstract: The objective of this study was to compare the effects of biochar and straw applications on rice yield and soil fertility during a three-year period. The three treatment conditions were: BC (barley straw biochar 2000 kg ha^{-1}), BS (barley straw 2000 kg ha^{-1}), and BC + BS (barley straw biochar 1000 kg ha^{-1} + barley straw 1000 kg ha^{-1}, respectively). Each treatment area was separated by an untreated control (CN) area. During the study, rice yields for CN, BC, BS, and BC + BS treatments ranged on average from 473 to 515, 497 to 532, 516 to 528, and 583 to 602 g m^{-2}, respectively. Among the treatments, the BC + BS treatment produced the highest average rice yield and the BC + BS rice yield was stable during the three-year study. The soil changes after the final rice harvesting were different in the BC and BS application areas. Soil bulk density and pH were improved in all treatments except the CN treatment when compared to those of raw soil. The SOC and TN content after BC application increased by 0.56 and 0.08 g kg^{-1}, respectively, compared to those of the CN soil, while those after BS and BC + BS application increased by 0.89–1.36 and 0.16–0.3 g kg^{-1}, respectively. The soil CEC values after BC, BS, and BC + BS treatment were 0.55, 0.37, and 0.49 cmol$_c$ kg^{-1} higher than those in the CN, respectively. Therefore, such an approach can reduce the application of inorganic fertilizer, thereby encouraging the development of sustainable organic agriculture.

Keywords: rice yield; soil fertility; barley straw; barley straw biochar; sustainable organic agriculture

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1. Introduction

Rice is the most important, major food resource in most Asian countries including South Korea. However, the rice cultivation area is decreasing as rice prices have fallen after the rice tariffication law (Jeong et al., 2021). As a result, rice production in South Korea in 2016 was 14.6% lower than that in 2009. In addition, environmental problems in agriculture are increasing in seriousness due to the excessive use of inorganic fertilizers, strong rainfall in the summer, and frequent tilling, which combine to bring about a deterioration in the physical properties of the soil and increased CH_4 and N_2O emissions (Kang et al., 2016; Kang et al., 2018). To overcome this, researchers have studied the application of related organic materials such as straw, green manure crops, and compost, but there is little research on the use of biochar in South Korea.

Biochar is a material obtained after pyrolyzing biomass under anaerobic conditions, and this true carbon-negative method has attracted much attention as a means of converting plants to biochar and then incorporating it in the soil (Lehman, 2007; Major, 2010). Biochar has been reported to be useful in many environmental aspects such as carbon sequestration, climate change response, energy production, soil improvement, and waste management (Yamato et al., 2006; Case et al., 2012; Angst et al., 2014).

Barley straw is a good biomass for improving the physical properties of the soil, but its incorporation into the soil after a barley harvest can lead to an increase in organic acids and nitrogen starvation. This phenomenon occurs because the harvesting period of barley and the rice transplanting period are similar due to the characteristics of the cropping system in South Korea. Hence, the application of biochar derived from barley straw in terms of efficient recycling of resources and environmental conservation is expected to be advantageous for the agricultural environment. Therefore, the objective of this study was to compare the effects of biochar and straw applications on rice yield and soil properties during a three-year period. The results obtained in this study can be applied to develop a biochar application method for use in a rice cultivation environment in the future.

2. Materials and Methods

The raw soil was a sandy loam with a bulk density of 1.31 Mg m^{-3}, porosity of 56.3%, pH of 5.87, and cation exchange capacity (CEC) of 6.64 $cmol_c$ kg^{-1}.

Barley straw (BS) was used as the raw feedstock to produce barley straw biochar (BC). The furnace controller was programmed to drive the internal biomass chamber to a temperature of 400 °C at a rate of 3 °C min^{-1}, after which the peak temperature was sustained for 1 h. The pH, total nitrogen (TN), P_2O_5, K_2O, and CEC of the BC used in the experiment were 7.72, 0.42%, 0.30%, 1.41%, and 21.7 $cmol_c$ kg^{-1}, respectively; in addition, the BC was mostly comprised of C (>70%).

The field experiment was conducted to evaluate and compare the effects of BC and BS applications on rice yield, soil properties, and GWP under paddy field conditions at Sepung-ri (34°56′33″ N, 127°33′56″ E), Gwangyang-eup, Gwangyang-si, Jeollanam-do, South Korea. Figure 1 shows the temperatures and precipitation recorded at the paddy field during the experimental period.

The field experiment was conducted during the rice cultivation seasons of 2015–2017. The three treatment conditions were: BC (barley straw biochar 2000 kg ha^{-1}), BS (barley straw 2000 kg ha^{-1}), and BC + BS (barley straw biochar 1000 kg ha^{-1} + barley straw 1000 kg ha^{-1}, respectively). Each treatment area was separated by an untreated control (CN) area. BC was applied once in 2015, whereas BS was applied every year. In this study, no inorganic fertilizers were used during rice cultivation, completely dried BC and BS were used. Water management in the paddy field was carried out through irrigation when rice was transplanted, and drainage was performed 3 weeks before the rice harvest.

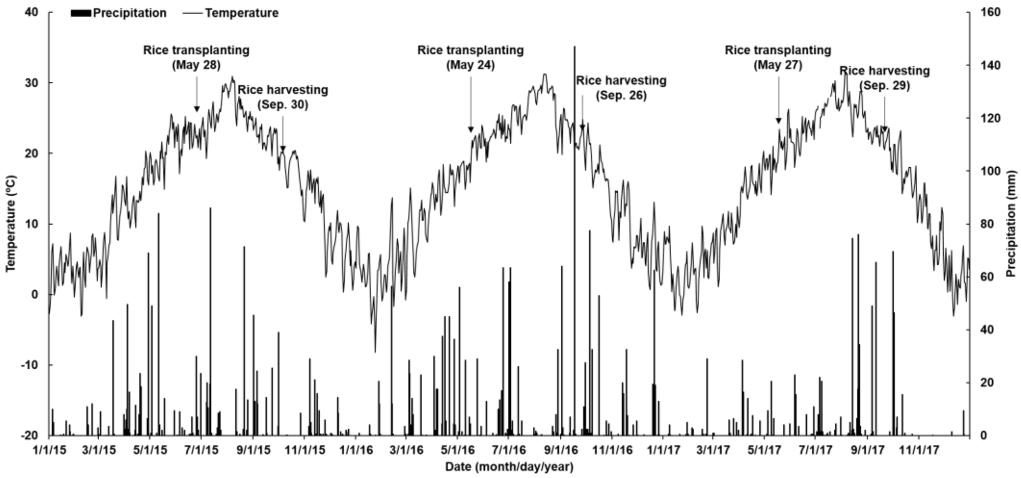

Figure 1. Mean daily precipitation and air temperature during the rice cultivation period.

After rice harvesting, soil samples were collected from the surface layer (15 cm depth) using a soil sampler (auger) in each treatment area and were then air-dried and passed through a 2 mm mesh. Randomized soil samples were obtained from each plot, and a total of 15 soil samples were collected under each treatment condition. In this study, all soil analyses were performed using the methods described in NIAST (2000).

3. Results and Discussion

The rice yields under each of the treatment conditions during the three-year study were significantly affected by the application type (Figure 2). Rice yields were significantly different among treatments, and the effect was particularly evident in 2017. During the study, rice yields for CN, BC, BS, and BC + BS treatments ranged on average from 473 to 515, 497 to 532, 516 to 528, and 583 to 602 g m^{-2}, respectively. Among the treatments, the BC + BS treatment produced the highest average rice yield and the BC + BS rice yield was stable during the three-year study. Under the BS treatment condition, rice yield tended to increase year by year, with the final yield (year 3) showing an increase of 2.4% from that in year 1. On the other hand, under the BC treatment condition, the rice yield tended to decrease gradually, and in 2017, the rice yield decreased by about 6.7% from that in 2015. In this regard, the application of a BC + BS mixture appears to be a very positive combination for maintaining stable rice production and soil quality. In the BC + BS treatment, rice productivity was maintained at 582.6–601.6 g m^{-2} during the three-year study, higher than that from the other treatments. The BC + BS treatment produced relative increases of 11.4–15.1% in 2015, 8.65–14.6% in 2016, and 13.9–27.1% in 2017 compared to those of CN, BC, and BS treatments. The effect of increasing rice yield due to BC application decreased in 2017, but BS application results in a gradual increase in the rice yield. Considering this, it seems that the advantages of BC and the advantages of BS complement each other in the BC + BS treatment condition. It was showed that BS compensates for insufficient nutrients in BC, and BC retains nutrient elution by BS. These results agree with those in previous reports that BC application combined with additional nutrients can increase the overall nutrient availability to agricultural soil (Agegnehu et al., 2016; Chan et al., 2007; Yamato et al., 2006). Therefore, our results indicate that the positive effect of BC + BS application on rice productivity is the result of an improvement in the quality of soil over the three-year rice cultivation period, although some differences were seen depending on treatment conditions.

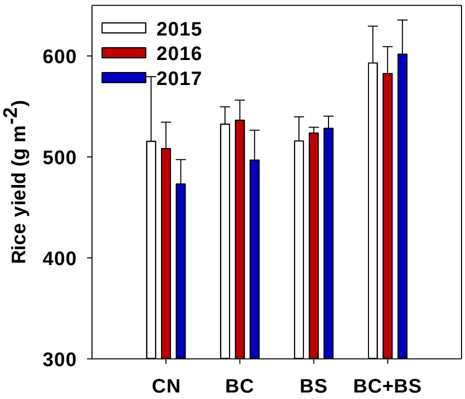

Figure 2. Changes in rice yield from each of the tested areas.

Table 1 shows the changes in soil physicochemical properties following biochar and straw treatments and after the final rice harvesting. The range of soil property values after rice harvesting were as follows: soil bulk density between 1.25 and 1.33 Mg m^{-3}, pH between 5.78 and 5.96, EC between 0.18 and 0.20 dS m^{-1}, SOC content between 9.04 and 10.4 g kg^{-1}, TN content between 1.39 and 1.69 g kg^{-1}, Avail. P_2O_5 content between 55.5 and 60.0 mg kg^{-1}, and CEC between 6.25 and 6.80 $cmol_c$ kg^{-1}. The soil changes after the final rice harvesting were different in the BC and BS application areas. Soil bulk density and pH were improved in all treatments except the CN treatment when compared to those of raw soil. The SOC and TN content after BC application increased by 0.56 and 0.08 g kg^{-1}, respectively, compared to those of the CN soil, while those after BS and BC + BS application increased by 0.89–1.36 and 0.16–0.3 g kg^{-1}, respectively. The soil CEC values after BC, BS, and BC + BS treatment were 0.55, 0.37, and 0.49 $cmol_c$ kg^{-1} higher than those in the CN, respectively.

Table 1. Soil properties of experimental treatment sites after rice harvesting.

Treatment	Bulk Density	pH	EC	SOC	TN	Avail. P_2O_5	CEC
	(Mg m^{-3})	(1:5H_2O)	(dS m^{-1})	(g kg^{-1})		(mg kg^{-1})	($cmol_c$ kg^{-1})
CN	1.33 b [1]	5.78 a	0.18 a	9.04 a	1.39 a	56.5 ab	6.25 a
BC	1.26 a	5.94 b	0.19 bc	9.60 ab	1.47 b	55.5 a	6.80 b
BS	1.25 a	5.93 b	0.18 ab	10.4 b	1.69 d	58.6 ab	6.62 ab
BC + BS	1.26 a	5.96 b	0.20 c	9.93 ab	1.55 c	60.0 b	6.74 b

[1] Different letters within the same column indicate significant differences, as determined by Tukey's test with $p < 0.05$.

The correlation among rice yield and the major soil characteristics in the study's paddy field during three-year study are shown in Figure 3. The results show a synergy between BC and BS, achieving the increasing rice productivity among all treatments during three year. This is demonstrated by the results obtained through the application of BC and the appropriate application of BS.

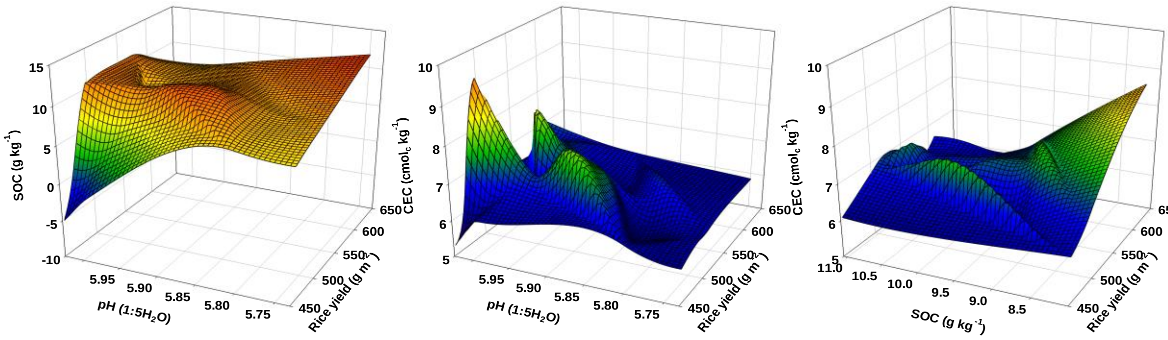

Figure 3. Correlations among rice yield and major soil characteristics.

4. Conclusions

Based on our results, the utilization of BC and BS in rice paddy fields is effective in maintaining or increasing soil quality and the rice crop growth capacity of rice paddy soils. The single BC alone application had a disadvantage in that it resulted in inconsistent rice production, but, a combination of a single BC treatment and annual BS supplementation produced the greatest increase in rice yield. Therefore, taking into consideration the other benefits of BC and BS applications such as improving soil quality and replacing the use of inorganic fertilization, we recommend using a combined application of BC and BS. Such an approach can reduce the application of inorganic fertilizer, thereby encouraging the development of sustainable organic agriculture.

Institutional Review Board Statement:

Informed Consent Statement:

Data Availability Statement:

References

1. Agegnehu, G.; Nelson, P.N.; Bird, M.I. The effects of biochar, compost, and their mixture and nitrogen fertilizer on yield and nitrogen use efficiency of barley grown on a Nitisol in the highlands of Ethiopia. *Sci. Total Environ.* **2016**, *569–570*, 869–879.
2. Angst, T.E.; Six, J.; Reay, D.S.; Sohi, S.P. Impact of pine chip biochar on trace greenhouse gas emissions and soil nutrient dynamics in an annual ryegrass system in California. *Agric. Ecosyst. Environ.* **2014**, *191*, 17–26.
3. Case, S.D.C.; McNamara, N.P.; Reay, D.S.; Whitaker, J. The effect of biochar addition on N_2O and CO_2 emissions from a sandy loam soil—The role of soil aeration. *Soil Biol. Biochem.* **2012**, *51*, 125–134.
4. Chan, K.Y.; Zwieten, L.V.; Meszaros, I.; Downie, A.; Joseph, S. Agronomic values of green waste biochar as a soil amendment. *Aust. J. Soil Res.* **2007**, *45*, 629–634.
5. Jeong, O.Y.; Park, H.S.; Baek, M.K.; Kim, W.J.; Lee, G.M.; Lee, C.M.; Bombay, M.; Ancheta, M.B.; Lee, J.H. Review of rice in Korea: current status, future prospects, and comparisons with rice in other countries. *J. Crop Sci. Biotechnol.* **2021**, *24*, 1–11.
6. Kang, S.W.; Kim, S.H.; Park, J.W.; Seo, D.C.; Ok, Y.S.; Cho, J.S. Effect of biochar derived from barley straw on soil physicochemical properties, crop growth, and nitrous oxide emission in an upland field in South Korea. *Environ. Sci. Pollut. Res.* **2018**, *25*, 25813–25821.
7. Kang, S.W.; Park, J.W.; Seo, D.C.; Ok, Y.S.; Park, K.D.; Choi, I.W.; Cho, J.S. Effect of biochar application on rice yield and greenhouse gas emission under different nutrient conditions from paddy soil. *J. Environ. Eng.* **2016**, *142*, 04016046.
8. Lehmann, J. A handful of carbon. *Nature* **2007**, *447*, 143–144.
9. Major, J. *Guideline on Practical Aspects of Biochar Application to Field Soil in Various Soil Management Systems*; International Biochar Initiative: Canandaigua, NY, USA, 2010
10. NIAST. *Methods of Soil and Plant Analysis, National Institute of Agricultural Science and Technology*; RDA: Suwon, Korea, 2000.
11. Yamato, M.; Okimori, Y.; Wibowo, I.F.; Anshori, S.; Ogawa, M. Effects of the application of charred bark of Acacia mangium on the yield of maize, cowpea and peanut, and soil chemical properties on South Sumatra, Indonesia. *Soil Sci. Plant Nutr.* **2006**, *52*, 489–496.