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APPLICATION OF EFFECTIVE MICROORGANISMS AND BIOCHAR SUPPRESS THE SOIL-TO-PLANT TRANSFER OF RADIOACTIVE CESIUM DURING THE CONTINUOUS CROPPING OF KOMATSUNA

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Abstract. Agricultural land contaminated with radioactive cesium (Cs) in Fukushima Prefecture has been treated with potassium fertilizer as a means to suppress the transfer of radioactive Cs from soil to agricultural crops. Two additional methods for Cs control, Effective Microorganisms (EM･1®) and rice-husk-derived biochar have been studied in the present work. EM･1®, a microbial inoculant used as a soil improver, is reported to suppress the transfer of radioactive Cs from soil to agricultural crops and grass when used alone or as EM fermented compost. Further, it has been reported that rice-husk-derived biochar showed high adsorption rates with respect to the radioactive Cs in irrigation water, thereby suppressing its availability to plants. Rice-husk-derived biochar is an attractive option for the suppression of the transfer of radioactive Cs from soil to agricultural crops and grass as it is inexpensive and widely available in the rural areas of Japan. Biochar not only improves the physical properties of the soil but also enhances the activity of soil microorganisms. Furthermore, as it is not easily decomposed; therefore, it is maintained in the soil for a long time. In this work, we have investigated whether the application of rice-husk-derived biochar and EM together enhance the suppression of the transfer of radioactive Cs from soil to agricultural crops during three continuous croppings of Komatsuna (*Brassica rapa* var. perviridis). Experimental results show that compared with the untreated plot, the application of biochar or EM alone significantly suppressed the soil-to-plant transfer of radioactive Cs in the test plot. Additionally, the combined use of the rice-husk-derived biochar and EM improved the repressive effect over each successive cropping. Finally, a higher suppressive effect was observed owing to the combined application of biochar and EM during the continuous cropping of plants.

Introduction

Research on the countermeasures against radioactive contamination utilizing Effective Microorganisms (EM･1®) began at the Institute of Radiobiology (IRB), National Academy of Sciences of Belarus in the latter half of the 1990s. It has been reported that application of effective microorganisms (hereafter referred to as EM) not only increases the yield of agricultural crops but also suppresses the transfer of radioactive cesium (Cs) and strontium (Sr) from soil to crops and grasses [1]. Based on these findings, we have been investigating the effectiveness of EM remediation in Fukushima Prefecture since 2011 [2–4]. Another remediation prospect is rice-husk-derived biochar (hereafter referred to as biochar), reported to remove radioactive Cs contained in irrigation water by filtration, the mechanism of which is thought to be due to its high adsorption rate to radioactive Cs [5]. Biochar is inexpensive and easy to obtain in the rural areas of Japan; it is excellent at improving water-holding capacity, permeability, and breathability of the soil. Further, it enhances the activity of soil microorganisms. Furthermore, its resistance to decomposition results in its long-term presence in soil. In light of these observations, the planter test was conducted over three continuous croppings of Komatsuna (*Brassica rapa* var. perviridis) to evaluate if the suppression of radioactive Cs transfer from soil to plants is enhanced by the combined application of biochar and EM.

Materials and methods

Four treatment plots were used: untreated (control), EM, biochar, and EM + biochar. Komatsuna was seeded at 20 plants per planter with contaminated soil ($^{134}Cs + ^{137}Cs$=~7,000 Bq/kg). A base chemical fertilizer, 15-15-15, was applied to all plots at a rate of 14 g/planter and 7 g/planter at the first and third cropping, respectively. In the plot where biochar was applied, biochar was mixed with 5% of soil (v/v) only at the first cropping. In the plot to which EM was applied, a 1% dilute solution of EM was irrigated suitably through all three croppings. At the same time, tap water was irrigated in the control plot and biochar plot. The first cropping was cultivated in the summer (seeded on June 11, 2017, harvested after 25 days), the second cropping in the autumn (seeded on October 17, 2017, harvested after 45 days), and the third in April (seeded on March 29, 2018, harvested 39 days). After measuring the fresh weight of the above-ground plant at the time of harvest, the concentration of radioactive Cs in the Komatsuna plant and soil was measured using geranium semiconductor and sodium iodide (NaI) scintillation detectors, respectively.

Results and Discussion

Radioactive Cs concentration ($^{134}Cs + ^{137}Cs$) in Komatsuna was significantly lower in biochar-, EM-, and EM + biochar-treated plots compared with the control plot in all three cropping seasons (Fig. 1). With respect to the transfer factor (TF), it was significantly decreased in the EM and EM + biochar plots compared with the control plot at the first cropping (Table 1). The second and third cropping showed significant decreases in the biochar, EM, and EM + biochar plots (Table 1). These results highlight that more TF reduction was achieved by EM + biochar in the first and second cropping than either EM or biochar alone. The reduction rate in the TF value between the first and third cropping changed from 11.8% to 52.8% in the biochar plot, from 21.6% to 81.5% in the EM plot, and from 27.1% to 79.1% in the EM + biochar plot. Therefore, the reduction rate increased from 3 to 4.5 times from the first to the third cropping (Table 1).

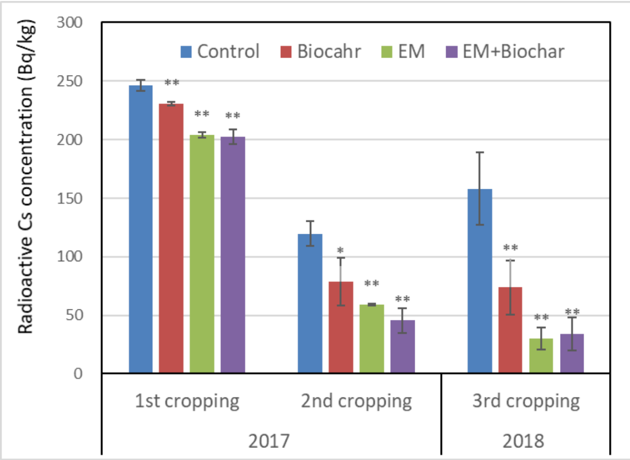

Fig. 1 Effect of EM and Biochar on radioactive Cs concentration in Komatsuna plant at different cropping season.
Values are expressed as mean ± SD (n = 3)
*and** indicate significance at α = 0.05 and 0.01, respectively

The exchangeable potassium content (mg/100-g dry soil) in the soil at the first cropping was similar between the EM and EM + biochar plot (statically insignificant) and was highest in the biochar plot. At the second and third cropping, exchangeable potassium content was significantly higher in the biochar, EM, and EM + biochar plots (Fig.2). Although there was not a significant increase in exchangeable potassium content at the first cropping in EM or EM + biochar plots, it was significantly increased at the second and third cropping, suggesting that continuous EM application may function to increase exchangeable potassium content in the soil.

Table 1 Effect of Biochar and EM on the TF of radioactive Cs from soil to Komatsuna plant at the different cropping season.

Treatments	1st cropping (Summer)		2nd cropping (Autumn)		3rd cropping (Spring)	
	TF	Reduction (%)	TF	Reduction (%)	TF	Reduction (%)
Control	0.0398±0.0027	–	0.0177 ± 0.0018	–	0.0254 ± 0.0045	–
Biochar	0.0351±0.0011^{ns}	11.8	0.0121 ± 0.0029*	31.6	0.0120 ± 0.0038**	52.8
EM	0.0312±0.0022*	21.6	0.0090 ± 0.0002**	49.2	0.0047 ± 0.0015**	81.5
EM + biochar	0.0290±0.0039**	27.1	0.0073 ± 0.0018**	58.8	0.0053 ± 0.0019**	79.1

*and** indicate significance at α = 0.05 and 0.01, respectively

Exchangeable potassium is known to prevent the absorption of radioactive Cs from plant roots. Recently, soil application of biochar has been reported to increase concentrations of exchangeable potassium and suppress the transfer of radioactive Cs to plants [6], and results from this experiment are consistent with that report. However, since radioactive Cs transfer was suppressed at the first cropping in EM and EM + biochar plots, where the exchangeable potassium content was similar to the control plot, exchangeable potassium content cannot be the only the mechanism responsible for the observed suppression. According to Nikitin *et al.*, application of EM on soil reduces the rate of water-soluble and ion-exchangeable Cs that can be easily absorbed into the plant roots [7]. Therefore, it is plausible that such a mechanism could have been present in the suppression of radioactive Cs transfer in this study as well. In addition, the combined use of biochar and EM together showed the most significant suppression of the transfer of radioactive Cs to the Komatsuna plant, and this suppressive effect was further improved under continuous cropping. Finally, the sustained application of biochar promotes the physical adsorption to radioactive Cs, the supply of exchangeable

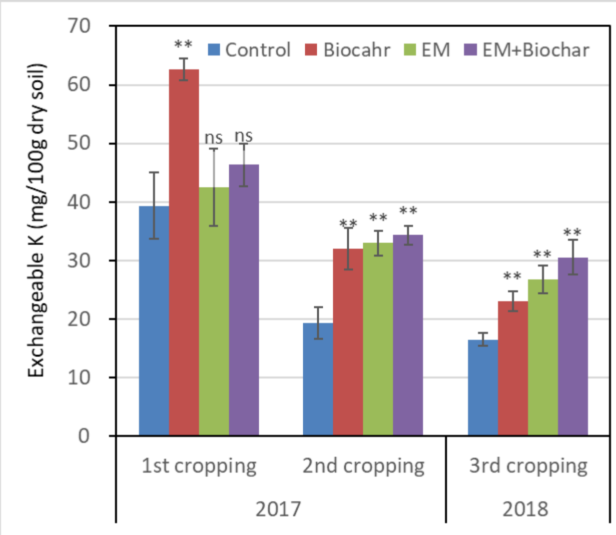

Fig. 2 Exchangeable potassium content in the soil at different cropping season.
**: indicate significance at α = 0.01 in comparison to the Control

potassium, and the activity of soil microorganisms, thereby enhancing the effect of suppressing the transfer of radioactive Cs through the application of EM. This suppression is thought to exert cumulative, synergistic effects during continuous cropping.

Conclusion

The combined use of rice-husk-derived biochar and EM with the continuous cropping of Komatsuna further improves the effect of suppressing the soil-to-plant transfer of radioactive Cs.

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