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Research Article

Influence of Effective Microorganisms on the Activity of ^{137}Cs in the Soil Contaminated due to the Accident on the Chernobyl NPP

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Abstract

Microbiological soil improvers have a potential as a tool for regulation transfer of induced radioisotopes and other pollutants into crops. During the development of a method using effective microorganisms (EM) to reduce the soil-to-plant transfer of ^{137}Cs on land contaminated with radioactive cesium, an unexpected effect of EM on the reduction of the ^{137}Cs activity in soil samples was observed. Laboratory experiments were then conducted to evaluate the impact of EM and fermented organic fertilizer (EM Bokashi) on the ^{137}Cs activity in soil samples to investigate this observation. The experimental results indicate an increase in the ^{137}Cs decay rate of up to 4 times the usual decay rate corresponding to the half-life of ^{137}Cs, which is 30.17 years. Our results suggest that EM accelerates the radioactive decay of ^{137}Cs in soil.

Keywords: Cesium-137, Effective microorganisms, Radioactive decay, Radioactive isotopes, Soil

1. Introduction

Nuclear accidents are highly undesirable but potential events in the process of operating nuclear power plants. Fukushima, Chernobyl, and other accidents have caused considerable areas to become contaminated with radioactive isotopes [1,2]. One of the most critical and challenging tasks following such accidents is the decontamination of man-made radioisotopes in the soil. Current methods of decontamination are expensive and ineffective for large areas [3,4]. Therefore, it is important to find innovative technologies to clean contaminated areas.

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One option to economically use farmlands contaminated with ^{137}Cs is to substantially increase the application of potassium chemical fertilizers [5,6]. However, this approach may lead to a decrease in economic efficiency compared to non-contaminated areas, as well as adverse ecological effects [7,8]. Consequently, it is critical to develop new approaches to regulate the uptake of radioactive isotopes by plants.

Soil microorganisms can affect the bioavailability of man-made radioisotopes in the soil [9,10]. Our research team (Institute of Radiobiology of the National Academy of Sciences of Belarus and EM Research Organization Inc., Japan) has investigated the possibility of using microbiological soil improver additives to decrease ^{90}Sr and ^{137}Cs transfer into crops [11–15]. Toward this goal, we tested mixtures of microorganisms known as effective microorganisms (EM). An EM is a people-friendly and environmentally safe microbial product that achieves synergistic effects by combining beneficial microorganisms that exist in nature, such as lactic acid bacteria, yeast, and phototrophic bacteria.

EM was initially developed in 1982 by Professor Teruo Higa to improve soils [16]. Following multiple studies, EM has now been in use for over 25 years in numerous fields, including sustainable agriculture, animal husbandry, and environmental conservation [17]. In addition, EM is distributed in more than 100 countries worldwide.

The results of our experiments confirm that EM and EM Bokashi reduce the transfer of ^{137}Cs and ^{90}Sr in corn, barley, lettuce, and vegetables [12,13]. We suggested two mechanisms for this effect: a decrease in the bioavailable (soluble and exchange) forms of the radioisotopes in soil under the impact of EM, and an increased migration of these radioisotopes downward in the soil profile. In our attempts to test these hypotheses, we observed an imbalance in the ^{137}Cs in the experimental system. After checking all the possible ways of losing radionuclides and all the sources of error, we suggest another hypothesis: the application of EM to soil increases the rate of ^{137}Cs radioactive decay. This study is devoted to confirming this hypothesis.

2. Materials and Methods

2.1. Soil samples

Sod-podzolic soil from the Chernobyl exclusion zone with a ^{137}Cs activity of approximately 7 kBq/kg was used in this experiment. The soil samples were dried and sieved through a 1-mm sieve. The entire volume of the soil was evenly mixed to provide a homogenous distribution of the ^{137}Cs activity and the physical and chemical properties of the soil. The soil was placed in a 100-ml container and mixed with different concentrations of EM or EM Bokashi.

2.2. Effective microorganisms (EM)

The EM (EM1®) used in the experiments was supplied by EM Research Organization Inc., Japan. For application to soil, the EM was prepared in two forms: a liquid form (an EM solution) and a solid form (EM Bokashi). The EM solution was prepared by mixing EM with sugar cane molasses and water with a ratio of 1:1:20 (v/v). The mixed ingredients were transferred to a plastic container, which was tightly closed with a plastic lid and incubated for 20–25 days at $35\pm 2^{\circ}$C to promote fermentation. The EM solution was considered ready for use when it produced a pleasant fermentation smell and the pH was below 3.5. In Japanese, bokashi refers to fermented organic matter. EM Bokashi is an anaerobic fermentation product made from solid agricultural byproducts inoculated with EM. In EM Bokashi, organic matter serves as a growth medium for the microorganisms and provides a suitable microenvironment for EM in the soil. The EM Bokashi was prepared according to the method described in [16]. A mixture of 0.4 L of EM, 0.4 L of sugar cane molasses, and 4 L of chlorine-free tap water was added to 10 kg of wheat bran and mixed until homogeneous. The mixture was then placed in a plastic bag, which was hermetically sealed and kept under dark and warm conditions for 30 days. After the 30-day fermentation period, the EM Bokashi had a sweet-sour smell. The EM Bokashi was dried at room temperature prior to application.

2.3. Experimental layout

The different conditions of the experiment were as follows:

(1) Absolute control (dry soil).
(2) Positive control (wet soil).
(3) Positive control 2 (wet soil + organic matter (OM)).
(4) EM-1 1% + molasses.
(5) EM-1 5% + molasses.
(6) EM-110% + molasses.
(7) EM Bokashi 1%.
(8) EM Bokashi 5%.
(9) EM Bokashi 10%.
(10) EM-1 10%

There were three types of control experiments: dry soil (absolute control); wet soil with the addition of water (positive control); and wet soil with the addition of water, molasses, and wheat bran as organic matter (OM) (positive control 2). The experimental treatments were 1%, 5%, and 10% EM with molasses (Mo) and 1%, 5%, and 10% EM Bokashi. A treatment with EM but without molasses was also performed. Different exposure periods to the experimental treatments were set to 6, and 18 months. Each treatment for each exposure period was repeated 15 times.

EM Bokashi was applied to the soil only at the beginning of the experiment. The EM, water, and molasses were added to the soil at the beginning of the experiment and every six weeks. Before adding the solutions, the containers were opened to allow for natural water evaporation. For the remainder of the time, the containers were sealed.

Soil samples were kept at room temperature (20–24°C) under natural light conditions.

2.4. Measurements

The ^{137}Cs activity was measured before and after each period of the experiment. The activity of the samples was determined in the containers where the samples were kept. The samples ware positioned precisely on the same axis as the detector to obtain a more stable result.

A GX 2018 gamma-spectrometry complex CANBERRA with a coaxial germanium detector with an extended energy range was used for the measurements. The gamma-spectrometry measurement time was 600 s. The relative error in the measurements of the ^{137}Cs activity was less than 0.5%.

At the time of analysis, water was added to the samples to return the sample weight to its value at the time of the first measurement.

3. Results and Discussion

Table 1 shows the ^{137}Cs activity for each treatment at the beginning and end of the experiments during the 6, 12, and 18 months exposure periods. The ^{137}Cs activities at the beginning of the experiment were in the range of 692–929 Bq. Each sample in the experiment included precisely 100 g of evenly homogenized soil; however, we could not obtain a lower level of variability in these naturally contaminated samples.

After 6 months, the ^{137}Cs activity in the variants decreased to 686–924 Bq, and after 12 months, it decreased to 686–919 Bq. This is equivalent to 0–4.4% and 1.0–5.9% decreases with respect to the initial activity, respectively.

In the 18-month experiment, the ^{137}Cs activity in the samples decreased to 720–903 Bq. Therefore, the measured ^{137}Cs activities in the samples decreased by 0.81–4.75% after 18 months.

Table 1. The ^{137}Cs activity in the samples after different exposure periods.

Treatments	6-month exposure		12-month exposure		18-month exposure	
	May 2016	Nov. 2016	May 2016	May 2017	May 2016	Nov. 2017
Absolute control (dry soil)	924±30	924±32	929±57	919±47	890±24	883±33
Positive control (wet soil)	692±51	686±51	694±27	686±23	743±59	720±63
Positive control 2 (wet soil + molasses,and wheat bran)	845±31	824±30	842±18	811±15	836±25	812±25
EM-1 1% + molasses	912±20	893±20	916±22	861±23	917±25	873±26
EM-1 5% + molasses	901±15	879±21	915±25	886±20	904±23	880±15
EM-1 10% + molasses	898±40	860±44	901±48	869±20	916±32	874±32
EM-bokashi 1%	929±41	901±39	913±36	862±29	908±45	865±47
EM-bokashi 5%	918±29	877±26	880±34	829±32	886±25	845±21
EM-bokashi 10%	854±48	830±36	901±48	869±37	852±43	825±35
EM-1 10%	904±24	886±23	912±32	887±37	917±19	903±22

The decrease in the ^{137}Cs activity after 6 months due to radioactive decay is 1.1% because the half-life of the ^{137}Cs radioisotope is 30.17 years. The reduction rates in the dry soil and wet soil control groups were nearly the same as the usual decay rate (Fig. 1).In all the other treatment groups, the rates were higher than the usual decay rate. In particular, a significant difference was detected in the wet soil with OM, 5% and 10% EM, and 1%, 5%, and 10% EM Bokashi treatments. The difference between these treatments and the usual decay rate was 1.3–3.3% (Fig. 1).

The usual decrease in the ^{137}Cs activity for 12 months is 2.3%. The actual reduction rates were higher than the usual decay rate for all treatments except the dry soil and wet soil treatments (Fig. 2). In addition, there were significant differences in the reduction rates of the wet soil with organic matter, 1% EM, and 1% and 5% EM Bokashi treatments compared to the usual decay rate. The difference between these treatments and usual decay rate was 1.3–3.7%.

The usual decrease in the ^{137}Cs activity for 18 months is 3.4%, which is shown by the dashed line in Fig. 3. The 1% EM and 1% and 5% EM Bokashi treatments had a significantly higher reduction rate than the usual decay rate (Fig. 3). The difference between these treatments and the usual decay rate was 1.2–1.4%.

Therefore, in the 6, 12, and 18 months exposure experiments, the 1% and 5% EM Bokashi treatments consistently had significantly higher reduction rates than the usual decay rate. While not consistent, the 1% EM treatment had a significantly higher reduction rate for the 12 and 18 months exposure experiments. Therefore, the application of EM and EM Bokashi to soil appears to have an impact on the radioactive decay rate.

The physical half-life of radionuclides is known to be very stable. Therefore, this observation is counter to the current understanding of radionuclides. However, similar results have been confirmed in another experiment and in field observations.

A similar laboratory experiment was conducted in Fukushima [18]. In the 690 days of the experiment, the reduction in the ^{137}Cs activity in soil treated with EM with molasses was confirmed to be greater than the usual decay value.

Monitoring of the $^{134+137}$Cs contamination of soils in paddy fields with long-term (more than 20 years) and short-term applications of EM in the Fukushima area shows significantly more rapidly decreasing radioisotope activities compared to the physical decay value [19]. Furthermore, the rate of decreasing radioactive cesium concentration in the soil on another farm was higher in a field treated with EM-fermented cow manure compost than in an adjacent area using a chemical fertilizer [20].

According to the conventional scientific paradigm, the rate of radioactive decay is not affected by operations such as heating, the addition of water, or the addition of organic matter. It should only decrease exponentially according to the law of radioactive decay. However, according to the hypothesis of bio-transmutation [21–23], some microorganisms may alter the rate of radioactive decay.

Vysotskii and Kornilova [21] have indicated that microorganisms can accelerate the radioactive decay rate. He

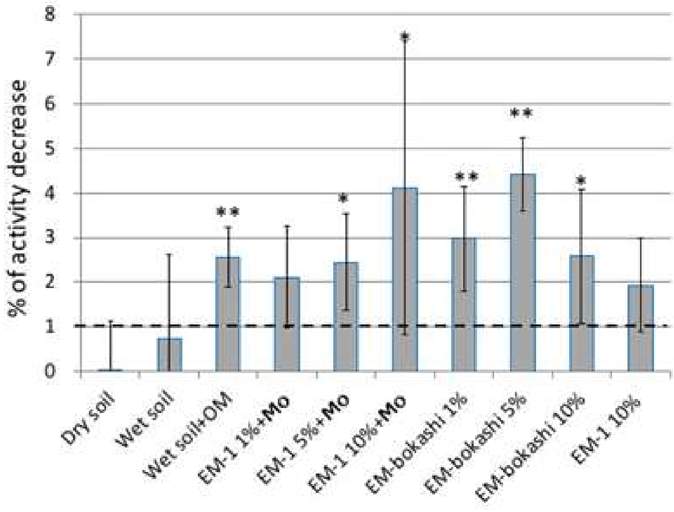

Figure 1. The reduction rate of the ^{137}Cs activity in soil samples after the 6-month exposure treatments (mean±confidence interval, $p = 0.054$). The dashed line indicates the calculated decrease in the activity due to radioactive decay with a half-life, $T_{1/2}$, of 30.17 years. * and ** indicate significant differences with respect to the calculated value at $p < 0.05$ and $p < 0.01$, respectively.

observed an increased decay rate of ^{137}Cs in experiments with an MCT (microbial catalyst transmutator) under the presence of different additional salts and propose his explanation of it. He believes that nuclear transmutations in mild

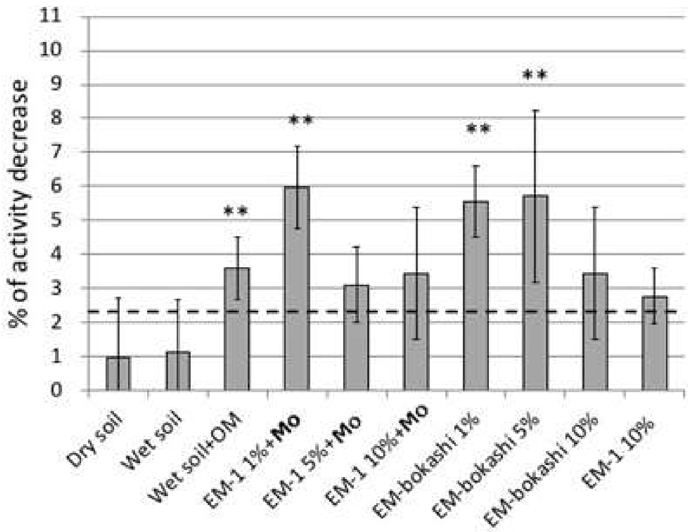

Figure 2. The reduction rate of the ^{137}Cs activity in soil samples after the 12-month exposure treatments (mean±confidence interval, $p = 0.05$). The notation is the same as in Fig. 1.

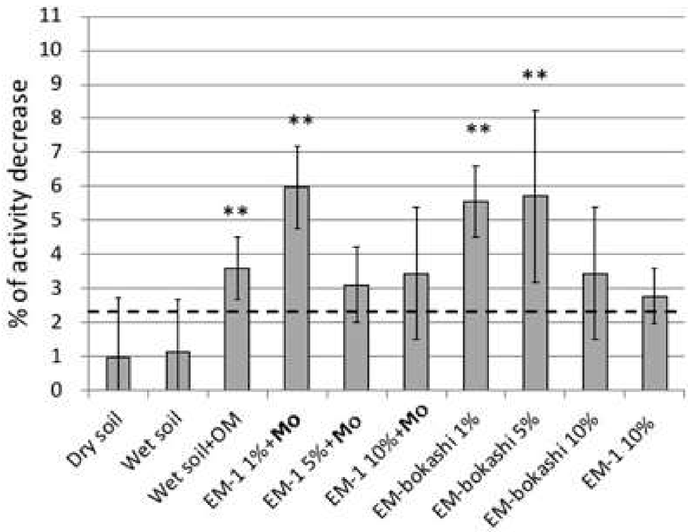

Figure 3. The reduction rate of the ^{137}Cs activity in soil samples after the 18-month exposure treatments (mean±confidence interval, $p = 0.05$). The notation is the same as in Fig. 1.

conditions are possible due to coherent correlated states of interacting particles.

Lu and Zhang [24] had shown that negative ions of hydrogen could be generated in photochemical biotic systems under the sunlight. Negative ions of hydrogen react with cesium radioactive isotope with formation of stable barium isotope same way as negative hydrogen ions can react with potassium-39 with formation of calcium-40. It is another possible explanation of the effect we seen in our experiment.

So, the obtained results suggest that EM accelerates ^{137}Cs decay in soil. Therefore, during 6 and 12 months of the experiment, soil samples with the addition of organic matter only (positive control 2) loss activity of ^{137}Cs significantly more than usual decay rate. It can indicate that not only microorganisms from EM-1 or EM-bokashi can cause the effect of increasing rate of radioactive decay of ^{137}Cs, but species of microorganism naturally inhabit the soil have a similar ability. Nothing is surprising because strains included in the EM composition were selected from the natural environment [16]. Simultaneously loss of the radioisotope activity in the soil samples with EM-1 or EM-Bokashi reached the highest level. Therefore, the impact of EM on the decay rate of ^{137}Cs is more pronounced in comparison with naturally occurring microorganisms.

The differences of ^{137}Cs activity decreasing between usual and observed levels in the soil samples with EM-1 or EM-bokashi reached the maximum level after 12 months of the exposure. The effect did not increase after 18 months of exposure. We can explain that by the death of microorganisms in the samples where EM-bokashi was added. However, new microorganisms were added repeatedly in the samples with EM-1 according to the design of the experiment.

Depletion of ^{137}Cs stock in the bio-available forms could be another explanation of the effect. Cesium firmly absorbed by clay minerals in the soil. Only a small part of the stock of this element in soil is available for plants or microorganisms intake. If we assume that the rate of the ^{137}Cs decay increases inside the cells of some species of microorganisms then we must consider only available for them part of the radionuclide. The additional analysis had shown that only 1.0–1.5% of ^{137}Cs in the soil samples was in soluble and exchangeable forms. These forms are mainly available for microorganisms. It is complicated to register the decline of soluble and exchangeable forms of ^{137}Cs in the soil samples due to intake by microorganisms on the background of 100-folds more total activity. Therefore, the decline of bio-available forms may the cause of decreasing the effect of EM on the rate of ^{137}Cs decay in the soil samples.

In view of the magnitude of these findings for mitigating radiation disasters, we need to obtain additional confirmations of this phenomenon under different conditions. If confirmed, it could be used for the remediation of areas contaminated with radioactive isotopes of cesium.

4. Conclusions

The results of the experiments suggest that EM accelerate the radioactive decay of ^{137}Cs in soil. Further studies are needed to understand the impact of EM on ^{137}Cs activity.

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