Microbial contribution as countermeasures against radioactive contamination

Shuichi Okumoto[1], Masaki Shintani[1,2] and Teruo Higa[3]

[1]EM Research Organization, Inc., Kitanakagusuku-son, Okinawa 901-2311, Japan (email: sokumoto@emro.co.jp)
[2]Tokyo Women's Medical University, Tokyo, Japan
[3]International Research Center for EM Technology, Meio University, Nago-city, Okinawa, Japan

Abstract— **The large area was radioactively contaminated by the Fukushima Daiichi Nuclear Power Plant accident in 2011. Among many disastrous problems, agriculture was of the most concern from the point of food safety. Aiming at developing countermeasures against radioactive contamination in farmlands, we started a series of experiments, starting from May 2011 in Fukushima prefecture, with Effective Microorganisms (EM) Technology. We report here our experimental results regarding the microbial contribution to the suppression of radioactive cesium transfer from soil to agricultural products. In addition, a challenging possibility of microbial potential for reduction of soil radioactivity is discussed.**

Keywords—Effective microrganisms, EM·1, compost, ^{134}Cs, ^{137}Cs, Fukushima Daiichi Nuclear Power Plant (FDNPP)

I. Introduction

A large area of eastern Japan was contaminated by radioactive materials diffused from the accident at Fukushima Daiichi Nuclear Power Plant (FDNPP) in March 2011. All the inhabitants had to be evacuated from the heavily contaminated area. Even in less contaminated place, people were forced to face various risks. Among them, production of safe agricultural products posed one of the most crucial issues. The development of countermeasures was acutely needed to restore an environment which enables risk-free agricultural activity. Similar situations existed in Belarus after Chernobyl Nuclear accident which broke out in 1986. A few years afterwards, Institute of Radiobiology, National Academy of Sciences of Belarus started to develop countermeasures against radioactive contamination.

Effective Microorganisms™ (EM) is a consortium of beneficial microorganisms such as lactic acid bacteria, photosynthetic bacteria and yeast. It was originally developed by Teruo Higa in 1990s as a soil improver [1]. EM has since been used as a microbial inoculant to increase the microbial diversity and improve the quality of soil in agriculture [2]. Several lines of previous observations suggested EM to be useful as countermeasures against radioactive contamination. In Belarus, effective suppression of radioactive Cs from soil to plant was observed [3]. Also, in some farmlands radiation doses were found to decline by EM (EM·1®) spraying. In Fukushima, no appreciable (less than 1Bq/kg) soil-to-plant transfer of radioactive Cs was reported from 11 farms which used EM for a long time. In 2012, Fukushima prefecture announced, based on their own tests, that application of EM compost significantly reduced the transfer of radioactive Cs into plants compared with both control and potassium fertilizer (KCl). They presumed, however, the observed effect was due to high level of potassium content in the EM compost [4].

In order to confirm and extend these observations, we set up a research base in a contaminated area in Fukushima Prefecture in May 2011. Experiments have since been conducted to develop a countermeasure technology against radioactive contamination. Through field tests and green house tests it has been shown that application of activated EM (EM · 1®) and EM fermented compost effectively suppressed the soil-to-plant transfer of radioactive Cs. These results have been reported at academic meetings and at international conferences, etc [5-7].

In this paper, we present some of our experimental results regarding the effects of EM and EM fermented compost on reducing the soil-to-plant transfer of radioactive Cs. Finally, we would refer to our preliminary results which suggest the potentiality of EM *per se* in reducing the radioactivity of Cs.

II. Materials and Methods

A. Planter experiments

In the first planter experiment, contaminated soil (^{134}Cs+^{137}Cs:12,000 Bq/kg dry soil) was placed into the planter, and Komatsuna (Japanese spinach) was seeded. To see the effect of EM, 1% dilution of activated EM was added, with water for control (Fig. 1). Komatsuna plants were harvested 55 days after seeding. After weighing their above-ground parts, radioactivity of Cs was measured using a Germanium semiconductor detector. To measure radioactivity of the soil at harvest time, a Na(TI) scintillation spectrometer was used. For the second planter experiment, contaminated soil (^{134}Cs+^{137}Cs: about 9,000 Bq/kg) was mixed with EM cow manure compost (termed EM Compost) or with regular cow manure compost (termed Compost) at 40t/ha. For comparison, contaminated soil was mixed with chemical fertilizer 14-14-14 (1,000 kg/ha). These soil preparations were placed into the planter and Italian ryegrass was seeded. In the third planter experiment, contaminated soil was mixed with EM cow manure compost effluent (termed EM effluent) or with regular cow manure compost effluent (termed Effluent) at 40t/ha. These mixtures were placed into the planter and Italian ryegrass was seeded. In the second and third experiments, the potassium content was adjusted to be equal for of all mixtures. The grass was harvested after 52 days of seeding for the compost experiment and 88 days for the effluent experiment. After weighing the above-ground part of the grass, Cs radioactivity was measured as described in the first planter experiment. All the planter experiments were carried out inside the green house.

Fig. 1. Planter experiment with Komatsuna plant.

B. Reduction of radioactivity with EM

The soil was collected from the land contaminated with radioactive Cs in Fukushima. The soil was air dried, filtered through a 1.5 mm mesh sieve and mixed well. Six experimental groups were set up with U8 plastic containers filled with 80g of contaminated soil. They were 4 EM groups in which activated EM was added at concentrations of 25, 50, 75 and 100%, water group where water was added and control group with no addition. For each group, triplicate samples were prepared. Each U8 container was sealed with a lid, put in a plastic bag, and placed in a foamed polystyrene container. These U8 containers were kept at room temperature for 690 days, from 18th of December 2013 to 7th of November 2015. During this period, EM or water was added at intervals 6 times in total. For measuring the radioactivity, soil samples were placed in the drying oven at 70℃ to evaporate water. The specific activity of ^{134}Cs and ^{137}Cs was measured with a NaI(TI) scintillation spectrometer.

III. Results and Discussion

The present experiments were prompted by an observation in Belarus after Chernobyl Nuclear accident in 1986. That is, the transfer of radioactive Cs from contaminated soil to plant was effectively suppressed by spraying EM on the farmland. It was not clear, however, that the observed effect was really due to EM treatment. In order to look into the details of what was observed, the planter experiments were designed using EM or its related preparations.

A. Suppression of radioactivity from soil to plants

In the first planter experiment where the effect of activated EM was evaluated, the radioactivity of Cs (^{134}Cs+^{137}Cs) detected in Komatsuna was 37.0 Bq/kg for control and 14.5 Bq/kg for EM sample. Obviously, with the use of EM, the transfer of radioactive Cs into plants was significantly suppressed compared with control. The transfer factor was 0.00118 for EM and 0.00313 for control, corresponding to 62% suppression of transfer with EM usage (Fig.2).

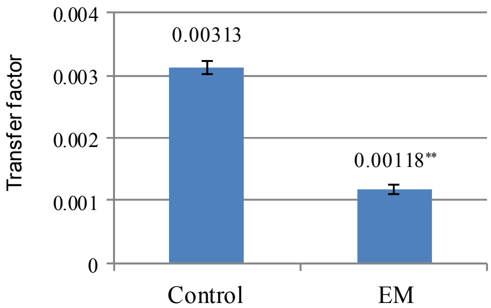

Fig.2. Transfer factor of radioactive Cs in Komatsuna plant.

**: $p<0.01$ (n=3)

It has been known that the presence of potassium tends to decrease the uptake of radioactive Cs. However, the potassium content of EM which was used was only 0.1~0.2%. Also, in the experiment described above, the activated EM was diluted 100 times before spraying. Therefore, the observed suppression effect is hardly due to the potassium in EM but rather to other mechanisms.

Essentially the same results were obtained in the second planter experiment. In this experiment, the EM compost was tested. The radioactivity of Cs (^{134}Cs+^{137}Cs) transferred into the grass was 88±13 Bq/kg in control, 61±6 Bq/kg in Compost and 45±8 Bq/kg in EM compost. The EM compost showed a significant difference at $p<0.01$ compared with control and at $p<0.05$ even compared with Compost (Fig.3A). Transfer factors for control, Compost and EM compost were 0.01035, 0.00643 and 0.00496, respectively. Compared with control, there was a 38% reduction in Compost and a 52% reduction in EM compost in the transfer factor (Fig.3B). The exchangeable potassium content (mg/100g dry soil) in the soil for control, Compost and EM Compost were 68±26, 72±21 and 98±4, respectively, showing no appreciable difference between them. An added observation was that the fresh weight of grass per planter showed a significant increase in Compost and EM Compost group as compared with that of control. Namely, they were 100±11g, 128±9g and 134±6g for control, Compost and EM compost, respectively.

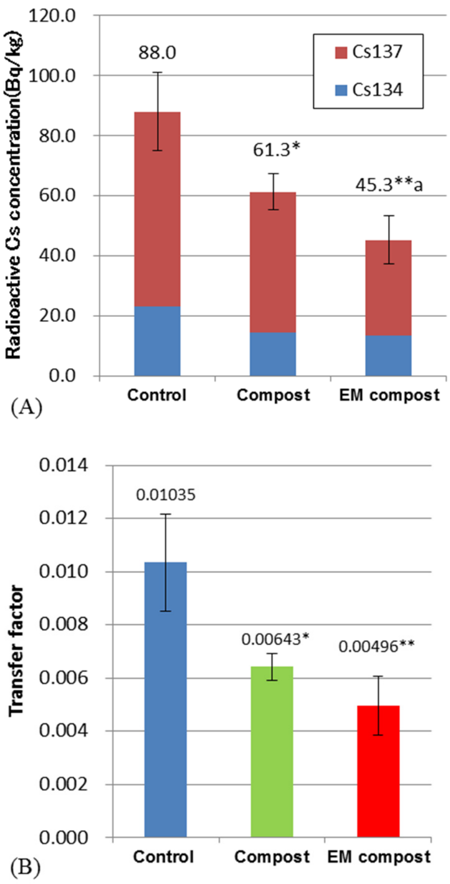

Fig.3. Effect of EM compost on radioactive Cs concentration in grass (A) and transfer factor of Cs to grass (B). Values are expressed as mean ±SD (n=3). * and **: significant difference at 0.05 and 0.01 level, respectively in comparison to the Control. a:significant difference at 0.05 level in comparison to the Compost.

In the third planter experiment, the effect of effluent from cow manure was tested. The radioactivity of Cs was 79±19 Bq/kg for Effluent and 54±4 Bq/kg for EM effluent. The reduction effect was recognized in EM effluent group at $p<0.05$ (Fig.4A). The transfer factors for Effluent and EM effluent were 0.00683 and 0.00483, respectively. No significant difference ($p=0.057$) but a tendency of reduction in EM effluent group was detected (Fig.4B). The exchangeable potassium content (mg/100g dry soil) in the soil for the Effluent and the EM effluent were 66±6 and 63±3, respectively, showing no significant difference. As in the second planter experiment, fresh weight of the grass per planter was 68±3g for Effluent and 75±4g for EM effluent, showing a significant difference in EM effluent group ($p<0.05$).

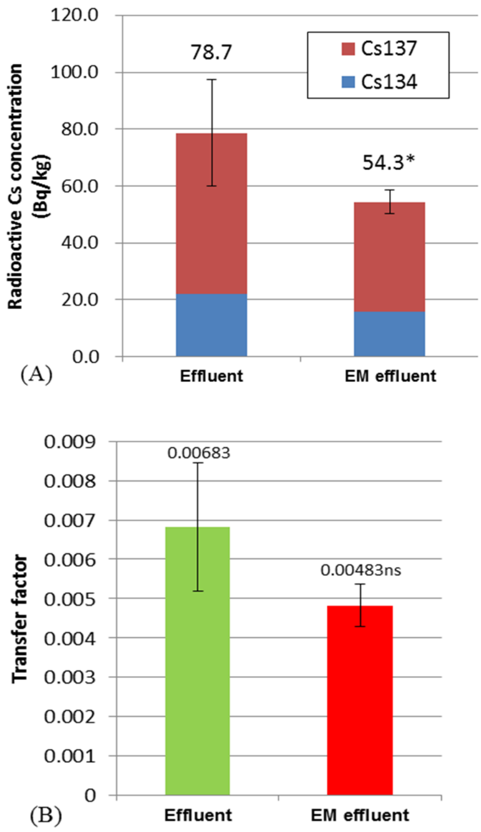

Fig.4. Effect of EM effluent on radioactive Cs concentration (Bq/kg) in grass (A) and transfer factor of radioactive Cs to grass (B).Values are expressed as mean±SD (n=3), *: significant difference at 0.05 level in comparison to the Control. ns: no significant difference (p=0.057)

It should be referred here to the case in Takizawa farm. Takizawa farm (Minamisouma-city, Fukushima) is located 21 km from Fukushima Daiichi Nuclear Power Plant. When EM fermented cow manure compost and its effluent were applied to the pasture, the transfer of radioactive Cs from soil to grass was suppressed compared to the chemical fertilizer (Fig.5, Table I)[8].

Fig.5. Pasture field (Left), EM compost (Right) .

TABLE I. Radioactive Cs and transfer factor in different kinds of grass.

Oats harvested in December, 2012

Area	Cs* in Oats	Transfer factor
Chemical	34.0	0.00892
EM	23.6	0.00800

Italian ryegrass harvested in June, 2013

Area	Cs* in Italian ryegrass	Transfer factor
Chemical	24.5	0.00613
EM	13.8	0.00521

*Cs: Total value of ^{134}Cs and ^{137}Cs (Bq/kg)

Nikitin *et al*. reported that application of EM or EM Bokashi on the soil decreased the rate at which water-soluble Cs and ion exchangeable Cs were absorbed through plant roots [9]. It would appear that the similar mechanism is in action in the present experiments.

From these results, it was concluded that application of EM, EM fermented cow manure compost and EM effluent was effective in the suppression of transfer of radioactive Cs to the grass. The data also argue that the observed effects are not due to the potassium in EM, but rather to some other mechanism inherent in EM *per se*.

B. Does EM per se deactivate radioactivity?

Preliminary observation in Belarus showed that radiation doses declined by EM spraying over the some farmlands contaminated by Chernobyl Nuclear accident. In Takizawa dairy farm as well, an observation existed that the radioactivity in the soil of EM-sprayed area declined more extensively compared with the adjoining area which used chemical fertilizer [8]. In order to confirm and extend this observation, we set up an experimental field in blueberry farm in Iitate village, Fukushima. We repeatedly sprayed activated EM over the field, and radioactivity of Cs was measured before and after EM spraying. At the start, the radioactivity of Cs was 20,000 Bq/kg. Two months afterwards, it declined to 5,000 Bq/kg. A possibility was excluded that radioactive Cs penetrated into the deep part of the soil or was washed away due to rain [10].

Based on this observation, we conducted a laboratory experiment to examine in a more defined way the potential of EM *per se* for deactivating radioactivity. The soil collected from contaminated land in Fukushima was added EM or water as scheduled, and sealed in U8 container as described in Materials and Methods. Firstly, the radioactivity of ^{134}Cs before and 690 days after the treatments was measured (Fig.6). Since the half-life of ^{134}Cs is 2.065 years, the theoretical reduction rate during 690 days was calculated to be 47.0%. The reduction rate of control group was 46.5%, very close to the theoretical estimate. For other treatment groups, the reduction rate was 47.3% for Water, 52.4% for EM25%, 54.8% for EM50%, 57% for EM75% and 56.7% for EM100%. These data show the reduction rate of EM groups was significantly higher ($p<0.01$) than Control group, and support the previous observations in Belarus and in Takizawa Farm. There were significant differences in all EM treated. Also, noted is that the reduction rate seems to increase as does the concentration of EM.

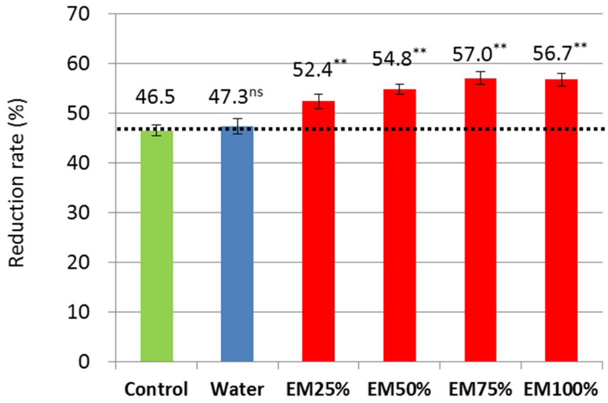

Fig.6. Effect of EM application on reduction rate of ^{134}Cs. Values are expressed as mean ±SD (n=3). **: significant difference at the 0.01 level in comparison to the Control (Dunnett's test). ns: no significant difference. Dotted line: Theoretical reduction rate of ^{134}Cs after 690 days is 47.0% (half life 2.065 years)

Next, the radioactivity of ^{137}Cs before and 690 days after the treatment were measured (Fig.7). ^{137}Cs has a longer physical half-life of 30.04 years and the theoretical reduction rate during 690 days is 4.3%. The reduction rate of the Control group was 3.4%, which was very close to the theoretical reduction rate. For the other experimental groups, the reduction rate was 8.4% for Water, 9.1% and for the EM25%, 12.0% for EM50%, 13.4% for EM75% and 14.8% for EM100%. Compared with the reduction rates of these groups with the Control group, those of EM groups were all significantly higher difference ($p<0.01$, except EM25%). Again, the reduction rate increased along with the concentration of EM.

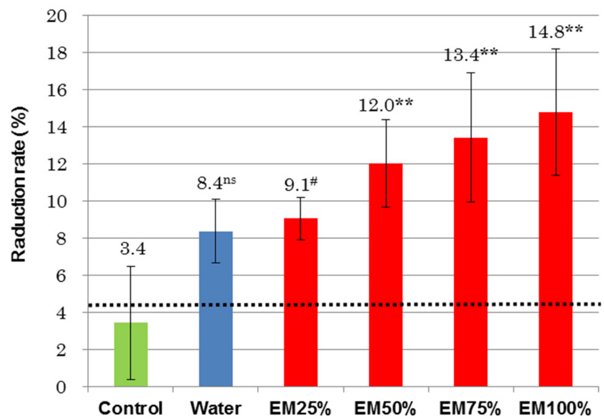

Fig.7. Effect of EM application on reduction rate of ^{137}Cs. Values are expressed as mean ±SD (n=3). **: significant difference at the 0.01 level in comparison to the Control (Dunnett's test). #: significant difference at the 0.06 level in comparison to the Control (Dunnett's test, p-value=0.058). ns: no significant difference. Dotted line: Theoretical reduction rate of ^{137}Cs after 690 days is 4.3% (half life 30.04 years)

The physical half-life of radionuclides is known to be quite stable against environmental change. Therefore, this observation stands in a flat contradiction with the current view. Quite challenging though, some scientists referred to the possibility of biological transmutation. In view of the magnitude of these findings in mitigating the radiation disaster, we should stay open to all possibilities. Further experiments are currently in progress to confirm and to extend what were observed.

IV. Conclusion

Based on the field research and green house experiments described above, it is clear that EM and EM fermented compost can reduce the soil-to-plant transfer of radioactive Cs. Also, noted is the correlation between the extent of reduction and the concentration of EM. A challenging possibility was experimentally suggested and is currently pursued that EM *per se* acts on mitigating radioactivity.

References

[1] T. Higa, "An Earth Saving Revolution: Solutions to Problems in Agriculture, the Environment and Medicine" English edition: Sunmark Publising, 1993.

[2] M. Olle and I.H. Williams, "Effective microroganisms and their influence on vegetable production" Journal of Horticulture Science & Biotechnology: 88, pp.380-386. 2013.

[3] N.V. Shamal, M.N. Zakharenka, O.N. Khomchenk, A.A. Ammon, and V.P. Kudryashov, "Using microbial preparations for reducing the transfer of ^{137}Cs and ^{90}Sr in lettuce and carrot. Collection of scientific papers "Vegetable farming" " 18,pp.361-367, 2010.

[4] Fukushima Prefecture, Agriculture, Forestry and Fisheries Department. "FY2011 Test results of demonstration project for radioactive material removal and reduction technology (Part 2)".

[5]M. Shintani, A. Nikitin, S. Okumoto, Y. Nishibuchi, N. Shamal, A. Dvornik, and T. Higa, "Studies on the suppressive effect on and the relevant mechanism of the transfer of radioactive materials into crops through soil improvement by EM (Effective Microorganisms)" In: Proceedings of 2do Conference for remediation of radioactive contamination in the environment. Tokyo, Japan (in Japanese). 131p. 2013

[6] M. Shintani, S. Okumoto, and T. Higa, "Safe food production in Fukushima by applying technology of effective microorganisms (EM)" In: Proceedings of International Scientific Conference "Low Doses". Gomel, Republic of Belarus. pp.165-166, 2012

[7] S. Okumoto, M. Shintani, and T. Higa, "Influence on the suppression of transfer of radioactive cesium from soil to grass using cow manure compost and its effluent fermented by Effective Microorganism^{TM}". In: Proceedings of International scientific Conference "Radiobiology: <<MAYAK>>, Chernobyl, Fukushima"". Gomel, Republic of Belarus. pp.167-170. 2015.

[8] S. Okumoto, M. Shintani and T. Higa, "Application of Effective Microorganisms^{TM}(EM) technology contributes to the reconstruction of a cycle based dairy farm in Fukushima (A case study)". In: Proceedings of International Conference "Radiology: man-made radiation", Gomel, Republic of Belarus, p.153. 2014.

[9] A.N. Nikitin, E.A. Klementjeva, N.V. Shamal and A.A. Dvornik. "Effect of microbiological factor on redistribution of ^{137}Cs by physicochemical forms". *In*: Proceedings of the International Scientific Conference "Radiation and Environment and Thecnosohere". Gomel, Repbulic of Belarus. pp113-115. 2013.

[10] M. Shintani and S. Okumoto, "A trial to bioremediate radioactively contaminated farm lands in Fukushima by using Effective Microorganisms. International Scientific Conference "Radiation and Chernobyl: Science and Practice", held at Institute of Radiobiology of NAS of Belarus, Gomel, Republic of Belarus. 13-14 October 2011.