Chapter 8
Adverse Effects of Radiocesium on the Promotion of Sustainable Circular Agriculture Including Livestock Due to the Fukushima Daiichi Nuclear Power Plant Accident

Noboru Manabe, Tomotsugu Takahashi, Chunxiang Piao, Junyou Li, Keitaro Tanoi, and Tomoko M. Nakanishi

Abstract Appropriate treatment is urgently needed for farm and ranch waste that has been contaminated with radioactive cesium from the Fukushima Daiichi nuclear power plant accident. We previously developed an aerobic ultra-high temperature fermentation (more than 115 °C) method to inhibit intestinal infectious diseases. Fermented waste (compost), in which pathogens were sterilized, was useful as a fertilizer to grow crops. In the present study, we examined the kinetics of radioactive cesium in farming fields to promote sustainable circular agriculture including livestock in farms and pasture fields in wide areas of Tohoku and Kanto, in an approximately 200 km radius from the nuclear power plant. The compost produced at the experimental ranch of the Animal Resource Science Center, the University of Tokyo, was contaminated with radioactive cesium (approximately 900 Bq/kg). Some crops (soybean, sweet corn, eggplant, bitter gourd, potato, cabbage, and ginger) were cultivated in cubic holes (approximately $1 \times 1 \times 1$ m) that were filled with contaminated compost in the field of the experimental ranch. Each crop was planted in a hole and cultivated in an appropriate manner for a suitable time period. Radiocesium levels in the roots, stems, leaves, and fruits of each crop at harvest were lower than 20 Bq/kg, which was below the new reference/

N. Manabe (✉)
Animal Resource Science Center, Graduate School of Agricultural and Life Sciences, The University of Tokyo, Kasama 319-0206, Japan

Osaka International University, Osaka 570-8555, Japan
e-mail: n-manabe@oiu.jp

T. Takahashi • C. Piao • J. Li
Animal Resource Science Center, Graduate School of Agricultural and Life Sciences, The University of Tokyo, Kasama 319-0206, Japan

K. Tanoi • T.M. Nakanishi
Graduate School of Agricultural and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan

T.M. Nakanishi, K. Tanoi (eds.), *Agricultural Implications of the Fukushima Nuclear Accident*, DOI 10.1007/978-4-431-55828-6_8

regulation value (100 Bq/kg) for food. In conclusion, when crops were planted using compost contaminated with radioactive cesium (900 Bq/kg; more than twice the new tolerance value of 400 Bq/kg for fertilizer and compost), the radiocesium levels in the crops were as low as one-fifth of the new reference/regulation value.

Keywords Aerobic ultra-high temperature fermentation • Compost • Crop contamination • Fertilizer • Livestock • Manure processing • Sustainable circular agriculture • Radiocesium • The Fukushima Daiichi nuclear power plant accident

8.1 Introduction

The greatest invention of the twentieth century is considered to be the ability to produce ammonia industrially in large quantities at a low cost. Ammonia was produced from nitrogen in the air by the Haber–Bosch process in large factories. The nitrogen-based chemical fertilizers, ammonium sulfate, ammonium nitrate, and urea, were stably and inexpensively provided, and they markedly increased food production. If this ammonia synthesis method had not been invented, the population of the world would have remained at less than a quarter of the current population. However, the provision of a sufficient amount of organic fertilizers, in addition to chemical fertilizers, is known to be essential for the continuous and stable production of crops. Thus, compost is an important agricultural material for promoting sustainable circular agriculture including livestock.

A devastating earthquake occurred in the Kanto and Tohoku regions, northeastern areas of Japan, on March 11, 2011, which also led to the Fukushima Dai-ichi nuclear power plant accident. The Japanese government subsequently took a series of measures to deal with the consequences of this accident. New reference/regulation values were established by the Ministry of Health, Labour, and Welfare, Japan (MHLW) on April 1, 2012. Radioactive cesium will hereafter be used to refer to radionuclides, and radiocesium levels include the total values for ^{137}Cs and ^{134}Cs. Radiocesium levels in drinking water, in milk and infant foods, and in other foods (including cereals, vegetables, fruits, meat, eggs, and fish) had to be maintained at less than 10, 50, and 100 Bq/kg, respectively. These new reference/regulation values remain the standard today. In response to these new reference/regulation values, the Ministry of Agriculture, Forestry and Fisheries, Japan (MAFF) published new tolerance values on March 23, 2012 in which they limited the acceptable radioactive cesium levels in livestock feed and bedding, and in fertilizers such as compost for crop production (MAFF 2012). Radioactive cesium levels in feed for meat production had to be maintained at less than 100 Bq/kg for dairy cattle and horses, 80 Bq/kg for pig feed, 160 Bq/kg for chicken feed, and 40 Bq/kg for farmed fish. In addition, radiocesium levels within livestock bedding, fertilizers and compost, soil for crop cultivation, and soil-improving materials had to be maintained at less than 400 Bq/kg. Because Japanese people have characteristic eating habit and farming systems, fundamental research to reflect these Japanese styles and animal feeding methods is needed for revisions of reference/regulation values and tolerance values.

Radioactive cesium crop absorption is considered to compete with potassium absorption; thus, an excessive potassium fertilization technique has been developed to reduce the levels of radiocesium absorption. Appropriate amounts of phosphorus- and nitrogen-based chemical fertilizers were used in this technique, but no organic fertilizers (such as compost produced from the feces of livestock). If farmers continue to use only chemical fertilizers for a long period of time, then the decreases occur in crop production. An appropriate amount of an organic fertilizer is therefore essential for stable agricultural production.

We determined the quantities of radioactive cesium (released by the nuclear power plant accident) that contaminated plants for food and feed and quantities that migrated from feed to livestock and livestock products. We also determined the amount of radiocesium-contaminated feces produced by livestock, the amounts of radiocesium that moved to soil from fermented feces (compost), and the amount that was transferred to plants from soil fertilized with compost. In addition, we summarized the adverse effects of radiocesium on the promotion of sustainable circular agriculture including livestock.

8.2 Aerobic Ultra-High Temperature Fermentation Technique for Livestock Feces

Over the past 10 years, we have developed a novel, aerobic, ultra-high temperature fermentation technique for livestock feces at the experimental ranch of the Animal Resource Center, The University of Tokyo (Kasama, Japan) to prevent the spread of digestive tract infectious diseases (Manabe et al. 2014a, b). Briefly, we built 4 fermenters (4.3 m width × 2.4 m height × 8 m depth) surrounded on 3 sides by a wall and a floor made of concrete. Two grooves (10 cm × 10 cm) were dug into the floor. A vinyl chloride tube (9 cm in diameter) for delivering air was placed inside each groove. Air was continuously sent through this tube from the blower, which was placed outside the fermenter. The fermentation process was as follows (Fig. 8.1). Fermentation feedstock (including the excretions of farm animals, litter residues, residues of livestock feed, and residues of crop silage and haylage) was mixed with an equal amount of the end products of fermentation. These farm residues were contaminated with radioactive cesium due to the nuclear power plant accident. An appropriate amount of air was supplied during the fermentation process. Three days after initiating fermentation, the temperature of the central area of the fermenter increased to more than 115 °C. Denaturing gradient gel electrophoresis analysis revealed that the dominant bacteria in the flora of the ultra-high-temperature fermenter were the *Geobacillus* family (*Geobacillus thermodenitrificans*, *Geobacillus tropicalis*, and *Geobacillus stearothermophilus*), *Bacillus thermodenitrificans*, *Sphingobacteriaceae bacterium*, *Thermoactinomyces*

Fig. 8.1 Aerobic ultra-high temperature fermentation process for livestock feces and farm residues. (**a** and **b**) Overview of fermenters (4.3 m width × 2.4 m height × 8 m depth). Three side walls and a floor were made of concrete. An appropriate amount of air was supplied from 2 vinyl chloride tubes installed in the floor grooves of the floor without interruption from the electric blower, which was placed outside of the fermenter. (**c**) Feedstock (mixture of the excretions of farm animals, litter residues, livestock feed residues, and residues of crop silage and haylage) before fermentation. (**d**) Appearance of the fermenter of the start of the fermentation stage. Feedstock was mixed with an equal amount of the end products of fermentation (mostly the dormant spores and sprouts of high temperature fermentation bacteria). (**e**) During fermentation, all fermenting mixtures were moved into a neighboring fermenter using a wheel loader. This mixture process of fermenting substances was repeated every 7 days. (**f**) After being mixed 6 times, the fermenting substances became powdery (moisture content less than 35 %) 7 weeks after the start of fermentation. The fermented product at the final point was used as an organic fertilizer for crops and pasture cultivation

sanguinis, *Thermus thermophilus*, *Thermaerobacter composti*, and *Bacteroidetes* bactereria. Bacteria from the *Planifilum*, *Rhodothermus*, *Thermaerobacter*, and *Thermus* families were also detected. The ultra-high temperature continued for 2 or 3 days. Seven days after the initiation of fermentation, all of the fermented mixture was moved into the neighboring fermenter using a wheel loader. This exchange was repeated six times. The fermented product at the final point (7 weeks after initiation) became powdery (moisture content less than 35 %). Most of the end products of the final fermentation were mixed with the next fermentation feedstock, and the next fermentation process was started. The end products were used as an organic fertilizer for crops and pasture cultivation at the experimental ranch. The radioactive cesium contamination level in the compost was approximately 900 Bq/kg, more than twice the new tolerance value (400 Bq/kg). Pathogens were sterilized in the fermented waste, which inhibited the spread of intestinal infectious diseases. In our preliminary experiments, aerobic ultra-high temperature-fermented compost exhibited excellent effects as an organic fertilizer on 22 different crops including rice, soybean, kidney bean, green peace, onion, green onion, cucumber, tomato, eggplant, potato, pepper, cabbage, radish, and turnip.

8.3 Radiocesium Dynamics in Crops Grown with Contaminated Compost

Prior to the nuclear accident, the average level of radioactive cesium in farmland soil in Japan was approximately 20 Bq/kg (between 5 and 140 Bq/kg). After the accident, the Japanese government established a new tolerance value (400 Bq/kg) for farmland soil, soil improvement materials, and fertilizers. An appropriate method for treating farm waste contaminated with radioactive cesium has not yet been developed. In order to obtain fundamental understanding for the development of such a method, we examined radiocesium dynamics in crops. These crops were cultivated using aerobic ultra-high temperature-fermented compost produced at the ranch of the University of Tokyo, which is located approximately 130 km southwest of the Fukushima Daiichi nuclear power plant.

Approximately 3 months after the accident, June 13, 2011, ^{131}I was not detected in the soil of farm fields, although radiocesium levels in the soil were 50–240 Bq/kg. We prepared haylage of Italian ryegrass, which was grown in farm fields. The radioactive cesium level in the haylage was 3900 Bq/kg (the new tolerance value for cattle, goat, sheep, and horse feed was less than 100 Bq/kg). Our preliminary experiment performed in June, 2011 showed that radioactive cesium levels in the skeletal muscle of goats (native Japanese Shiba goat: body weight of approximately 40 kg) were approximately 130 Bq/kg (the new reference/regulation value for humans was 100 Bq/kg) when they were fed this contaminated haylage (60 g/kg of body weight/day: 2.4 kg/goat/day, and 9360 Bq/goat/day) for 1 month (Manabe et al. 2014c). Radioactive cesium levels in the feces of these goats (approximately 1 kg/goat/day) were approximately 10,000 Bq/kg.

Between June and September, 2011, approximately 40 milking cows, 120 goats, 20 horses, and 30 pigs were reared in the experimental ranch of the University of Tokyo. The feces, straw litter residues, feed residues, and the waste feed of livestock were used to produce the fermented compost. Radioactive cesium levels in aerobic ultra-high temperature-fermented compost were approximately 900 Bq/kg.

We examined the circulation of radioactive cesium in crops, using this compost as a crop fertilizer, by the following process (Fig. 8.2). First, we dug holes (approximately 1 m $\times$ 1 m $\times$ 1 m) in a field at the experimental ranch. Second, each hole was filled with compost contaminated with radiocesium (900 Bq/kg). Third, each crop (soybean, sweet corn, eggplant, bitter gourd, potato, cabbage and ginger) was planted in a cubic hole and cultivated in an appropriate manner for a sufficient period of time. Finally, we measured radiocesium levels in the roots, stems, leaves and fruits of each crop were at each crop's time harvest.

Radioactive element concentrations in each sample were measured using a germanium semiconductor detector, and each nuclide was identified by gamma-ray spectrometry. ^{134}Cs and ^{137}Cs were quantified at 604.7 and 661.6 keV, respectively, and each Bq value was then calculated by the calibration of count values. Each radionuclide concentration was calculated based on the weight of each sample. The detection limit was set to three times the standard deviation of the background. The radioactive cesium levels included both ^{134}Cs and ^{137}Cs levels.

Radioactive cesium levels in the roots, stems, leaves, or fruit of each crop were lower than 20 Bq/kg (1/5 of the new reference/regulation value for human food). Thus, the present empirical research results confirmed that radiocesium levels in roots, stems, leaves, or fruit of crops cultivated in radiocesium-contaminated compost were less than one fifth of the reference/regulation value. These results suggested that the transition rate of radioactive cesium to crops from soil and compost was low.

We also conducted preliminary experiments. Briefly, we planted and cultivated barley, buckwheat, sweet corn, dent corn, Italian rye grass, soybean, green peas, eggplant, tomato, bitter gourd, potato, sweet potato, cabbage, green onion, onion, ginger, bitter gourd, cucumber, and lotus root in soil contaminated with approximately 200 Bq/kg of radiocesium (half of the new tolerance value) mixed and fertilized with radiocesium-contaminated compost in a field at the Animal Resource Science Center. Similar to the hole-culture experiment described above, each crop was planted in the ridge of the field and was cultivated in an appropriate manner for a sufficient period of time. Radiocesium levels in the roots, stems, leaves, and fruit of each crop were measured at the harvest time of each crop. Radioactive cesium was below the detection limit in all parts of the crops examined.

The results of the present study demonstrate a low migration rate of radioactive cesium to plants from soil containing contaminated compost. However, the mechanism of radioactive cesium migration into crops has not yet been elucidated in detail. We speculate that one of the mechanisms involves the dormant spores and

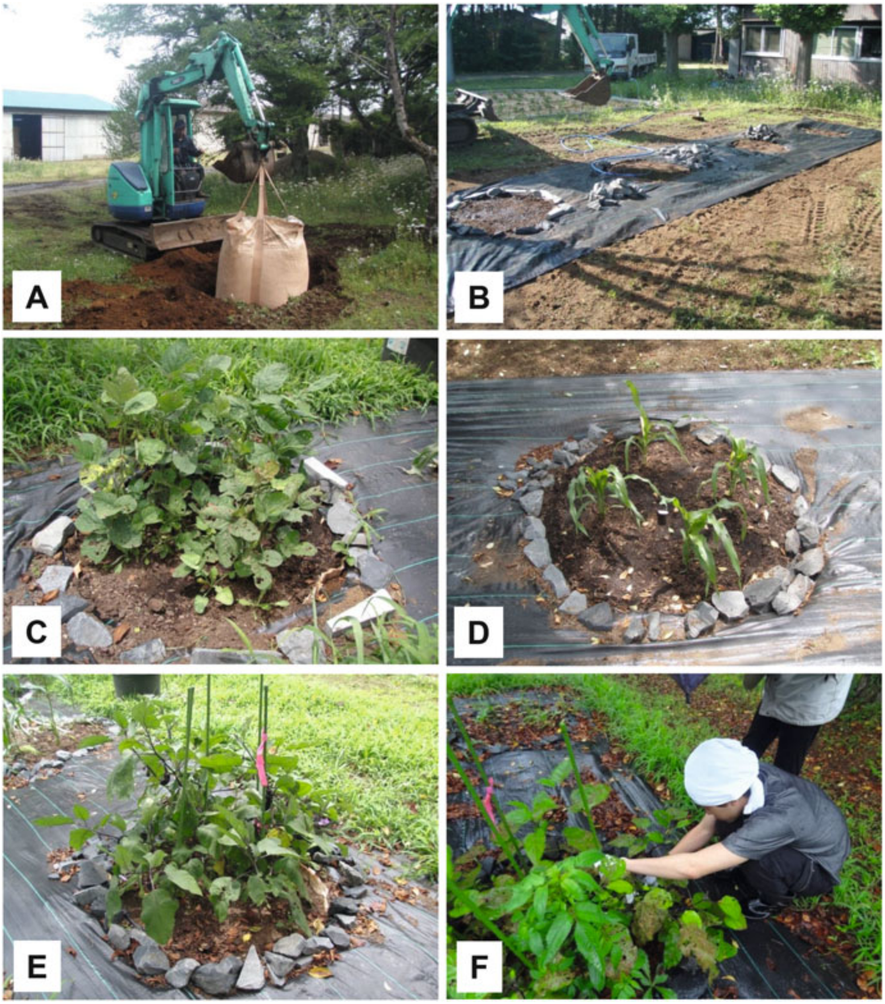

Fig. 8.2 Overview of the crop cultivation experiment. (**a** and **b**) One cubic meter holes were dug and filled with radiocesium-contaminated compost (approximately 900 Bq/kg). (**c** and **d**) Cultivation of soybean and sweet corn, respectively, in each cubic hole. (**e** and **f**) Eggplant was planted in the cubic hole and was cultivated in an appropriate manner for a sufficient period of time. Radiocesium levels in the roots, stems, leaves, and fruit of each crop were measured at the harvest time

sprouts of high temperature fermentation bacteria. During fermentation, bacteria incorporate radioactive cesium into their bodies. Radioactive cesium then strongly binds with fine and stable organic and inorganic materials in the bacterial body. Since the radioactive cesium remained strongly and stably bound to bacterial materials after compost was mixed with the soil, radiocesium could not be easily absorbed into the plant.

8.4 Conclusion

Crops were grown in soil contaminated with radioactive cesium (900 Bq/kg; twice the new tolerance value for soil). The radioactive cesium levels in the roots, stems, leaves, or fruits of each crop were less than 20 Bq/kg, which is lower than the new reference/regulation value for human food, 100 Bq/kg. Moreover, when a range of crops was cultivated in soil contaminated with radioactive cesium (approximately 200 Bq/kg, i.e. half of the new tolerance value for soil), radioactive cesium was not detected in the roots, stems, leaves, or fruits of each crop. These practical research results indicate that the tolerance values of radiocesium for agriculture should be reviewed. Sustainable agriculture, including livestock, need to be revived within radiocesium-contaminated areas of Japan, as they are important food production regions. The utilization and production of livestock compost play an important role in such sustainable cycling agriculture system. In conclusion, the results of the present study contribute to the revival of cycling agriculture.

References

Manabe N, Takahashi T, Li JY (2014a) Future of livestock waste processing with an emphasis on safety of livestock products. Sustain Livest Prod Hum Welf 68:447–451

Manabe N, Takahashi T, Li JY, Tanaka T, Tanoi K, Nakanishi T (2014b) Effect of radionuclides due to the accident of the Fukushima Daiichi nuclear power plant on the recycling agriculture including livestock. New Food Ind 56:45–50

Manabe N, Takahashi T, Li JY, Tanaka T, Tanoi K, Nakanishi T (2014c) Farm animals and livestock products contamination with radioactive cesium due to the Fukushima Daiichi nuclear power plant accident. Sustain Livest Prod Hum Welf 68:1085–1090

Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF) (2012) Setting the tolerance improvement materials and feed fertilizer including radioactive cesium: 2. Allowable radioactive cesium in the feed. http://www.maff.go.jp/j/syouan/soumu/saigai/supply.html (in Japanese)