Phytoremediation of radiocesium in different soils using cultivated plants

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A huge amount of radionuclides were released into the environment after the Fukushima Dai-ichi nuclear power plant accident. Radiocesium, which is one of the more prevalent radionuclides, was deposited in the soil. It is well known that radiocesium is adsorbed into the soil and binds strongly to clay. As a result, it is difficult to reduce the contamination level in the soil. We examine the possibility of decontamination by means of phytoremediation. Four species of plants (sunflower, sorghum, amaranth, and buckwheat) were sown in light-colored Andosol and gray lowland soil. When the plants matured, they were harvested and separated into their different parts, i.e., flower, leaf, stem, and root. The removal percentage of ^{137}Cs for the aboveground parts, which is defined as the ratio of the total content of ^{137}Cs in the aboveground biomass of plants to that in the cultivated soil of 0–15 cm depth, was 0.013–0.93% for the light-colored Andosol and 0.0072–0.038% for the gray lowland soil. The plants exhibiting the highest value cultivated in the light-colored Andosol and gray lowland soil were amaranth (0.093%) and sunflower (0.038%), respectively. This indicates that it is difficult to remove radiocesium from contaminated soil by means of phytoremediation.

Key Words : *phytoremediation, soil, cultivated plant*

1. Introduction

A huge amount of radionuclides were released into the environment after the Fukushima Dai-ichi nuclear power plant accident. Agricultural land and forests were heavily contaminated with radiocesium: ^{134}Cs (half-life: 2.07 y) and ^{137}Cs (half-life: 30.1 y)[1)]. Parts of eastern Japan sustained the highest amounts of exposure to radioactive material; Fukushima prefecture, in particular, was heavily contaminated. Radiocesium, which is one of the more prevalent radionuclides, was deposited in the soil. Following the nuclear power plant disaster, more than 90% of the radionuclides were distributed in the upper 6 cm of the soil column in wheat fields, and within 4 cm of the surface in rice paddies, orchards, and cedar forests[2)]. It is well known that radiocesium is adsorbed into the soil and binds strongly to clay. As a result, it is difficult to reduce the contamination level in the soil. It was reported that phytoremediation using rice plants in a paddy field was also difficult[3)]. We examine the possibility of decontamination by means of phytoremediation using four agricultural plants in upland fields.

2. Materials and methods

(1)Experimental field and plants

The field experiment was performed from June to September of 2011 on light-colored Andosol and gray lowland soil located in Fukushima prefecture. The concentrations of ^{137}Cs in light-colored Andosol and gray lowland soil of 0–15 cm depth were 1,680 ± 602 (n = 12) and 1,453 ± 182 (n = 12) Bq kg^{-1} dry wt, respectively. Four species of plants were used in the experiment: sunflower(*Helianthus annuus*), sorghum (*Sorghum bicolor*), amaranth(*Amaranthus*), and buckwheat (*Fagopyrum esculentum*). The plants were cultivated in three 1.6 m^2 (2.0 × 0.6 m) farming plots of light-colored Andosol and gray lowland soil. The planting density was 625 plants per 100 m^{-2} for sunflower, sorghum, and amaranth; they were sown so that each plant grew 20 cm apart. The density for buckwheat was 18,000 plants per 100 m^{-2}; it was sown to grow in pairs of lines, with 50 cm separating each plant. The amount of N and P_2O_5 (excluding K_2O) applied was 6 kg per 100 m^{-2} for sunflower and sorghum, and 1 kg per 100 m^{-2} for amaranth and buckwheat.

Plant sampling

When the plants matured, they were cultivated and separated into their different parts (flower, leaf, stem, and root; for sorghum, the plants were separated into leaves, stems, and roots). Sampling was carried out from September 6–13, 2011.

Soil sampling

After the plants were sown, soil samples were collected from the sunflower, amaranth, and sorghum lines in June, and from the buckwheat line in July or August. Soil sampling was performed by mixing from five point at a depth of 0–15cm.

Plant and soil analysis

The separated plant samples were rinsed in water and dried at 80 °C for 3 d. The dried samples were pulverized with a cutter, compressed, and filled into plastic vials (U-8). The soil samples were–air-dried at room temperature of approximately 25 °C for 10 d, and then passed through a 2-mm mesh sieve. The soil samples were also compressed into plastic vials. The radioactivity of the samples was measured with a germanium semiconductor detector connected to a multichannel analyzer (Canberra) over a period of 3,000–48,000 s for the plants and 1,200 s for the soil samples. The decay was corrected according to the sampling period.

3. Results and discussion

Yield among the plants

The total yield of biomass cultivated in the light-colored Andosol and gray lowland soil is shown in Fig. 1. The total yield of biomass was five times higher for the sorghum in the gray lowland soil (2.91 kg dry wt m^{-2}) than for the buckwheat in the light-colored Andosol (0.57 kg dry wt m^{-2}). However, the total yield of the same kind of plant cultivated in the light-colored Andosol and the gray lowland soil was within a factor of 2. Sorghum had the highest total yield of biomass both in the light-colored Andosol and the gray lowland soil.

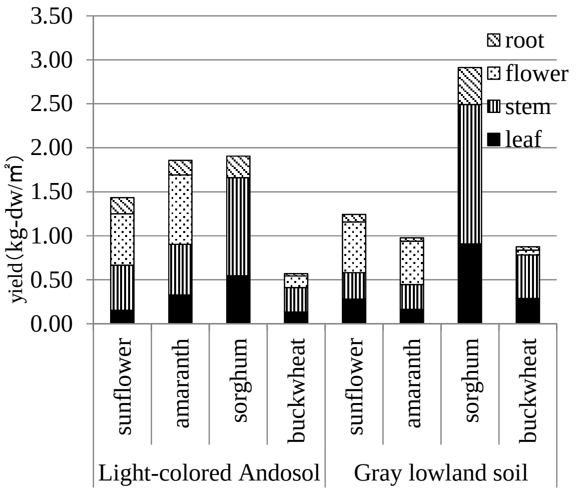

Fig.1 Yield of four plants cultivated in light-colored Andosol and gray lowland soil.
Sampling from September 6–13, 2011.

Concentration of ^{137}Cs in the soils and plants

The concentrations of ^{137}Cs in different plants for each soils are indicated in Table 1.

The concentration of ^{137}Cs in the plant components is indicated in Table 2. Among the components, the leaves exhibited the highest concentration of ^{137}Cs, an exception being sorghum cultivated in the light-colored Andosol. Among the plants in each soil type, the concentration of ^{137}Cs in the roots, including adhered soil particles, was relatively similar. However, in the stem, the maximum concentration was five times and six times greater than the minimum concentration in the light-colored Andosol and gray lowland soil, respectively. The ^{137}Cs concentration in the aboveground part of the plant was 36.7–78.9 Bq kg^{-1} dry wt in the light-colored Andosol, and 18.0–69.1 Bq kg^{-1} dry wt in the gray lowland soil. The concentration of ^{137}Cs in the aboveground part of the plant was in the following order: buckwheat < sorghum < sunflower < amaranth in the light-colored Andosol, and sorghum < buckwheat < amaranth < sunflower in the gray lowland soil.

Total content of ^{137}Cs in the four-plant biomass

The total content of ^{137}Cs in the biomass was 19.8–132.0 Bq m^{-2} for the four plants cultivated in the Light-colored Andosol, and 17.6–79.8 Bq m^{-2} for the four plants cultivated in the gray lowland soil (Table 2). The concentrations in amaranth and sunflower were the highest in the light-colored Andosol and the gray lowland soil, respectively.

Removal percentage of ^{137}Cs

The removal percentage of ^{137}Cs, which is defined as the ratio of the total content of ^{137}Cs in the plant biomass (19.7–153.9 Bq m^{-2}) to that in the cultivated soil of 0–15 cm depth (154,000–247,000 Bq m^{-2}), was 0.015–0.109% for the light-colored Andosol and 0.008–0.039% for the gray lowland soil. The plants exhibiting the highest values cultivated in the light-colored Andosol and the gray lowland soil were amaranth (0.11%) and sunflower (0.039%), respectively . The removal percentage of ^{137}Cs for aboveground parts, which is defined as the ratio of the total content of ^{137}Cs in the aboveground biomass of the plants (17.6–132.0 Bq m^{-2}) to that in the cultivated soil of 0–15 cm depth (154,000–247,000 Bq m^{-2}), was 0.013–0.093% for the light-colored Andosol and 0.007–0.038% for the gray lowland soil. The plants exhibiting the highest values cultivated in the light-colored Andosol and the gray lowland soil were amaranth (0.093%) and sunflower (0.038%), respectively (Table 5). The ratio of the removal of radiocesium from the surface soil to that of the cultivated biomass, i.e., sunflower, amaranth, sorghum, and buckwheat, was negligible. This indicates that it is difficult to remove radiocesium from contaminated soil by means of phytoremediation.

References

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Table 1 Concentration of ^{137}Cs in soils.

soil	plant	^{137}Cs concentration of soils (Bq kg^{-1} dry wt)
Light-colored Andosol	Sunflower	1,694 ± 506
	Amaranth	1,490 ± 479
	Sorghum	2,011 ± 875
	Buckwheat	1,526 ± 163
Gray lowland soil	Sunflower	1,437 ± 106
	Amaranth	1,392 ± 229
	Sorghum	1,337 ± 65
	Buckwheat	1,646 ± 98

Decay correction was done from September 6–13, 2011. Average ± SD (n = 3).

Table 2 Concentration of ^{137}Cs in each plant.

soil	plant	^{137}Cs concentration of plants (Bq kg^{-1} dry wt)				whole body	Aboveground of plant
		leaf	stem	flower	root		
Light-colored Andosol	Sunflower	152.4 ± 28.7	45.8 ± 7.4	23.4 ± 2.5	141.5 ± 119.1	67.6 ± 9.1	48.4± 6.4
	Amaranth	183.8 ± 57.7	48.8 ± 31.6	56.5 ± 11.0	113.0 ± 48.4	49.9 ± 4.9	78.9± 15.8
	Sorghum	71.5 ± 8.4	24.6 ± 12.5	-	156.4 ± 9.9	20.5 ± 4.1	41.6± 9.4
	Buckwheat	104.2 ± 26.4	9.2 ± 0.1	32.7± 10.7	149.7 ± 9.9	22.4 ± 1.9	36.9± 5.4
Gray lowland soil	Sunflower	230.8 ± 4.7	30.1 ± 8.7	11.2 ± 2.3	38.5 ± 13.9	64.8 ± 11.6	69.1± 11.6
	Amaranth	157.1 ± 10.9	10.7 ± 3.8	38.0 ± 7.5	29.2 ± 12.6	84.3 ± 14.2	50.5± 5.6
	Sorghum	40.6 ± 7.4	5.1 ± 1.4	-	34.7 ± 8.7	58.3 ± 7.4	18.0± 4.1
	Buckwheat	40.9 ± 3.5	7.8 ± 1.3	34.2 ± 3.6	38.3 ± 2.6	42.8 ± 5.0	20.8± 2.5

Decay correction was done from September 6–13, 2011. Average ± SD (n = 3).

Table 3 Content of ^{137}Cs in the four-plant biomass.

soil	plant	Content of ^{137}Cs (Bq m^{-2})				whole body	Aboveground of plant
		leaf	stem	flower	root		
Light-colored Andosol	Sunflower	23.9 ± 8.7	23.6 ± 4.2	13.6 ± 2.6	30.1 ± 18.7	91.2 ± 12.1	61.1 ± 15.7
	Amaranth	62.3 ± 26.2	25.6 ± 12.6	44.1 ± 7.8	22.0 ± 1.4	153.9 ± 22.0	132.0 ± 20.8
	Sorghum	38.9 ± 4.8	30.6 ± 18.2	-	40.1 ± 1.9	109.6 ± 10.4	69.6 ± 21.0
	Buckwheat	13.1 ± 0.8	2.6 ± 0.1	4.2 ± 1.1	4.3 ± 0.9	24.2 ± 4.2	19.8 ± 1.2
Gray lowland soil	Sunflower	64.4 ± 11.1	9.0 ± 2.3	6.4 ± 1.2	4.2 ± 1.3	83.9 ± 25.8	79.8 ± 12.2
	Amaranth	25.7 ± 1.1	3.0 ± 1.1	18.8 ± 4.1	1.2 ± 0.4	48.7 ± 10.6	47.5 ± 5.8
	Sorghum	37.1 ± 7.7	8.2 ± 2.4	-	14.7 ± 5.2	60.0 ± 13.6	45.3 ± 12.2
	Buckwheat	11.9 ± 2.4	3.9 ± 1.0	1.8 ± 0.2	2.1 ± 0.2	19.7 ± 4.3	17.6 ± 4.4

Decay correction was done from September 6–13, 2011. Average ± SD (n = 3).

Table 4 Removal percentage of ^{137}Cs by cultivated plant.

soil	plant	^{137}Cs content of soil	^{137}Cs removal percentages (%)	
			whole body	aboveground of plant
Light-colored Andosol	sunflower	175,000 ± 64,000	0.059 ± 0.029	0.036 ± 0.007
	amaranth	154,000 ± 61,000	0.109 ± 0.039	0.093 ± 0.032
	sorghum	208,000 ± 11,000	0.056 ± 0.030	0.033 ± 0.023
	buckwheat	158,000 ± 21,000	0.015 ± 0.001	0.013 ± 0.001
Gray lowland soil	sunflower	216,000 ± 20,000	0.039 ± 0.009	0.038 ± 0.009
	amaranth	209,000 ± 42,000	0.024 ± 0.004	0.023 ± 0.003
	sorghum	201,000 ± 12,000	0.030 ± 0.007	0.022 ± 0.005
	buckwheat	247,000 ± 18,000	0.008 ± 0.002	0.007 ± 0.002

Decay correction was done from September 6–13, 2011. Average ± SD (n = 3).