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Effect of application timing of potassium fertilizer on root uptake of ^{137}Cs in brown rice

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Abstract We investigated the optimal timing and quantity of K to reduce radiocesium in brown rice. The concentration of ^{137}Cs in brown rice was reduced from 32 Bq kg^{-1} without K fertilizer to 2.0 Bq kg^{-1} with 16 g m^{-2} of basal K. The concentration of exchangeable ^{137}Cs in the soil decreased from 234 to 25 Bq kg^{-1} with increasing application of K fertilizer from 0 to 57 g m^{-2}. Hence, heavy application of K fertilizer in the early growing period can decrease the uptake of ^{137}Cs by rice plants and the concentration of exchangeable ^{137}Cs in the soil.

Keywords ^{137}Cs · Brown rice · Potassium fertilizer · Soil-to-brown rice transfer factor · Exchangeable K · Exchangeable^{137}Cs

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Introduction

The accident at the Fukushima Daiichi Nuclear Power Plant in March 2011 released large amounts of radiocesium into the atmosphere, contaminating agricultural land and forests around Fukushima Prefecture in Japan.

Because of their long half-lives (^{134}Cs, 2.06 y; ^{137}Cs, 30.2 y) and strong adsorption to soils, there is concern that radiocesium isotopes will remain on the soil surface and persist in the environment for a long time [1, 2]. To investigate their distribution, we began monitoring the radiocesium in soil in Fukushima Prefecture in March 2011 [3]. Using our data, the Nuclear Emergency Response Headquarters delimited rice planting areas outside the 20-km exclusion zone and the deliberate evacuation area in Fukushima prefecture. However, brown rice grown in some areas in the north of the prefecture exceeded the provisional regulation value at that time for agricultural crops of 500 Bq kg^{-1} [4]. Consequently, the planting of rice crops for 2012 has been restricted in these areas.

We reported that the concentration of radiocesium in soil decreased with an increasing concentration of exchangeable K after the accident, and the topdressing with K fertilizer decreased the concentration in brown rice [5]. Here, we investigated the optimum timing and amount of K application to reduce ^{137}Cs uptake by brown rice.

Materials and methods

Experimental field

We grew rice in a 0.2-ha field in the northern part of Fukushima Prefecture where rice has been grown for many years. The field was contaminated with radiocesium: the

Table 1 Physicochemical properties of the experimental field soil (0–15 cm)

$pH(H_2O)$	T–C ($g\ kg^{-1}$)	Exchangeable K ($mg\ kg^{-1}$ DW)	CEC ($c\ mol_c\ kg^{-1}$)	Particle size composition		
				Sand (%)	Silt	Clay
6.3	41	147	44	24	34	42

brown rice produced in this field in 2011 exceeded the provisional regulation value at that time (500 Bq kg^{-1}), and the planting of rice in this area was restricted in 2012. Rice straw had been applied to the field every year. The radiocesium concentration in the irrigation water (including suspended matter and the dissolved fraction) was 0.3–1.4 Bq kg^{-1}.

Cultural method

The experiment used a split-plot design with 3 replications; each plot was 3.0 m × 10 m (30 m^2). Fertilizer was applied at 6.0 g m^{-2} N and 4.4 g m^{-2} on 17 April 2012. The field was plowed on 20 April, puddling on 4 May, and planted out on 10 May at 17.1 hills m^{-2} (30 cm × 19.5 cm). In experiment 1, K fertilizer (Potassium chloride) was applied at 8.0 g m^{-2} before puddling or at 50 days (Before mid-summer drainage), 70 days (Panicle formation stage), or 80 days (Meiosis stage) after transplanting. In experiment 2, it was applied at 8.0, 16, 38, or 57 g m^{-2} before puddling. The rice was harvested on 19 September.

Sample collection and preparation

The soil was classified as a Gray lowland soil (Table 1). After harvest, soil samples were collected from each plot on 19 September, 2012, with a stainless steel auger 30 cm in length and 5 cm in diameter. The samples were air-dried for 21 days, thoroughly mixed, and sieved through a 2 mm sieve before analysis. Threshed grain samples retained on a 1.8-mm sieved were used for analysis.

Sample analysis

The dried soil was compressed into cylindrical polystyrene containers. The brown rice samples were compressed into 0.7-L Marinelli beakers. The concentration of ^{137}Cs in each was measured with a Ge gamma- ray detector connected to a multichannel analyzer for 3,600–7,200 s. Exchangeable K was extracted by the Semimicro-Schollenberger method and its concentration was measured by atomic absorption spectrophotometry. Exchangeable ^{137}Cs was extracted by

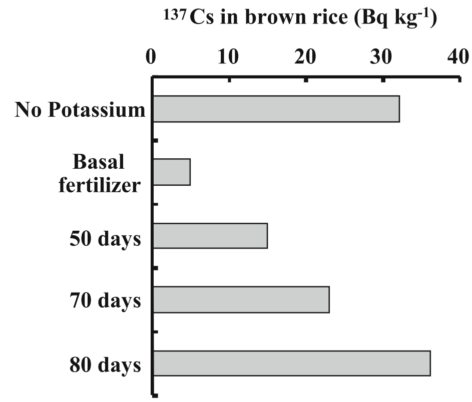

Fig. 1 Concentrations of ^{137}Cs in brown rice by timing of K fertilizer application

the batch method, and its concentration was measured by the Ge gamma-ray detector for 36,000 s.

Calculation of soil-to-brown rice transfer factor

The soil-to-brown rice transfer factor (TF) is used to compare the abilities of plants to bioaccumulate materials from soil. TF is a simple but important parameter that can be used to estimate the concentrations of radionuclides in plants from different fields. As TF can vary widely, it should be evaluated under site-specific conditions. To compare the accumulation of radiocesium in brown rice, we calculated the TF, as the ratio of radiocesium in the brown rice (Bq kg^{-1}) to that in the soil (Bq kg^{-1} dry weight).

Results and discussion

Experiment 1

The concentrations of ^{137}Cs in our field were almost uniform at 3,262–3,983 Bq kg^{-1}. We assume that plowing

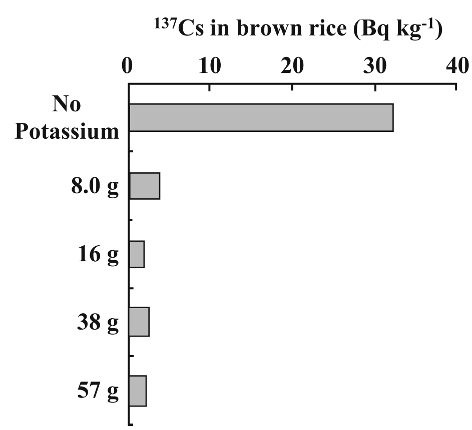

Fig. 2 Concentrations of ^{137}Cs in brown rice by amount of basal K fertilizer application

Table 2 Relationship between exchangeable K, ^{137}Cs in soil and soil-to-brown rice transfer factor

Timing of K fertilizer	Amount of K fertilizer (g m^{-2})	Exchangeable K (mg kg^{-1} DW)	Exchangeable ^{137}Cs (Bq kg^{-1} DW)	Transfer factor of ^{137}Cs
No potassium	0	95.4	234	0.0092
Basal fertilizer	8	107	209	0.0013
Basal fertilizer	16	318	43.8	0.00059
Basal fertilizer	38	356	31.0	0.00076
Basal fertilizer	57	395	25.0	0.00052

and puddling homogenized the distribution. The ^{137}Cs concentrations in brown rice were 32 Bq kg^{-1} without K, 5.0 Bq kg^{-1} with 8.0 g m^{-2} of basal K, 15 Bq kg^{-1} with K applied at 50 days after transplanting, and 36 Bq kg^{-1} with K applied at 80 days (Fig. 1). Therefore, basal application of K fertilizer decreased the uptake of ^{137}Cs the most.

Experiment 2

The ^{137}Cs concentration in brown rice was 32 Bq kg^{-1} without K. 4.0 Bq kg^{-1} with 8.0 g m^{-2} of K, and 2.0 Bq kg^{-1} with 16 g m^{-2} of K (Fig. 2). Higher rates had no further effect. Thus, increasing the rate of K to 16 g m^{-2} decreased the concentration of ^{137}Cs in brown rice. Further, even if increasing the rate of K, the yield of brown rice did not decrease.

The TF value ranged from 0.00052 to 0.0092, an 18-fold variation (Table 2). The geometric mean of the TF of brown rice in paddy fields contaminated by fallout from the Fukushima accident was 0.0075–0.11 in 2011 [5]. The higher TF observed in 2011 may be attribute to un-uniform distribution of radiocesium in the available fractions at the early stage of the aging periods after deposited onto the soil.

Previous research showed that the TF of ^{137}Cs in brown rice decreases with increasing K concentration in soil [6–9]. Consistent with this, the average TF decreased with increasing application of K (Table 2). Hence, heavy application of K fertilizer reduced the concentration of ^{137}Cs in brown rice.

We previously found no correlation between total radiocesium in paddy soil and in brown rice [5]. Therefore, we focused on exchangeable radiocesium as a proxy for available radiocesium. Heavy application of K decreased the mean value of exchangeable ^{137}Cs in the soil from 270 to 25 Bq kg^{-1} dry weight. Hence, heavy application of K fertilizer in the early growing period could decrease the uptake of ^{137}Cs by rice plants, and the concentration of exchangeable ^{137}Cs in the soil.

Conclusions

The present study indicated that heavy application of K fertilizer in the early growing period can decrease the uptake of ^{137}Cs by rice. In order to reduce radiocesium in brown rice, K fertilizer has been applied in excess in the paddy fields of highly contaminated areas now. Therefore, we must build the appropriate K application method as soon as possible.

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