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REVIEW ARTICLE

Review: Agricultural Countermeasure against Radiocesium Contaminated Field

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ABSTRACT

In 2011, Great East Japan Earthquake and subsequent tsunami caused severe damage on the TEPCO's nuclear power plants in Fukushima prefecture. A large area of agricultural fields in Eastern Japan was suffered by substantial amount of radioactive materials (especially radiocesium) and tremendous efforts has been taken to remediate the contaminated fields. Though phytoremediation was expected to be effective to remove radiocesium, it did not work at least in this area. Actually physical decontamination was carried out, while it is still required to mitigate the transfer of the remaining radiocesium to the crops. For this purpose potassium application is adopted as a reliable method.

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INTRODUCTION

In the early afternoon of March 11, 2011, a sudden, long, slow tremor made me realize that a major earthquake had occurred in a remote area. Then came the unexpected tsunami, the resulting damage to the TEPCO's Fukushima Daiichi Nuclear Power Plant (FDNPP), and the hydrogen explosion caused by the loss of electric power that scattered radioactive materials into the surrounding environment. In April, the areas where farming could be resumed were indicated based on the level of soil contamination, but farmers were still searching for appropriate cultivation methods under different conditions with radioactive materials. Therefore, several societies belonging to agricultural science established a working group to investigate the behavior of radioactive materials in soil and crops in March, and quickly compiled and published a number of reviews [1], which became an important landmark for researchers, producers and also for administrators.

PHYTOREMEDIATION

It is clear from the media reports of the time that there were widespread efforts to remove radioactive cesium that had fallen on the soil surface through plants. In fact, sunflower seeds were sown in many places in Fukushima Prefecture, and the sowing scene by the then Minister of Agriculture, Forestry and Fisheries was also reported. However, it was pointed out that there was no scientific knowledge that radioactive cesium, which is strongly adsorbed by clay minerals in soil, could be easily removed by plants, nor was it the case that its absorption capacity was particularly high in sunflowers among plant species (Watanabe, personal communication). Even so, there was a strong hope that the idea of removing harmful substances by plants (phytoremediaton) could be used to decontaminate farmland contaminated

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by radioactive materials by cultivating sunflowers instead of general crops. This idea was verified by Fukushima Prefecture and National Agriculture and Food Research Organization. However, the actual removal rate was very low, and it was concluded that decontamination by phytoremediation was not realistic [2]. Trial of decontamination using grasses was also carried out, but the effect was negligible [3]. At that time, we did not think that there was no possibility at all, and we thought that the rate of radioactive cesium would decrease in subsequent crops, especially if the plants absorbed the available radioactive cesium, but this was not necessarily the case. That is available radioactive cesium was replenished from the soil.

TOP SOIL REMOVAL/ INVERSE TILLAGE

It was reported in the Chernobyl accident that the vertical downward penetration of radioactive cesium due to rainfall was extremely slow, and this was thought to be based on the fact that it was strongly fixed in the weathered layer of clay minerals [4]. This is thought to be based on the fact that the clay minerals are strongly fixed in the weathered layer [5]. This survey was also conducted in the affected area and it was found that 95% of the clay minerals remained in the surface layer of 2.5 cm even after six months [6]. Therefore, when there is a certain amount of contamination (in the case of paddy rice, the field that can be planted should be less than 5,000 Bq/kg of soil in order not to exceed the provisional standard value (500 Bq/kg) as early as April 8, 2011 [7], this became an indicator to decide using agricultural field in the affected area at that time. In fact, in some areas, topsoil stripping was done below that level, while in other areas, stripping was done above it. Of course, this method generates a large amount of soil waste, so inversion tillage was widely used in grasslands. However, in inversion tillage, it was pointed out that in some grasslands, roots reached the layer of inverted root mat (which adsorbed a large amount of radioactive cesium) and absorbed radioactive cesium from there [8]. Therefore, instead of simply performing inversion tillage, the method of performing inversion tillage after mixing the topsoil well with manure and/or potassium materials is currently being taken. Deep plowing is a method of reducing the concentration of radiocesium in the crop soil by plowing deeper (30 cm depth) than the normal soil layer of 15 cm. In the actual production areas, these methods were combined as appropriate to decontaminate or reduce the concentration of radioactive cesium of the plant.

MEASURES TO CONTROL RADIOACTIVE CESIUM MIGRATION BY POTASSIUM

The criteria for topsoil stripping were based on the results of long-term monitoring of rice paddies and fields throughout Japan for radioactive cesium from atmospheric nuclear testing (global fallout), were used as a benchmark for cultivating the rice so as not to exceed the provisional standard value of 500 Bq/kg for general food as of 2011. The maximum concentration of radioactive cesium in the average Japanese soil was about 40 Bq/kg around 1960, and in brown rice it was slightly more than 4 Bq/kg. Therefore, it was considered reasonable to consider the maximum transfer factor (or concentration ratio, radiocesium concentration in harvested products / radiocesium concentration in soil) to be 0.1 even in the situation where there was some fallout from the atmosphere (Figure 1).

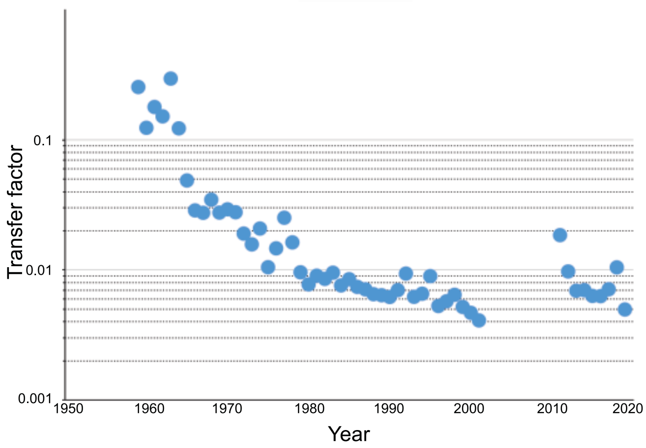

Figure 1 Transfer factor of 137Cs to brown rice (average, n = 6-15) during and after global fallout in representative paddy fields in Japan. Data were provided by the National Institute of Agrobiological Sciences (https://vgai.rad.naro.go.jp/).

As the 2011 harvest season approached, unfortunately, some areas exceeded the provisional standard values, and it was reported that the exceedances were observed in fields with extremely low soil exchangeable potassium concentration [9]. Therefore, a new method to increase the exchangeable potassium concentration in the soil above a certain level was established as a new countermeasure for planting in 2012 [10]. In addition to potassium fertilizers, compost and other potassium-containing materials have been shown to have similar effects, and this countermeasure used not only for rice but also for various crops such as soybeans, buckwheat, and grasses. In addition, it is difficult to completely remove radioactive cesium even from a field that has been decontaminated by stripping the topsoil (think of actual work in a field), so the application of potassium fertilizer is extremely effective in controlling the transfer of remaining radioactive materials in the agricultural fields.

BEHAVIOR OF POTASSIUM IN SOIL

It was shown that potassium was effective in controlling migration, but detailed analysis showed that the effect differed depending on the soil. It was shown that clay minerals derived from yellow sand were involved in the adsorption of radioactive cesium [11], and that the dynamics of potassium as well as the dynamics of radioactive cesium varied greatly depending on the type and amount of clay minerals constituting the soil. It has also been shown that not only the dynamics of radioactive cesium but also that of potassium varies greatly depending on the type and amount of clay minerals constituting the soil. Conventionally, exchangeable potassium (potassium extracted by 1M ammonium acetate, which is considered to be potassium available to plants) has been used as an indicator for potassium, but it is also considered to be non-exchangeable potassium, which is not extracted by 1M ammonium acetate, but is extracted by a certain level of TPB or thermal nitric acid and this non-exchangeable potassium is also considered to be important factor to regulate transfer factor [12,13].

On the other hand, there are also differences in the transfer factors among plant species. Since the transfer factor is an important indicator in determining whether or not to maintain food production in the event of a nuclear accident, including a nuclear power plant accident, information from the IAEA, which was based on information gathered after the Chernobyl accident, was used as a reference after FDNPP accident [14]. However, it was difficult to use this information because the values varied greatly depending on various factors. Later, a new TECDOC was completed in 2020 based on the investigation after the accident in Fukushima [15]. In addition to showing the differences in transfer coefficients among various crop species, it was clearly shown that the transfer factor is strongly regulated by exchangeable potassium at the field level. In addition, the transfer factors were higher for soybean and buckwheat than for rice even at the same exchangeable potassium level. This may be due to the difference between paddy and field soils, and also to the fact that soybeans accumulate a large amount of potassium in their seeds [16].

FUTURE PERSPECTIVES

It has been shown that the distribution of radiocesium taken up into the body itself is controlled by potassium nutrition, but the details of the mechanism remain unclear. In the case of absorption, it was shown that it was possible to significantly decrease radiocesium absorption even at the field level by suppressing the expression of the high-affinity potassium transporter, which is thought to be the main component of this process, through mutation [17]. On the other hand, the absorption of radiocesium was indirectly suppressed by mutation of the transcription factor involved in sodium exclusion [18], indicating that the absorption and removal of cesium, which is an unnecessary element for plants, is carried out by secondary effects because it is not essential. Further research from a broader perspective is required. In order to comply with the current standard values for radioactive cesium (100 Bq/kg for general foods produced in Japan), even if the absorption of radioactive cesium can be reduced by half, the cost savings in the cultivation field will be extremely large.

As plants actually absorb radiocesium from the soil solution, and it is necessary to be able to predict changes in the concentration of cesium and potassium in the soil solution more accurately and to assess the risk of increased concentration of radiocesium in the soil solution. For this purpose, the importance of refining the solid-liquid partition coefficient of radioactive cesium in soil and analyzing the physical and chemical properties of soil related to radioactive cesium, such as Radiocesium Interception Potential (RIP), has been pointed out [19], and it was shown that detailed analysis of the transfer factor by dividing it into the solid-liquid partition coefficient and the concentration ratio of soil solution is expected to more accurately explain the differences in transfer factors among soils [20] . In addition, from the plant side, there is a difference in absorption ability of radiocesium. For example a significantly higher absorption capacity of radiocesium was observed in a leguminous fodder crops, compared to soybeans during the same period of cultivation in the same field (the radiocesium concentration of the shoot was 1165.0 Bq/kg compared to 126.6 Bq/kg in soybean, Kubo et al. unpublished data). Elucidation of the mechanism of this phenomenon may help to clarify the differences in cesium absorption capacity among plant species. Rhizosphere as the area of contact between the plant and the soil is assumed to be extremely important for such active absorption of radiocesium by plants. Studies using lupin have revealed that the roots secrete carbon that is assimilated above ground intensively in a very specific rhizosphere area [21], suggesting that direct action from plants to soil may affect the dynamics of radiocesium in soil. It is expected that the analysis of such active rhizosphere by introducing the latest research methods will create a new research field.

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