Effects of preferential flow and radiocesium-rich microparticles (CsMPs) on spatial heterogeneity of ^{137}Cs in forest soils after the Fukushima accident

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Horizontal spatial heterogeneity of ^{137}Cs in soil is extremely high even within small areas of forest, resulting in reduced accuracy of models predicting downward migration and uptake by plants. Therefore, this study focused on preferential flow and radiocesium-rich microparticles (CsMPs) as factors causing spatial heterogeneity at the centimeter scale. Although the preferential flow pathways occupy only a small proportion of the soil matrix, most of the water and solutes permeate through them. Therefore, preferential flow is expected to have a strong effect on ^{137}Cs spatial distribution due to its high adsorption ability on soil particles. CsMP has a very high ^{137}Cs concentration but low solubility and is derived from a mixture of melted nuclear fuels and structural materials. There are some studies on the contribution of CsMPs by region, but there are few studies on the variation in the degree of CsMPs contamination at smaller scales.

In this study, we conducted an artificial rainfall experiment using a dye tracer (2 g L^{-1} rhodamine B solution) in a cedar plantation forest in the former evacuation zone of Fukushima Prefecture to visualize the pathway of preferential flow. After then, soil samples from stained and unstained areas were collected at 2.5 cm intervals and 25 core samples were taken at three depths (0-5 cm, 10-15 cm and 20-25 cm). The ^{137}Cs concentrations, physico-chemical properties (three-phase distribution, porosity, saturated hydraulic conductivity, bulk density, total carbon, total nitrogen and radiocesium interception potential) and the amounts of CsMPs were measured to discuss the effects on the spatial heterogeneity of ^{137}Cs in soil and their interrelationships.

As a result, the extracted rhodamine B concentration in the soil of the stained area is more than 100 times higher than that of the unstained area, indicating the occurrence of preferential flow from the surface layer although even with a rainfall intensity of approximately 90 mm and a rainfall rate of 160 mm. The ^{137}Cs concentration also tended to be higher in the stained area, and in particular, the variability of the ^{137}Cs concentration in stained area was significantly higher at especially 10-20cm. The variability of the ^{137}Cs inventory at 10-15 cm of soil depth was largest compared to 0-5 cm and 20-25 cm. In addition, significant negative correlation was found between the ^{137}Cs inventory and bulk density or saturated hydraulic conductivity, which is associated with preferential flow. In addition, not only the ^{137}Cs but also carbon, nitrogen and other exchangeable cations were also correlated with bulk density. On the other hand, there was not significant correlation between the ^{137}Cs inventory and bulk density at depths of 0-5 cm and 20-25 cm. This was thought to be because at 0-5 cm, the pathway of the selective flow was easily changed due to plant root growth and death, and the penetration was uniform, so the variation was small. At 20-25 cm, it was thought to be because the amount of ^{137}Cs that reached the surface was small compared to the preferential flow. At the surface 0-5 cm layer, a tendency was observed that the higher the Cs concentration, the greater the amount of CsMPs contained. However, the contribution of CsMPs to the total ^{137}Cs in soil was low, so CsMPs could not explain the large spatial heterogeneity in ^{137}Cs concentration. These results may suggest that not only rainfall water and the elements such as carbon and ^{137}Cs but also particles such as CsMPs accumulate in areas where the preferential flow penetrates.