Cosmogenic, anthropogenic, and airborne radionuclides for tracing the mobile soil particles in a tile-drained heavy clay soil

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Abstract
The atmospherically-derived cosmogenic (^{7}Be), anthropogenic (^{137}Cs), and airborne radionuclides ($^{210}Pb_{xs}$) were used to investigate the origin and travel time of the mobile soil particles discharged from the tile drain in a heavy clay soil. These radionuclides were accumulated mainly in the surface layer of the soil profile; nevertheless, they were detected with high activities in all the mobile soil particle samples collected from the tile drainage water in a rainfall event. This indicates that the major origin of the mobile soil particles discharged from the tile drain is the mobile soil particles in the uppermost surface soil. The average travel time of the mobile soil particles moving from the uppermost surface soil to the tile drain is estimated as about 35 d based on the difference in the activity ratio ($^{7}Be/^{210}Pb_{xs}$) of the mobile soil particles between in the surface runoff and in the tile drainage waters.

Key Words
^{7}Be, ^{210}Pb, ^{137}Cs, half life, travel time.

Introduction
The mobile soil particle is important as a carrier of environmental pollutants of poor water solubility or strong adsorptivity such as phosphorus, heavy metals, etc (Kretzschmar *et al.* 1999; Suzuki *et al.* 2005). This study tried to determine the origin and travel time of the mobile soil particles discharged from the tile drain in a heavy clay soil under field conditions. We applied an environmental radioisotope tracer technique using the atmospherically-derived cosmogenic (^{7}Be), anthropogenic (^{137}Cs), and airborne radionuclides ($^{210}Pb_{xs}$) that has been developed for determining the watershed-scale transit time of sediments in surface water systems (Bonniwell *et al.* 1999; Matisoff *et al.* 2005).

Methods
Study site
The study was conducted in a soybean field (100 × 30 m) of the Hokuriku Research Center, Niigata prefecture, Japan. The soil is a smectitic heavy clay soil classified as a fine-textured Mottled Gley Lowland soil (Cultivated Soil Classification Committee 1995). The tile drains are installed at a depth of 65 cm.

Radionuclide activity in bulk soil
The soil to a depth of 20 cm was sampled with depth increments of 1–5 cm by using a scraper plate (15 × 30 cm) (Loughran *et al.* 2002) and that between the depths of 20 and 100 cm was taken with a depth increment of 10 cm by using a soil auger with a diameter of about 6.5 cm. The soil samples were air-dried and the activity of bulk soil radionuclides (^{7}Be, ^{137}Cs, ^{210}Pb) was measured by gamma spectrometry.

Radionuclide activity in mobile soil particles in surface runoff and tile drainage waters
The surface runoff and tile drainage waters (~20 L) were collected with a peristaltic pump with a time interval of several hours during and just after a rainfall event. The water samples were filtered with a membrane filter with a pore size of 0.025 µm to collect the mobile soil particles.

Results
The atmospherically-derived cosmogenic (^{7}Be), anthropogenic (^{137}Cs), and airborne radionuclides ($^{210}Pb_{xs}$ = total ^{210}Pb – supported ^{210}Pb; see Figure 1) were accumulated mainly in the surface layer of the soil profile (Figure 1). The short-lived (half life = 53.1 d) radionuclide, ^{7}Be, as well as the long-lived radionuclides,

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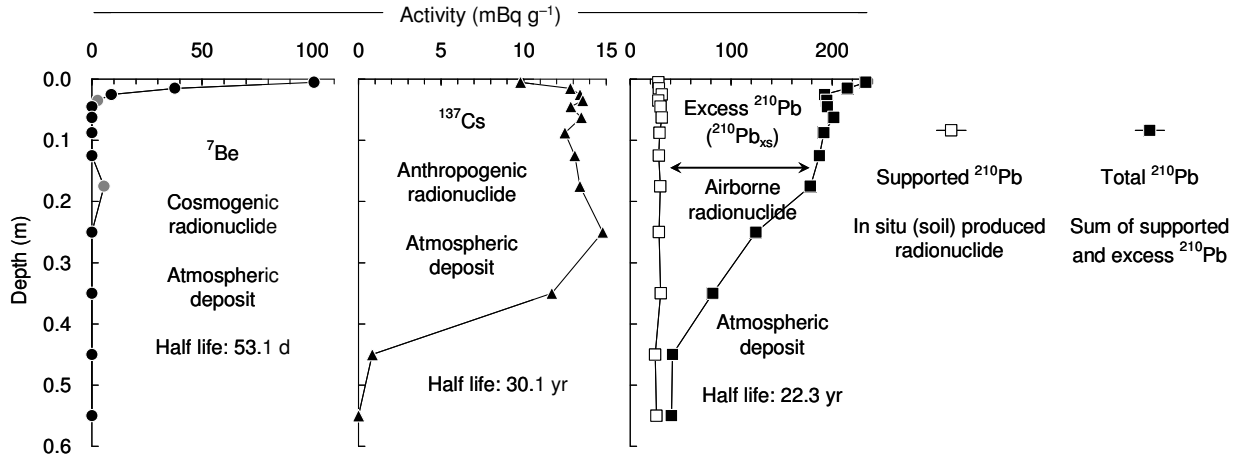

Figure 1. Vertical profiles of the bulk soil ^{7}Be, ^{137}Cs, and ^{210}Pb activities in the heavy clay soil. The gray plot for ^{7}Be indicates that the detected value was below the quantitation limit.

^{137}Cs and $^{210}Pb_{xs}$, were detected in all the mobile soil particle samples collected from the tile drainage water (Table 1) and their activities were higher than those of the bulk soil (Figure 1). These results indicate that the major origin of the mobile soil particles discharged from the tile drain was the mobile soil particles in the uppermost surface soil and that the ^{7}Be-bearing mobile soil particles moved quickly through some preferential flow paths such as the large cracks frequently observed in the heavy clay soil. The average travel time of the mobile soil particles moving from the uppermost surface soil to the tile drain is estimated as about 35 d (Figure 2) based on the difference in the activity ratio (^{7}Be/$^{210}Pb_{xs}$) of the mobile soil particles between in the surface runoff and in the tile drainage waters.

Table 1. Activity of atmospherically-derived radionuclides (^{7}Be, ^{137}Cs, $^{210}Pb_{xs}$) in mobile soil particle samples collected from the surface runoff and tile drainage waters in a rainfall event on 21–22 November 2008. Numerals in parentheses are standard deviations (*n* = 4 for surface runoff; *n* = 5 for tile drainage).

	^{7}Be (mBq g^{-1})	^{137}Cs (mBq g^{-1})	$^{210}Pb_{xs}$ (mBq g^{-1})	Activity ratio ^{7}Be/$^{210}Pb_{xs}$
Surface runoff	1126 (±72)	16.7 (±1.5)	483 (±42)	2.26 (±0.30)
Tile drainage	555 (±86)	20.3 (±0.8)	371 (±73)	1.45 (±0.17)

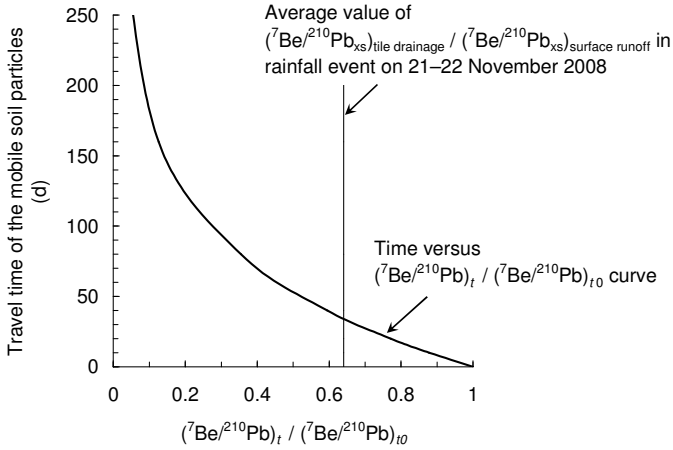

Figure 2. Estimation of the travel time of the mobile soil particles moving from the soil surface to the tile drain based on the difference in the activity ratio (^{7}Be/$^{210}Pb_{xs}$) of the mobile soil particles between in the surface runoff, $(^{7}Be/^{210}Pb_{xs})_{surface\ runoff}$, and in the tile drainage waters $(^{7}Be/^{210}Pb_{xs})_{tile\ drainage}$.

Conclusion

The high activities of the atmospherically-derived cosmogenic (^{7}Be), anthropogenic (^{137}Cs), and airborne radionuclides ($^{210}Pb_{xs}$) of the mobile soil particles in tile drainage water indicate that the major origin of the mobile soil particles discharged from the tile drain is the mobile soil particles in the uppermost surface soil. The average travel time of the mobile soil particles moving from the uppermost surface soil to the tile drain is estimated as about 35 d based on the difference in the activity ratio ($^{7}Be/^{210}Pb_{xs}$) of the mobile soil particles between in the surface runoff and in the tile drainage waters.

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