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短　報

Movement of Soil and Litter down Slopes in Three Types of Forests (II)
Movement of Gravel in Comparison with Movement of Soil*

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I. Introduction

The downhill movement of surface soil often becomes a considerable amount even in forests of normal growth (IWAKAWA *et al.*, 1987a ; HIGASHI, 1989 ; TSUKAMOTO, 1989). The amount of moved soil differs with the location on the slope, slope inclination, and slope form (IWAKAWA *et al.*, 1987a, b; TSUKAMOTO, 1989). A result of this situation is that mosaic like distributions of the sites, which differ from each other in the balance between input and output of the moved soil, are produced on forested slopes. Chemical and physical properties of the surface soil may differ between the sites of different balance sheets and may change with time on the sites where input and output do not balance.

To predict the distribution of the soils of different properties on slopes and the direction and speed of the changes occurring in the properties of the surface soil, we must have much more knowledge of the downhill movement of the surface soil than we have now.

In the previous paper, the author reported the downhill movement of soil ($\phi < 2$ mm) (TSUKAMOTO, 1989). IWAKAWA *et al.*(1987b) reported that the downhill movement of soil ($\phi < 2$ mm) and that of gravel ($\phi > 10$ mm) were differently related to the factors affecting the movement. In this paper, first the author examine the downhill movement of gravel ($\phi \geqq 2$ mm) in comparison to that of soil. Next, the author suggest the need of some grouping of the soil material according to particle diameters to estimate the amount of the movement of the soil down forest slopes under natural conditions.

II. Methods

1. Site descriptions

Studies were made in the Hokigamine Prefectural Forest Park of Kochi Prefecture (33°40′N, 133°40′E), located about 20 km N-E. of Kochi City, Shikoku Region, Japan. Subsurface geology of this area is an alteration of strata of Paleozoic sandstone and mudstone. Values for the mean annual temperature and precipitation in this area over the last three decades averaged 14.2°C and 3, 307 mm, respectively. About 80% of the annual precipitation is concentrated in the warmer period, April to September.

Seven plots, A-I, A-II, S-I, S-II, H-I, H-II, and H-III, were established on the upper parts of adjoining slopes covered with forests. The efficiency of the ground cover to check the downhill movement of the soil ($\phi < 2$ mm) in reverse order was the Japanese cypress (*Chamaecyparis obtusa* ENDL.) plantations (H-I, II and III) < the Japanese cedar (*Cryptomeria japonica* D.DON) plantations (S-I and II) < the natural mixed stands (A-I and II) (TSUKAMOTO, 1989).

Detailed stand and site descriptions are given by TSUKAMOTO (1989).

2. Measurements of the amounts of soil moving down slopes

On each plot, 10 trap boxes, each one of which could collect the soil and litter passing across a line 25 cm long, were placed on the soil surface at almost regular intervals along a contour line 10 m long. Soil and litter deposited in the trap boxes were collected 34 times during the period from December 1984 to December 1986. Detailed descriptions of the trap box and collection method are given by TSUKAMOTO (1991).

The collected material was sorted into litter, soil ($\phi < 2$ mm), and gravel ($2 \text{ mm} \leqq \phi$). The gravel collected from Plots H-I, II, and III at 13 out of 17 collection times of the first year of the investigation was

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separated further into four size classes according to particle diameters, 2～5 mm, 5～10, 10～20, and 20+, by using mesh sieves. The air-dried soil and gravel were oven-dried at 105 °C for 24 h and the dry weight of each fraction then was determined. The mean value of 10 samples was used for each collection period. On Plot A-II, a trap box received an extremely large stone of more than 200 g in weight in the collection period 25 July to 15 August 1985. For this period the mean value was calculated from the other nine samples. Several corrections were made for the data disturbed by animal activities and a typhoon (see TSUKAMOTO, 1989).

3. Collection and processing of precipitation data

Precipitation data were obtained from the daily reports of the Shigeto Meteorological Observatory, which is located about 1 km north and 100～150 m lower in elevation than the study area.

A "Precipitation Index" was calculated for each continuous rainfall from the total precipitation in a continuous rainfall period (P) multiplied by the maximum of one-hour precipitations in the same period (I). PI was summed up (ΣPI) within the interval of collection, when more than two rainfalls were included in one collection period.

4. Measurements of gravel contents of surface soils

After the final collection of the deposited soil and litter was completed, 10 samples of the uppermost soil layer (0～4 cm) were taken from an area about 3 m wide in front of the row of the trap boxes using cylindrical samplers 100 cm^2 in basal area and 4 cm in depth. The litter and roots were excluded from the air-dried samples. The rest was sieved into the soil ($\phi <$ 2 mm) and the gravel ($\phi \geqq$ 2 mm). The oven-dry weight (105°C, 24 h) of each fraction then was determined. Percentages of the gravel in the total soil and gravel were calculated on an oven-dry weight basis.

III. Results and Discussion

1. Annual amounts of moved gravel

Table 1 gives the annual amounts of moved gravel together with the annual amount of precipitation. In relation to the types of forest, the amounts of moved gravel in reverse order was the natural mixed stands (A-I and II) < the Japanese cedar plantations (S-I and II) < the Japanese cypress plantations (H-I, II, and III). Excluding the natural mixed stands where the downhill movement of the soil was checked effectively by the ground cover (TSUKAMOTO, 1989), the amount of moved gravel was greater in the first year of investigation having larger precipitation than in the second year. These patterns were found also in the amount of moved soil (TSUKAMOTO, 1989).

The annual amounts of moved gravel were not greater necessarily on the plots of larger slope inclinations when comparisons were made within the same type of forest (slope inclinations were A-I < A-II, S-I < S-II, and H-II < H-I < H-III; see TSUKAMOTO, 1989). TSUKAMOTO (1989) reported that when the Precipitation Index was not very large, the amount of moved soil was greater on steep and convex slopes than on gentle and concave to straight slopes. The reverse was the case when the Precipitation Index was extremely large because extremely heavy rains tended to bring about unusually large amounts of localized movements of the soil on gentle and concave to straight slopes. The situation was about the same as to the movements of gravel.

Thus, the differences in the movements of soil and those in the movements of gravel among forest types, between years of investigation and between landforms, generally exhibited the same trends.

2. Relationships between amounts of gravel and "Precipitation Indices"

Table 2 gives the correlation coefficients (r) in the curvilinear regressions of the amounts of moved gravel

Table 1. Amount of moved gravel (2 mm$\leqq \phi$) (g/10 m/year)* and precipitation (mm/year) on plots

Periods	A-I	A-II	S-I	S-II	H-I	H-II	H-III	Precipitation
Dec. 1, 1984～Dec. 17, 1985	256	332	4410	3205	5227	7271	10746	3267
Dec. 18, 1985～Dec. 3, 1986	394	398	2360	1654	3460	4204	—	2436
Average	325	365	3385	2340	4344	5738	—	2852

* Dry weight oven-dried at 105°C.

Table 2. Correlation coefficients (r) between amounts of moved gravel and "Precipitation Indices" (PI) in curvilinear regression analyses applying $\log E = a + b \times \log(\Sigma PI)$ *

Seasons	Number of samples	r						
		A-I	A-II	S-I	S-II	H-I	H-II	H-III
Months without freezing (April to November)	25(12)**	0.536	0.555	0.877	0.324	0.812	0.907	0.639
Throughout the year	33(17)**	0.434	0.384	0.758	0.344	0.768	0.875	0.731

* E, Amount of moved gravel; a and b, Constant; P, Total precipitation in a continuous rainfall period; I, Maximum of one-hour precipitations in the same period; ΣPI, Sum of PI in a collection period.
** Numbers in parentheses are for Plot H-III.

to ΣPI. The value of r for the period of a whole year was smaller than that found between the amount of moved soil and ΣPI on any one of the plots studied (see TSUKAMOTO, 1989).

Some factors other than the rain factor are considered to have greater effects on the movements of gravel than on the movements of soil.

3. *Gravel contents of moved soils*

Table 3 gives the gravel contents of the moved soils together with that of the surface soils. Generally speaking, in the warmer period, April to November, the gravel contents of the moved soils tended to be somewhat smaller than those of the surface soils. On the contrary, in the colder period, December to March, the gravel contents of the moved soils clearly were greater than those of the surface soils.

KITAHARA *et al.* (1985) demonstrated that frost heaving and melting became selective forces causing the fall of relatively larger soil particles among the original soil material on the slopes. OOMI and TSUNAMOTO (1968) observed that it was mostly the gravel ($\phi \geqq 2$ mm) that was raised by frost pillars and that the gravel contents of the eroded soils tended to increase in the winter period, December to March, as compared to the summer period, May to November.

On the study sites, also freezing of the surface soil was often observed in winter. The fall of gravel caused by the freezing and melting of the surface soil is considered to have been an important factor in the larger gravel content of the soil material moved in the winter period than in the summer. Accordingly, the fall of gravel is considered to have been also one of the important factors that weakend the correlation between the amount of moved gravel and the Precipitation Index. In fact, the correlation coefficients between the logarithms of the amounts of moved gravel and ΣPI were greater for periods without freezing than for periods of whole years on the plots excluding the Plots S-II and H-III (Table 2). Plots S-II and H-III were on steep and convex slopes (TSUKAMOTO, 1989) and probablly had relatively large potentials of falls of gravel throughout the year. As a result, the value of r was markedly small on Plot S-II and was the smallest on Plot H-III among the three plots of Japanese cypress.

Thus, the effect of the gravity force makes it difficult to estimate from the rain factor the amount of downhill movement of the soil consisting of particles of various sizes especially when connected with frost

Table 3. Gravel contents* of moved soils and surface soils (0~4 cm)

Plots		A-I	A-II	S-I	S-II	H-I	H-II	H-III
Moved soils	April~November	30.2	32.5	45.4	67.0	49.5	45.6	51.9
	December~March	55.2	62.8	64.4	65.8	76.2	68.8	72.6
	Through a year	33.5	38.9	46.9	66.8	51.2	47.4	55.0
Surface soils (n=10)	Mean	35.6	41.1	44.0	54.6	46.8	52.8	59.1
	Standard deviation	10.7	10.5	11.5	11.5	13.2	9.4	12.2

* Percentages of gravel ($\phi \geqq 2$ mm) to total of gravel and soil ($\phi < 2$ mm) on the basis of dry weight oven-dried at 105°C.

heaving and melting.

4. Grouping of soils according to particle diameters in studying their downhill movements

To predict the distribution of soils of different properties on slopes and the directions and speeds of the changes occurring in the properties of the surface soils, we must be able to estimate the amounts of downhill movements of the soils at every position on the slopes.

Excluding animal activities, the major processes of the downhill movements of soils are erosion by the rain and falls by the gravity force. The relative importance of the two processes in downhill movements changes with the particle-size distribution of the moving soil. The greater the particle size is, the smaller the direct effect of the rain factor becomes. On the other hand, the chance for a particle rolling down the slope to stop through micro irregularities of the soil surface decreases with increasing particle sizes. Moreover, the importance of the land form as the factor affecting the downhill movement was reported to differ with the particle sizes of the moving soil (IWAKAWA *et al.*, 1987b). Under conditions such as this, it is practical for the estimation of the amount of downhill movement of soil material to divide it into several fractions according to particle sizes and to develop an optimal estimation method for the respective fractions. However, the grouping of soils from this viewpoint has not yet been established, although demarcation at 2 mm has been used often according to the particle size classification system adopted by the International Society of Soil Science.

Table 4 gives the correlation coefficients (r) in the linear regressions of the amounts of moved gravel of different particle diameters to the amounts of moved soils in the Japanese cypress plantations. The value of r was rather large with the fraction, 2 mm $\leqq \phi <$ 5 mm and became smaller with increases in particle diameters. As stated above, the soil and the gravel moved down the studied slopes in about the same manner in relation to the types of forest, years of investigation, and slope forms. This fact implies that the gravel fractions ($\phi \geqq$ 2 mm) included such particles in rather great amounts as responding to erosive factors similarly with the soil ($\phi <$ 2 mm). Table 5 gives the correlation coefficients in the curvilinear regressions of the amounts of different fractions of the moved soils to ΣPI in the Japanese cypress plantations. Although the value of r tended to decrease with increasing particle diameters, the decline was rather gentle within the range of diameters less than 10 mm and turned sharply down beyond the boundary of 10 mm. IWAKAWA *et al.* (1987a) reported that the amount of moved gravel ($\phi >$ 10 mm) was greater in the colder season having little precipitation than in the warmer season having greater precipitation, and the reverse was the case with the amounts of moved soil ($\phi <$ 2 mm) and gravel (2 mm $< \phi <$ 10 mm).

These facts suggest that a demarcation at 10 mm in particle diameter is more practical than that at 2 mm to estimate the amount of soils moving down a slope.

Although many more studies must be made, it is necessary to establish a practical grouping of soils according to particle diameters for the estimations of the amounts of downhill movements consisting of various-sized particles which respond differently to the erosive factors.

Table 4. Correlation coefficients (r) in regressions of amounts of moved gravel of different particle sizes to amounts of moved soils in the following equation: $G=a+b\times S$*

Plots	Number of samples	Particle diameters (mm)			
		2〜5	5〜10	10〜20	20+
H-I	13	0.853	0.518	0.332	0.188
H-II	13	0.741	0.668	0.558	0.108
H-III	13	0.789	0.694	0.359	0.158

* G, Amount of moved gravel ($\phi \geqq 2$ mm); S, Amount of moved soil ($\phi < 2$ mm).

Table 5. Correlation coefficients (r) in regressions of amounts of moved soils of different particle sizes to the "Precipitation Indices" in the following equation: $\log E=a+b\times\log(\Sigma PI)$*

Plots	Number of samples	Particle diameters (mm)				
		〜2	2〜5	5〜10	10〜20	20+
H-I	13	0.902	0.789	0.746	0.482	0.250
H-II	13	0.851	0.864	0.881	0.692	0.178
H-III	13	0.959	0.835	0.747	0.272	0.261

* E: Amount of moved soil material, a, b, P, I, and ΣPI are the same as in Table 2.

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