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Effect of geologic variability on sediment yields from yarding and forest roads

Yukiyoshi Teramoto[1*] and Etsuro Shimokawa[1]

Abstract: We investigated sediment yields from yarding roads and their grain size characteristics, and studied the effect of differences in geology on yarding and forest roads. The study site included yarding roads within an abandoned former plantation forest that had been clear-cut, located near Kuma-mura, Kumamoto Prefecture, Japan. The geology of the study site consists of sedimentary rocks. To clarify sediment yields from yarding roads and grain size characteristics of the sediment yield, two experimental catchments were installed. Yearly sheet erosion rates in R1 (experimental catchment with an 86-m^2 area and 8° average slope) and R2 (experimental catchment with a 111-m^2 area and 6° average slope) were about 3.3 mm and 0.9 mm, respectively. These rates were about 33% and 9%, respectively, compared to those measured in a weathered granite catchment. The reason for this difference is that cohesion in sedimentary rocks was greater than that in weathered granite. The median grain diameter for individual sediment yields in R1 was between 0.27 mm and 0.75 mm, and for R2 was between 0.67 mm and 5.45 mm. Grain size distributions of sediment yields in R2 were variable in comparison with grain size distributions of sediment yields in R1.

1 Introduction

Preparation of yarding and forest roads requires continued management of forests, which accounts for about 70% of the area of Japan. This maintenance is also essential for generating effective wood products. In particular, preparation of yarding roads to introduce forest machinery to forest lands according to cutting schedules is critical to the working environment. These conditions are necessary to introduce high-quality forestry machines, which reduce the costs of wood production.

The exposure and compaction of subgrade surface soil due to preparation of yarding and forest roads cause a decrease in soil infiltration capacity and an increase in sediment yields through sheet erosion and sediment discharge. Moreover, erosion of hillsides, stream beds, embankments and coastal areas due to debris flows caused by sheet erosion often occurs. These activities cause considerable damage to the hillsides and coastal forest growths. Thus, it is important to quantitatively investigate the sediment yields from yarding and forest roads to aid in the conservation of hillside and coastal ecosystems.

The studies of Minematsu *et al.* (1983), Furutani *et al.* (1983), Fukushima *et al*. (1984) and Inoue *et al*. (1999) demonstrated topographic changes in rill erosion of Japanese forest roads, characteristics of the sediment yields, and suspended discharge and water discharge on forest roads, and provided analysis of sediment yields and surface water discharge using a runoff model and a sediment discharge formula. However, information is lacking regarding grain size characteristics of the sediment yields of yarding and forest roads with respect to differences in geology.

The purpose of this research is to identify grain size characteristics and sediment yields from yarding and forest roads, as well as to study the effect of geologic variability on these features in the study area.

2 Study area and methods

The study area is composed of yarding roads within an abandoned plantation forest that had been clear-cut, located near Kuma-mura, Kumamoto Prefecture, Japan (Figure 1). Clear-cutting was conducted in 2002, and the area of abandoned forest (the area enclosed by the solid line in Figure 1) is 0.89 km^2. The plantation forest included cedar and cypress planted in 1962. The age of the trees at the time they were cut was 40 years. The geology of the area consists of sedimentary rocks.

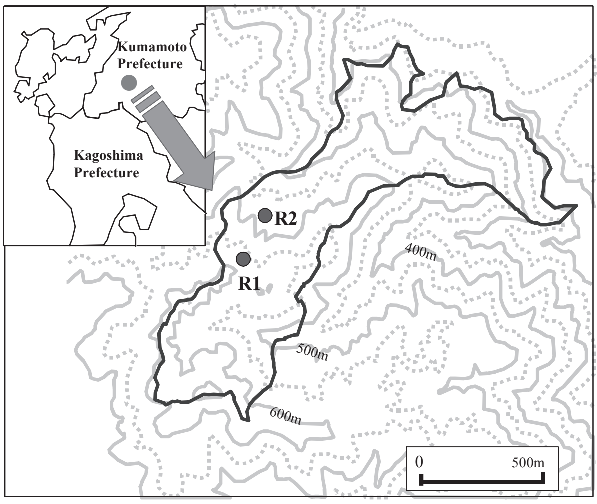

Figure 1: Study area location

[1]Faculty of Agriculture, Kagoshima University, 1-21-24 korimoto, Kagoshima 890-0065, Japan

*Corresponding author: sabot@agri.kagoshima-u.ac.jp

To measure sediment yields from sheet erosion from these yarding roads, two experimental catchments were installed at 560 m and 480 m above sea level, respectively (Figure 1). The experimental catchments were installed on different yarding roads within the study area. In this paper, we refer to the experimental catchment with an 86-m^2 catchment area and 8° average slope as "R1", and the experimental catchment with a 111-m^2 catchment area and 6° average slope as "R2" (Table 1, Figure 2 and Photo 1). In the lowest part of the experimental catchment, a plastic box was installed to measure sediment yields from sheet erosion (Figure 2 and Photo 1). Measurements were conducted during October 2007 and October 2008. Both the topography of the R1 and R2 catchments, and the distributions of collection points of surface soil on rills and interrills were measured in April 2008 (Figure 2). Table 2 shows results of soil tests in surface soil collected on rills and interrills in R1 and R2. The grain diameters of surface

Table 1: Outline of the experimental catchments

Catchment	Area m^2	Average slope degree	Altitude m	Geology
R1	86	8	560	Sedimentary rock
R2	111	6	480	

Table 2: Results of soil tests in surface soils collected on rills and interrills in R1 and R2

Catchment		Average value						
		Median grain diameter mm	Coefficient of uniformity	Coefficient of curvature	Grain diameter			
					Silt <0.074mm %	Fine sand 0.074-0.42mm %	Coarse sand 0.42-2.0mm %	Gravel >2.0mm %
R1	Rill	14.83	25.02	3.83	0.73	7.89	11.80	79.58
	Interrill	1.12	10.10	0.92	4.71	22.89	40.11	32.29
R2	Rill	4.46	4.15	1.25	0.65	2.47	12.77	84.11
	Interrill	1.32	19.06	1.07	9.20	22.21	31.40	37.19

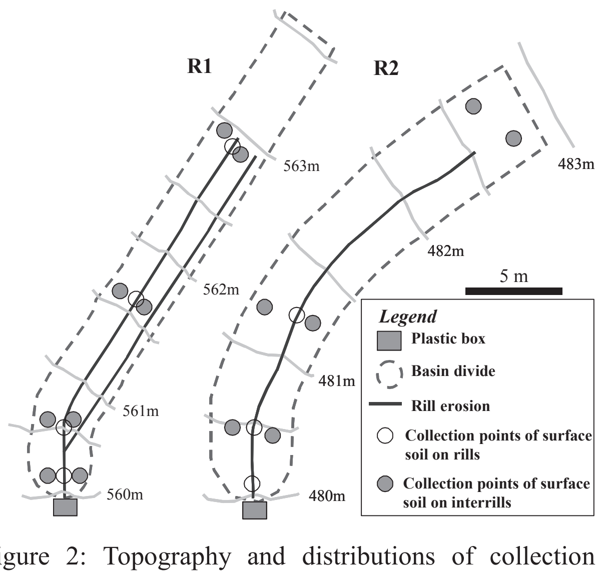

Figure 2: Topography and distributions of collection points of surface soil on rills and interrills in R1 and R2

soils on rills were larger than those on interrills. The armoring of surface soil in rills preceded that in interrills in R1 and R2. Constituent grains of surface soil in R1 were rougher than those in R2. At the same time, the sediment yields from sheet erosion in R1 and R2 were collected. The sediment was used to determine grain size distribution, coefficient of uniformity and coefficient of curvature (Kawakami, 1983). Rainfall data used in this paper were collected by a Isyochi automated meteorological data acquisition system, situated to the southwest at a location of about 1.2 km away from R1 and R2.

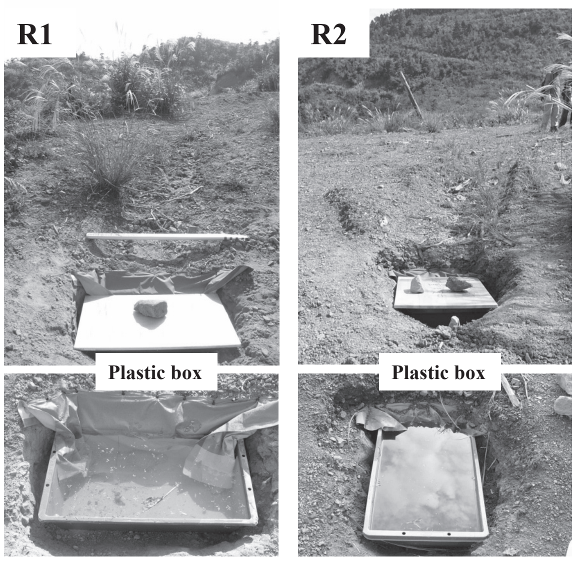

Photo 1: Experimental catchments

3 Results and discussion

3.1 Sediment yields from sheet erosion and erosion rates

Figure 3 (a) shows the temporal change in cumulative rainfall measured in nearby R1 and R2, and Figure 3 (b) shows the temporal changes in cumulative sediment yield by sheet erosion in R1 and R2. At the same time, the rainfall and sediment yield by sheet erosion measured in a weathered granite catchment with a 306-m^2 area and 6° average slope on forest roads located in the southern part of Shiga Prefecture, Japan (Fukushima *et al*., 1984), are indicated in Figure 3 (a) and (b). The rainfall and sediment yield made the measurement start date a starting point. The value of sediment yield was divided by individual catchment area, and was expressed in millimeters. The sediment yield in R1 was larger than that in R2. In addition, although cumulative rainfall in nearby R1 and R2 was greater than that in the weathered granite catchment, cumulative sediment yield in R1 and R2 was smaller than that in the weathered granite catchment.

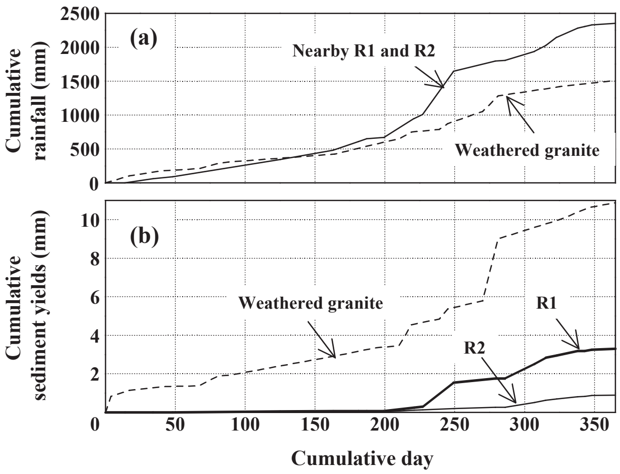

Figure 3: Temporal change in cumulative rainfall (a) and cumulative sediment yields from sheet erosion (b) in R1, R2 and a weathered granite catchment

Figure 4 (a) shows the relationship between total rainfall and sediment yields by sheet erosion, and Figure 4 (b) shows the relationship between maximum rainfall per 60-minute interval and sediment yields by sheet erosion in R1 and R2. At the same time, the sediment yield by sheet erosion and rainfall measured in the weathered granite catchment on a forest road located in the southern part of Shiga Prefecture, Japan (Fukushima *et al*., 1984), are indicated in Figure 4 (a) and (b). The total rainfall expresses the sum of rainfall from measurement date of sediment yield to next measurement date of sediment yield. Sediment yield by sheet erosion tended to become larger with increased rainfall intensities. In cases where rainfall intensities were of the same degree, sediment yield by sheet erosion in R1 and R2 was smaller than that in the weathered granite catchment. Sediment yield by sheet erosion for individual sediment yield in R1 and R2 was between 0.00014 mm and 1.24 mm (average 0.11 mm), and for the weathered granite catchment it was between 0.02 mm and 3.22 mm (average 0.64 mm).

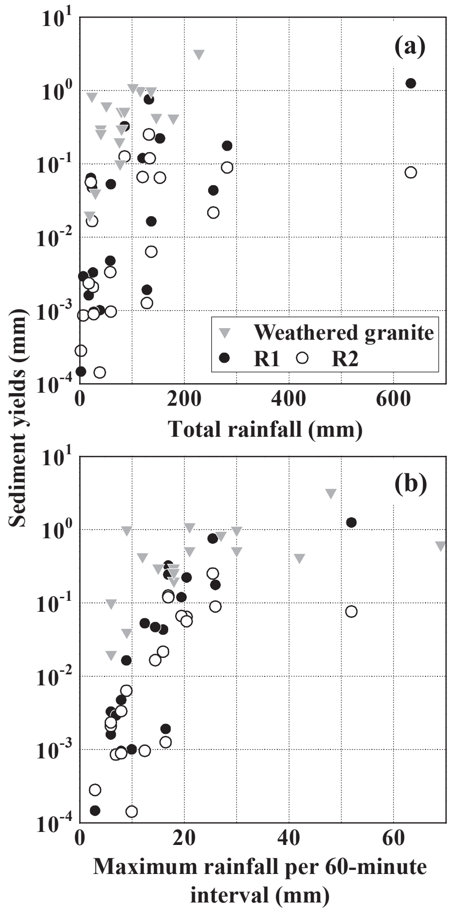

Figure 4: Relationship between total rainfall and sediment yields from sheet erosion (a) and relationship between maximum rainfall per 60-minute interval and sediment yields from sheet erosion (b) in R1, R2 and a weathered granite catchment

Table 3 shows a comparison of yearly sheet erosion rate in R1, R2 and the weathered granite catchment (Fukushima *et al*., 1984), with yearly rainfall during October 2007 and October 2008, and during September 1982 and September 1983 (Fukushima *et al*., 1984). Although yearly rainfall in nearby R1 and R2 was about 158% of that measured in the weathered granite catchment, yearly sheet erosion rate in R1 and R2 of sedimentary rock catchment was about 33% and about 9% of that measured in the weathered granite catchment, respectively.

Table 3: Comparison of yearly sheet erosion rates in R1, R2 and a weathered granite catchment

Catchment	Term	Area m^2	Average slope degree	Yearly sheet erosion rate mm	Yearly rainfall mm	Geology
R1	Oct., 2007-Oct., 2008	86	8	3.3	2,354	Sedimentary rock
R2		111	6	0.9		
Fukushima *et al.*(1984)	Sept., 1982-Sept., 1983	306	6	10.0	1,511	Weathered granite

Furthermore, the total amount of individual sediment yield by sheet erosion measured in the summer season period during June 2008 and September 2008 in R1 and R2 accounts for about 93% and about 86% of the total amount of sediment yield during October 2007 and October 2008, respectively. The total amount of individual rainfall measured in the summer season period in nearby R1 and R2 accounts for about 60% of the total amount of rainfall during October 2007 and October 2008. The total amounts of sediment yield by sheet erosion and rainfall measured in the summer season period during June 1983 and September 1983 in the weathered granite catchment account for approximately 70% and about 51% of the total amounts of sediment yield and rainfall during September 1982 and September 1983, respectively (Fukushima *et al.*, 1984). These results are in accordance with the current study.

The reason that sediment yield from R1 and R2 in the sedimentary rock catchment was smaller than that from the weathered granite catchment (Fukushima *et al.*, 1984) is that cohesion in the former was greater than that in the latter (Miki, 1978), and that consequently, resistance to sheet erosion in sedimentary rock was greater than that in weathered granite.

3.2 Grain size characteristics of sediment yield by sheet erosion

Figure 5 (a) shows the relationship between total rainfall and the median grain diameter in sediment yields from sheet erosion, and Figure 5 (b) shows the relationship between maximum rainfall at 60-minute intervals and the median grain diameter in sediment yields from sheet erosion in R1 and R2. In cases where rainfall intensities were of the same degree, the median grain diameter in sediment yields from sheet erosion in R2 was larger than that in R1. The median grain diameter for individual sediment yields in R1 was between 0.27 mm and 0.75 mm (average 0.46 mm), and for R2 it was between 0.67 mm and 5.45 mm (average 2.58 mm).

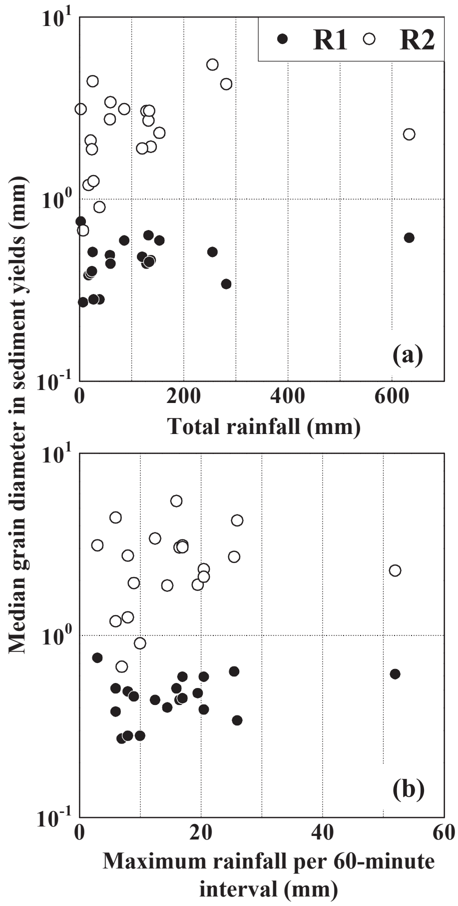

Figure 5: Relationship between total rainfall and median grain diameter in sediment yields from sheet erosion (a) and relationship between maximum rainfall per 60-minute interval and the median grain diameter in sediment yields from sheet erosion (b)

Table 4 shows results of soil tests with respect to sediment yields from sheet erosion for R1 and R2. These results indicate the average value of soil tests for individual sediment yields measured in R1 and R2. The median grain diameter in sediment yields from sheet erosion in R2 was larger than that in R1. Constituent grain diameters of sediment yields in R2 were rougher than those in R1. Moreover, coefficients of uniformity and coefficients of curvature in R2 were larger than those in R1. The observations indicated that the greater the value of coefficient of uniformity, the wider the distribution area of grain diameter became. Coefficients of curvature of 1 to 3 indicated that the grain size distribution was fine (Kawakami, 1983). Thus, grain size distributions of sediment yields in R2 were more variable in comparison with those in R1. Grain size distribution of sediment yields and surface soils in R1 and R2 showed an inverse relationship. The reason for this trend is that the spatial distribution of grain sizes and the vertical distribution of surface soils in the catchments of R1 and R2 varied with the occurrence of sheet erosion. In addition, the area contributing to the occurrence of Hortonian overland flow changed with different rainfall intensities. However, a more detailed study of these processes will be needed to elucidate this problem. Table 5 shows results of soil tests on sediment yields from sheet erosion for R1 and R2 in the sedimentary rock catchment. For comparison, results of soil tests on sediment yields from sheet erosion in a Paleozoic strata catchment with a 200-m^2 area and 6° average slope on a forest road located in Kyoto Prefecture, Japan (Furutani *et al*., 1983), are indicated in Table 5. The results of these soil tests indicate the average value for individual sediment yields. Grain diameter distributions in R2 and the Paleozoic strata catchment showed a similar trend, whereas the grain diameter distribution in R1 followed a different trend. Insufficient studies have been conducted on sediment yields and their grain size characteristics from yarding and forest roads. Thus, it is necessary to generate more data in the future on sediment yields and their grain size characteristics for various geological conditions.

Table 4: Results of soil tests in sediment yields from sheet erosion for R1 and R2

Catchment	Average value						
	Median grain diameter mm	Coefficient of uniformity	Coefficient of curvature	Silt <0.074mm %	Fine sand 0.074-0.42mm %	Coarse sand 0.42-2.0mm %	Gravel >2.0mm %
R1	0.69	6.74	0.91	6.15	44.38	30.90	18.57
R2	2.58	14.62	1.44	3.07	14.62	28.77	53.54

Table 5: Results of soil tests in sediment yields from sheet erosion for sedimentary rock catchments and a Paleozoic strata catchment

Catchment	Average value: Grain diameter				Geology
	<0.074mm %	0.074-2.0mm %	2.0-10.0mm %	>10.0mm %	
R1	6.2	75.3	14.2	4.3	Sedimentary rock
R2	8.1	45.6	43.3	3.1	
Furutani *et al*.(1983)	1.9	44.6	43.6	9.9	Paleozoic strata

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References

[1] Fukushima, Y., Kuroda, Y. and Watari, M. (1984): Discharge and sediment yield on forest road, *Bull. Kyoto Univ. For.*, 56, pp.145-154. (in Japanese with English abstract)

[2] Furutani, S., Sakai, T., Fujii, Y. and Sasaki, I. (1983): Study on erosion of forest road surface (Ⅳ) - The results of investigation on the erosion in 1982 -, *Bull. Kyoto Univ. For.*, 55, pp.230-241. (in Japanese with English abstract)

[3] Inoue, S., Oh, J. and Matsuda, K. (1999): An experiment on suspended sediment discharge from forest road using simulated rainfall, *Jour. Rainwater Catchment Systems*, 5(1), pp.1-5. (in Japanese with English abstract)

[4] Kawakami, F. (1983): Soil mechanics (The fifth edition), *Morikita Publishing Co., Ltd.*, 292pp. (in Japanese)

[5] Miki, K. (1978): Knowledge on rock and bedrock, *Kajima Institute Publishing Co.,Ltd.*, 318pp. (in Japanese)

[6] Minematsu, H., Minamikata, Y., Nishio, K., Itou, K. and Kanda, K. (1983): The area of application of the optimum spacing fomula to open top culvert on forest roads, *Jour. Japanese Forestry Society*, 65(12), pp.465-470. (in Japanese)

[7] Isyochi automated meteorological data acquisition system (2007, 2008): Observed data.

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