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Temporal changes in small particle sediment yielded from the catchment following to forest growth after clear cutting

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Landscape change caused by forest disturbance would be expected to influence on the acceleration of soil erosion of hillslopes. Most of the soil eroded from a hillslope flow through the stream channel and out of the catchment as fine particle sediment such as suspended load (Chikita, 1996). In this study, temporal changes in the volume of fine particles yielded from small catchments were monitored at five catchments varying from 2.2 ha to 4.2 ha in area, 10.1° to 17.2° in slope, and 5 years to 70 years (almost secondary forest) in elapsed time after clear cutting. The volume of sediment transported by stream flow, which was trapped in a couple of sampler boxes set up at the mouth of each catchment, was measured every month for five months. The result shows that the amount of the fine particle sediment of two catchments elapsed 15 to 18 years after clear cutting was larger than that of the other catchments elapsed 3 to 6 years after clear cutting. Furthermore, the volumetric peak of fine particle sediment yielded first appeared during 10 and 15 years after clear cutting. From the results, the influence of the clear cutting on the volume of small particle sediment yielded from a catchment tend to appear after a time elapse of 10 to 15 years following clear cutting.

INTRODUCTION

From the worldwide viewpoint of soil and water conservation, it has been important to make guidelines for land use change such as clear cutting. The volume of fine particle sediment eroded from hillslope is assumed to be different according to the magnitude of ground surface exposure and geomorphic characteristics (Johnson, 1993). Basically, suspended sediment yield in wide range is controlled by rainfall and geology (Hicks *et al.*, 1996). Then, Wischmeier *et al.* (1978) developed the Universal Soil Loss Equation (USLE) considering rainfall erosivity, soil erodibility, length–slope–steepness factor, management factor and soil conservation practice factor. Rainfall erosivity and soil erodibility are assumed to be constant within a narrow range in the same geological area. On the other hand, management factor and soil conservation practice factors are determined to assess the agricultural effects (Wishmeier *et al.*, 1971; Cummins *et al.*, 1972; Costa, 1975), however, forestry practices of effects has not been practically included here (Ferguson and Stott, 1987). Because forest influence on surface erosion of hillslope is expected to be different according to forest features such as age structure, species, tree density and type of artificial /natural (Francis *et al.*, 1989), geomorphology

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such as slope and catchment area must be unified as the experimental conditions. Among them, forest growth measured as age structure after clear cutting followed by young trees planted could be related to the temporal changes in volume of fine particle sediment eroded from hillslopes. In this paper, temporal changes in the volume of fine particles yieled from small cathments were monitored at five catchments varying from 2.2 ha to 4.2 ha in the area, 10.1° to 17.2° in the slope, and 5 years to 70 years (almost secondary forest) in the elapsed time after clear cutting. This paper analyzes the relationship between the volume of fine particle sediment and the catchment slope gradient as a geomorphic factor of catchment and forest age structure in the entire catchment respectively.

STUDY SITE

Five sub–catchments located in the Oyabu Creek, tributary of the Hitotsuse river, Kyushu Island (Experimental research forest of Kyushu–univ. in Shiiba, Miyazaki Prefecture) were chosen for measurement of their monthly fine particle sampling (Fig. 1). The averaged annual rainfall of this creek is 3500 mm. Channel bed consists of fractured sandstone and mudstone underlain by the Nobeoka–Shibisan tectonic line.

The characteristics of each catchment are briefly described in Table 1. Each catchment has different characteristics in vegetational and morphological aspects. They also have various elapsed year after clear cutting.

METHOD

The daily rainfall is closely correlated with direct runoff. That is, fine particle yield affected by direct runoff is expected to change according to the amount of rainfall. The whole period of the investigation in the field was divided into six "sub period", depending

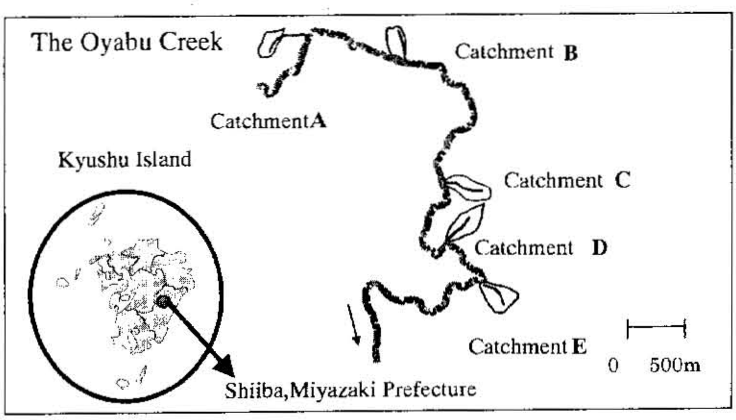

Fig. 1. Location of the Oyabu Creek

Table 1. Characteristics of each catchment

	Catchment A	Catchment B	Catchment C	Catchment D	Catchment E
Averaged catchment slope (°)	11.3	17.2	10.1	16.2	14.9
Catchment area (ha)	2.89	2.2	4.2	2.76	2.98
Cutting year	1996	1920s	1993	1985	1982
Forest	Hinoki Cypress Sawleaf zelcova	Natural Forest (Secondary Forest)	Hinoki Cypress	Japanese Sugi Hinoki Cypress	Japanese Sugi Hinoki Cypress
Condition of forest land	Covered with herbaceous plants and litter	Covered with a little of litters	Almost Covered with herbaceous plants	Covered with moss and litter	Covered with herbaceous plants

on dates for collecting the data. Then, duration rainfall was calculated as the sum of daily rainfall at each sub period. Daily rainfall was measured by a tipping-bucket rain gauge located close to the upper stream of the Oyabu Creek (Fig. 2).

In many previous studies, fine particles yielded has been proven to increase in proportion with water discharge (Walling, 1977; Charles *et al*, 1996). In this study, water discharge is used to estimate the fine particles yielded in each catchment (Ferguson, 1986). An automatic water-level gauge was set at the catchment F (excluded from study area) to obtain water discharge data here. The H–Q relationship was obtained from

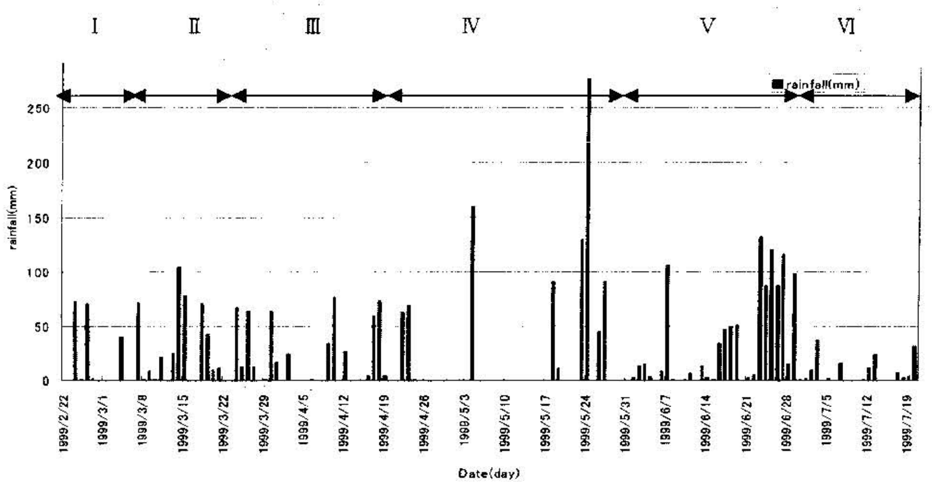

Fig. 2. Duration rainfall in the Oyabu Creek

water–level data and discharge measured directly at the field. The relationship between discharge and water–level at the catchment F is given by

$$Q=(6.1772H-1.0867)^{2}$$

At the same time, since the catchment area is relatively small enough, water discharge from the catchment is assumed to have a linear relationship with its area. With the assumption of linear relationship, water discharge of the other catchments which do not have a water–level gauge can also be estimated by specific discharge of the catchment F.

$$Q_n = qA_n \qquad (1)$$

where q is specific discharge of the catchment F in m^3/sec,
A_n is area of catchment n in ha,
and Q_n is discharge of catchment n in m^3/sec.

Then, sediment from each study catchment could be calculated with the discharge from equation (1).

Fine particles transported to catchment outlet were collected by a couple of boxes set up at the mouth of each catchment (Fig. 3). This method was used on the experimental field study by Oostwoud *et al* in 1998.

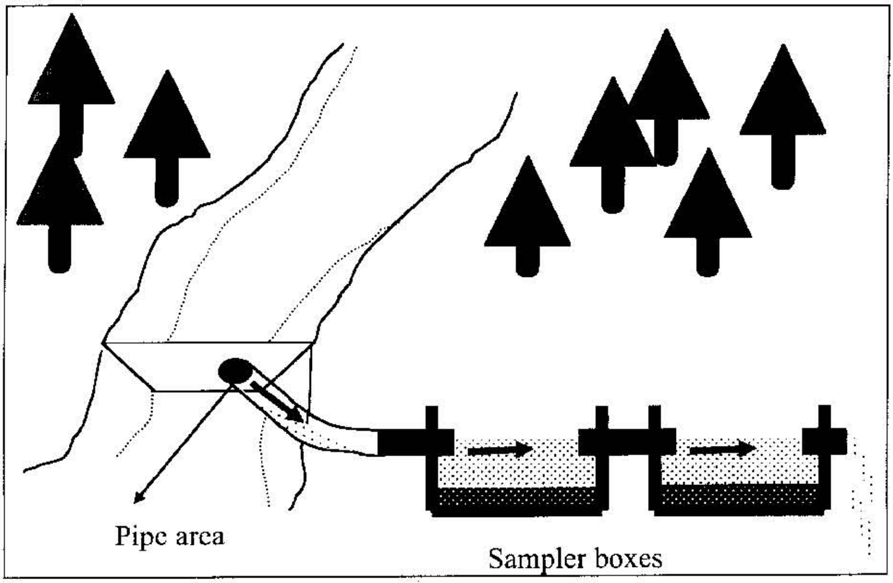

Fig. 3. Setting of Sampler boxes

Table 2. Estimated total fine particle sediment yield

Unit: g/ha

Sub Period	Catchment A	Catchment B	Catchment C	Catchment D	Catchment E
I (Fed 24–Mar 3)	0	–	4.7	7.8	2.3
II (Mar 3–Mar 22)	6.9	–	16.1	45	57.5
III (Mar 23–Apr 21)	0	–	19.7	46.6	141.7
IV (Apr 22–May 28)	17.2	300.3	132.5	1188.1	773.8
V (May 29–June 29)	30.9	2220.5	768.5	2656.3	1464.2
VI (June 30–July 20)	1.9	43.6	23.9	16	28.3

Stream water containing fine particles continually flowed into the boxes through the plastic drain installed against the flow direction. To allow fine particles to settle through sub periods, two boxes were connected with a short pipe (10 cm in length). The net at the exit of both boxes prevented sediment more than 2 mm in diameter from flowing out of the box. Fine particles collected were dried in the oven at 110°C and analyzed gravimetrically. After that, by using the ratio of the discharge flow in through pipe and total discharge in the catchment, total fine particle yield in each catchment was calculated (Table 2). That is, the total volume of fine particle in each catchment through each sub period is given as follows.

$$Yt = Qt \cdot Qp^{-1} \cdot Ys, \qquad (2)$$

where Yt is total fine particle yield in g/ha,
Qt is total discharge in m^3,
Qp is the discharge through the pipe in m^3,
and Ys is the fine particle yielded in the sampler boxes in g/ha

The particle size analysis was also carried out with sediment trapped in the box to diagnose the effect of particle size on fine particle sediment yield. The particle sizes of fine particle up to 75μm (coarse and fine sand) in diameter were separated using a standard sieving method, and those less than 75μm (silt and clay) were separated by the method based on Stoke's law. (Vaithiyanathan *et al.* 1992; Nakano 1995; Nicholas 1996).

RESULT

Particle size analysis in fine particle sediment from each catchment

The particle–size distribution of the fine particles shows that the less than 75μm diameter fraction accounts for nearly 50% of all the fine particles by the river in any catchment. Particle size was distinguished as shown in Fig. 4. The particle size from catchment C was the finest among the five catchments. More than 80% of fine particles consisted of silt and clay.

Relations between discharge and fine particle sediment yield

Since the relationship between total discharge and rainfall through each sub period

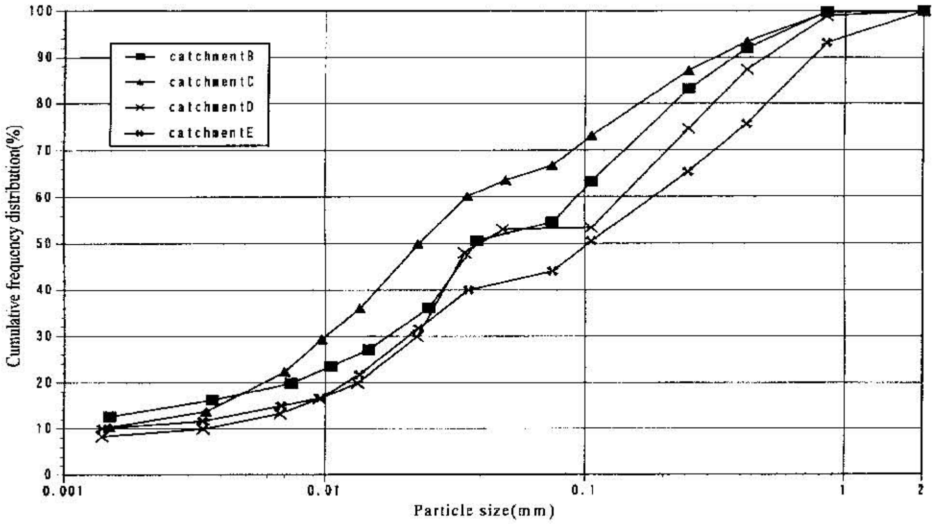

Fig. 4. Cumulative frequency distribution of fine particle at each catchment

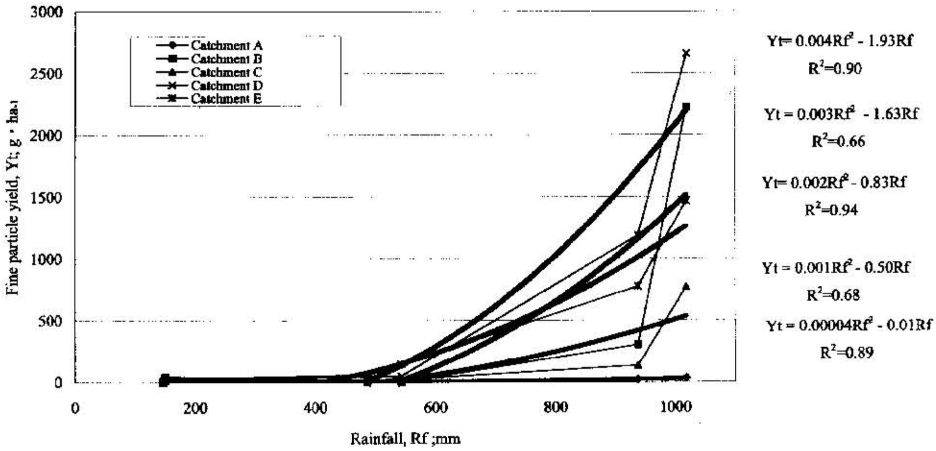

Fig. 5. Relation between rainfall and fine particle yield

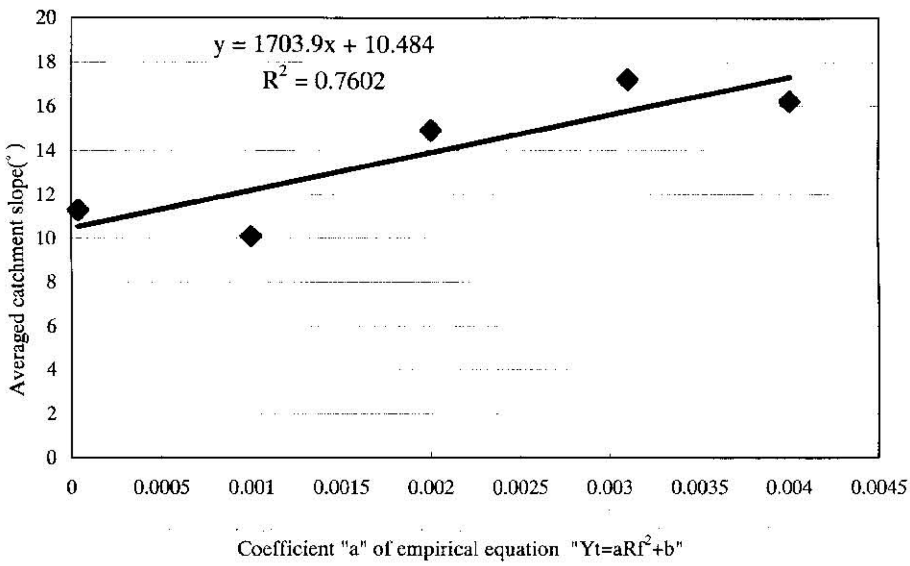

Fig. 6. Relation between increasing rate of fine particle yield and catchment slope.

(Fig. 5) was resulted in a linearly increasing curve, sediment of fine particle size from each catchment is represented as the function of rainfall.
In this graph,

$$Yt = aRf^2 + b, \quad (3)$$

where Yt is total fine particle yield in g/ha,
Rf is cumulative rainfall,
and a and b are coefficients.

Figure 5 shows that the increasing rate of fine particles yielded against cumulative rainfall is different among all catchments. Catchment slope is one of geomorphologic factors to affect the amount of sediment yielded at fine particle size. The average catchment slope is described by coefficient "a" of the empirical equation ($Yt=aRf^2+b$), establishing a linear relationship here (Fig. 6).

Relations between passage years of clear cutting and fine particle yield

Figure 7 shows that after clear cutting, amount of fine particle increases until 15 years, then, it decreases from 15 to 18 years. In subsequent years, it is shown that the amount of fine particle remains constant regardless of time (year) elapsed though is no catchment to be studied from 15 to 70 years (secondary forest) in figure 7. From that phenomenon, the time lag from forest disturbance and its effect on turbidity at the catchment mouth is suggested to be about 15 years in the study site.

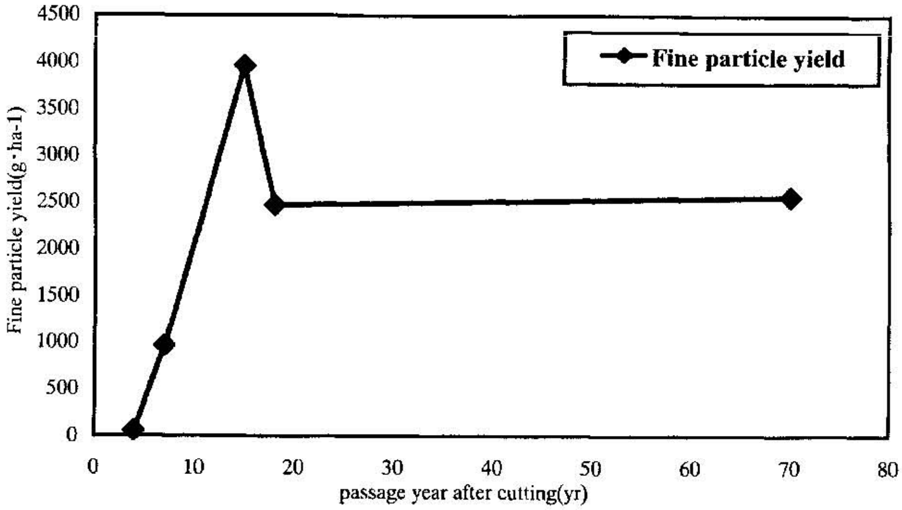

Fig. 7. Volumetric change in fine particle yield

Catchment C has relatively gentle slope but most of the surface was covered with grass, pampas grass and moss except the planted area. On the contrary, particles in catchment E is coarser than in catchment C. Therefore, it can be concluded that more the surface covered with grasses, the less coarse the sand exists in catchments and vice-versa.

CONCLUSION

The relationship between clear cutting and forest growth could be demonstrated from this field measurement. First of all, as the averaged catchment slope is steeper, the amount of fine particle is higher. Secondly, there is 15-year time lag between forest disturbance and the increase in fine particle yield caused. That reason is considered because the hillslope surface just after clear cutting is still covered with grass and twigs from the tree removed. However, there is not sufficient data to propose the evidence although similar tendencies have been seen in England (Ferguson and Stott, 1987; Kirby *et al.*, 1991). Quantitative explanation also could not be included in the demonstration for the present. Thus, it is required to estimate how many years it take to recover and what intensity of cutting is desirable for preventing soil from the effects of forest disturbance in order to plan watershed management.

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