SEDIMENT MOVEMENT ON STEEP SLOPE OF A MONOCULTURE *CHAMAECYPARIS OBTUSA* (HINOKI) PLANTATION

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Abstract
Chamaecyparis obtusa (Hinoki) is one of the main species for plantations in Japan. Severe soil erosion in monoculture Hinoki plantations has been considered a serious problem for soil conservation in steep mountainous areas. We investigated and analyzed sediment movement rates in the form of sediment erosion or deposition at three experimental plots set on different altitudes of a monoculture Hinoki plantation situated in steep mountainous area of Kochi prefecture in Shikoku Island, Japan. Each experimental plot was assumed as an isolated and inclined small tract of land on an arbitrary horizontal plane. The changes in soil mass volumes during the time elapsed between successive field-measurements were calculated to find out the eroded or deposited soil mass volumes in each tract of land. The field measurements were usually done after every heavy rainfall event in the summer and at least once in every 2 months in the winter. There was a more or less similar tendency of sediment movement in plot I (upper) and plot II (middle), while it was different in plot III (lower). Slope intervened in sediment movement in terms of its form, gradient, length and position. We found mean erosion heights of 7.41 mm, 2.31 mm and 5.96 mm per year in plot I, II and III respectively during the common observation period from 17th June 2000 to 24th November 2003. A fall in erosion rate was observed after thinning in plot I due to fair soil compaction caused by the thinning operation. Sediment movement on the experimental slope occurred even after a little rainfall, which is not usually considered erosive.

Additional Keywords: erosion, deposition, rainfall, thinning.

Introduction
Estimating soil erosion on steep slopes is important to determine land use practices of a particular mountainous area to ensure long-term productivity of the soil. In a high rainfall area with mountainous and forested landscape like Shikoku island of Japan, rainfall is the primary factor of sediment detachment and movement. Naturally, the steeper the slope of a field, the greater is the amount of soil loss from erosion by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. The other factors influencing sediment movement on a forested slope are mainly physical and chemical properties of soil as well as topography, canopy cover and cover on the soil surface, such as litter and under woods. There have been few studies on sediment movement on steep forested slopes of Japan other than those concerning weathered granitic rock mountains. The anti-erosive effect of vegetation, especially of forest, is well recognized. Kawaguchi (1951) reported an erosion rate of 0.1-0.01 mm year^{-1} in case of grasslands or forest cover in Japan. Hiura *et al.* (1983) determined the erosion rate of denuded slopes due to shallow slides in the weathered granitic rock mountain areas of Japan to be on the order of millimeters per year**.** Thus, the vegetation can substantially reduce the erosion rate. In case of monoculture reforestation of Hinoki (*Chamaecyparis obtusa*), fast fragmentation of the scale like leaves falling on the forest floor causes plug up the macro pores with the fragmented leaves due to raindrops striking the soil surface. After subsequent drying, it forms a crust system on the sloping ground that decreases the infiltration capacity of soil leading to severe soil erosion. The objective of this study was to evaluate sediment movement in the form of erosion and deposition at three plots set on a steep slope reforested with Hinoki in Kahoku area of Kochi prefecture, Japan.

Materials and Methods
Study area
The study area is located 30 km northeast of Kochi city and 5 km north of the center of Kahoku town in Kochi prefecture, Japan (Figure 1). The area is completely mountainous with steep slopes. The slope under study faces the west and the mean inclination is about 39.7 degrees (Hiura, 1998). The geology of the base rock is sandstone-rich, alternate of sandstone and shale of the early to middle Jurassic era in the Chichibu belt of Shikoku island, in which limestone is distributed in patches along northwest-southeast strike. Sandstone and limestone are outcrops. Boulders and rocks are scattered over the slope along with weathered and broken bits of sandstone and limestone. The angle of repose of sandstone is about 30 degrees (Hiura *et al.*, 1999). Comparing this with a higher mean inclination of slope, a slight disturbance on the soil surface may cause the superficial materials to move downward easily.

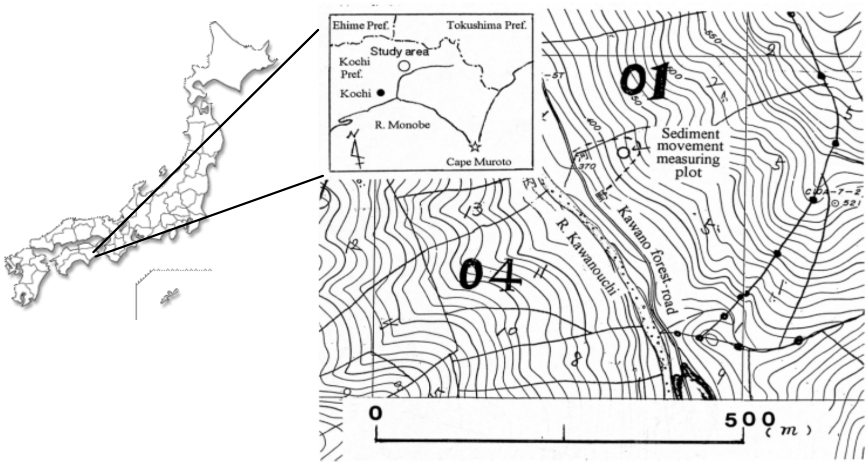

Fig. 1. Location map of the study area

The slope is covered with an even-aged monoculture plantation of Hinoki reforested in 1971. At the beginning of the study in 1995, canopy of the forest was closed and there was almost no undergrowth. The forest was thinned to reduce the density of trees from 2350 to 1368 stems per hectare in September, 1997 (Figure 2). The average height of trees was 13 m and average diameter at breast height was 18 cm as measured in 2001.

Characteristics of the soil

Soil particles from fine sand to silt of diameter ranging from some centimeters to some ten micro meters were observed. Fine materials on the slope surface are not stable due to steepness of the slope and high amount of coarse materials on the surface. Table 1 indicates some physical characteristics of soil in the study area. The soil type is thin dry brown forest soil (Bc type) with scattered L and F layer. Bc type soil is formed under alternate conditions of dryness and wetness. The horizon sequence is A, AB and B. AB-horizon is fairly thick, A horizon is soft, while B horizon is fairly hard. It is supposed that the A horizon plays an important role in superficial sediment movement.

Figure 2. Study slope just after thinning

The soil structure of A horizon is summarized as follows: the upper part of the slope is nutty, while at the lower part, three types of structures - granular, nutty and blocky types are observed. The mixed appearance of the soil structure at the lower part of the slope suggests the repeated deposit of sediment transported from upslope, while on the upper part, surface materials always move downward.

Table 1. Permeability of soil at different depths (from Tachikawa, 1997)

Slope position	Depth of the soil		Permeability (ml/min)
Upper slope	A layer	0-35 cm	125
	AB layer	35-80 cm	143
Lower Slope	A layer	0-15 cm	207
	AB layer	15-60 cm	140

As shown in Table 1, the lower part of the slope has greater permeability than does the upper slope. Murai and Iwasaki (1975) found the permeability of the forest soil to be 156.0-580.5 ml/min in Gunma prefecture of Japan. Permeability of soil in our study area ranges from 125-207 ml/min, which is substantially low.

Method of observing sediment movement and calculating sediment volume

The total length of the experimental slope is about 380 m. Three experimental plots were established at different elevations near the lower part of the slope (Figure 3a). Each experimental plot was assumed as an isolated and inclined small tract of land on an arbitrary horizontal plane. Figure 3b shows the point gauge for measuring the change in height of the slope surface on the arbitrary plane to calculate soil erosion or deposition.

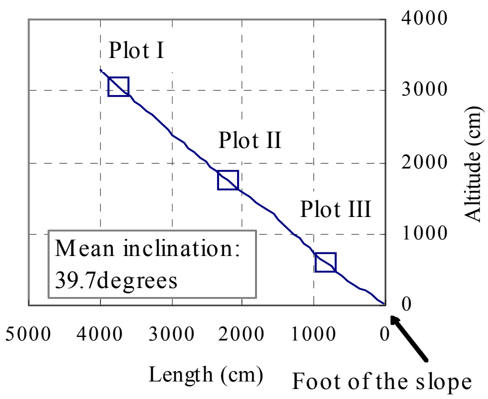

Figure 3a. Longitudinal profile of the slope and measuring plots

Figure 3b. Measuring apparatus on plot I

The measurement consists of three steps, each of which has three observation lines with ten observation points per line, thus nine lines with a total of 90 observation points are set (Figure 4a). Heights of these 90 observation points are measured during every field visit. The distance between two successive points in a line is 10 cm. The distance between two successive lines in one step is 15 cm.

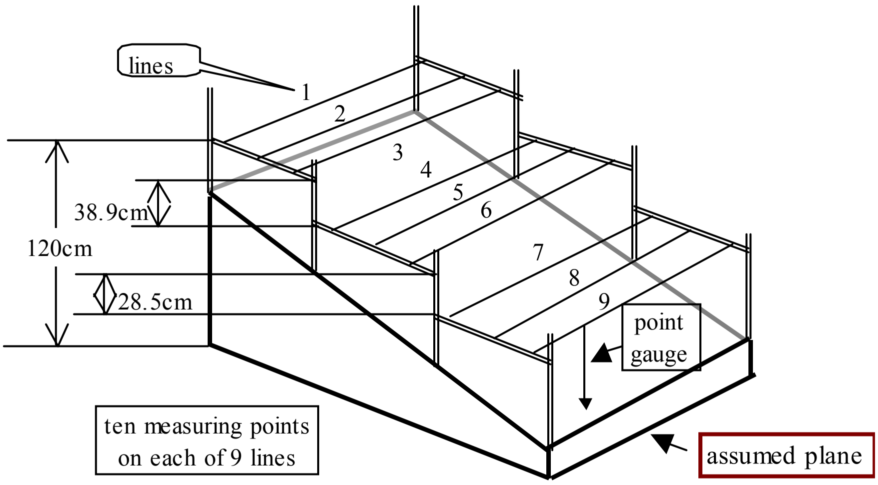

Figure 4a. Measurement system

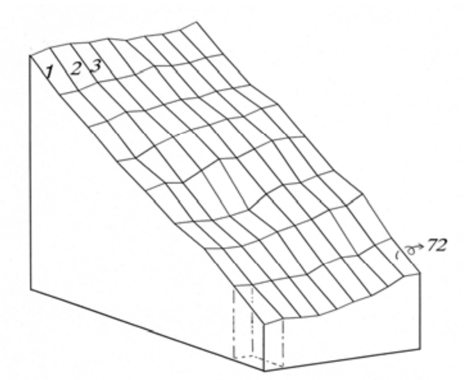

Figure 4b. Arbitrary pillars for volume

Deep volume of a sloping plot was arbitrarily divided into 72 small pillars under 90 observation points having different forms with an inclination on the top (Figure 4b). The volume of each pillar was calculated by the following equation:

Volume = average height of four observation points in a pillar ×length × width (10 cm)

The deep volume of the plot was calculated by summarizing the volumes of 72 arbitrary pillars at each observation. The fluctuation of the deep volume relative to the antecedent observation was evaluated to determine soil erosion or deposition during the time elapsed between two observations. In Plot I, 80 observations were made from 19th October 1995 to 24th November 2003. For plot II and III, observation was initiated on 17th June 2000 and 38 observations were so far made.

Results and Discussion

Sediment movement in different plots

As seen in Figure 5, there was a more or less similar tendency of sediment movement in plot I (upper) and plot II (middle) in most of the observations. Sediment movement tendency in plot III is a bit different and irregular compared to that of plot I and II. All the three plots showed net soil erosion at the final observation made on 24th November 2003.

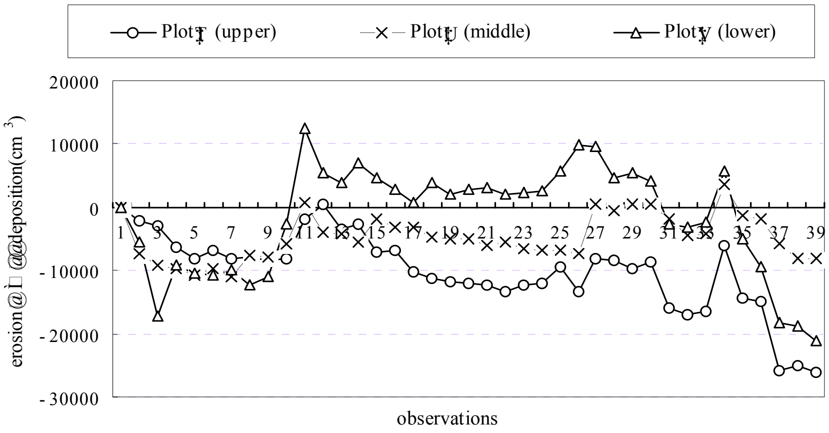

Figure 5. Sediment movement on plot I, II and III

According to Wischmeier and Smith (1978), the rate of soil erosion increases substantially as slope length increases. In our study, we found that erosion rate is highest in plot I having the longest slope length. But it is different in case of plot II and III. Although plot II has a longer slope length than plot III, it showed smaller erosion rate than plot III Wischmeier (1974) mentioned that even with a smooth average slope, sediment transport is reduced on a warped or concave slope due to localized sedimentation, but increased on a convex slope due to the gradient of the steepest portion. As eroding plots age and exposed to severe erosion, they become more and more concave, since the base of the plot stays fixed and the middle of the plot erodes more quickly than the top (Roose, 1996). Plots trapping and depositing sediments for long time may become more and more convex, which results in increased erosion after heavy storm events. Thus, slope surface of long term experimental plots may face repeated change over time, which has strong influence on soil erosion and deposition. In our experimental plots, we also noticed small changes in the shape of the slope over time, which also influenced sediment movement tendency. It is evident in our study that slope intervenes in soil erosion and deposition in terms of its form, gradient, length and position.

We found mean erosion heights of 7.41 mm, 2.31 mm and 5.96 mm per year in plot I, II and III respectively during the common observation period from 17th June 2000 to 24th November 2003. Plot I and III erosion rates are higher than the erosion rate of the denuded slope of granitic rocks mountains found by Hiura *et al.* (1983). There was no evidence of rill or gully erosion in our experimental slope, only sheet erosion was found.

Fluctuation of sediment movement in plot I

Fluctuation of observed cumulated sediment volumes during the observation period from 19th October 1995 to 24th November 2003 at plot-I is shown in Fig. 6, whose initial value was set at zero. Minus values indicate that there was an occurrence of net erosion in plot I in all observations. A rise in the curve indicates a sediment deposition in comparison to the antecedent observation period, which was mostly observed during winter season with few rainfalls. We found an immediate fall in erosion tendency on plot I after thinning as shown in Figure 6. The linear equations to estimate cumulated sediment volume in plot I at any arbitrary time are expressed as:

$$y \text{ (sediment volume in cm}^3) = -44.955 \times x \text{ (days)} - 4272.5 \text{ (before thinning)}$$
$$y \text{ (sediment volume in cm}^3) = -14.721 \times x \text{ (days)} - 23847 \text{ (after thinning)}$$

According to Yoho (1980), soil compaction from timber harvest operations increase soil erosion and adversely impacts forest productivity. Most erosion comes from skid trails on timber harvest units because of the reduced infiltration rates and disturbance to the organic layer (Robichaud *et al.*, 1993). The decrease in the number of trees results in a decrease in evapotranspiration, which contributes to increased subsurface flow, streamflow, and channel erosion. Thinning also exposes more surface soil under the direct impact of raindrop. However, compaction of soil results in reduction of macro porosity, while micro porosity increases as large pores are compacted into smaller ones. An increased microporosity can lead to greater available water-holding capacity throughout a site, but this increase is usually at the expense of aeration and drainage (Incerti *et al.*, 1987). Because of increased soil strength, compacted soils may have lower erodibility and consequently suffer less erosion for the same amount of runoff (Liew, 1974).

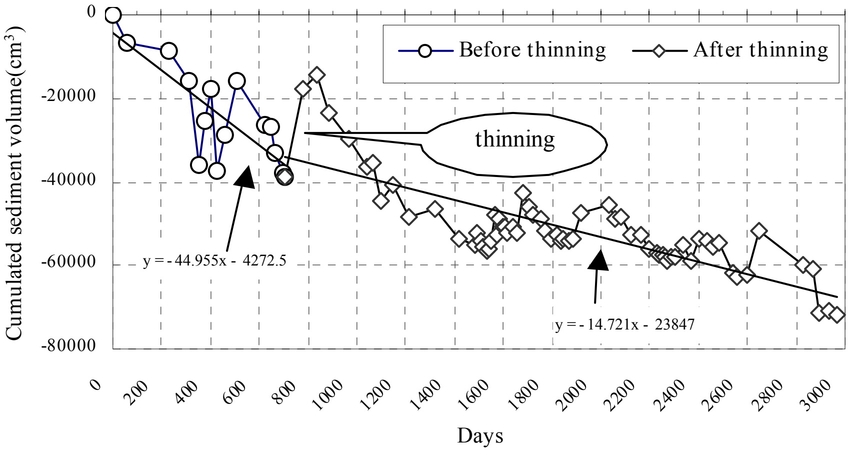

Figure 6. Fluctuation of sediment volume in plot I

In our experimental slope, all of the cut trees were kept on the forest floor without removal from the forest area. As felled tree were kept along the slope, not across the contour lines, it had little influence on preventing soil erosion. The fall in erosion tendency was found mainly due to the fair soil compaction caused by the thinning operation. We found mean erosion height of 8.69 mm/year in plot I for observation period of 8 years from 19th October 1995 to 24th November 2003, which is higher than the mean erosion height of 7.41 mm $year^{-1}$ we calculated during the observation period from 17th June 2000 to 24th November 2003. This increased value came from higher erosion rate before the thinning operation.

Rainfall Indices to relate sediment movement

Wischmeier and Smith (1978) defined an erosive storm event as a rain shower with at least 13 mm of rainfall and separated from other rain periods by more than 6 dry hours. We calculated average hourly erosive rainfall by dividing total amount of erosive rainfall with total duration to use as a rainfall intensity index for evaluating sediment movement in plot I. But we found soil erosion and deposition tendency even without any erosive rainfall events as defined above. This indicates that sediment movement on the experimental slope is influenced even by a little amount of rainfall, which is not usually considered erosive in other areas.

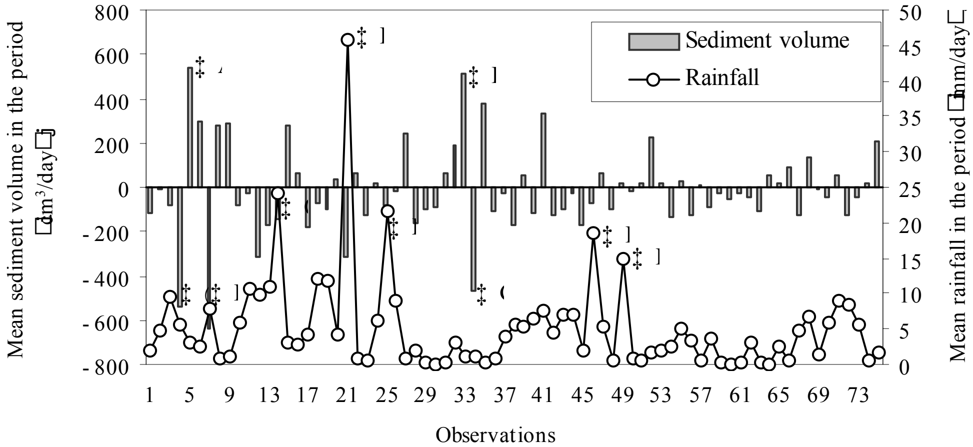

Figure 7. Relation between sediment volume and rainfall

Then we calculated mean daily rainfall by dividing total rainfall amount with the number of rainy days during every observation period, which was found as a more effective rainfall intensity index to evaluate sediment movement tendencies. Figure 7 indicates the fluctuation of the mean daily sediment volumes in plot I during 75 observations in relation to mean daily rainfall. Most of the deposition was found in the winter season having little rainfall, whereas most of the erosion was found in the summer and rainy seasons. In Figure 7, labels □, □ and □ represent observations in the winter season and rest of the labels represent observations in the summer and rainy seasons. Erosion tendency strongly coincides with rainfall values in case of Φ and □. It indicates that erosion occurs even in winter if there is high daily rainfall intensity. Labels □ and □ show deposition tendencies with less value of rainfall in the summer and winter respectively. Labels □□□, □ and □ show smaller erosions despite of much rainfall, whereas □ and □ show higher erosion tendencies with less rainfall values followed by much deposition in the antecedent observations of □ and □ respectively. This means deposition occurs very temporarily on the sloping plot which is again eroded by even small rainfall events.

Conclusion

We evaluated the sediment movement tendencies in three experimental plots on a steep mountainous slope reforested by Hinoki situated in Kochi prefecture of Shikoku Island, Japan. We found mean erosion heights of 7.41 mm, 2.31 mm and 5.69 mm per year in plot I (upper), II (middle) and III (lower) respectively during the common observation period from 17th June 2000 to 24th November 2003. In case of plot I, observation started previously from 19th October 1995 and the mean erosion height was found 8.69 mm/year after calculating for 8 years of observation. This increased value for plot I came from higher erosion rate before the thinning operation executed in September 1997. Fair soil compaction contributed to an immediate fall in erosion tendency after thinning. The mean erosion height on the steep slope forested with Hinoki is higher than that of denuded weathered granitic mountain slopes found by Hiura *et al.* (1983). It is evident in our study that slope intervenes in soil erosion and deposition in terms of its form, gradient, length and position. Erosion rate is highest in plot I having the longest slope length. But erosion rate is lower in plot II than plot III, although plot II has a longer slope length than plot III. Sediment movement on the experimental slope occurs even after a little rainfall, which is not usually considered erosive. We found mean daily rainfall as an effective rainfall intensity index to evaluate sediment movement tendencies. Most of the deposition was found in the winter season having little rainfall, whereas most of the erosion was found in the summer and rainy seasons. Deposition occurred very temporarily on the sloping plots, which was again eroded even after small rainfall events. We have been continuing our observations to develop an appropriate model to define the quantitative mechanism governing the movement of sediment and estimate annual soil erosion on the sloping forested land.

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*The English title is tentatively translated by the authors of this paper from the original Japanese title.