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The role of forest management practices in soil and water conservation

– Case study of a small watershed in Shikoku island, Japan –

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Abstract: Forest management practices for soil and water conservation was investigated to address current forest management related issues in Japan. This case study was conducted in the Ehime University Forest, Ehime Prefecture, Japan. The main objective was to find the forest management practice as to control soil erosion in artificial forests in the studied area. Among the forest characteristics analyzed in this paper figure forest type (natural forest and artificial Japanese cedar and Japanese cypress) in one hand and on stand density of Japanese cedar and cypress in the other hand. Relative yield index (Ry) was used as an indicator of stand density to reflect the degree of management operations in the watershed. For each forest characteristic (forest type and stand density), soil loss was measured. Data analysis was conducted using General Linear Model Analysis of Statistical Package for the Social Sciences in order to test whether differences in soil loss were statistically significant in different treatments after different rainfall amount and intensities, followed by Tukey's HSD test in case of significance. Multiple regression analysis was conducted to compare soil loss among those different forest conditions which mainly differ from the degree of forest management practice based on thinning operations. Findings showed that areas having experienced forest thinning operations showed lower values of soil loss in comparison to those without any operations. The best scenario of forest management was found in Japanese cedar plantations having Ry between 0.60 and 0.70, followed by the same plantation with Ry between 0.50 to 0.60 and in Japanese cypress plantations having Ry between 0.60 to 0.70. Thus, an appropriate forest management operation is needed not only for timber productions but also for soil conservation which can be insured by stand density control.

1 Introduction

Poorly managed cypress plantations in Japan suffer from surface erosion, as first noted by Akenaga and Shibamoto (1933). Also, surface erosion generally does not occur in forests because forest litter and undergrowth from a protective surface cover. However, Japanese cypress plantations have little surface cover, in part because cypress litter decomposes into small pieces within 2 or 3 months (Sakai and Inoue, 1988) and a rapid disappearance of its leaf litter from the soil surface on the slope has long been recognized (Tsukamoto, 1991). In addition, some silvicultural practices like the introduction of undergrowth and increase of litter on the forest floor are suggested so far; the effects, however, are not made clear quantitatively and forest management has not been established from the view of soil conservation in Japanese cypress plantations (Hattori et al., 1992). Tsukamoto (1991) found that rain factor had strong influence on Japanese cedar and especially cypress litter movement. As for Japanese cedar plantations, fewer studies related to soil erosion have been reported compared to Japanese cypress. Miura et al. (2003) reported the importance of forest cover conditions on young cedar plantations; Tsukamoto (1991) pointed out that in the case of cedar species, litter does not move easily because it remains attached to branches on the forest floor for a long time.

Although various researches have been done on various forested mountains in Japan in relation to forest soil conservation or forest related soil erosion (e.g. Mihara, 1951; Kawaguchi and Takiguchi, 1957; Murai, 1960; Kawana et al., 1963; Hosoyamada and Fujiwara, 1984; Kitahara et al., 1988; Kitahara et al., 2000; Miura et al., 2003 and others), there are scarce information making in relation soil erosion and stand density, especially using relative yield index (Ry) as an indicator of stand density. Relative yield index gained trust as for its ability to characterize forest plantations for an objective of forest management aiming timber production (Ando, 1982). This indicator is widely used by forest managers in the country, supported by the Ministry of Agriculture, Forestry and Fisheries of Japan. A question is raised on the possible contribution of the late thinning operations in Japanese plantations to sediment-related damages or disasters occurring in low stream areas, considering its vast area among total forest cover in the Japanese territory (man-made forest cover occupies 41% of total forest area; Japanese cedar and Japanese cypress cover respectively 44% and 24%) (Tanaka and Otsuka, 1997).

The significance of cover near the ground for erosion processes on slopes has previously pointed out in artificial rainfall experiment (Mihara, 1951; Kawaguchi and Takiguchi, 1957). We focused on the assumption that soil loss is sensitive to forest conditions change, especially on stand density.

The study area is covered by artificial forest plantations consisting mainly of Japanese cedar (*Cryptomeria japonica*, Taxodiaceae), Japanese cypress (*Chamaecyparis obtusa*, Cupressaceae), and with natural broadleaved forest. Since preliminary studies determined that soil physical properties were different in forest plantations with and without thinning (Razafindrabe, 2004; Razafindrabe et al., 2006a and Razafindrabe et al., 2006b), this study is aimed at determining which forest management practices, referring to the extent of thinning operations, needs to be applied to target soil and water conservation.

2 Materials and Methods

2.1 Study area

This study is conducted in the Ehime University Forest, Shikoku Island. It contains warm to cool temperate natural forests and plantations of Japanese cedar and cypress. The

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highest annual rainfall amount recorded was in 1980 and 1993 with respectively 2673.6 mm and 2673 mm and the lowest in 1994 and 2002, respectively 969 mm and 943 mm. The highest annual average temperature was in 1990 with 13.5°C and the lowest in 1980 with 11.3°C. The study area consists of a small watershed of 191.46 ha; the elevation ranges from 515 m to 950 m above sea level, with slopes ranging from 30-50 degree. Forest age ranged from 22 to 62 years for artificial coniferous forest plantations. Natural broadleaves were much older with an age range of approximately 120 years (Table 1).

2.1.1 Determination of the extent of forest thinning

According to Ando (1982), Ry varies from 0.1 indicating stands with high stem density but with very low standing volume, to 1.0 corresponding to the fully-packed stand, very high density. Two models for Japanese cedar and Japanese cypress, applicable for the area of Shikoku Island in Japan, were used to calculate relative yield index (Ry) for each site based on the following formula:

$$\mathbf{Ry = V / V_{Rf}} \quad (1)$$

For Japanese cedar

$$V = (0.074343H^{-1.388481} + 5065.0H^{-2.900328}/N)^{-1} \quad (2)$$

$$V_{Rf} = (0.074343H^{-1.388481} + 5065.0H^{-2.900328}/N_{Rf})^{-1} \quad (3)$$

$$\log N_{Rf} = 5.38221 - 1.51185 \log H_a \quad (4)$$

For Japanese cypress

$$V = (0.053887H^{-1.183794} + 7663.1H^{-3.201510}/N)^{-1} \quad (5)$$

$$V_{Rf} = (0.053887H^{-1.183794} + 7663.1H^{-3.201510}/N_{Rf})^{-1} \quad (6)$$

$$\log N_{Rf} = 5.992602 - 2.017716 \log H_a \quad (7)$$

where: Ry: relative yield index; V: standing volume (m^3/ha); V_{RF} standing volume in area of maximum density (m^3/ha); N: stem density (trees/ha); N_{RF}: stem density in area of maximum density (trees/ha); H: tree height (m); H_a: tree height in area of maximum density (m) (Ando, 1982)

In this study, low Ry values show mature stands having experienced a high thinning intensity added with those having experienced damages due to typhoons and gradually reducing as Ry values increase. Relative yield index close to 0.80 and 0.95 represent stands without any previous thinning operations conducted. Ry values in the study are extracted from the density management curve developed by Ando (1982) based on stem density (trees/ha), standing volume (m^3/ha), tree height (m) and DBH diameter at breast height (cm). Forest type/species include natural broadleaves stands, *Cryptomeria japonica* (Japanese cedar) and *Chamaecyparis obtusa* (Japanese cypress) plantations. Eleven treatments with different forest conditions were identified within the first and second subdivisions of the University forest based on forest type/species composition and relative yield (Table 1).

2.1.2 Soil loss measurement

Sediment traps were used to measure soil loss after rainfall events. Two traps were set up in each

In each of the eleven treatments, two experimental plots were set, with different slopes (one plot set in midslopes of less than 40 degree, another one in midslopes equal or more than 40 degree). One of the reasons of this subdivision is to arrive to demonstrate the difference (if it applies) between the two slopes. Experimental plots were set up in each treatment (from T1 to T11). Transported sediments are collected in a plastic bucket preceded by a metallic tray linking the plot to the bucket.

For further data analysis, rainfall intensity was classified as very low (VL), low (L), medium (M), high (H) and very high (VH) for rainfall intensities (expressed in mm/10 min), 2, 2.5 – 3, 3.5 – 4, 5.5 – 7.5 and > 8 respectively (inspired from Schultz and Cruse, 1993). This was done to better distinguish soil loss produced by different rainfall intensities.

2.1.3 Data analysis

Means of soil loss under the different classes of rainfall intensity were analyzed, based on each forest type/species (natural forest, Japanese cedar and Japanese cypress) as well as on each treatment.

General Linear Model Analysis of variance (Two-way ANOVA) was chosen in order to test whether soil loss were statistically different in the eleven treatments. In case of significance, mean values were compared using Tukey Honestly Significant Difference at $p<0.05$. Multiple regression analysis was conducted to compare soil loss among those different forest conditions which mainly differ from the degree of forest management practice based on thinning operations.

3 Results

Results showed that Japanese cypress showed the highest amount of soil loss ($p< .05$), followed by Japanese cedar. Natural forest showed the lowest values of soil loss.

For slope class above 40 degree, the highest soil loss recorded was found in T11 corresponding to Japanese cypress with Ry: 0.80-0.90 (10957.11 g/2m^2/year) which accounted for more than 1/5 the total soil loss in the whole area in a year. The second one was found in the same cypress species with Ry: 0.70-0.80 (9321.19 g/2m^2/year) accounting for 18.53% of total soil loss.

These results suggest that cypress species are more subject to soil erosion than other areas. As for Japanese cedar, the highest loss recorded was in plantations with Ry: 0.80-0.90 (7577.04 g/2m^2/year) accounting for 15.07% of total soil loss. Areas where thinning operations have not been conducted (cedar and cypress confounded) accounted for 64.16% of total soil loss, mostly occurring in cypress plantations (corresponding to 40.32% of total soil loss, against 23.84% for cedar species). The lowest value was found in natural forest (921.93 g/2m^2/year), followed by cedar with Ry: 0.60-0.70 (1251.97 g/2m^2/year) accounting for 1.83% and 2.49% of total soil loss respectively.

In the case of the second slope class (<40 degree), similar results were found. The highest soil loss recorded was found in T11 corresponding to Japanese cypress with Ry: 0.80-0.90 (9166.77 g/2m^2/year) which accounted for 21.94% of total soil loss; followed by the same cypress species with Ry: 0.70-0.80 (7525.98 g/2m^2/year) accounting for 18.01% of total soil loss.

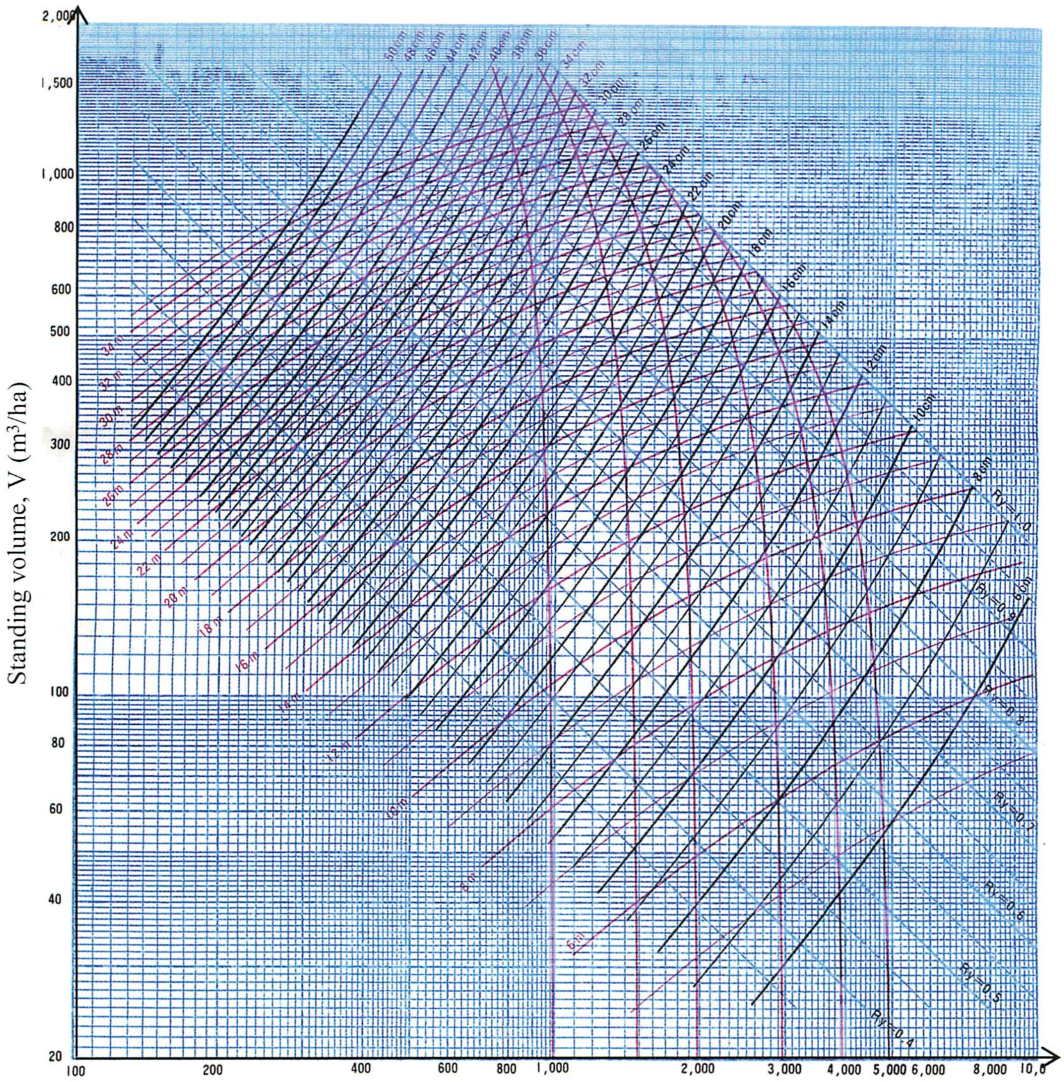

Figure 1: Stand density management curve for Japanese cedar *(Cryptomeria japonica)*

Japanese cedar with Ry: 0.80-0.90 had 6327.42 g/2m^2/year which accounted for 15.15% of total soil loss. The lowest soil loss recorded was in T1 (natural forest) having a soil loss of 881.17 g/2m^2/year accounting for 2% of total soil loss. Areas showing too high density, corresponding to Ry close to 1 where thinning operations have not been conducted showed the highest soil loss recorded (63.59% of total soil loss). Therefore, soil loss recorded in Japanese cypress with high stand density was in general the highest in the area for both slope classes.

3.4 Soil loss according to rainfall intensity classes on forest types

Due to the strong effect of rainfall intensity on soil loss and for further analysis, rainfall intensity class including VL, L, M, H, VH intensities were used. As shown in Figure 4, soil loss recorded in slope class > 40 degree was in general higher than that of slope < 40 degree, especially during high (H) and very high (VH) rainfall intensities.

3.4.1 Slope > 40 degree

For natural forest, although soil loss was proportional to rainfall intensity as in cedar and cypress species, soil loss amount recorded was in small proportion. H and VH class showed the highest soil loss with 43.07 and 49.53 g/2m^2 respectively. Japanese cedar showed a different tendency with a higher soil loss amount. VH showed the highest soil loss amount (272.77 g/2m^2), followed by H with 185.94 g/2m^2. The three other classes (M, L, VL) did not show significant differences. As for Japanese cypress, soil loss recorded was higher than in cedar; the highest value corresponded to VH with 482.82 g/2m^2 followed by H with 266.94 g/2m^2 and M (96.82 g/2m^2). VL and L were not significantly different at the .05 level. In addition, regardless of rainfall intensity, results related to the amount of soil loss in each treatment with different density showed that in cedar, the different classes of density were significantly different with each others. Therefore, the highest soil loss mean was found in Ry: 0.80-0.90 with a value of 184.806 g/2m^2 (Table 2) followed by Ry: 0.70-0.80 (107.619 g/2m^2).

Table 1: Description of the study area

Treatment	Characteristics	Slope aspect	Slope angle (degree)	Volume (m3)	Stem density (trees/ha)	AGE (years)	Ry	Clay (%)	Silt (%)	Sand (%)	Texture (0-25 cm depth)
T01	Natural forest	-	40 33	-	-	120	-	38.91	5.38	55.71	Sandy clay
T02	Japanese cedar Ry: 0.37-0.50	SW	40 35	83	1568	51	0.44	15.86	19.99	64.15	Medium Sandy loam
T03	Japanese cypress Ry: 0.37-0.50	S	40 35	88	1620	24	0.46	16.44	19.58	63.98	Medium Sandy loam
T04	Japanese cedar Ry: 0.50-0.60	S	40 35	195	1324	62	0.58	31.74	12.36	55.90	Sandy clay loam
T05	Japanese cypress Ry: 0.50-0.60	SE	40 36	288	570	51	0.51	19.05	14.28	66.68	Medium Sandy loam
T06	Japanese cedar Ry: 0.60-0.70	S	41 37	198	2103	32	0.67	26.23	18.30	55.47	Sandy clay loam
T07	Japanese cypress Ry: 0.60-0.70	NE	42 38	300	930	22	0.61	18.26	19.55	62.20	Fine Sandy loam
T08	Japanese cedar Ry: 0.70-0.80	SE	42 38	242	2214	51	0.76	9.08	26.63	64.29	Medium Sandy loam
T09	Japanese cypress Ry: 0.70-0.80	S	42 39	197	2665	32	0.73	7.09	20.61	72.31	Coarse Sandy loam
T10	Japanese cedar Ry: 0.80-0.90	N	45 39	520	1641	32	0.85	5.13	26.10	68.77	Coarse Sandy loam
T11	Japanese cypress Ry: 0.80-0.90	SE	44 39	300	1995	32	0.82	3.32	31.14	65.55	Coarse Sandy loam

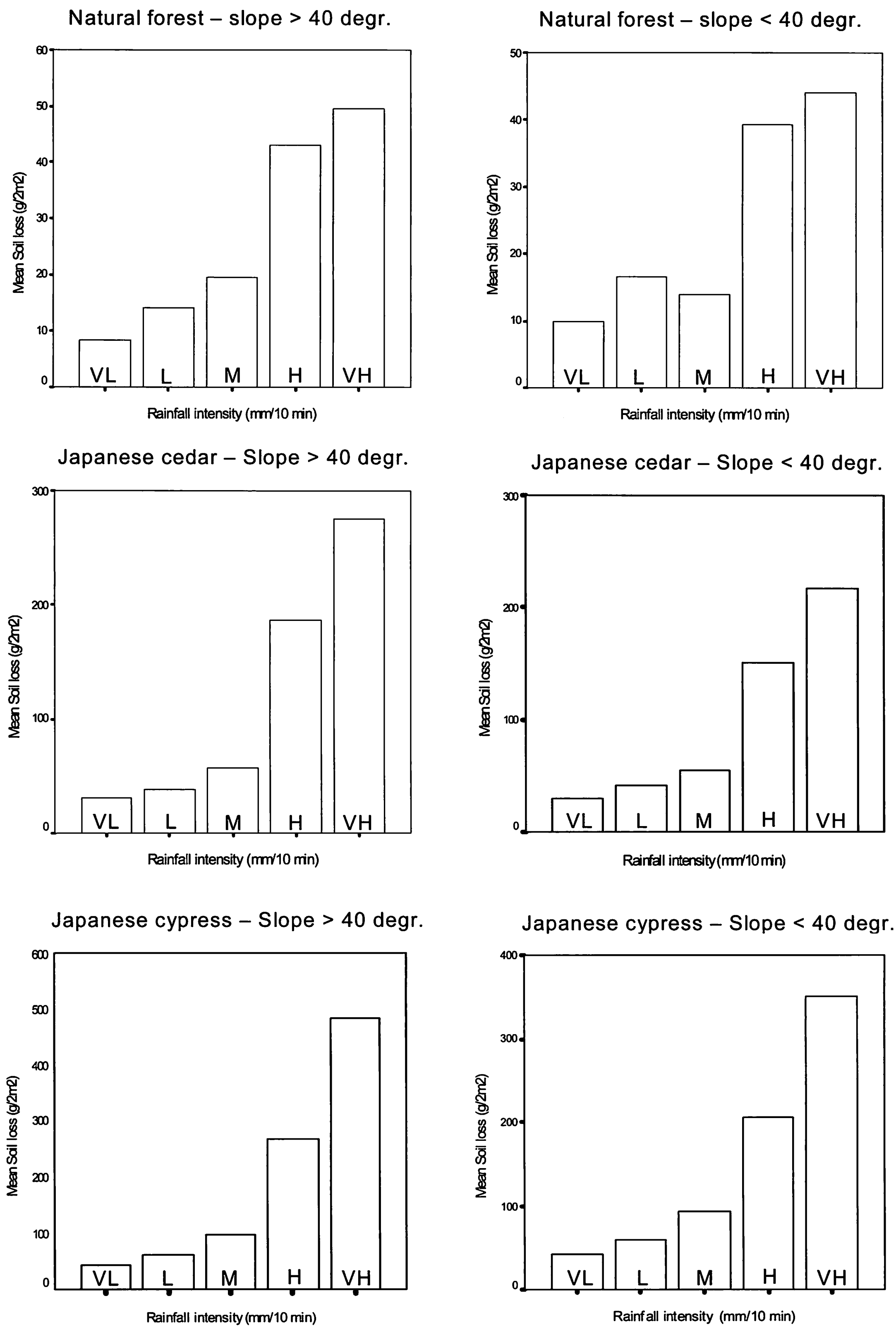

Figure 2: Mean soil loss in each forest type, according to each rainfall intensity class (mm/10 min)
[VL, very low < 2; L, low 2.5 – 3; M, medium 3.5 – 4; H, high 5.5 – 7.5 and VH, very high > 8]

Areas experiencing moderate forest thinning operation corresponding to Ry: 0.60-0.70 had the lowest amount of soil loss which was about 3 to 6 orders of magnitude smaller than those areas without thinning operations (Ry close to 1).

3.4.2 Slope < 40 degree

In natural forest, VH rainfall intensity class showed the highest mean of soil loss (44.07 g/2m^2) followed by H class with 39.35 g/2m^2. VL, L and M classes did not show any significant difference among them; however, they were 3 to 5 orders of magnitude smaller than that after H and VH intensity (Figure 2).

Moreover, Japanese cedar showed higher amount of soil loss. VH corresponded to 216.490 g/2m^2, the highest amount of soil loss. It was followed by H with 151.63 g/2 m^2. The three remaining classes (M, L and VL) did not have any significant difference at the .05 level. In Japanese cypress, although similar tendency with Japanese cedar was observed, the amount of soil loss recorded was found higher. VH showed the highest mean of soil loss, corresponding to 350.71 g/2m^2 followed by H with 205.89 g/2m^2. M corresponded to 95.53 g/2m^2 but L and VL did not have any significant difference.

Moreover, regardless of rainfall intensity, the highest soil loss measured in cedar species was found in density with Ry: 0.80-0.90 (similar to that of slope > 40 degree) with a mean value of 154.33 g/2m^2 followed by Ry: 0.70-0.80 (insufficient thinning operation) and Ry: 0.37-0.50 (excessive thinning) which did not differ significantly (Table 2).

3.4.3 Results regardless of slope angle

For all slopes combined, although soil erosion was found to be slightly different (0.05 level) for slopes above and below 40 degrees, the trend was similar in a matter of soil loss fluctuation. Results showed the same tendency as those presented earlier considering the two slope classes. The highest amount recorded was in Japanese cypress Ry: 0.80-0.90 averaging 245.41 g/2m^2 followed by the same species with Ry: 0.70-0.80 (205.45 g/2m^2). The four first highest values were found in all treatments without or with very few forest operations. Those having experienced forest operations (T6, T4, T7, T3, T5, T2) showed low values of soil loss although moderately thinned plots had the lowest ones (T6, T4, T7) and comparable to that of the natural forest.

4 Discussions

Results showed that soil loss differed according to slope, although the difference was much less than in other parameters such as rainfall intensity or stand density. This finding related to slope is already accepted by most researchers in soil erosion field. Due to this reason, analyses were done separately for each slope class in major part of this study.

4.1 Impacts of forest management practices on soil environment

Results showed that soil loss collected in Japanese cypress were the highest, in comparison with Japanese cedar and natural forest, regardless of rainfall intensity. Also, results showing that cedar species recorded less soil loss compared to cypress plantation may be due to the difference of forest floor condition between the two species. Sakai and Inoue (1988) reported that the form of the leaf litter in cedar and cypress differed markedly, cypress leaf litter breaks down into flakes within 2 or 3 months of falling and is readily transported on slopes, while cedar litter does not move easily because it remains attached to branches on the forest floor for a long time (Tsukamoto, 1991). This explains the differing properties of the leaf litter leading to different floor litter conditions and as our results showed, although having almost the same stand density in T10 (Japanese cedar Ry: 0.80-0.90) and T11 (Japanese cypress Ry: 0.80-0.90), cedar species showed lower values of soil loss than in cypress. The same case happened for T8 and T9.

On the other hand, not only we found soil erosion to differ according to the forest species but also to their stand densities. Soil loss was found higher in areas having high relative yield index, in both cedar and cypress plantations. This could be again due to forest floor conditions. Although forest cover dynamics under various densities (different Ry) was not conducted, direct observation showed that fewer understory vegetation was found in plantations with high Ry (especially those close to 1.0). Light intensity in the plots could be one of the reasons since areas having experienced no thinning operations, too dense, did not give enough chance to the development of understory vegetation. Shiozaki (1977) explained the development of understory plant growth due to the increase in sunlight penetration to the forest floor. Miura et al. (2003) also found that transport rates in young Japanese cedar and cypress increased abruptly after cover removal although the floor cover conditions in the experimental plots differed markedly. This indicates that in our case, the high amount of sediments collected in T11, T9 and T10 (decreasing order in a matter of sediments produced) may have originated from the floor cover conditions where, due to the absence of forest thinning operations thus less sunlight penetration, there were fewer floor cover and understory vegetation compared to other areas.

Considered separately according to different slope class or analyzed simultaneously, soil erosion tendency was similar for the area. Thus, the fewest soil loss recorded was found in cedar species with Ry comprised between 0.60 and 0.70, comparable to that of undisturbed natural forest. Beside the fact explained earlier on the difference of forest condition between cedar and cypress species, relative yield index has an important role in soil erosion control. If Ry was earlier used as an indicator of forest management for an objective of timber production (Ando, 1982), it can also be an important tool for stand density and soil erosion control. For timber production, a relative yield of 0.70 is encouraged in Japan (ibid.). Based on our findings, a stand density control with Ry between 0.60 and 0.70 could reduce soil loss in forested slopes. This concept is not only valid for cedar plantations but especially for cypress plantations where stand density control is a must since these plantations are more subject to soil erosion. As our results showed, keeping cypress with Ry between 0.60-0.70 reduced soil loss up to 5 or 6 orders of magnitude.

Based on these results, forest floor cover appears to be an important factor controlling erosion. If the effect of understory vegetation was mentioned in previous sections, alone, it is not enough to influence soil erosion as reported by Miura et al. (2003) who suggested the development of a method of predicting temporal changes in floor cover conditions. Kiyono (1990) proposed a dynamic understory model estimating the height and coverage of the understory in Hinoki (cypress) plantations. However, the understory in Hinoki plantations quickly decreases as the Hinoki trees grow, and subsequently the floor cover is mainly dependent on the cover formed from litter (Miura 2000). The development of a predictive model that estimates floor cover percentage from both floor litter and understory is required (Miura et al., 2003). Therefore, although we found that Ry was crucial in the soil erosion control in our results, further studies on Ry and related floor cover conditions, based on both floor litter and understory vegetation appear to be necessary to be able to suggest the most appropriate decision for soil conservation based on relative yield.

4.2 Forest management and soil properties relationship

Also, our results from previous chapters support the fact that different "forest floor conditions" are caused by various reasons. One of them is the physical properties of soil under different species and densities (through Ry parameter) especially soil texture, moisture and infiltration rate. As shown in the previous chapter, results showed that in topsoil, the highest infiltration rate and macroporosity among forest plantation were found in Japanese cedar and cypress having relative yield between 0.50 and 0.60 and comparable to that of natural forest, followed by cedar with Ry: 0.60-0.70. Areas without forest operations and having high relative yield (Ry: 0.70 and above) showed the lowest values. This explains that most areas having better soil physical properties also appear to show low soil loss recorded. Areas with high relative yield having bad physical properties showed the highest amount of soil erosion. Our results indicate that soil physical properties in particular infiltration rate and macroporosity affected the degree of erosion.

Moreover, although organic matter analysis was not conducted in the present study, soil color distribution gives some ideas on organic matter content since all areas have the same forest brown soil type of forested mountainous area in Japan.

Areas with high relative yield were in general lighter in color than those with higher ones. Some researchers found soil color to be related to organic matter content, and lighter-colored soil represent in general lower organic matter content which is also reflected from lower moisture content (as reported by Persson, 2005). This could affect the stability of aggregates and in turn will affect soil erosion. However, soils with available moisture may be subjected to more microbial activities and influence macroporosity and water infiltration (Lee and Foster, 1991).

In the other hand, results of microorganism investigation in the same study area showed that the number of microorganisms was higher in cedar plantations than in cypress, both without forest thinning operations (Noda, 2006).

However, this amount was found to be the same for cedar and cypress with thinning below 35%. More microorganisms were found in cypress after higher intensity of thinning operations (above 35%). This finding suggests that although cypress plantations are knows for their fragile soil environment (Miura et al., 2003; Yamashita et al., 2004), at lower tree density, cypress species can grow better in a more stable environment as far as soil microorganisms are concerned. Yamashita et al. (2004) also reported that when provided with more space in the canopy to expand more needles and in the soil to develop more fine roots to exploit sufficient resources, the individual cypress trees have the potential to grow faster. This can be added by other findings showing that organic matter had been easily mineralized in cypress species compared to that of the cedar species (Ichikawa *et al.*, 2003; Nakane, 1995). Also, decomposition rates increased in thinned plots where soil organic matter was more abundant (similar findings in Tang *et al.*, 2005 and Misson *et al.*, 2005). The available moisture added with light penetration may have been creating more understory plants which added with leaf litter gave birth to an abundant organic materials, especially in those areas with moderate thinning operations. This abundance of organic materials as substrate will favor higher microbial activity and organic matter decomposition (Fisher and Binkley, 2000). According to Franzluebbers (2002), the enhancement of organic matter decomposition will improve the formation of stable aggregates and soil structures thus improving the overall aeration of the soil. This appears to have affected the amount of soil erosion in lower stand density plantations (Ry: 0.50 to 0.70).

4.3 Rainfall intensity is worsening soil erosion

Although factors related to the environment (forest conditions) alone affected soil loss, its intensity was regulated by rainfall intensity. Although soil loss was recorded from rainfall intensities of 1.5 mm/10 min and above, its amount was minimal for rainfall intensities of up to 3 mm/10 min. Already, at that level, difference of soil loss amount was palpable especially in cypress plantations without thinning operations having high Ry. This difference is at its maximum when rainfall intensity exceeded 5.5 mm/10 min. Since infiltration rate for areas with lower Ry were from 4.6 to 7.7 mm/10 min, runoff was still prevented in those areas unlike the case of cedar and cypress plantations with Ry above 0.70 where infiltration rate was less than 4 mm/10 min. It should be considered that infiltration rate calculated in this study represents values that derived from the saturated sample conditions before the experiments, which is not the same condition in situ before rainfall events occur. Results showed that an important part of soil loss recorded originated from rainsplash.

Table 2: Results of Tukey's HSD test for soil loss in cedar and cypress for slope > 40 degree

Japanese cedar		Slope >40 degr.	Slope <40 degr.
Treatments	N	Soil loss ($g/2m^2$)[1]	
Cedar Ry: 0.60-0.70	41	30.537 e	29.105 d
Cedar Ry: 0.50-0.60	41	56.821 d	49.119 c
Cedar Ry: 0.37-0.50	41	84.848 c	80.348 b
Cedar Ry: 0.70-0.80	41	107.619 b	86.498 b
Cedar Ry: 0.80-0.90	41	184.806 a	154.328 a
F- value		12.209	14.111
Sig.		0.000	0.000

Japanese cypress		Slope >40 degr.	Slope <40 degr.
Treatments	N	Soil loss ($g/2m^2$)	
Cypress Ry: 0.60-0.70	41	65.900 c	53.635 c
Cypress Ry: 0.37-0.50	41	89.086 c	67.022 c
Cypress Ry: 0.50-0.60	41	89.985 c	70.273 c
Cypress Ry: 0.70-0.80	41	227.347 b	183.561 b
Cypress Ry: 0.80-0.90	41	267.248 a	223.581 a
F- value		11.395	15.606
Sig.		0.000	0.000

[1]Means are presented. Means with the same letter did not differ significantly (P< 0.05)

Nanko et al. (2004) reported that throughfall raindrops were fewer in number and larger in size than open rainfall drops and total raindrop impact energy from throughfall was over twice than that of open rainfall in Japanese cypress plantations. There may be in our result a possibility that throughfall raindrops did not always have a uniform distribution between different events as in the findings of Nanko et al. (2004). This finding is in contrary of those of Mosley (1982) and Brandt (1989) where throughfall raindrops had the same distribution independently of open rainfall intensity.

Marshall and Palmer (1948) also reported that open raindrop distribution correlates with rain intensity. This explains the result that even when rainfall intensity did not exceed infiltration rate, a certain amount of rainsplash-induced erosion may have taken place.

One of the crucial questions to be answered is how open the canopy should be to overcome these problems. Relative yield parameter helps characterize stand density and simultaneously canopy cover. Results showed that high Ry dense forest plantations (close to 1) registered high soil loss amount. Considering that throughfall raindrops are one of the soil loss influencing factors, soil loss amount may not have differed that much among treatments with similar tree heights and close relative yield values (reflected through Ry calculation, Ando (1982)). Thus, other parameters such as understory vegetation which were developed according to the canopy characteristics as well as leaf-litter originating from the trees themselves appear to have strongly affected soil erosion. Previous studies (Razafindrabe, 2004) showed that forest age and slope aspect did not significantly affect soil physical properties (0.05 level). Based on our results, though forest age parameter was important as a forest condition indicator, Ry seemed to have better explanation as far as soil physical properties and soil effect are concerned. One of the reason for this is that in unknown plantation age, or in uneven growth of trees of the same age, based on the degree of management, its soil environment can be determined through the use of relative yield index (Ando, 1982), tool recognized by the Japanese authorities.

Magarisawa et al. (1992) reported that weak penetration of sunlight into the Japanese cypress forest results in poor growth of forest undergrowth. This seems to be the case in cypress plantations with high relative yield close to 1 where most soil erosion have occurred. Moreover, since sandy loam and sandy clay loam soils were dominant in this study area, erosion occurred immediately after forest cover decreased. Coarse sand loams present in areas without thinning operations were the impact of the deterioration of soil physical properties due to the local environment conditions and which in turn led to more erosion in the area.

In conclusion, the importance of litter and understory vegetation (Miura et al, 2003; Hattori et al., 1992), closely related to the degree of forest thinning operations, seems to affect most part of the results of this study and need further considerations.

5 Conclusion

Findings in this study demonstrated that less or absent thinning operations led to higher amount of soil loss and stand density control through forest management practices, is an important process to be conducted to reach the objective of soil and water conservation. Forest management practices, in particular forest thinning operations are proved to be playing an important role in preventing soil erosion in Japanese forest plantations. The best scenario of forest management was found in Japanese cedar plantations having Ry between 0.60 and 0.70, followed by the same plantation with Ry between 0.50 to 0.60 and in Japanese cypress plantations having Ry between 0.60 to 0.70. Thus, an appropriate forest management operation is needed not only for timber productions but also for soil conservation which can be insured by stand density control through forest thinning operations.

This study also mentioned the importance of forest floor cover and understory in their influence on soil erosion. Although some indicators of forest floor conditions have been presented, a direct investigation of soil organic matter content as well as forest litter composition and its amount have not been realized. The knowledge of this information would fill the gaps in this study. Therefore, we suggest the development of a method for forest floor analysis coupled with soil erosion assessment in the area. It should be in spatial dimension to cover various forest conditions, especially stand density and species, topography, as well as in temporal dimension to be able to identify the variations in different period.

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