Stand Density affects Soil Infiltration Rate in Coniferous Forests

Bam Haja Nirina RAZAFINDRABE[1], Toshiko KAKIHARA[2], Shuichi KOHNO[2], Masafumi FUJIHISA[2], Noriyuki KOBAYASHI[1] and Tsugio EZAKI[1]

Abstract: The effect of stand density to soil infiltration rate was assessed in this study. The study site was in the Ehime University Forest, Ehime Prefecture, Shikoku Island, Japan. Soil samples were taken and brought to the laboratory for further laboratory works to determine soil infiltration rate. Eleven treatments were identified according to the forest type/species: natural forest, Japanese cedar and cypress plantations with relative yield index (Ry) ranging from 0.37 to 0.95. Three sampling sites were established for each treatment with 3 replicates. Samples were taken from both topsoil and subsoil. Data analysis was conducted using the Statistical Package for the Social Sciences using the General Linear Model Analysis of Variance (One-way Anova) to test whether infiltration rate was statistically different in the eleven treatments. Tukey Honestly Significant Difference was used to compare means in case of significance ($p<0.05$). Results showed that in topsoil, the highest infiltration rate among the forest plantation was found in Japanese cedar and cypress having relative yield between 0.50 and 0.60 and comparable to that of natural forest. Those areas without forest operations and having high relative yield (Ry: 0.70 and above) showed the lowest values. There was almost no significant difference for subsoil except slight high infiltration rate for natural forest and Japanese cedar with Ry of 0.50 to 0.60. These results indicate the need of forest operations and the importance of stand density control, a guarantee for a better soil physical property, in particular soil infiltration rate.

Keywords: *Forest thinning; Soil physical properties; Cryptomeria japonica; Chamaecyparis obtusa; Natural broad-leaved forest*

1 Introduction

Infiltration is the process by which water arriving at the soil surface enters the soil (Hillel, 1980). It is an important soil feature that controls leaching, runoff, and crop water availability (Franzluebbers, 2002). Infiltration rates depend mostly on the rate of water input to the soil surface, the initial soil water content and internal characteristics of the soil (Fisher and Binkley, 2000). Many studies showed that water infiltration rates in forest-covered soils were found greater than in nonforested soils (e.g. Fisher and Binkley, 2000; Wood, 1977) and lower on bare soil than beneath trees and shrubs (Blackburn, 1984). However, what is the case within a forested watershed?

Moreover, many foresters generally consider forest operations as a management to promote increased growth rate, size and value of the remaining trees (e.g. Moorhead and Jackson, 1998). How thinning influences soil properties still remains unclear since few researches have been done in this concern. In Japan, in spite of the awareness of forest policy makers on the need for forest operations, especially thinning, by elaborating "Measures for thinning" in 1971 or the "Forest stand improvement project" in 1976; "Core Forest Development Region", the "Pilot project for the Promotion of Stable-distribution of Thinned Logs" in 1977 (Handa, 1988) and in 1985 the "New comprehensive project for the Promotion of Thinning", several issues still occurred. These are mainly caused by the lack of sylvicultural tending, particularly the last decade (Sasse, 1998). The same author reported that around 1988, about 60% of the plantations in Japan are in the 16-35 year age group and are due, or overdue, for thinning. One of the reasons for the appearance of the thinning problem is the insufficient knowledge and technology about thinning on the side of the forest owners (Handa, 1988). Other reasons are the lack of workers to do the work because the size of the workforce has declined and the average age of workers has increased. Recruitment of forestry labor has been poor because of the relatively poor pay and conditions compared with other industries and the continuing decline in rural populations since the beginning of the manufacturing boom in Japan has shrunk the pool of potential labor (Sasse, 1998).

The above mentioned facts are added with current issues observed in the field study concerning the lack of information about the need for forest operations and its impact to the soil properties in particularly soil infiltration rate. It is apparent that there is a need to understand the soil impacts caused as a result of forest management activities among forest land-owners, resource managers and others involved in forest management.

Elliot and Coleman (1988) reported that the type of management practice and period of time under that management will determine the actual macroporosity of a soil, which will in turn influence the infiltration rate.

The study area is covered by artificial forest plantations consisting mainly of Japanese cedar (*Cryptomeria japonica*, Taxodiaceae), Japanese cypress (*Chamaecyparis obtuse,* Cupressaceae), and with natural broadleaved forest. Although many studies have been conducted on the performance of Japanese cedar and Japanese cypress as plantation tree species and their influence on forest ecosystems, little is known about their impact on soil physical properties especially on soil infiltration rate.

So far, the previous studies reported include the changes in soil chemical and physical characteristics in Japanese cypress (Takahashi et al., 1999b), comparison of organic matter dynamics in soil between Japanese cedar forest and adjacent Japanese red pine (*Pinus densiflora*) forest established on flatland (Takahashi et al., 1999a), comparison of nutrient dynamics between these two species (Ichikawa *et al.*, 2003), protective effect of floor cover against soil erosion with Japanese cypress (Miura et al., 2003) and changes in physical properties of soil after clearcutting of Japanese cypress (Ono, 2005). Also some studies have been conducted to determine the change in infiltration capacity after a forest fire (e.g. Inoue et al., 2004).

[1]The United Graduate School of Agricultural Sciences, Ehime University, 3-5-7 Tarumi, Matsuyama-Shi, Ehime, 790-8566 Japan
[2]Faculty of Agriculture, Ehime University, 3-5-7 Tarumi, Matsuyama-Shi, Ehime, 790-8566 Japan

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 expected to give more details in which area in those thinned and unthinned forest are the most influencing soil properties, in particular soil infiltration rate.

Therefore, infiltration rate was compared in sites with different forest conditions, referring to stand density of artificial plantations indicated by relative yield (Ry) which was calculated from stand volume and stem density, and forest species consisting of natural broadleaved forests (broadleaves), Japanese cedar and Japanese cypress. Relative yield was chosen as an indicator of forest conditions based on Ando (1982) stipulating that Ry is among the best tools to describe forest stands and prescribe appropriate forest management. Soil infiltration rate was calculated from laboratory measurements in saturated conditions from undisturbed samples taken from the fields. The main objectives of this study were to clarify how stand density (through Ry) affect soil water infiltration rate.

2 Materials and Methods

2.1 Study Site and Treatment Description

Study Site

Located 18km northeast of Matsuyama City in Ehime Prefecture (Shikoku Island, Japan), the study site (Ehime University Forest) contains warm to cool temperate natural forests and plantations of Japanese cedar and cypress.

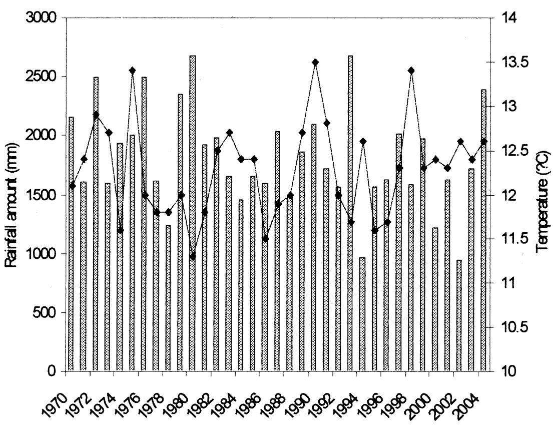

Figure 1. Annual rainfall amount and temperature in the study site (Ehime University Forest, 2002, updated to 2004)

The 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 (Figure 1). The study area consists of a small watershed of 191.46ha (Figure 2); the elevation ranges from 515m to 950m above sea level, with slopes ranging from 30-50 degrees. Forest age ranged from 10-80 years for artificial coniferous forest plantations while the natural broadleaves were much older with an age range of approximately 85-120 years.

Model and Treatment Description

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 (Ry), indicator of stand density. 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.

Soil sampling and Analysis

Three sampling sites were established for each treatment with 3 replicates, making a total of 99 samples for topsoil (0-20 cm) and the same number for subsoil (20-40 cm). Soil core samples were taken in April and May 2005 with a sharp-edged steel cylinder of 112.8 mm diameter by 40 mm height on midslopes. Core samples were taken and analyzed for infiltration rate, determined by using a laboratory infiltrometer (Figure 3) measuring the over flow after 5min and 15min (average value) of a uniform flow of water applied above the saturated sample for one minute, based on Kawada and Kojima (1976).

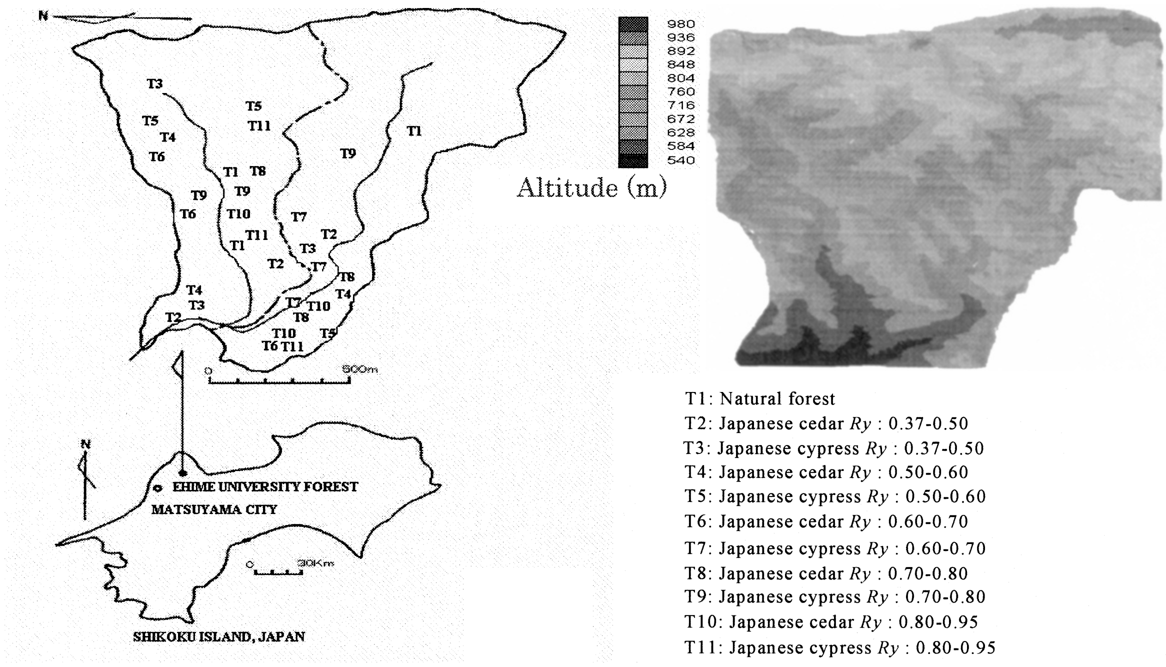

Figure 2. Map of the study area, the Ehime University Forest, Ehime Prefecture.

Infiltration rate was calculated as follows:

$$k = \frac{Q}{At} \times \frac{l}{h} \qquad (8)$$

where:
k: infiltration rate (cm.s-1)
Q: volume of infiltrated water (cc), (average volume taken after 5-6 min and 15-16 min)
A: surface area of sampler (cm2), A= 100cm2
t: time during which the infiltrated water is collected, corresponding to 1mn
l: sampler's height, l= 4cm
h: head, after measurement, h= 4.7 cm

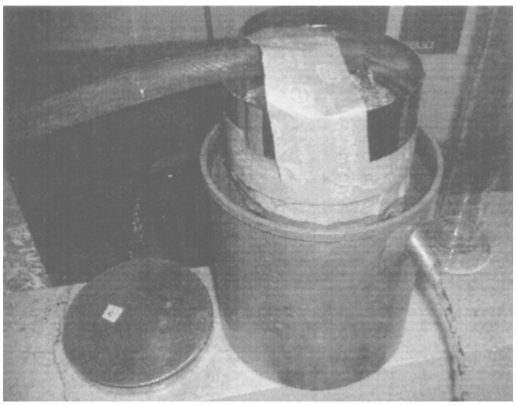

Figure 3: Laboratory infiltrometer to determine infiltration rate

Data Analysis
Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS, ver.*11.0*).

General Linear Model Analysis of variance (One-way ANOVA) was chosen in order to test whether infiltration rate was statistically different in the eleven treatments. In case of significance, mean values were compared using Tukey's HSD test at the 0.05 level of significance. The objective was to know which treatment showed the extreme values of infiltration rate.

3 Results and Discussions

Case of topsoil (0-20 cm)
We found infiltration rates to vary notably within treatments. As shown in Table 1, the highest means of infiltration rate was found in T1, T4 and T5 representing respectively natural forest, Japanese cedar with Ry comprised between 0.50 and 0.60 and Japanese cypress plantations with the same range of Ry. The lowest values were found in T11, T10 and T9 representing Japanese cypress and cedar with Ry 0.80-0.95 and Japanese cypress plantations with Ry 0.70-0.80. The difference among these treatments is about six orders of magnitude.

These results indicate that infiltration rate was higher in areas having more sunlight penetration to the forest floor due to the lower stand density (Ry: 0.50-0.60) and resulting to the development of understory plant growth (Shiozaki, 1977).

Areas with high relative yield (Ry) almost reaching the maximum value of 1.0 characterizing a fully packed plantation, with a very high density and where thinning operations have not been conducted showed less infiltration rate and soil macroporosity than other treatments. Also, soils were found much harder in those areas than in others. However, areas with the lowest stand density did not have the highest infiltration rate (T2 and T3 representing Japanese cedar and cypress plantations with Ry:

0.37-0.50) although enough sunlight was present in the stand; maybe due to the excessive thinning operations or heavily damaged by natural disasters, creating too much distances between trees and destabilizing the whole stand.

Table 1. Description of the treatments

Treatments	Characteristics
T1	Natural forest
T2	Japanese cedar Ry: 0.37-0.50
T3	Japanese cypress Ry: 0.37-0.50
T4	Japanese cedar Ry: 0.50-0.60
T5	Japanese cypress Ry: 0.50-0.60
T6	Japanese cedar Ry: 0.60-0.70
T7	Japanese cypress Ry: 0.60-0.70
T8	Japanese cedar Ry: 0.70-0.80
T9	Japanese cypress Ry: 0.70-0.80
T10	Japanese cedar Ry: 0.80-0.95
T11	Japanese cypress Ry: 0.80-0.95

Another reason to explain the differences among the treatments is the abundance of organic materials as substrate which would favor higher microbial activity and organic matter decomposition (Fisher and Binkley, 2000). Berg (2000) also pointed out that the modification of forest litter composition as substrate for microbial decomposition led to enhance organic matter turnover. This could be one of the contributing effects of thinning operations on soil physical properties and particularly on infiltration rate since thinning operations have enhanced the secondary growth of other species at the ground level that result to a more diverse composition of organic materials compared to the unthinned forest. Another possibility is the high organic matter content in thinned plots (Ry: 0.50 - 0.60 or Ry: 0.37-0.50) which affects aggregate development and creates more macropores (Mapa, 1995). In addition, since litter layers are present in most areas with lower Ry rates, run-off is delayed and there is more time for infiltration to take place, increasing the water intake of such soils (Heermann and Duke, 1983). Araki et al., (2005) found areas with thinning operations to show understory plants development as well as slashes which contribute to attenuate the surface soil and retain moisture.

Moreover, 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). However, this difference of forest floor condition appears to be overcome in cypress with Ry: 0.50-0.60 (Figure 4) due to the fact that appropriate thinning operations have been conducted, reaching this interval of stand density. Also, cedar species that could differ from cypress plantations showed similar poor infiltration rate in areas without experiencing any forest operations (Ry above 0.70).

A direct investigation of forest floor conditions, which could have helped to understand fully the impact of understory vegetation and leaf litter to the soil physical properties have not been conducted in this study.

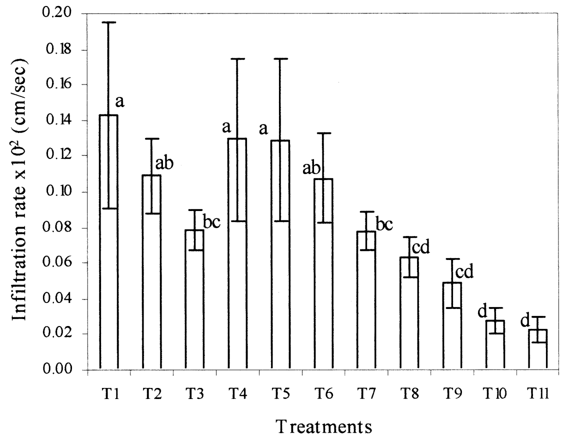

Figure 4: Topsoil infiltration rate in different treatments in the study area. Mean values and standard deviation are presented. Means followed by the same letter(s) are not significantly different based on Tukey's HSD test (0.05 level)

Case of subsoil (20-40 cm)

Unlike the case of topsoil variables, subsoil variables did not differ much among the treatments. Infiltration rate was higher only in T1 and T4 (respectively represented by natural forest and Japanese cedar with Ry: 0.50-0.60) and did not have any significant difference for the other treatments at the 0.05 level.

These results mean that although some differences were identified in some treatments, subsoil variables were in general not significantly affected by the different forest conditions.

4 Conclusion

This study helped to understand that forest thinning is very important and has important impact to soil infiltration rate.

Effectively, soil infiltration rate was the highest in those plantations of Japanese cedar and cypress having experienced thinning operations (case of topsoil) and corresponding to relative yield (Ry) comprised between 0.50 and 0.60. The actual stand density recommended in Japan for timber production has a relative yield of about 0.7 (Ando, 1982), slightly higher than this interval. This study informs on the need to reduce the stand density to this level to be able to have a better soil physical property, essential step that forest managers need for a stable forest environment in a matter of soil physical characteristics, necessary to satisfy the function of soil and water conservation.

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