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Effect of strip thinning on rainfall interception in a Japanese cypress plantation

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S U M M A R Y

We examined the effect of strip thinning on rainfall interception (E_i) in a 32-year-old Japanese cypress plantation in central Japan. Strip thinning was conducted in the catchment in October 2011; that removed 50% of the stems. The gross precipitation (P_g), throughfall (*TF*) and stemflow (*SF*) were monitored in a 12-m × 13-m plot before and after thinning. E_i was calculated as the difference between P_g and the sum of *TF* and *SF*. The interception processes were illustrated using the revised Gash model with quantifying interception parameters. The results showed that the Gash model successfully predicted E_i on a rainy-season basis in both pre- and post-thinning periods. Thinning altered the interception components whereas the largest part during and after rainfall accounted for similar proportion in both periods. Additionally, after thinning, the annual *TF* rate was increased from 61.4% to 73.0%, whereas the annual *SF* rate was decreased from 9.8% to 6.1%, and the annual E_i rate was decreased from 28.7% to 20.8%. The summarized findings of previous studies indicate that the degree of decline in the E_i caused by thinning is related to P_g and the thinning ratio. These results provide useful information for understanding the changes in interception processes induced by thinning, and for acquiring a more accurate forecast of the effects of forest management practices on water resources in the watershed. The response in rainfall partitioning to strip thinning can also help us to acquire an integrated understanding of the changes in canopy water balance under different forest practices.

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1. Introduction

Forest thinning alters the cover and structure of the forest canopy to increase the amount and density of understory vegetation and the growth rate of residual trees (Aussenac et al., 1982; Dodson et al., 2008; Maleque et al., 2007b; Thomas et al., 1999). These changes can also enhance the biodiversity of forest ecosystems (Maleque et al., 2007a; Nagaike et al., 2006). Moreover, forest thinning plays an important role in regulating the hydrological cycle at multiple temporal and spatial scales by altering ecosystem water balances (Andreassian, 2004; Breda et al., 1995; Dung et al., 2012; Simonin et al., 2007). Rainfall interception (E_i) is one of the primary elements of the forest water cycle (Komatsu et al., 2007; Llorens and Domingo, 2007; Sun et al., 2014a). It represents rainwater loss evaporated from leaves, branches and stems of forest during and after rainfall events. E_i may account for 12–40% of the gross rainfall in coniferous forests (Sun et al., 2014a) and is important in influencing the water yield of forested watersheds. The variation of E_i was strongly determined by forest structural factors such as stand density and canopy cover structure (e.g., Deguchi et al., 2006; Komatsu et al., 2007). Thus, the thinning-induced changes in the characteristics of a forest stand should greatly affect E_i. In such, studies of the changes in E_i due to thinning are essential to improve our understanding of the changes in water resources in forested watersheds.

A number of attempts have been made to evaluate how forest management, including thinning, affects E_i in various tree species worldwide (e.g., Aussenac et al., 1982; Limousin et al., 2008; Molina and del Campo, 2012; Teklehaimanot et al., 1991). For example, Teklehaimanot et al. (1991) found that the mean annual rate of E_i to gross rainfall was 33%, 24%, 15% and 9% after treatments with 2-, 4-, 6- and 8-m spacing, respectively, in a *Picea sitchensis* forest in Cloich, Edinburgh. This reduction in E_i rate with increasing spacing treatments was related to the changes in the boundary layer conductance. Many thinning experiments have shown that the declining degree in the E_i rate is not proportional to the amount of biomass removed. For instance, Whitehead and Kelliher (1991)

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reported that removing 56% of the stems with respect to a control resulted in only a 27.2% decrease in E_i in a *Pinus radiata* forest in New Zealand. Additionally, environmental conditions (e.g., fog entrapment) can also influence how thinning affects rainfall partitioning. For example, Aboal et al. (2000) reported that thinning increased throughfall due to the enhancement of fog entrapment in a *Pinus canariensis* plantation in Tenerife. The hydrological responses to land management and cover change vary greatly because of the complex interactions among climate, soil, and vegetation from individual tree to landscape scales (Bosch and Hewlett, 1982; Zhang et al., 2001). Therefore, it is necessary to quantitatively evaluate the effect of forestry practices on E_i in forested watersheds. An understanding of the relationship between the canopy water balance and the forest would play an important role in accurately predicting how forest management affects rainfall partitioning and, consequently, water resources.

Different thinning methods (e.g., strip thinning and selective thinning) may result in different changes in the structure of the forest stand (e.g., the spatial distribution of canopy density) and the boundary layer conductance. Thus, the different thinning methods would result in different effects on E_i. Although many studies dealing the effect of thinning on E_i exist, few data are available to document the change in E_i caused by strip thinning (Aussenac and Granier, 1988; Aussenac et al., 1982). Strip thinning is a form of heavy, cost-effective thinning which open corridors regular intervals and the width of the retained sections is usually two to three crown widths. Linear sections of the plantation are harvested parallel to the direction of the slope and often perpendicular to the forest road to extract timber efficiently. Strip thinning requires less time and skill in terms of tree selection than does conventional selective thinning (Taniguchi, 1999) whereas the stand structure cannot be improved efficiently. In Japan, strip thinning has been applied widely in poorly managed coniferous plantations. Recently, Sun et al. (2014c) examined the responses of tree transpiration to strip thinning at individual tree and stand levels in a Japanese cypress (*Chamaecyparis obtusa* Endl.) plantation. However, the effect of strip thinning on E_i has been rarely reported. Studying the changes in the forest water cycle under different forestry practices has become a priority for policy makers because adopting thinning practices could provide powerful changes in the hydrological function of the forest ecosystems.

The changes in canopy structure can alter interception parameters, including canopy water storage capacity (S), direct throughfall proportion (p), and the rate of evaporation to rainfall intensity ($\bar{E}/\bar{R}$). These forest structural and climatic parameters influence E_i (Gash, 1979; Link et al., 2004; Pypker et al., 2005; Sun et al., 2014a). Pypker et al. (2005) examined the role of canopy structure in affecting E_i in Douglas-fir (*Pseudotsuga menziesii*) forests in USA. They reported that S, p and $\bar{E}/\bar{R}$ were affected by both short-term (seasonal) changes in phenology and long-term horizontal and vertical development of the forest canopy. Sun et al. (2014a) applied the revised Gash analytical model to estimate E_i on the basis of the quantification of these interception parameters in an abandoned Japanese cypress plantation. They reported that the model successfully predicted E_i and exhibited the interception processes. Forest thinning immediately changes the canopy structure, and has a great effect on these interception parameters and its processes. However, few studies have attempted to illustrate the changes in interception processes, to improve the understanding of thinning effect on E_i.

Therefore, the objectives of this study were to (1) quantify the changes in interception processes using the revised Gash analytical model on the basis of determination of the interception parameters, and (2) examine the changes in rainfall partitioning after 50% strip thinning in a dense and mature Japanese cypress plantation in central Japan. Lastly, we reviewed and collated literatures to evaluate how thinning influences E_i.

2. Methodology

2.1. Study site

The study site is 156 m^2 (12 × 13 m) in area on a hillslope (31°) with south-west exposure. It is located in a headwater catchment K2 on Mt. Karasawa, Tochigi Prefecture, Japan (36°22′ N, 139°36′ E, 198 m a.s.l.) (Fig. 1a–c). The study area has a humid and temperate climate. The mean temperature between 1991 and 2011 was 14.1 ± 0.6 °C. The mean annual precipitation was 1265 ± 220 mm. There are two dominant storm periods: the Baiu season from late June to mid-July, and the typhoon season from late August through October. During the rainy season (May–October), the mean precipitation was 941 ± 196 mm, accounting for 74% of mean annual precipitation. More detailed descriptions of the study plot are available in our previous studies (Sun et al., 2014a,b).

Japanese cypress plantation forests are distributed in the catchment and have been abandoned since they were planted in the 1980s. Strip thinning which involves felling two tree lines in alternative pattern was performed in the catchment K2 in October 2011. All thinning operations were conducted by forest workers using machinery no heavier than chainsaws to minimize soil disturbance on the hillslope. All twigs, branches, and timber from the thinned trees were removed from the forest. The stems were thinned by 50% from 2198 to 1099 trees ha^{-1}, representing 48% of the basal area, i.e., from 50.4 to 26.2 m^2 ha^{-1} (Table 1, Fig. 1d). Before thinning, the experimental plot included eight tree lines. After thinning, four tree lines remained (Fig. 1c). The number of trees in the plot decreased from 28 to 13. The change in average DBH was relatively small, i.e., from 19.1 to 18.9 cm (Table 1). There was no change in the 0.11–0.13-m and 0.17–0.19-m DBH size class in the study plot after thinning. The canopy cover fraction decreased from 0.974 to 0.758, as measured by fisheye photos of the stand crown just above each rain gauge (Table 1).

2.2. Measurements

Meteorological conditions were measured using an automatic weather station (HOBO U30-NRC Weather Station; Onset Computer Corporation, MA, USA). It was installed in an open field, 250 m from the studied hillslope. The gross precipitation (P_g) was measured at 2 m height above ground by a funnel-type gauge with a 0.2-mm tipping bucket. Snowfall was not included in the analysis. Wind speed and direction were measured using a three-up anemometer (AC750, Makino Applied Instruments Corp., Tokyo, Japan). Other meteorological parameters, including the solar radiation (R_s), temperature (T) and relative humidity (RH), were also measured at 2 m height above ground. The data were stored every 5 min with a data logger.

Throughfall (TF) was observed by 20 tipping-bucket rain gauges of the same type (Davis Instruments 7852 M, Hayward, CA). The number of tips for each gauge was recorded simultaneously at 10 min intervals using a data logger (OWL2pe; EME System, Berkeley, CA). Cumulative rainfall records for each rain gauge were assessed manually to identify rain gauges that had failed or clogged during an individual event. The average TF was computed from all functioning rain gauges. The gauges were arranged in a lattice-like pattern on an approximately 2 × 2-m grid within the experimental plot (Fig. 1c). Each gauge was set on a platform that was approximately 0.4 m above the forest floor. All of the rain gauges were maintained in the same position throughout the pre- and post-thinning periods.

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