

Rainfall Interception in Two Contrasting Forest Types in the Mount Gongga Area of Eastern Tibet, China

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Abstract

An important component of the water cycle in ecological systems, rainfall interception by virgin forests was here calculated from gross precipitation minus through fall and stem flow. The through fall measurement system was designed on the basis of a 3 m long trough mounted beneath the canopy and able to operate successfully under a range of rainfall conditions. Stem flow was measured using spiral collars consisting of a split plastic hose attached to sampled trees, with gross precipitation measured in an open area via a tipping-bucket rain gauge. This study was carried out to evaluate rainfall interception and distribution patterns of gross precipitation in two contrasting rainforest types (coniferous and broadleaved/coniferous mixed) in the Mount Gongga area on the eastern fringe of Tibet, China, from 2008 to 2009. Net precipitation was found to be primarily composed of through fall, while stem flow contributed less than 0.5% (0.1% and 0.4% in conifer and mixed forest, respectively) to total gross precipitation (GP) and was thus negligible in both forest types. The difference in the interception loss fraction between conifer and mixed forest was greater than 30%, with the interception loss of the former apparently more than that of the latter mainly due to the increased presence of small droplets produced by coniferous leaves. Additionally, interception loss in conifer forest was more dependent on rainfall than that in mixed forest. In contrast, through fall and stem flow exhibited the opposite pattern, likely attributable to a through fall lag of 8 to 10 h after rainfall in mixed forest but not in conifer forest.

Keywords: Rainfall interception; Through fall; Forest ecosystem; Stem flow; Mountain area

Introduction

Rainfall interception is believed to play an important role in the water balance of catchments and plant ecosystems. An essential component of forest water balance is the interception of rainfall by the canopy and its subsequent evaporation to the atmosphere. Normally, the amount of water intercepted by and evaporated from a forest canopy (interception loss (IE)) can be estimated by calculating the difference between gross (above canopy) and net (below canopy) precipitation, the latter being the sum of through fall (TF) and stem flow (SF) [1]. It has been observed that evaporation loss direct from the canopy due to interception by a rainforest system can be very high, particularly in areas under 'maritime' conditions such as those experienced on continental edges and islands [2]. As a significant component (25-75%) of overall evapotranspiration [1], interception loss from forests apparently varies with the characteristics of different forest types, as well as climatic factors [3]. In temperate forests [4], interception loss ranges from 9% to 48% of gross precipitation, is influenced by canopy structure, and is widely reported to account for 10-40% of annual rainfall [5]. David et al. [1] reported interception loss to represent 22% of gross rainfall in a Mediterranean savannah; Link et al. [6] recorded values of 22.8% and 25.0% of gross rainfall in temperate rainforest in 1999 and 2000, respectively. Annual interception loss was found to range from 8.5% to 12% in Japanese lowland tropical forest [7]. The annual interception loss measured in five forest transects varied from 25% to 52% of incident rainfall in tropical montane forests [8], whereas apparent annual rainfall interception losses were 7.7% and 29.6% of gross precipitation in upper and lower tropical montane forests in the eastern Andes of Central Peru, respectively [9].

The highest levels of rainfall interception have been found in natural forests, where 30% (median) of gross precipitation can be

re-evaporated back into the atmosphere; the through fall percentage also increases significantly with decreasing tree height in tropical forest [10]. Vernimmen et al. [11] found that interception losses in Lowland Evergreen Rain Forest (16.4%) and tall Heath Forest (9.6%) in Indonesia were close to figures obtained for other similar forest types. However, interception loss in stunted Heath Forest (21.3%) was unexpectedly high. Annual rainfall interception was recorded at 10.8% of gross rainfall in moose bamboo (*Phyllostachys pubescens*) forest [12], and about 8% of gross rainfall in an Olive orchard with an average leaf area index of 1.1 [13].

All the above reports demonstrate that rainfall interception varies not only with forest type, but also with geographical location. It is particularly difficult to draw any general conclusions regarding the relationship between interception losses and particular forest types due to the former's dependence on the type of rainfall and other meteorological conditions [3]. As a result, it is essential to understand the characteristics of interception at each specific site. The main objective of this study was to compare the interception distribution process in a mixed broadleaved/coniferous forest with that in a

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coniferous forest, and then to analyze the effects of vegetation cover and rainfall characteristics on interception losses in the Mount Gongga area of south-western China.

Materials and Methods

Study area

The study area is a primitive forest of *Abies fabri*, situated at an elevation of 3,000 m in Hailuo Ravine on the eastern slope of Mount Gongga, Sichuan Province, in the upper reaches of the Yangtze River at a latitude of 29°20'-30°20' N and a longitude of 101°30' - 102°15' E. In terms of its geomorphological situation, the mountain stands on the accumulated glacial lateral moraines formed on the left bank of a glacial valley and the eastern edge of the alluvial fan of a glacier debris flow [14]. Two different soil types can be found, associated respectively with the influence of temperate valley glaciers and debris flows, i.e. moraine soil pushed by glaciers and the soil of a slope deposit lashed by glacier debris flow. The study area consists mainly of *Abies fabri* (Mast.) Craib (Faber's Fir) and *Populus purdomii* Rehder (Purdum's Poplar). According to the succession process of *Abies fabri*, the study region can be divided into areas of young, middle-aged, mature and over-mature forest. The mature forest grows in the slope deposit soil, while the young, middle-aged and over-mature forests grow in moraine soil.

The thin soil root zone in the study area contains many pebbles; moisture thus permeates quickly with virtually no surface runoff or soil gravity erosion. The study area is also characterized by a dry season (from Nov. to Apr.) and a rainy season (from May to Oct.); rainfall (approximately 2,200 mm) during the latter period accounts for about 80% of annual precipitation, most of which is of low intensity and long duration. About one third of rainfall has an average intensity of 1.0-1.5 mm/h, with only a quarter having an average intensity of 1.5 mm/h. Annual mean air temperature is 4.2 °C, with the monthly mean maximum of 12.5 °C occurring in August and the minimum of -4.8 °C in January. The snow-free period below the forest canopy extends from April through to the following January.

Since it is easier to obtain samples from the slope deposit soil, i.e. in mature forest with a thick litter and moss layer, the research was conducted on slope deposit soil in middle-aged forest plots. Two types of forest were examined: coniferous forest and a broadleaved/conifer mixed forest. The two selected areas are 500 m apart on sites of similar topography (south-eastern slopes with a gradient of approximately 20%). Dominated by *Abies fabri*, the conifer forest has a density of 0.8 trees m⁻², with tree heights ranging from 15-30 m, tree diameters from 10-35 cm and a leaf area index (LAI) value of 2.85 (measured by a LAI-2000 Plant Canopy Analyzer). Characterized mainly by the presence of *Populus purdomii*, *Abies fabri*, *Sorbus pohuashansis* (*Sorbus multijuga* Koehne) and Himalayan birch (*Betula utilis* D. Don), the mixed forest has a density of 1.2 trees m⁻², with tree heights ranging from 5-20 m, diameters from 5-30 cm and an LAI value of 2.94. The conifer: broadleaved ratio is approximately 35% to 65%.

Methods

Gross precipitation was measured using a tipping-bucket rain gauge (0.202 mm per tip) at both sites in areas with no vegetation canopy. The rain gauges were installed at a height of 1 m and were connected to data loggers to record the precipitation events.

Stem flow was measured using spiral-type gauges comprising a split plastic hose (2.0 cm internal diameter) attached to the tree trunks, draining into a tipping bucket measurement system equipped with data

loggers. The plastic hose was attached to the tree trunk with staples and its clean smooth surface was used as drainage. Sampled tree selection involved site survey to determine the distribution of tree sizes, with a representative sub-set then selected as characteristic of the range of tree sizes found on each plot. Size selection was made irrespective of tree species or bark texture, with tree size measured in terms of diameter at breast height (DBH). Tubing of diameter 2 or 3 times tree DBH plus an additional 30 cm was used for each tree. Apart from the last 30 cm, the tubing was split longitudinally using a specially designed cutter in order to ensure both pieces had the same dimensions. The un-split end portion of the tubing hose was first fixed to the tree using a galvanized saddle and nails, with each half of the remaining tubing then attached to the tree in an upward spiraling direction, again with galvanized nails. The two halves of the hose which overlapped at the back of the tree were removed, as well as any excess. The hose was then sealed to the bark of the tree with silicon sealant; the seal between the collar and tree was maintained regularly over time by applying a coating of waterproof grease. Five and eight trees were sampled in the coniferous forest and broadleaved/coniferous mixed forest plots, respectively. Simultaneously, the amount of water required to saturate the tree bark was measured via manual sprinkling until the water emerged at the lower end of a circle cut around the tree circumference.

Through fall was measured using three V-shaped steel troughs (3.00 m × 0.25 m × 0.30 m) to cover the total crown projection area of 0.22 m² in each forest plot. Troughs were installed at an angle of about 15% to the horizontal to ensure efficient drainage, with the lower end of each trough fitted with fine 10 mm × 10 mm wire mesh covers in order to prevent the collection of leaf litter that could potentially cause a blockage at the outlet. The horizontal (projection) collection area was calculated accounting for the installation angle of each trough. Troughs were mounted on brackets fixed to steel posts at a height of 2 m. The tipping bucket measurement system was housed in a steel box, with the water flowing through a tube positioned directly over the centre of the system.

All the above measurements were taken from May 2008 to September 2009. However, stem flow and through fall data were not recorded during the winter freezing period (November 2008 to February 2009).

Results

Tree interception characteristics at the research sites

During the measurement period (April to September 2009), each site experienced continual rainfall without any apparent separation between individual events. Although a substantial correlation between rainfall and interception was observed at both sites, interception loss varied distinctly between the two forest types. In the conifer forest (Figure 1), the total interception loss (1164.6 mm) was 75.7%, with net precipitation (stem flow and through fall) (373.6 mm) 24.3% of gross rainfall (1538.2 mm) during the five month period. These figures were 45.5% and 54.5% of gross precipitation (1047.0 mm) respectively, in the mixed forest (Figure 2). This represents a difference in the interception loss fraction of about 30% between conifer and mixed forest, with interception loss greater in the former than the latter.

Furthermore, stem flow was only 0.1% and 0.4% of gross precipitation in conifer and mixed forest, respectively.

Relationship between interception and rainfall

The results show interception to be significantly ($P < 0.0001$)

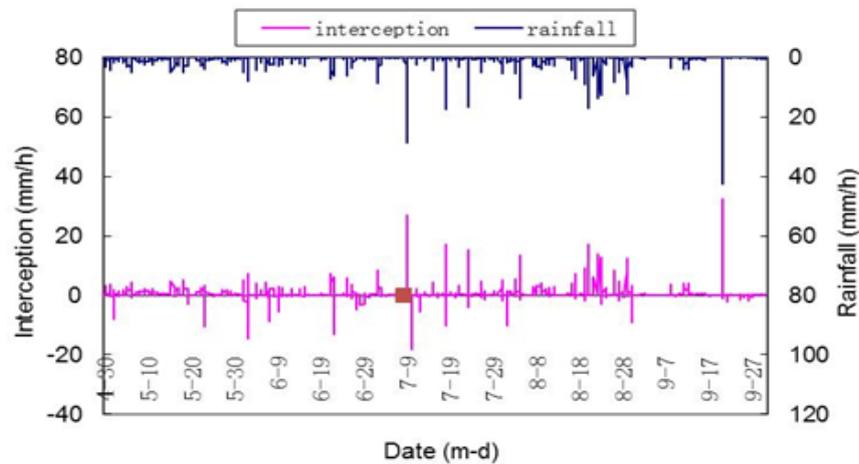


Figure 1: Variation in rainfall interception in the conifer forest during the experimental period.

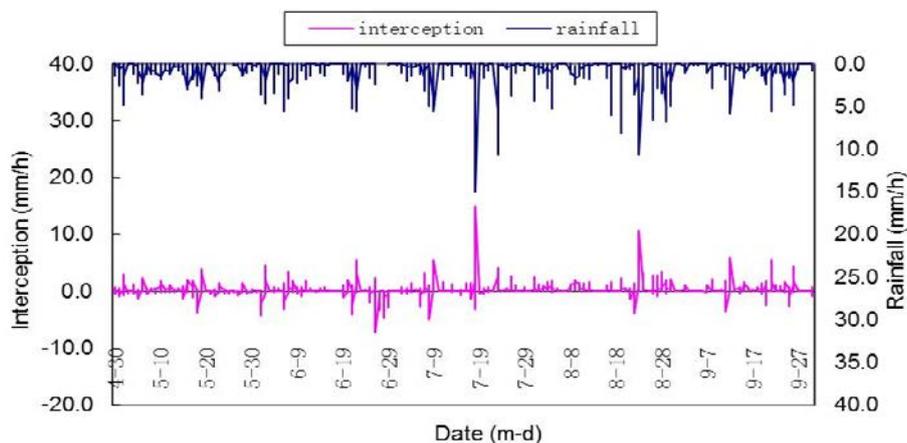


Figure 2: Variation in rainfall interception in the mixed forest during the experimental period.

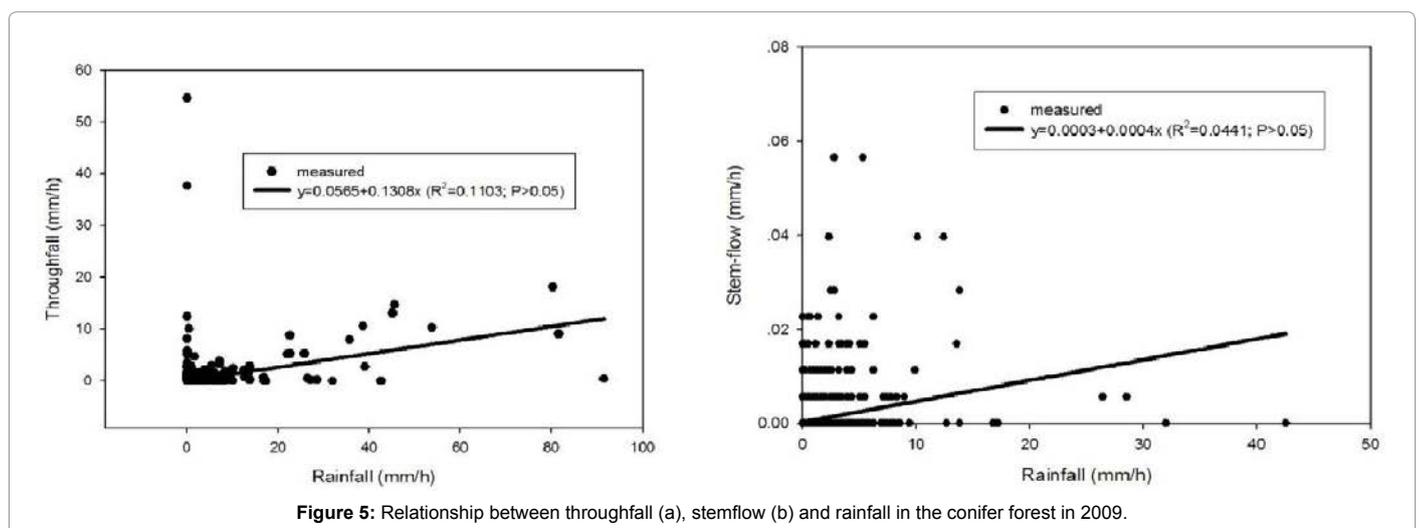
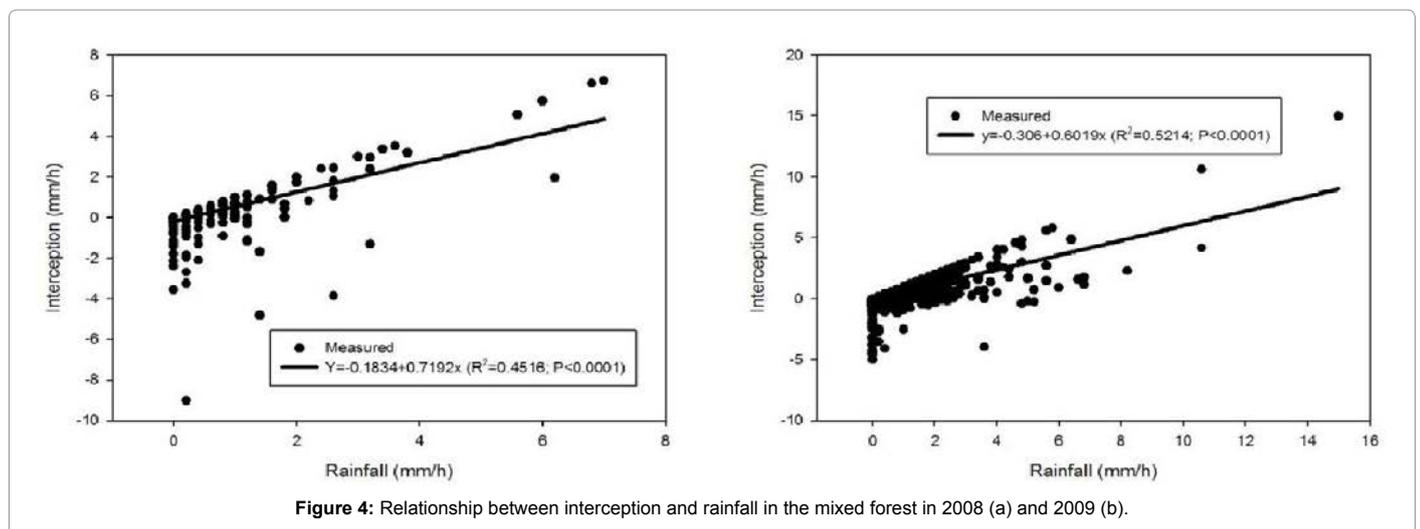
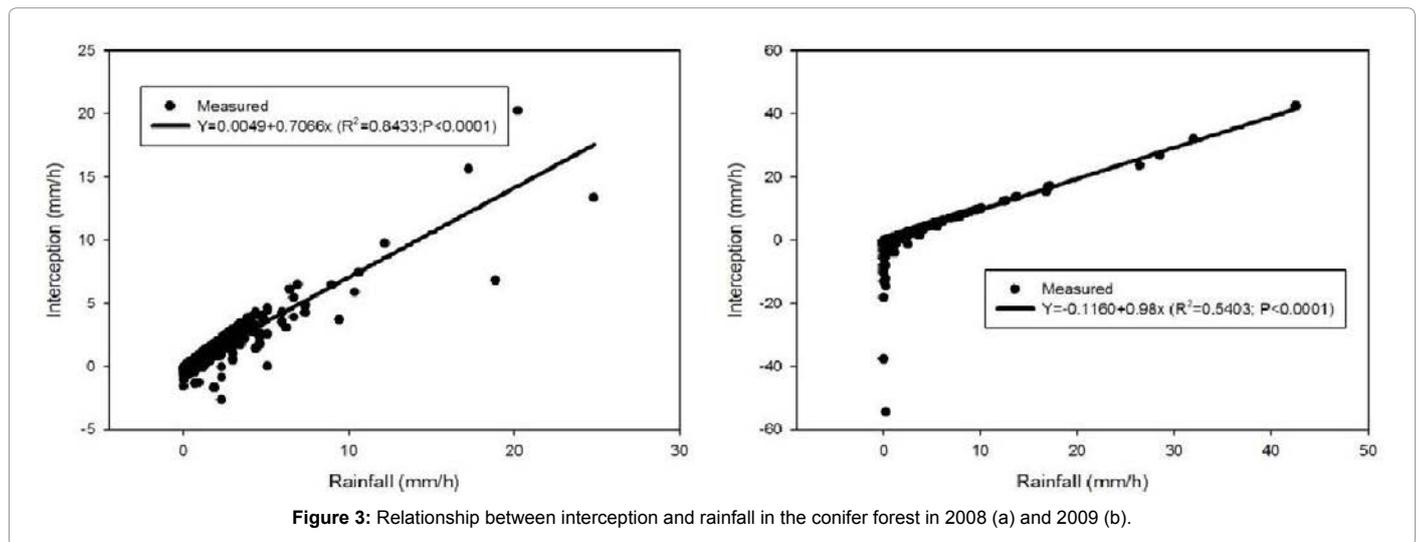
positively correlated to rainfall in both the conifer (Figure 3) and the mixed forest (Figure 4), with interception loss rising as rainfall increased. The correlation coefficients (R) and constants of the linear regression equation varied significantly between the period of 2008 (Figure 3a, 3b and Figure 4a) and 2009 (Figures 3b and 4b) when weather conditions, especially rainfall parameters, differed, suggesting that weather conditions had an apparent effect on this relationship. The correlation coefficients in the conifer forest (Figure 3) were higher than those in the mixed forest (Figure 4) in both 2008 and 2009, illustrating that interception loss was more dependent on rainfall in the former than in the latter forest type.

However, the data also indicate that through fall (Figure 5a and Figure 6a) and stem flow (Figures 5b and 6b) were not significantly related to rainfall in either the conifer (Figure 5) or the mixed forest (Figure 6), while the correlation coefficients exhibited the opposite tendency with respect to the observed relationship between interception and rainfall. Indeed, the correlation coefficient for the conifer forest (Figure 5) was lower than that for the mixed forest (Figure 6) for both through fall and stem flow, suggesting that these parameters are less dependent on rainfall in the conifer than in the mixed forest.

Discussion

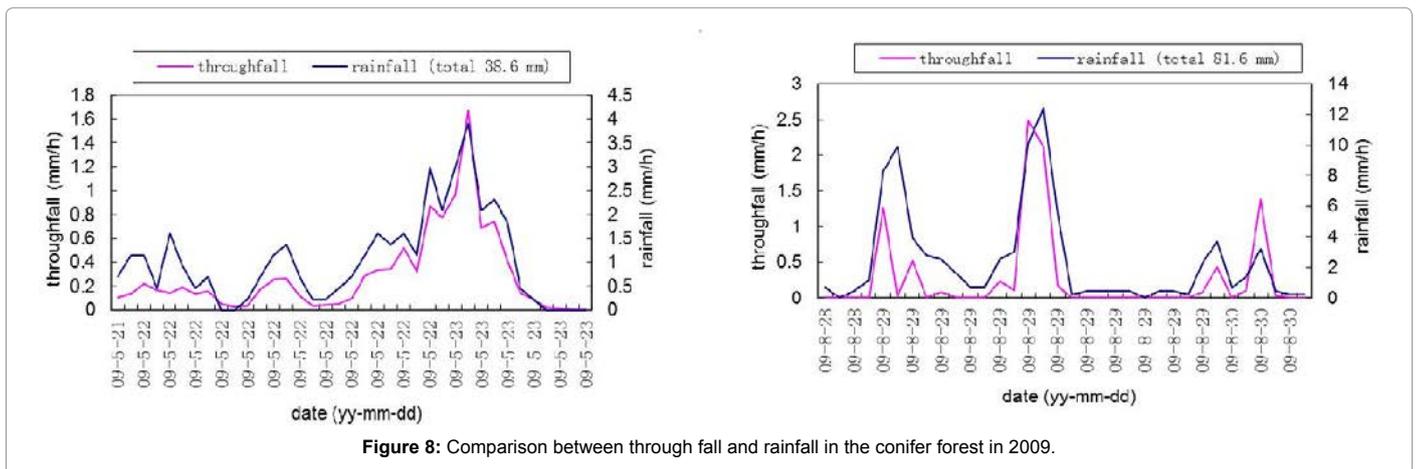
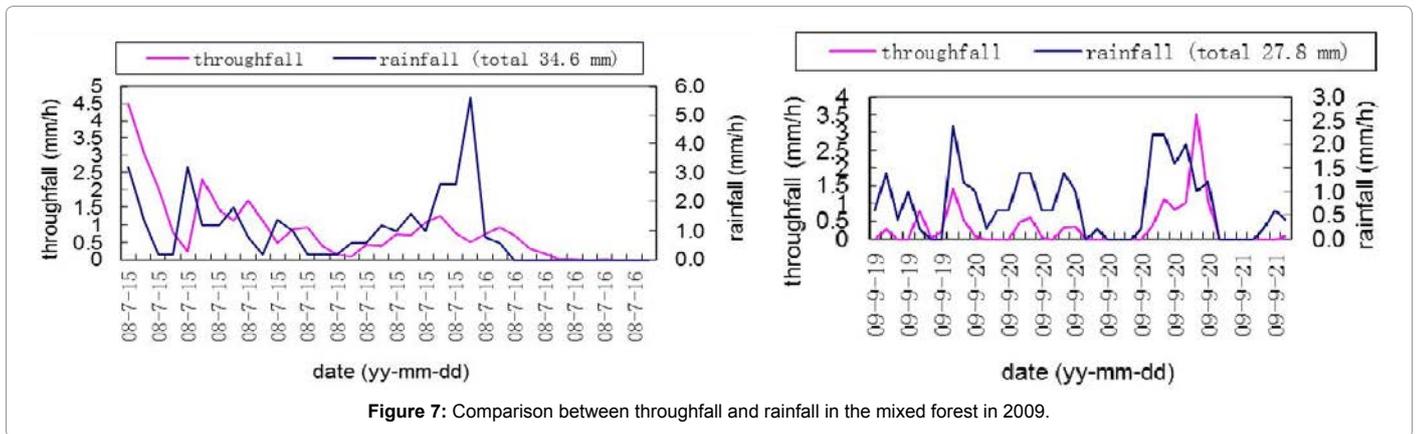
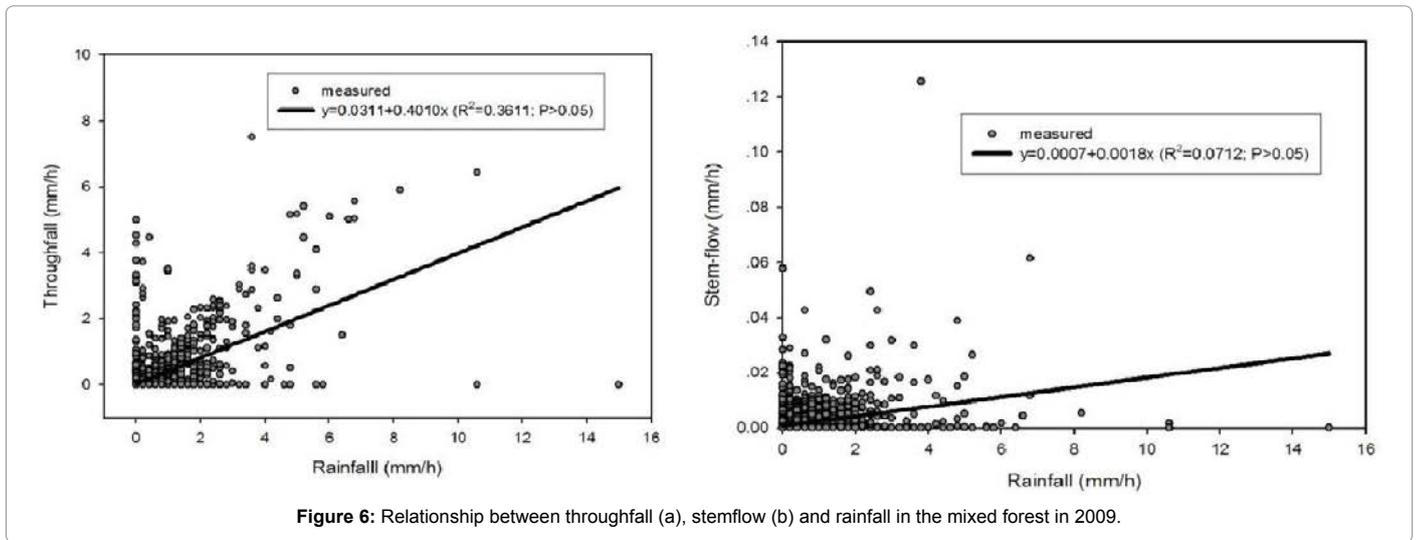
Our research data show that interception loss in the conifer forest was substantially higher than that in the (broad-leaf dominated) mixed forest, a result consistent with most studies carried out in the U.S. [15]. This can be attributed to the fact that more water is evaporated from coniferous than broad-leaved forests as a greater number of small droplets are available for evaporation on coniferous than broad leaves [16]. The negative interception values (Figures 1 and 2) observed here reflects the delay in throughfall shown in Figures 7 and 8.

A number of tree characteristics are known to influence interception [3], including trees/ha, branch angle, uniformity of crown height, nature and thickness of bark layer, leaf shape, inclination and leaf area index. Although the tree density and LAI of the two sites selected in the present study are slightly different, the higher values of both parameters in the mixed forest did not result in increased interception loss. These results imply that the recorded interception patterns are less associated with variation in crown cover and rather more closely with rainfall characteristics [17]. As Fleischbein et al. [8] noted, canopy density can explain only part of total variation in interception loss. While LAI values were here also significantly correlated with interception loss,



the former accounts for only 12% of variation in the latter. Indeed, the direct throughfall fraction was found to be significantly negatively correlated with interception loss, explaining 59% of its variation.

Interception was significantly related to rainfall amount in both the conifer and the mixed forest, a result consistent with data reported by Komatsu et al. [15] and Dunkerley [18]. Both authors have stated



that it is critical to consider variation (of amount) in annual rainfall when assessing the difference in rainfall interception induced by forest properties. However, other studies have shown interception loss to be more dependent on rainfall intensity [16]. The present study revealed interception loss to be more dependent on rainfall in the conifer than in the mixed forest (Figures 3 and 4). We believe that this dependence is related to the delay in throughfall after rainfall events, with a clear delay of around 8 to 10 h in the mixed forest (Figure 7) and not in the conifer

forest (Figure 8). Reid and Lewis [5] have suggested that interception loss occurs mainly during storm events (54%) and not during the post-storm period (46%). Therefore, such a delay could result in reduced interception loss in mixed forest.

The amount of measured stemflow was very small, with the values of less than 0.5% of gross precipitation in both forests consistent with data reported for tropical montane forests in the eastern Andes of

Central Peru by Gomez-Peralta et al. [9]. These authors suggested that stemflow at their study site was in fact negligible, since it contributed less than 0.2% of annual rainfall. This latter figure is much lower than that recorded in deciduous Mediterranean forests, where stemflow accounts for 4.5% of gross precipitation [19], and is also less than that observed in lowland rain forest types in Central Kalimantan, where a range of values from 0.8% to 2.0% of gross precipitation have been reported [11]. Such low stemflow may be the result of water consumption by bark-dwelling mossy epiphyte vegetation [20], which has been measured to have a water saturation mean of 0.8 L.m^{-2} in both conifer and mixed forest.

Conclusions

The obtained results reveal the specific interception loss characteristics of two different forest types in Hailuo Ravine, situated on the eastern slope of Mount Gongga, Sichuan Province, China. A difference in the interception loss fraction of about 30% was observed between the studied conifer and mixed forests, with values greater in the former mainly due to the presence of numerous small droplets produced by coniferous leaves. Stemflow was insignificant, amounting to 0.1% and 0.4% in conifer and mixed forest, respectively. Additionally, interception loss was more dependent on rainfall amount in the conifer than in the mixed forest, while throughfall and stemflow were both less dependent on rainfall characteristics in the conifer than in the mixed forest. The latter pattern can be attributed to a throughfall lag of 8 to 10 h after a rainfall event in the mixed forest but not in the conifer forest.

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