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Effects of rainfall intensity and slope on interception and precipitation partitioning by forest litter layer

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ABSTRACT

Rainfall interception and other hydrologic processes affected by the forest litter layer are usually related to litter characteristics and rainfall conditions, with limited studies that consider the influence of slope. To simulate the hydrological functions of the litter layer at different slope gradients, artificial rainfall experiments were conducted at four rainfall intensities (from 30 to 120 mm hr^{-1}) in horizontal and inclined trays (with the slope of 0°, 10°, 20° and 30°) with litter of *Pinus tabuliformis* or *Quercus variabilis*. The results indicated that (1) the dynamic process of litter interception had 3 phases: a rapid intercepted phase within the first 5 min, a moderate intercepted phase and a post-rainfall drainage phase; (2) the maximum interception storage (C_{max}) and the minimum interception storage (C_{min}) of *Q. variabilis* were larger than those of *P. tabuliformis*; (3) C_{max} and C_{min} were correlated with slope for both types of litter, whereas only C_{max} was correlated with rainfall intensity; and (4) lateral flow amount significantly increased with both slope gradient and rainfall intensity only for *Quercus variabilis*, whereas drainage volume showed significant correlation with rainfall intensity. Moreover, the ratio of lateral runoff and drainage was affected by slope gradient whereas percentage of litter interception had a good relationship with rainfall intensity, rather than slope, with litter interception and drainage contributing the smallest and the largest proportions, respectively. Overall, the results demonstrate the effect of rainfall and slope factors on hydrological processes in the forest litter layer.

1. Introduction

Forest litter, consisting of dead leaves, twigs, fruits and other fragmented organic materials (Sayer, 2006), has important hydrological and ecological effects on forest system. The forest litter layer can affect root water uptake and soil moisture evaporation and drainage to mineral soil (Benyon and Doody, 2015; Marin et al., 2000; Ogée and Brunet, 2002; Park et al., 2010). Furthermore, many studies have reported the litter layer functions in regulating runoff and protecting soil erosion (Kimoto et al., 2002; Liu et al., 2017; Miyata et al., 2009; J.M. Sun et al., 2016; L. Sun et al., 2016).

Litter interception is an important portion of rainfall partitioning, accounting for 2–70% of gross precipitation because of differences in temporal scales, tree species and rainfall conditions (Brye et al., 2000; Helvey and Patric, 1965; Sun et al., 2014). The immersion test is a common method to reflect water conservation capacity of forest litter, but its condition of sufficient water supply greatly exceeds that of natural rainfall. Therefore, many authors have focused attention on simulated rainfall experiments to explore the hydrological processes of forest litter (Li et al., 2017; Putuhena and Cordery, 1996; Sato et al., 2004). Artificial rainfall tests have been conducted to investigate the characteristics of litter interception and potential influencing factors such as rainfall intensity, rainfall duration, litter type, litter mass and litter thickness, among others (Guevaraescobar et al., 2007; Marin et al., 2000; Pitman, 1989). However, most studies place the litter layer horizontally and few simulate the hydrological processes in sloping

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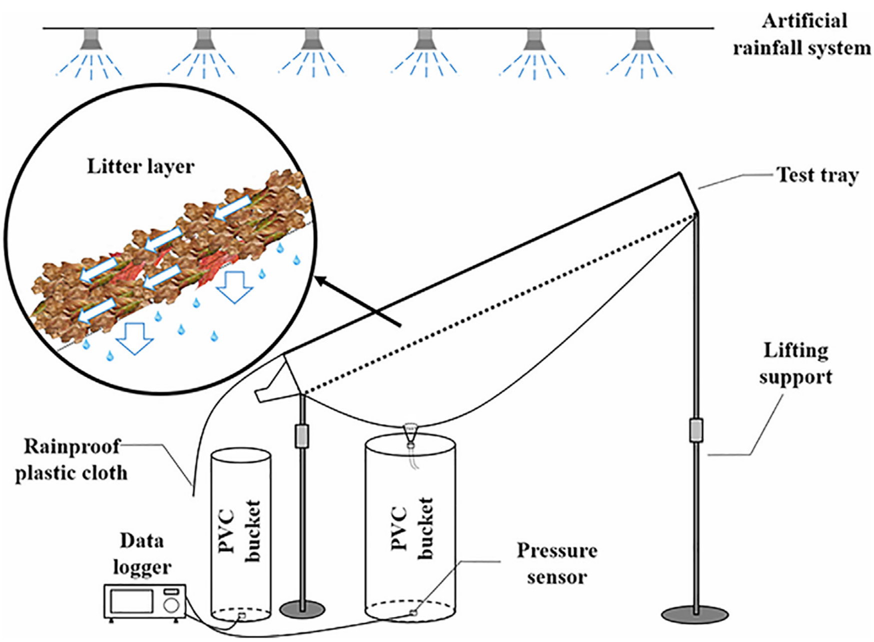

Fig. 1. Schematic of simulated rainfall experiment.

litter layers.

Overland runoff generation is potentially affected by vegetation cover because of varying infiltration capacity and slope roughness among different vegetation types (El-Hassanin et al., 1993; Mueller et al., 2007). Similarly, because of surface covers such as the litter layer, hydrologic processes on hillslopes increase complexity. For example, lateral flow in the organic horizon is regarded as a part of a linked network of preferential flow pathways (Noguchi et al., 1999; Sidle et al., 2001). Some studies found that surface runoff may be affected not only by Hortonian overland flow but also by another lateral runoff, that of biomat flow (Kim et al., 2014; Sidle et al., 2007). Sidle et al. (2007) observed that much of the rainfall was laterally transported through the upper 20 cm 'biomat layer'. By contrast, Coelho Netto (1987) found that litter-flow corresponds to a very low percentage of precipitation, with little significance as a streamflow component during a storm flow period. Most studies related to hillslope hydrology focus on the water budget of the topsoil layer including litter, humus and mineral soil, in addition to interactions among these sublayers, such as water repellency (hydrophobicity), in connection with soil moisture, soil structural stability and organic compounds, among others (Doerr et al., 2000; Mataix-Solera et al., 2011; Miyata et al., 2009; Valat et al., 1991), which complicate hydrologic processes. Hence, determining how rainwater passes in and out of the litter layer and how during this passage, rainfall might be partitioned as interception, infiltration and lateral runoff in the litter layer is of great importance.

The objectives of this study were the following: (a) to depict the dynamics of litter interception under simulated rainfall; (b) to determine the characteristics of litter interception under various rainfall intensities and on different slopes; and (c) to analyse how rainfall and slope factors affect precipitation partitioning within the litter layer.

2. Material and methods

2.1. Sample collection

The study site is located in Jiufeng National Forestry Park, Beijing, China (116°28′E, 39°34′N). Five 1 × 1 m^2 sample plots were selected by an S-shaped sampling method in two 20 × 20 m^2 areas of dominant forest types in northern China: a broad-leaf type, represented by *Quercus variabilis*, and a needle-leaf type, represented by *Pinus tabuliformis* (Allen, 1993; Wang et al., 2015). In each plot, the two layers of forest litter were measured, and then carefully collected by hand following Johnson (1992) and Keith et al. (2010): an undecomposed litter (L) layer, including relatively freshly fallen leaves, twigs and bark; and a fermentation (F) layer, consisting of half-decomposed leaves, and other recognizable plant tissues. After collection, litter was quickly transferred to the laboratory and weighed and then spread out to dry naturally for further testing.

2.2. Rainfall simulation system

Experiments were conducted under simulated rainfall at the Capital Metropolitan Region Forest Ecosystem National Research Station in Beijing. The rainfall simulation system (QYJY-503C, Qingyuan Measurement Technology, Co. Ltd., Xi'an, China) simulates a wide range of rainfall intensities from 10 to 300 mm hr^{-1} by controlling different nozzle valves and water pressure. The nozzles were installed at a height of 18 m, which allowed raindrops to reach the same terminal velocity as natural rainfall. The rainfall device has good controllability and performance, with rainfall uniformity > 80% (Huo et al., 2015). Based on the high requirement for precision in rainfall intensity, we chose a small test area to demarcate rainfall intensities for the tests to increase the rainfall uniformity up to 95%. Simulated rain is a useful experimental method because of its convenience and controllability, although it cannot perfectly imitate natural rainfall (Duan et al., 2004).

2.3. Experimental facility

The experimental facility is shown in Fig. 1. The sample tray used in this study had an area of 100 × 50 cm^2 and a height of 13 cm. The bottom side was made of nylon net composed of 2 mm diameter strands constituting a 1 × 1 cm^2 mesh or a 2 × 2 cm^2 mesh used to load needle-leaf litter or broad-leaf litter, respectively. The size of mesh was suitable to prevent leaf drop of litter and weaken surface tension between the strands of the mesh, which might affect the interception value. To avoid a drooping net after sampling, we tightened the net and inserted four metal sticks (diameter 5 mm) under the net every 20 cm along the long edge of the tray. Semi-decomposed litter (F) layer was evenly put on the tray first, and then, undecomposed litter (L) layer was placed on the F layer. For comparison, litter mass of the two types of tree species was