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Spatial variability of canopy interception in a spruce forest of the semiarid mountain regions of China

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ABSTRACT

Canopy interception has large spatial variability which complicates measurements and achievement of spatial representation. In the present study, we measured gross rainfall and throughfall from June 2011 to October 2012, and leaf area index (LAI), plant area index (PAI), and spatial locations of trees within *Picea crassifolia* forest in Qilian mountains of northwestern China. Spatial variability of canopy interception and related factors, and the minimum number and locations of collectors were analyzed by statistical techniques. The results show that spatial variation of canopy interception has a significant relationship with PAI, but not with LAI. This indicates that PAI is more appropriate parameters for a canopy interception model than LAI. Based on the relationship between canopy interception loss and PAI, the minimum number and locations of collectors were estimated. In this study, 10–12 collectors yielded representative throughfall in the forest, but these collectors required to be placed at the sites of mean values of PAI.

1. Introduction

Rainfall canopy interception is the amount of rain that is intercepted, stored, and subsequently lost by evaporation from the canopy (Savenije, 2004). Rainfall interception is an important process because it influences many hydrological processes including infiltration, erosion, soil moisture distribution, sub-surface runoff, and flood generation (Keim and Skaugset, 2003; Tsiko et al., 2012). In a forested area, rainfall interception is also important for the catchment water balance and moisture recycling which supports continental rainfall. The importance of rainfall interception has been repeatedly demonstrated in different forests under different ecological systems (Gash et al., 1980; Carlyle-Moses and Price, 1999; Xiao et al., 2000; Herbst et al., 2008; Tsiko et al., 2012).

Rainfall interception in temperate forests typically ranges between 9 and 48% of gross precipitation (Breuer et al., 2003; Gerrits and Savenije, 2011), and tends to be higher for coniferous than for broad-leaf forests. Rainfall interception is influenced by many factors including canopy structure, tree spacing, wind, rainfall intensity, and evaporation (Hörmann et al., 1996; Gerrits and Savenije, 2011). Canopy structure is used in most rainfall interception models as an important influence factor (Teske and Thistle, 2004; Deguchi et al., 2006); it is quantified usually by leaf area index (LAI). Canopy structure may be altered by changes in gap fraction, horizontal and vertical distribution of foliage, epiphytes, and changes in species composition (Ishii and Wilson, 2001; Franklin et al., 2002; Ishii and McDowell, 2002). Due to the influence of canopy structure, rainfall interception has a significant spatial variation, and is calculated as the difference between gross and net rainfall. Even a small fractional uncertainty in either gross or net rainfall can generate large errors in interception loss. An average value is therefore generally obtained by using a large number of collectors (Holwerda et al., 2006), a large collection area (Calder and Rosier, 1976; Cuartas et al., 2007), or by relocating collectors over time throughout a basin area (Lloyd and Marques, 1988); ultimately, these methods are time-consuming and therefore expensive. In the past decades, many scientists attempted to estimate throughfall using a minimum number of collectors (Peterson and Rolfe, 1979; Lawrence and Fernández, 1993; Deguchi et al., 2006). However, it is still very difficult to achieve a high spatial representation of throughfall measurements, and the relationship between the spatial variability of throughfall and the influence factors of rainfall interception remains unclear (Deguchi et al., 2006).

In the current study, we measured gross rainfall and throughfall from June 2011 to October 2012, and LAI, plant area index (PAI), and spatial location of trees within a *P. crassifolia* forest in the Qilian Mountains of northwestern China. This forest is a second-growth forest 70 years after logging disturbance. Fewer understory species are present in the second-growth forest than in the primary forest. Functional attributes of the forest have been described in previous

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studies (He et al., 2010, 2012). The aim of this case study was to: (1) examine the spatial variability of canopy interception in the forest, (2) analyze the influence of canopy structure on canopy interception, and (3) determine the minimum number and position of collectors basing on spatial variability of canopy interception.

2. Materials and methods

2.1. Site description

The study was carried out in the Qinghai spruce forest (*P. crassifolia*) of the Qilian Mountains (100°17′E, 38°24′N), near Zhangye City, in northwestern China's Gansu province. Mean annual rainfall is 376 mm (mean value from years 1994 to 2008) at an elevation of 2700 m, and precipitation generally increases with increasing elevation by about 4.3% per 100 m. About 65% of the precipitation falls during the summer (July to September). Mean annual temperatures decrease with increasing elevation, from 2 °C at the base of the catchment (2600 m) to −6.3 °C near the summit (3800 m). Owing to the large temperature and precipitation gradients, vegetation is present as a mosaic of patches of grassland, scrubland, and forest. Forests are mostly found on shaded (north-facing) and semi-shaded slopes at intermediate elevations (i.e., 2300–3400 m). South-facing slopes are mostly occupied by grasslands. In the Pailugou catchment, *P. crassifolia* is the only tree species in the study area, and is found primarily between elevations of 2650 and 3400 m. The dominant understory vegetation species are *Potentilla fruticosa, Potentilla glabra, Lonicera microphylla, Kobresia bellardii*, and *Polygonum viviparum.*

2.2. Gross rainfall

Gross rainfall was measured by an Environmental Integration System (ENVIS; IMKO Micromodultechnik GmbH, Ettlingen, Germany). An IMKO ENVIS was installed at the observation site (i.e., grassland with a Euclidean distance of 65 m to the throughfall observation site) to continuously monitor the local microclimate (for details, see Liu et al., 2007). Precipitation data were recorded from June 2011 to October 2012 using RG50 automatic precipitation sensors (SEBA Hydrometrie, Kaufbeuren, Germany). The diameter of rain gauge is 20 cm, and the sensitivity of sensor is 0.1 mm. The precipitation data were automatically collected and recorded by the ENVIS system at 30-min intervals.

2.3. Throughfall and stemflow

Throughfall and stemflow were measured in an 18 × 22 m plot at an elevation of 2750 m. Sixty throughfall collectors were evenly distributed across the plot area (Fig. 1). The diameter and height of throughfall collectors were 20 and 40 cm, respectively. Throughfall of each collector was measured by a measuring cup (sensitivity is 0.1 mm) within 1 h after rainfall had ceased. If rainfall was stopped at night, the throughfall was measured before the next day 8 o'clock. Stemflow was collected in a plastic tube (1 cm in diameter) which was wrapped around and attached to the tree trunk; 20 trees were selected to represent different tree diameters at breast height. Throughfall and stemflow were measured from June 2011 to October 2012; 46 individual rainfall events of different intensities were captured during that time period. To ensure that the canopy is dry before an event at least 2 days (calm weather) or 1 day (windy weather) without rain had to separate two events.

2.4. Tree spacing and canopy structure

We recorded the location (*x* and *y* coordinates) of every *P. crassifolia* individual and 60 throughfall collectors within the plot.

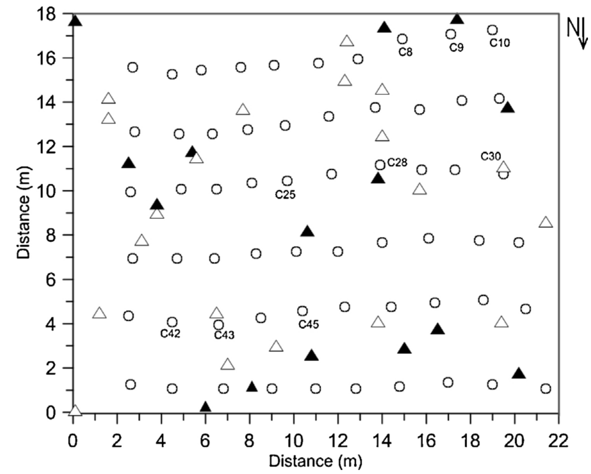

Fig. 1. Map of the experimental plot (18 × 22 m) showing the locations of trees and collectors; △, trees with stemflow collectors; ▲, trees without stemflow collectors; ○, collectors of throughfall.

Canopy structure was quantified with PAI and LAI, and PAI refers to all the light-blocking elements (stems, twigs, leaves), but LAI refers leaves only (Ross et al., 2000; Holst et al., 2004). PAI above each collector was calculated as the inverse of the Beer–Lambert extinction law (Holst et al., 2004):

$$\mathrm{PAI} = -\left(\frac{1}{k}\right)\ln\left(\frac{\mathrm{PAR}}{\mathrm{PAR}_0}\right) \quad (1)$$

where k is the canopy extinction coefficient which depends on the angle of incidence, it can be measured using HemiView canopy system (Delta-T Devices Ltd, UK). PAR is the photosynthetically active radiation measured below the canopy and PAR_0 is the incident photosynthetically active radiation above the canopy layer. To determine LAI, digital hemispherical photographs (Nikon D80 with a Sigma Fisheye lens) were taken above each one of the 60 throughfall collectors under an overcast sky on the 15th of July and August, 2011. The LAI over each of the collectors were represented by the projected LAI of a circle with a diameter of 2 m at the height of 13.8 m (average tree height) above the collector (Peng et al., 2011). In this article, the PAI and LAI of *P. crassifolia* forest were regarded as a constant during our observational period from June 2011 to October 2012, because *P. crassifolia* is a slow-growing evergreen tree species.

2.5. Calculation of canopy interception loss

Canopy interception loss (I) is the difference between the gross precipitation (P_g) falling on top of the canopy (or in an open area) and net precipitation (P_n) falling through the canopy. Net precipitation (P_n) consists of two components: throughfall (T_h) and stemflow (S_t).

$$I = P_g - P_n = P_g - (T_h + S_t) \quad (2)$$

$$S_t = aP_g(B_c/B_{co}) \quad (3)$$

where S_t is the stemflow volume, a is the slope of the linear regression equation, with the intercept set to zero, while P_g is the depth of gross precipitation (mm), B_c and B_{co} are the total basal circumference of all trees in the plot and total basal circumference of 20 trees which were selected to measure stemflow, respectively. T_h can be measured directly in throughfall collectors.