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Change of interception process due to the succession from Japanese red pine to evergreen oak

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Abstract

Extensive measurements of rainfall, throughfall and stemflow in a forest during succession from Japanese red pine (*Pinus densiflora* Sieb. et Zucc.) to a combination of red pine and lower canopy trees—evergreen oak (*Quercus myrsinaefolia* Blume) and evergreen theaceous tree (*Eurya japonica* Thunb.) allowed the effect of this succession on the interception of rainfall to be evaluated. The measurements were conducted on two occasions: 1984/1985, and 2001/2002 when the lower canopy trees had become dominant. During this period, 75% of the red pines had been removed, and there was a substantial increase in stemflow ($p<0.01$), essentially no change in throughfall ($p<0.01$), and a substantial decrease in interception ($p<0.01$). The increase in stemflow was attributed to the increase in lower canopy trees; trees that have steeply angled branches, smooth bark surfaces and water repellent leaves; all of which enhance stemflow. The decrease in interception was due to the decrease in canopy water storage (2.6–1.1 mm/event) and an increase in evaporation during rainfall event (0.7–1.1 mm/event). The decrease in storage partly resulted from the removal of red pines, the bark of which is thick, flaky, and therefore, very absorptive. It was responsible for 88% of the actual rainfall storage at the beginning of the experiment. During the 17 year-period, the size of the lower canopy trees increased more rapidly than that of red pines. The increase in evaporation was due to the increase in canopy gaps by the removal of 75% of the red pines during the succession, and was a minor factor in affecting interception loss.

Keywords: Bark; Interception loss; Lower canopy tree; Rainfall storage by tree surface; Stemflow; Succession

1. Introduction

Rainfall is partitioned into throughfall, stemflow and interception by forest canopies, and this partitioning is a very important part of forest hydrology. The partitioning is forest specific in the sense that different forests react differently. Another complexity is that they change until they reach maturity (vegetation climax). This is called succession. Of course the partitioning of rainfall will be influenced by succession. During succession, forests commonly have multi-layered canopies, the lower layers of which are called shade trees, and the upper layers sun trees. These changes will, of course, influence the partitioning of rainfall. It has been reported that the upper canopy of the taller trees generate much less stemflow

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than the lower canopies (e.g. Lloyd and Marques, 1988; Manfroi et al., 2004; Murai, 1970; Suzuki et al., 1979). Some recent review papers have suggested that the stemflow of lower canopy tree must be evaluated in order to accurately assess the interception (Kuraji and Tanaka, 2003; Levia and Frost, 2003).

Although succession could be expected to influence interception, there are a few reported studies. An important need for such studies is the influence of global warming, in that the vegetation climax may change, thus affecting the hydrology of large regions.

In this study, the change in interception loss during succession was assessed by comparing the rainfall partitioning data acquired at the beginning and end of a 17-year period. During this period the forest changed from sun trees to a mixture of sun and shade trees.

2. Observations

2.1. Study area

The study area of 0.017 km^2 (about 0.2 km wide and 0.1 km long) is generally flat and located at 36°07′N and 140°06′E, some 50 km northeast of Tokyo, at an altitude of 27 m within the Terrestrial Environment Research Center (TERC) of the University of Tsukuba, Ibaraki, Japan (Fig. 1). The annual rainfall was in the range of 900–1600 mm with an average of 1207 mm for the period of 1982–2001. The annual mean air temperature for this period was 14.1 °C. The observation plot was set up at the center of the forest (Fig. 1).

In this region, the vegetation climax has been *Quercus myrsinaefolia* Blume, a kind of evergreen oak and it is classified as the shade tree. This region, however, had been covered by Japanese red pine (*Pinus densiflora* Sieb. et Zucc.), a typical sun tree, since around 1800s through natural fires and the continuous use of pine trees and understory vegetation for general construction works and as firewood (Horiuchi, 1978). The red pine trees in the study area were estimated to have their origin in about 1950. The study area continued to be a pure pine forest until the 1980s, because forest managements such as cutting shrubs were conducted to produce firewood and material for buildings. After that, the human intervention to the forests by the use of red pines and understory shrubs almost stopped due to the introduction of gas and electricity as well as other construction materials (Iwaki and Koshizuka, 1981). As a result, the shade trees (mainly *Q. myrsinaefolia* Blume) started their penetration into the pine forest and the secondary succession started (Yamashita and Hayashi, 1987).

2.2. Changes in the forest from 1984/1985 to 2001/2002

Over a 17-year period two experiments were conducted. The first took place from September 1984 to August 1985 (1984/1985) (Sugita, 1987) and the second from August 2001 to July 2002 (2001/2002). Fig. 2 shows the changes of the numbers of red pines between 1984/1985 (A) and 2001/2002 (B), due to natural thinning. This figure clearly shows that the period of 1984/1985 is pre-succession and that of 2001/2002 is the middle of succession stages.

The relevant statistics on the forest structure in 1984/1985 and 2001/2002 are listed in Table 1. The main changes can be found in the large decreases of stand density and leaf area index (LAI), and an increase in diameter at breast height (DBH) of the pine trees. Also, the lower canopy trees, which were not there in the 1984/1985 period, became dominant in respect to stand density and LAI by the 2001/2002 period (Iida et al., 2003). Evergreen oak tree (*Q. myrsinaefolia* Blume), evergreen theaceous tree (*Eurya japonica* Thunb.) and deciduous rhus tree (*Rhus trichocarpa* Miq.) were 55.8, 27.5 and 8.7%, respectively, of the total lower canopy trees. In both periods, the study area had closed forest canopy, which was red pine in 1984/1985 and red pine and shade trees in 2001/2002. Although the red pine canopy had been very dense in 1984/1985, many gaps in the red pine canopy emerged due to the decrease in its stand density by 2001/2002 (Fig. 2 and Table 1).

2.3. Instrumentation and methods

2.3.1. Interception

The amount of interception by the canopy, including leaves, branches and stems, was evaluated by the following water balance equation:

$$I = P - (TF + SF) \quad (1)$$