Front. For. China 2007, 2(4): 448–452
DOI 10.1007/s11461-007-0071-7

RESEARCH ARTICLE

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Role of canopy interception on water and nutrient cycling in Chinese fir plantation ecosystem

Abstract The role of canopy interception on nutrient cycling in Chinese fir plantation ecosystem was studied on the basis of the position data during four years. Results indicate that the average canopy interception amount was 267.0 mm/year. Canopy interception play a significant role in water cycle and nutrient cycle processes in ecosystem, and was an important part of evaporation from the Chinese fir plantation ecosystem, being up to 27.2%. The evaporation from the canopy interception was an important way of water output from ecosystem, up to 19.9%. The flush-eluviation of branches and leaves caused by canopy interception brought nutrient input of 143.629 kg/(hm^2·year), which was 117.2% of the input 63.924 kg/(hm^2·year) from the atmospheric precipitation. The decreased amount of 80.1 mm precipitation input caused by canopy interception reduced the amount of rainfall into the stand surface and infiltration into the soil, reduced the output with runoff and drainage, and decreased nutrient loss through output water. Therefore, the additional preserve of nutrient by canopy interception was 8.664 kg/(hm^2·year).

Keywords Chinese fir plantation, canopy interception, intercepted evaporation, runoff, nutrition accumulation

1 Introduction

The process of canopy interception to precipitation has been studied by scholars, such as Cui (1980) and Wang et al. (1999). The characteristics of canopy interception to precipitation have been probed by Xie et al. (2002) and Wei and Li (1997) in different stands. Zhou et al. (1995) and Chen et al. (2005) have analyzed the factors that affected canopy interception. Wen et al. (1999) reported the action of canopy interception in fir plantation ecosystem. Li et al. (2004) concluded the characteristics of space distributing for penetrating precipitation under canopy interception in forest. Zhou et al. (1999) pointed that canopy interception has an effect on soil protection. Bao et al. (2004) studied the effects of forest vegetation on the chemical characters of precipitation. And others further put forward some physical models and mathematical laws for canopy interception (Kong et al., 1990; Wang et al., 1999). However, all of above studies only focused on the process of physical canopy interception, the quantity of interception and ratio of interception, while gave few discussions on water movement, energy balance, nutriments cycle and function in environment. For this paper, we dealt with water movement and nutriments cycle under the second generation of fir plantation canopy interception, based on four years successive observation data. We wanted to make the function of canopy layer in forest ecosystem clearer, and offered scientific data for the estimation of forest ecosystem.

Translated from *Scientia Silvae Sinicae*, 2006, 42(12): 1–5 [译自: 林业科学]

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2 Study site and methods

2.1 Study site

The study site was located in the third catchment area of Huitong Ecosystem Research Station of Central South University of Forestry and Technology, national key field scientific observation station (26°50′N, 109°45′E), in Shenchong forest farm, Guangping County, Hunan Province. Annual average temperature is 16.9°C, annual precipitation of 1,300–1,600 mm (1999–2002), relative humidity of above 80%. Typical subtropical humidity climate dominates this area. The soil is yellow. Elevation is about 270–400 m. Physiognomy is lower hills.

In the study area, original pure fir forests all fell in 1987, then the second generation of fir plantation was planted in the cut-over site in 1988. In 2000, the average stand height is up to 11.6 m, average breast diameter of 11.5 cm and canopy density of about 0.9.

2.2 Methods

We established two iron towers (above canopy) on slope side and lower land of water catchment area, in each iron tower we installed an SL-I model remote precipitation meter and a standard precipitation measure cylinder.

We set two (18–20 m^2) stem flow containers on the slope side and lower land of water collection area, and measured the stem flow volume under canopy with SW-40 model diary automatic water record machine.

We use polystyrene plastic tubes to enlace around base of trunks, its low end connecting a special porcelain jar to measure the effluent water from trunks, and take ten trees as a group to link to one SL-I model remote automatic precipitation measure meter.

SW-40 model diary automatic water record machine were set in an output catchment area to record the flux volume of surface runoff and underground water flow.

The volume of canopy interception is acquired by precipitation subtracting the volume of through fall water and volume of stem flow.

We adopted water volume balance equation to calculate forest evaporation supposing water variable was zero in forest and in air.

$$E = P - F_1 - F_2 - F_3$$

where E, F_1, F_2 and F_3 represent evaporation, precipitation, surface runoff, underground water flow, water and soil variable water volume, respectively.

Under different weather conditions, over 40 times data were collected including precipitation, through fall, stem flow, surface runoff and underground water flow, and the contents of NH_4-N, NO_3-N, Org-N, P, K, Ca and Mg were measured.

3 Results and analysis

3.1 Canopy interception

Canopy interception for precipitation is a reaction of canopy to precipitation, also an important part of relationships between forest and hydrology, and the function of forest structure. The systematic analysis on dynamic process and law for fir plantation canopy interception will help us understand the function of canopy interception in forest ecosystem water cycle and movement.

The 369 samples showed the action of canopy interception varies with different precipitation grades (Table 1). Below 0.5 mm precipitation, all precipitation can be intercepted with the ratio of interception 100%; precipitation at 4.9 mm, the interception ratio at 42.9%; precipitation increased 23.8 mm, the canopy interception decreased to 3.9 mm, the canopy interception ratio at 16.4%. With the increase of precipitation, canopy interception firstly increased, then decreased, but the change was not a linear decrease. There was a limiting value of interception volume. When an interception is up to the limiting value, the interception will no longer increase with the increase of precipitation. In practice, in a rainfall process, it is difficult for the precipitation to reach the infinite value, so we can not get the limiting canopy interception value for fir plantation in catchment area. It is extrapolated, from three times observed interception (6.1, 6.2 and 6.1 mm) at 100 mm precipitation, that at canopy density at 0.9 in fir forest, the limiting canopy interception was possibly 7 mm.

Table 1 Amount and ratio of canopy interception at different rainfall grades

Rainfall range /mm	Observation times	Rainfall /mm	Interception /mm	Ratio of interception /%
0.1–0.4	49	0.24	0.24	100
0.5–0.6	27	0.52	0.52	100
0.7–1.0	44	0.73	0.56	76.6
1.1–2.0	52	1.40	0.90	64.3
2.1–4.0	61	2.90	1.40	48.7
4.1–6.0	26	4.90	2.10	42.9
6.1–10.0	37	7.80	2.50	32.7
10.1–15.0	25	12.60	3.40	27.0
15.1–20.0	14	16.80	3.70	22.4
20.1–30.0	12	23.80	3.90	16.4
30.1–40.0	7	35.30	4.20	11.9
40.1–60.0	5	48.30	4.80	10.0
60.1–80.0	6	65.30	5.10	8.0
80.1–11.0	4	103.40	66.20	6.2

The ability of canopy interception is different from precipitation intensity. For example, in June, 1999, there were two rainfall processes: one was 32.9 mm, lasted 6 h, interception at 3.8 mm; another at 31.6 mm, lasted 9 h, interception at 4.7 mm. The later interception is 123.7% larger than the former, the ratio of interception is 3.2% larger. To the showery precipitation, the ability of canopy interception was reduced, because on the one hand, the bigger rain drop caused the branches and leaves to swag, which made the water easily fall; on the other hand, the shorter duration of rainfall with high intensity made the process of canopy interception less. To the drizzle, the duration is long, and the canopy interception rate is large with longer interception duration. At precipitation 2.5 mm/h, canopy interception duration lasted 40 h; at precipitation 17.5 mm/h, the duration decreased to only 5.8 h. The action of canopy interception was also affected by wetness degrees of leaves, and had a relationship with intervals to the former precipitation. The longer the interval of the former precipitation, the larger the canopy interception was. During May to June, 2001, it can be found from several precipitation between 15–20 mm, that under the condition of interval about 4 h, canopy interception was 1.8 mm, interval between 10–13 h, canopy interception 2.9 mm, and interval over one day, canopy interception can increase to 3.7 mm. The more wet the leaves and branches before precipitation, the less the canopy interception ability.

It can be seen from Table 2 that the annual variety of canopy interception of fir plantation in catchment area is determined by the characteristics of precipitation. In winter, precipitation is mainly light rain, thus canopy interception is

obvious, over 30%. In May and June, precipitation intensity become stronger, and canopy is in wetness in most cases, so the canopy interception decreased to 15%.

Table 2 Monthly changes of canopy interception in a Chinese fir plantation (1999–2002)

Month	Precipitation /mm	Canopy interception /mm	Runoff /mm	Ratio of canopy interception /%
1	44.0	13.6	30.4	30.8
2	54.9	17.1	37.8	31.2
3	92.3	19.5	72.8	21.1
4	149.2	31.0	118.2	20.8
5	251.7	39.3	212.4	15.6
6	257.5	36.3	221.4	14.1
7	150.3	18.9	131.4	12.6
8	158.8	20.8	138.0	13.1
9	34.9	10.1	24.8	28.9
10	107.8	28.8	79.0	26.8
11	61.7	18.8	42.9	30.5
12	43.8	13.8	31.0	31.4
Total	1,406.9	267.0	1,139.9	19.9

The effect of canopy interception is obvious on forest valid water and effect of hydrological process. In the small catchment area of fir plantation, annual canopy interception was about 267.0 mm, interception ratio 18.97%, which plays an important role in water and nutrition cycles in ecosystem.

3.2 Evaporation of canopy interception

There are two main ways of water output in fir plantation catchment area: runoff and evaporation. The annual average evaporation is 983.4 mm in fir plantation, accounting for 69.9% of the precipitation (Table 3).

Table 3 Evaporation of canopy interception in Chinese fir plantation (1999–2002)

Month	Precipitation /mm	Evaporation of canopy interception /mm	Total evaporation /mm	Canopy interception/total evaporation /%
1	44.0	13.6	34.0	40.0
2	54.9	17.1	30.2	56.6
3	92.3	19.5	37.6	51.8
4	149.2	31.0	72.1	43.0
5	251.7	39.3	121.7	32.3
6	257.5	36.3	140.2	25.9
7	150.3	18.9	163.2	11.6
8	158.8	20.8	155.1	13.4
9	34.9	10.1	76.8	13.2
10	107.8	28.8	66.9	43.0
11	61.7	18.8	51.4	36.6
12	43.8	13.8	34.2	40.4
Total	1,406.9	267.0	983.4	27.2

In the evaporation process of fir plantation catchment area, physical evaporation of canopy interception is 267.0 mm, accounting for 27.2% of the total annual evaporation. It can be concluded that the physical evaporation of canopy interception is the main composition of evaporation for fir plantation and main water output of fir plantation. Although the effects of canopy interception and canopy surface water distribution had been noticed, the role of physical evaporation of canopy interception was ignored in water balance, which was the process of evaporation in forest. Generally, it took 10% of evaporation for canopy interception in high density forest, especially for evergreen coniferous forest 20%–30%. It is wrong by using evaporation of tree to substitute evaporation of stand, or using canopy intercepted physical evaporation to substitute evaporation of canopy interception.

The total evaporation is 326.4 mm between January to April and October to December, while the physical evaporation of canopy interception is 142.6 mm, accounting for 43.7% of the total evaporation in corresponding period. The maximum of evaporation is over 50% in February and March; the minimal is above 11% in July and October (Table 3). The physical evaporation of canopy interception plays a significant role in the fir plantation catchment area, especially for less and lower intensity precipitation in winter.

3.3 Effects of canopy interception on nutrition input

In the process of through fall and stem flow to the ground after canopy interception in the catchment area, the concentration of some nutrient materials in water were changed. Analysis on the process of hydrology and dynamic nutrition in small fir plantation catchment area showed that: annual nutrient material input was 63.924 kg/hm^2. The most nutrient was Ca, 28.366 kg/hm^2, followed by K, 19.445 kg/hm^2, respectively 44.4% and 30.4% in precipitation, and the least was P, 0.253 kg/hm^2, 0.4% total input of nutrient materials (Table 4).

The annual input of nutrient materials was 143.329 kg/hm^2 (including stem flow), 79.405 kg/hm^2 more than in precipitation. N, P, K, Ca and Mg, respectively increased 6.397, 0.533, 6.895, 4.605 and 10.795 kg/hm^2. The maximal ratio of increase was Mg, increased by 783%, followed by Ca (281%), P (211%) and N (44.2%), and the last one was K (24.3%). Canopy interception brought about the enrichment of nutrition in forest.

The source of nutrient materials in fir plantation was mainly from soil and atmosphere. Soil forming needs thousands of years. In a short period, most nutrition comes from atmosphere. The dust in atmosphere bears more nutrient materials that mainly intercepted by canopy. The nutrient material enters the forest ecosystem after precipitation by means of canopy interception.

3.4 Effects of canopy interception on nutrition output

The output of nutrient materials in fir plantation was mainly through runoff (except the output from cutting commercial timber). The output of nutrition determined by runoff was relative to the interception from the died leaves on the ground, soil physical construction and characteristic of water

Table 4 Nutrient content of rain water (1999–2002) (unit: $kg \cdot hm^{-2} \cdot year^{-1}$)

Item	NH_4-N	NO_3-N	ORG-N	P	K	Ca	Mg	Total
Precipitation (1,406.9 mm)	4.024	2.352	8.105	0.253	28.366	19.445	1.379	63.924
Runoff (1,135.7 mm)	11.492	3.497	5.779	0.783	34.971	73.825	12.308	142.655
Stem flow (4.2 mm)	0.073	0.014	0.023	0.003	0.290	0.225	0.046	0.674
Washing	7.541	1.159	–2.303	0.533	6.895	54.605	10.795	79.405

penetration and water storage of soil. In the catchment area, precipitation is the only water source. Canopy interception of precipitation also decreased water entering ground and penetrating into soil, which affected the runoff and the output of nutrient materials with runoff.

Four-year data showed that the average runoff was 423.5 mm (runoff coefficient 0.301); underground runoff was 394.0 mm (runoff coefficient 0.280); and surface runoff was only 29.5 mm (runoff coefficient 0.021). The annual loss of nutrient materials was 3.919 kg/hm^2 through surface runoff, that through underground runoff was 40.667 kg/hm^2, and the total was 44.586 kg/hm^2, being 69.7% of precipitation and 31.1% of precipitation in forest. Runoff and nutrition output took place after canopy interception (267.0 mm).

Without canopy interception, the water to ground will increase to 267.0 mm, and will forms more surface runoff, and bring more nutrient loss, 35.470 kg/hm^2. According to the distribution of runoff, the increased water will generate new surface runoff 18.6 mm and underground runoff 248.4 mm, which will lead to the loss of 28.110 kg/hm^2 nutrient materials. According to the distribution of water balance, 70% evaporation, 30% runoff, the part of increased water will bring the increase of runoff to 503.6 mm, underground water to 74.5 mm and surface runoff to 5.6 mm, which will result in the nutrition output up to 8.644 kg/hm^2 annually.

It can be seen from the above analysis that canopy interception will reduce the precipitation arriving on ground, and also decrease the output of surface runoff and penetration to soil, further, the high concentration of nutrient materials in surface water and penetration water can be maintained in ecosystem. Therefore, the decrease of output of surface runoff and penetration means decreasing the loss of nutrient materials.

On the other hand, there existed two forms of output ways in the catchment area, evaporation and runoff. However, it has more significance for water output as vapor state than that as liquid state considering the nutrient conservation in forest ecosystem. Canopy interception led to precipitation loss as vapor state, which decreased the water amount entering forest and runoff from surface, and meanwhile decreased the nutrient losses. Therefore, canopy interception has an important function in nutrient materials conservation in forest ecosystem.

4 Conclusion and discussion

Canopy interception was 267.0 mm in small fir plantation catchment area, with an interception ratio of 0.199. Canopy interception was affected by wetness of leaves and condition of weather such as precipitation duration, precipitation intensity and characteristics of forest. In one precipitation process, the ability of canopy interception was limited, decreased along with the increase of precipitation, until interception arrived to a constant value. We got a limited canopy interception value of 7 mm in a fir plantation stand (density 2,400 tree/hm^2, average height 11.5 m, average breast diameter of 11.6 cm and canopy density of 0.9).

Annual evaporation of canopy interception was 267.0 mm, accounting for 27.2% of the total evaporation in fir plantation. In winter (small precipitation and light rainfall intensity), the evaporation of canopy interception accounts for 40% of the total. It is unreasonable using transpiration of forest to substitute evaporation, or ignoring physical evaporation of canopy interception, using them to substitute forest evaporation.

The runoff and evaporation were two ways of water output in the catchment area. Evaporation of canopy interception was 19.9% of water output in the catchment area. It is obvious that physical evaporation of canopy interception was a main way of water output.

Canopy interception changed the ways of precipitation washing on branches and stems, which also changed the concentration of nutrient materials in through fall and stem flow, and formed material flow of nutrient materials from atmosphere to ground. The nutrient materials in through fall and stem flow were 143.629 kg/hm^2 and 74.905 kg/m^2 more than that in precipitation 63.924 kg/hm^2, increased by 117.2%.

The impact of canopy interception on forest ecosystem nutrient output was significant. Canopy interception decreased the water amount arriving at forestland, and

Table 5 Nutrient elements exporting in runoff (1999–2002) (unit: $kg \cdot hm^{-2} \cdot year^{-1}$)

Item	NH_4-N	NO_3-N	Org-N	P	K	Ca	Mg	Total
Surface runoff (29.5 mm)	0.204	0.044	0.045	0.017	1.044	2.317	0.248	3.919
Underground runoff (423.5 mm)	0.479	1.610	0.157	0.278	7.470	24.010	6.660	40.667
Total runoff	0.683	1.654	0.202	0.295	8.514	26.327	6.911	44.586

decreased the loss of nutrient with runoff. On the other side, canopy interception as vapor loss will not bring nutrient loss. In this sense, canopy interception played an important role in the protection of nutrient in forest ecosystem.

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