Front. For. China 2008, 3(3): 264–270
DOI 10.1007/s11461-008-0053-4

RESEARCH ARTICLE

**Wenxing KANG, Xiangwen DENG, Zhonghui ZHAO**

# Effects of canopy interception on energy conversion processes in a Chinese fir plantation ecosystem

**Abstract** The functions of canopy interception on energy conversion processes in a Chinese fir plantation ecosystem were studied with the aid of long-term observation data in Huitong. The results showed that the absorbed, penetrated and reflected amounts of solar radiation were, respectively, $2.5543 \times 10^9$ J/($m^2$·year) (absorption rate of 0.827), $2.5306 \times 10^8$ J/($m^2$·year) (penetration rate of 0.082), and $2.7432 \times 10^8$ J/($m^2$·year) (reflection rate of 0.091) by the canopy. The conversion of net solar radiation to latent heat in the process of evaporation from canopy interception amounted to $6.3695 \times 10^8$ J/($m^2$·year) (accounting for 22.9% of total ecosystem net radiation and 30.4% of ecosystem evaporation), which was an important part of the budget of the energy system. Canopy interception consumed kinetic energy of raindrops in overcoming resistance of branches and leaves, which collected raindrops, followed with the conversion of potential energy in raindrops to kinetic energy with falling raindrops. In general, the diameter of raindrops from the canopy is larger than that of the raindrops above the canopy as a result of the collection effort by the canopy. The kinetic energy of raindrops from the canopy, therefore, was higher than that of raindrops in the atmosphere. The drop-size distribution from the canopy was affected by the structure of the canopy layer rather than the amount of precipitation and precipitation intensity. The canopy had no important nor efficient effects on decreasing the kinetic energy of raindrops in our case study with a first branch height of 7 m and precipitation amounts over 3 mm. However, the canopy would play a key role in decreasing kinetic energy of raindrops in two cases, that of a small amount of precipitation and one of heavy precipitation intensity, in which the canopy could intercept the largest amount of precipitation in the former condition and the canopy could scatter bigger raindrops to smaller raindrops with striking leaves in the case of heavy precipitation.

**Keywords** canopy, crown interception, radiation energy, latent heat energy, kinetic energy of raindrops

## 1 Introduction

Canopy is one of the important structural characteristics of a forest community, where energy and material exchange takes place between the forest ecosystem and the environment. Canopy interception is an important process of the forest ecosystem. Many investigators have studied canopy interception from a number of different aspects, such as transmission of light in the canopy (Liu and Zhang, 1985), light absorption and distribution of the canopy layer (Zhu and Cui, 1982) and canopy interception of rainfall (Wen et al., 1989; Zhou et al., 1995; Wei and Li, 1997; Xie et al., 2002; Chen et al., 2005). Some scientists have investigated the effects of canopy on the kinetic energy of raindrops (Wang, 1986; Lei, 1994; Zhou, 1997). There are but a few papers reporting the function of canopy interception in the process of systematic energy transfer. We have analyzed the distribution pattern of radiation energy in the canopy layer, the conduct of evaporation energy in canopy interception and the effects of canopy on kinetic energy of raindrops, based on continuous observations from the year 2000 to 2005. The objective was to disclose the effects of energy transfer and balance of canopy interception on the forest ecosystem.

## 2 Study area

The study was carried out in the area of the second water pool of the Huitong Ecology Station of the Central South University of Forestry and Technology. The station is located in the Shenchong forest farm, Huitong County, Hunan Province (26°50′N, 109°45′E). The area has an average temperature of 16.7°C, an annual rainfall of

---

Translated from *Scientia Silvae Sinicae*, 2007, 43(2): 15–20 [译自: 林业科学]

Wenxing KANG (✉), Xiangwen DENG, Zhonghui ZHAO
Central South University of Forestry and Technology, Changsha 410004, China
E-mail: kwx1218@126.com

1100–1600 mm, relative humidity above 80% and a typical, subtropical climate. The elevation is about 270–400 m, the topography consists of low hills and the soil is mainly mountain yellow earth. The stand we studied was a pure Chinese fir (*Cunninghamia lanceolata*) plantation with a density of 2000 stems per hm$^2$. Its canopy density was 0.9, the average height of the stand 16 m, the average diameter at breast height (DBH) 15.5 cm and the average height of the first branch 7 m.

## 3 Methods

A DFY2 sky radiation meter was installed above the canopy surface and a DFY3 type direct radiation meter below the canopy. The total radiation reaching the canopy, radiation reflected by the canopy and radiation penetrating through the canopy were measured. Absorbed radiation energy of the canopy can be calculated from the total radiation reduced by reflected radiation and penetrating radiation.

We installed an SL-1 remote rainfall meter above the observation tower to measure the rainfall above the canopy. Two penetrating water acceptor tanks (18–20 m$^2$) were installed below the canopy. A SW40 automatic daily rainfall meter was used to measure the amount of rainfall that penetrated the canopy. A polyethylene pipe was wound around the tree base, its lower end connected to an acceptor to measure stem flow. The canopy interception was calculated from the atmospheric rainfall reduced by the measured penetrating rainfall and stem flow. Evaporation energy consumption from canopy interception was calculated by water amount intercepted by canopy multiplying the heat energy that one gram water requires for changing into vapor at the same temperature.

A thin layer of lime on a one-square-meter plot and a fine layer of dry clay, also on a one square meter plot, were established both inside and outside the stand. The diameter of raindrops and distribution of rainfall were measured when it was raining.

## 4 Results and analysis

### 4.1 Effect of canopy interception in radiation energy allocation

Table 1 shows that there is a consistency between monthly change of reflected and absorbed radiation of canopy and total radiation energy, i.e., in months when the total radiation energy was large, the absorbed and reflected radiation of canopy was also large and vice versa. Two troughs of the reflection rate occurred during the year (an average over the six-year period), the first from April to May, with a reflection rate of only 7% and the second from September to October with a similarly low rate of 7%–8%. The peak of the reflection rate occurs in the warm months and reached 11.3% in August. The two troughs of the reflection rate (April to May and September to October) are almost synchronous with the prime stage of growth of Chinese fir and the peak just falls in the slow growth period. This indicates that there is a close relation between the change in canopy reflection and the growth of fir.

From Table 1, we see that the absorption and reflection rates of the canopy layer were determined by structural characteristics of the canopy layer and development of branches. In the dormancy period of trees, leaves are becoming old, hard and their color turns darker, which increases canopy interception and absorption and reduces the canopy penetration rate (6.2%–6.3%). During the growing season, old leaves begin to fall, but new leaves are still small, which reduces the radiation interception and absorption area of leaves and in turn increases the penetration of the canopy. This phenomenon is very obvious, especially during April and May, when penetration rate reaches about 9.6%–10.5%.

The total annual radiation reaching the forest canopy was $3.0817 \times 10^9$ J/m$^2$, of which $2.5543 \times 10^8$ J/m$^2$ was absorbed by the canopy, accounting for 82.9% of total radiation. The radiation that penetrates through the

**Table 1** Total radiation energy received and radiation balance above the canopy in a forest watershed

| month | total radiation/ $10^8$ J·m$^{-2}$ | astigmatic radiation/ $10^8$ J·m$^{-2}$ | direct radiation/ $10^8$ J·m$^{-2}$ | reflection radiation/ $10^8$ J·m$^{-2}$ | absorption radiation/ $10^8$ J·m$^{-2}$ | penetration radiation/ $10^8$ J·m$^{-2}$ | reflection rate/% | absorption rate/% | penetration rate/% |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.1823 | 0.8518 | 0.3305 | 0.1040 | 1.0089 | 0.0694 | 8.8 | 84.9 | 6.3 |
| 2 | 1.1143 | 0.8141 | 0.3002 | 0.1026 | 0.9249 | 0.0868 | 9.2 | 83.0 | 7.8 |
| 3 | 1.5368 | 1.1625 | 0.3743 | 0.1369 | 1.2766 | 0.1233 | 9.1 | 82.9 | 8.0 |
| 4 | 2.1552 | 1.6082 | 0.5470 | 0.1516 | 1.7759 | 0.2277 | 7.0 | 82.5 | 10.5 |
| 5 | 3.5382 | 2.5096 | 1.0286 | 0.2493 | 2.9508 | 0.3381 | 7.0 | 83.4 | 9.6 |
| 6 | 3.2682 | 2.5395 | 0.7287 | 0.3063 | 2.6843 | 0.2776 | 9.4 | 82.1 | 8.5 |
| 7 | 4.8200 | 3.1261 | 1.6939 | 0.5169 | 3.8903 | 0.4101 | 10.7 | 80.8 | 8.5 |
| 8 | 4.2213 | 2.6640 | 1.5573 | 0.4781 | 3.3892 | 0.3540 | 11.3 | 79.8 | 8.9 |
| 9 | 3.0569 | 1.7021 | 1.3548 | 0.2153 | 2.5813 | 0.2603 | 7.0 | 84.5 | 8.5 |
| 10 | 2.3133 | 1.5351 | 0.7782 | 0.1799 | 1.9737 | 0.1597 | 8.1 | 84.1 | 7.8 |
| 11 | 2.1118 | 1.3165 | 0.7953 | 0.1700 | 1.8089 | 0.1329 | 8.5 | 85.2 | 6.3 |
| 12 | 1.4995 | 0.9601 | 0.5394 | 0.1323 | 1.2765 | 0.0907 | 8.9 | 84.9 | 6.2 |
| Σ | 30.8168 | 20.7886 | 10.0282 | 2.7432 | 25.5430 | 2.5306 | 8.9 | 82.9 | 8.2 |

canopy and reaches the ground is only $2.5306 \times 10^8$ J/m$^2$, about 8.2% of total radiation. The radiation energy reflected by the canopy was $2.7432 \times 10^8$ J/m$^2$, accounting for about 8.9% of total radiation. The canopy of a Chinese fir stand has a huge functioning surface (leaf area index is 8) and overlapped branches (the average canopy layer depth is 9 m), which intercept and absorb radiation and consequently greatly decrease the radiation that penetrates the canopy. Therefore, this changes the energy distribution inside the ecosystem and forms a microclimate under the canopy.

### 4.2 Effect of canopy interception in evaporation energy consumption

The evaporation of intercepted water by the canopy has a transition period from a liquid phase to a gas phase, which consumes energy. The water intercepted by the canopy was 261.60 mm in the water collection area, requiring a total amount of energy of $6.3695 \times 10^8$ J/m$^2$, accounting for 22.9% of net radiation absorbed by our plantation ecosystem (i.e., the total energy reaching the canopy surface minus the reflection by the canopy).

The total annual amount of evaporated water in the plantation, calculated to be 862.03 mm by means of a water balance method, required an energy amount of $2.0952 \times 10^9$ J/m$^2$. Energy consumed by canopy interception was $6.3695 \times 10^8$ J/m$^2$, accounting for 30.4% of total energy consumed by evaporation of the plantation system. About one-third of latent heat energy of the plantation system is contributed by the evaporation of water intercepted by the canopy.

Table 2 shows that during the period February to April, when the temperature is low and precipitation infrequent, the energy consumed by evaporation of water intercepted by the canopy, accounted for 38.8%–47.8% of monthly net radiation energy that had reached and 49.6%–55.6% of monthly evaporation consumption energy. This was the largest portion in the energy output of the plantation ecosystem. It is suggested that the function of canopy interception will be especially important with low temperatures and during rainy seasons.

### 4.3 Effect of canopy interception on precipitation kinetics

The kinetic energy of raindrops is the major driving force for barren soil erosion. Some scientists proposed empirical formulae to calculate kinetic energy of raindrops (Disrud, 1970; Kinnell, 1981; Zhou et al., 1981; Jiang et al., 1983; Xu, 1983; Ulbrich and Atlas, 1985; Wang, 1987; Salles et al., 2002; Cai et al., 2003; Cai and Wang, 2003; Gong, 2005). They generally believed that canopy interception could weaken kinetic energy of raindrops and decrease the splashing of raindrops on surface soil. However, other investigators showed just the opposite results (Wang, 1986; Lei, 1994; Zhou, 1997).

#### 4.3.1 Speed of raindrops reaching the surface of canopies

Mou et al. (1983) proposed an empirical formula for raindrop velocity that was widely applied by other scientists. Qian and Tao (1998) deduced the distribution rule of

**Table 2** Energy for evaporation of water interception in a Chinese fir plantation

| month | NR/$10^8$ J·m$^{-2}$ | TET/mm | CIE/mm | TELE/$10^8$ J·m$^{-2}$ | CIELE/$10^8$ J·m$^{-2}$ | CIELE/NR/% | CIELE/TELE/% |
|---|---|---|---|---|---|---|---|
| 1 | 1.0783 | 32.73 | 14.10 | 0.8125 | 0.3502 | 32.4 | 43.1 |
| 2 | 1.0117 | 36.96 | 21.00 | 0.8703 | 0.4844 | 47.8 | 55.6 |
| 3 | 1.3999 | 45.06 | 25.30 | 1.1068 | 0.6209 | 44.4 | 56.1 |
| 4 | 2.0036 | 63.12 | 31.30 | 1.5672 | 0.7773 | 38.8 | 49.6 |
| 5 | 3.2889 | 107.22 | 34.10 | 2.6242 | 0.8345 | 25.4 | 31.8 |
| 6 | 2.9619 | 96.60 | 24.10 | 2.3156 | 0.5745 | 19.4 | 24.8 |
| 7 | 4.3031 | 130.97 | 13.40 | 3.1395 | 0.3202 | 7.4 | 10.2 |
| 8 | 3.7432 | 117.18 | 19.90 | 2.8465 | 0.4838 | 12.9 | 10.7 |
| 9 | 2.8416 | 83.68 | 22.20 | 2.0178 | 0.5357 | 16.1 | 26.5 |
| 10 | 2.1334 | 64.41 | 23.00 | 1.5324 | 0.5470 | 25.6 | 25.7 |
| 11 | 1.9418 | 45.93 | 17.70 | 1.1954 | 0.4657 | 24.1 | 39.0 |
| 12 | 1.3672 | 38.17 | 15.50 | 0.9242 | 0.3753 | 27.4 | 40.6 |
| Σ/average | 27.8736 | 862.03 | 261.60 | 20.9524 | 6.3695 | 22.9 | 30.4 |

NR: net radiation; TET: total evapotranspiration; CIE: crown interception evaporation; TELE: total evaporation latent heat energy; CIELE: crown interception evaporation latent energy.

**Table 3** Equilibrium speed of rainfall with different diameters

| diameter/mm | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 7.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| velocity/m·s$^{-1}$ | 2.31 | 3.67 | 4.81 | 5.82 | 6.75 | 7.63 | 8.46 | 9.24 | 10.00 | 10.73 | 11.43 | 12.12 | 13.43 |

terminal velocity of raindrops in the Loess Plateau according to the raindrop diameter distribution function of Best (1950). Yao and Tang (2001) also proposed an empirical equation of raindrop velocity according to a simulated hydraulic erosion function.

We studied the velocity of the raindrops directly according to the process of falling raindrops. One drop of rain in the process of falling is affected simultaneously by several forces. Gravity makes the raindrop fall and initially accelerates the raindrop; atmospheric buoyancy reacts against gravity, but it can be ignored for it is usually small; pressure difference resistance and viscosity resistance also react against gravity and these two forms of resistance jointly make the raindrop fall toward an equilibrium speed. It has theoretically been proven by Laiton (1980) that the sum of viscosity resistance and pressure difference resistance can be expressed as:

$$F_1 = k\pi D U^3 \tag{1}$$

where $F_1$ is the sum of viscosity resistance and pressure difference resistance, $k$ a coefficient ($3.3075 \times 10^{-5}$ kg/(s·m$^3$)), $D$ the diameter of the raindrop and $U$ the velocity of the raindrop.

The gravity of a raindrop can be expressed as:

$$F_2 = \frac{1}{6}\pi D^3 \rho g \tag{2}$$

where $F_2$ is gravity (mg), $\rho$ density of the raindrop and $g$ acceleration of gravity.

When the raindrop is falling under equilibrium conditions, i.e., when $F_1 = F_2$, the speed can be considered to be the equilibrium speed, also called terminal velocity.

According to Eqs. (1) and (2), the final velocity ($U$) can be calculated as:

$$U = \sqrt[3]{\frac{D^2\rho g}{6k}} \tag{3}$$

From Eq. (3) we can deduce that the final velocity of a raindrop can be obtained if we know its diameter.

We can now calculate the height that the raindrop falls when it achieves its equilibrium speed. The raindrop has only potential energy at the initial stage of its trajectory. According to Newton's Second Law, the falling acceleration is:

$$\frac{\mathrm{d}U}{\mathrm{d}t} = \frac{F_2 - F_1}{m} = \frac{mg - k\pi D U^3}{m} = \frac{k\pi D}{m}\left(\frac{mg}{k\pi D} - U^3\right) \tag{4}$$

where $m$ is the weight of the raindrop and $t$ is time. After indefinite integration of Eq. (4) and a separation of variables we obtain:

$$\frac{1}{6\left(\frac{mg}{k\pi D}\right)^{\frac{2}{3}}}\ln\left|\frac{U^2+\left(\frac{mg}{k\pi D}\right)^{\frac{1}{3}}U+\left(\frac{mg}{k\pi D}\right)^{\frac{2}{3}}}{U^2-2\left(\frac{mg}{k\pi D}\right)^{\frac{1}{3}}U+\left(\frac{mg}{k\pi D}\right)^{\frac{2}{3}}}\right| + \frac{\sqrt{3}}{3\left(\frac{mg}{k\pi D}\right)^{\frac{2}{3}}}\arctan\frac{\sqrt{3}}{3}\left(\frac{2U}{\left(\frac{mg}{k\pi D}\right)^{\frac{1}{3}}}+1\right) = \frac{k\pi D}{m}t + C \tag{5}$$

where $C$ is the constant of integration. This equation should meet the initial condition, i.e., when $t = 0$, $U = 0$, $C$ can be obtained:

$$C = \frac{\sqrt{3}}{3\left(\frac{mg}{k\pi D}\right)^{\frac{2}{3}}}\arctan\frac{\sqrt{3}}{3} \tag{6}$$

Joining Eq. (6) to Eq. (5), we obtain:

$$\ln\left|\frac{U^2+\left(\frac{mg}{k\pi D}\right)^{\frac{1}{3}}U+\left(\frac{mg}{k\pi D}\right)^{\frac{2}{3}}}{U^2-2\left(\frac{mg}{k\pi D}\right)^{\frac{1}{3}}U+\left(\frac{mg}{k\pi D}\right)^{\frac{2}{3}}}\right| + 2\sqrt{3}\arctan\frac{\sqrt{3}}{3}\left(\frac{2U}{\left(\frac{mg}{k\pi D}\right)^{\frac{1}{3}}}\right) - \frac{6g}{\left(\frac{mg}{k\pi D}\right)^{\frac{1}{3}}}t = 0 \tag{7}$$

We can obtain the equilibrium speed provided by Eq. (3) if we know the diameter of a raindrop. If we substitute the diameter in Eq. (7), we can obtain the time that the raindrop needs to reach the equilibrium speed. When time $t$ is entered in Eq. (8) we obtain the integral:

$$\int \mathrm{d}U = \int\left(g - \frac{6kU^3}{D^2\rho}\right)\mathrm{d}t \tag{8}$$

The height that the raindrop falls when it achieves its equilibrium speed can be calculated. According to our calculation, one raindrop with a 7.0 mm diameter can reach its equilibrium speed after falling 23 m. The smaller the diameter of the raindrop, the smaller this height. We can conclude that raindrops have already reached their equilibrium speed at a much higher elevation than the forest canopy.

### 4.3.2 Velocity of raindrops reaching the ground surface

The kinetic energy of raindrops is almost consumed in the canopy interception process due to the obstruction of branches and leaves. The initial energy of canopy raindrops is potential energy. There is a transfer from potential energy to kinetic energy during the fall of raindrops from canopy to ground. It is clear that, in principle, canopy raindrops behave in the same way as atmospheric precipitation. When $U$ is changed to time $t$ and we integrate Eq. (7) we obtain:

$$H=0.000714\left(\frac{D^2\rho g}{6k}\right)^2\left[1+248.3792\left(\frac{6kt}{D^2\rho g}\right)^{3/2}\right]-\frac{D^2\rho g}{12k}t-0.000714\left(\frac{D^2\rho g}{6k}\right)^2 \tag{9}$$

where $H$ is the height of raindrop falling at terminal velocity.

Given the height to the first branches in the fir plantation, we can calculate the time $t$ required for raindrops to reach the ground. With $t$ substituted for $U$ in Eq. (7), we obtain the speed of raindrops reaching the ground (Table 4).

**Table 4** Velocity of raindrops falling on the ground inside the stands

| diameter/mm | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 7.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| velocity/m·s$^{-1}$ | 2.3 | 3.7 | 4.8 | 5.8 | 6.7 | 7.1 | 7.4 | 7.7 | 7.9 | 8.1 | 8.3 | 8.5 | 8.9 |

### 4.3.3 Diameter size and distribution of atmospheric precipitation raindrops and canopy raindrops

The kinetic energy of raindrops depends not only on the speed but also on the weight of raindrops. For a nearly round raindrop, we can calculate its weight if we know its diameter.

Any precipitation is composed of raindrops of various sizes and the diameter of raindrops tends to increase with the increase of precipitation intensity. According to data analyzed of 270 occurrences of precipitation, the intensities of atmospheric precipitation ranged largely from 0.5 to 20 mm/h outside the fir plantation. We surveyed over 30 rainfall events, with intensity ranging from 0.5 to 15 mm/h and studied the diameter size of raindrops and their distribution. The results show that when precipitation intensity was below 10 mm/h, 90% of the diameters of raindrops changed from 0.5 to 3.0 mm; when the rain intensity was 10–20 mm/h, raindrops with a diameter of 0.5–3.0 mm accounted for over 80% of the total raindrops. According to the survey inside the plantation, when precipitation intensity ranged from 0.5 to 15 mm/h, the diameter of raindrops at each rainfall was larger than those outside the plantation (Table 5). This phenomenon is especially obvious when the intensity is not large, because raindrops that fall on leaf surfaces gradually form into bigger water drops. When gravity exceeds tension, raindrops fall from the edge of the leaf. It was also obvious that the canopy has the effect of convergence on raindrops, which enlarges the diameter of raindrops inside the plantation as well. At the same time, we found that the diameter of canopy raindrops was little affected by atmospheric precipitation intensity, due to the functions of the canopy. According to the survey, despite the variety of atmospheric precipitation intensity, the diameter of most raindrops falls into the range of 1.2–3.0 mm and the variation of diameter was largely affected by factors such as canopy closure, canopy thickness, direction of branches, leaf biomass, leaf area and viscosity of leaf surface to raindrops.

**Table 5** Mean diameter of rainfall inside and outside the plantation (unit: mm)

| rainfall type | rainfall intensity/mm·h$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.5 | 1.0 | 2.0 | 3.0 | 4.5 | 6.0 | 8.0 | 9.0 |
| rainfall outside plantation | 0.51 | 0.67 | 0.92 | 1.01 | 1.13 | 1.23 | 1.38 | 1.56 |
| rainfall inside plantation | 1.05 | 1.11 | 1.18 | 1.25 | 1.32 | 1.47 | 1.63 | 1.96 |

### 4.3.4 Kinetic energy of atmospheric precipitation at canopy surface and of canopy rainfall at ground surface

We calculated the kinetic energy that both the canopy and ground surfaces received during eight rainfall occurrences, according to the diameter and distribution of raindrops at different precipitation intensities, as well as the equilibrium speed at which raindrops reach the canopy and ground surfaces (Table 6). The kinetic energy of canopy rainfall includes two parts: one part of this kinetic energy originated from raindrops that directly penetrated the canopy and reached the ground surface, which can be calculated by the total kinetic energy of raindrops above canopy multiplied by the coefficient $A$, where $A$ equals 1 minus canopy closure; the other part came from the kinetic energy of canopy raindrops, for which the calculation has been stated above.

From Table 6, it can be seen that after the interception by the canopy with a closure of 0.9, the kinetic energy of

**Table 6** Kinetic energy of rainfall inside and outside the plantation

| precipitation intensity/ mm·h$^{-1}$ | duration of precipitation/ h | precipitation amount/ mm | kinetic energy on canopy/J·m$^{-2}$ | kinetic energy on ground/J·m$^{-2}$ |
|---|---|---|---|---|
| 0.5 | 6 | 3 | 16.29 | 7.72 |
| 0.5 | 10 | 5 | 19.36 | 27.09 |
| 3.0 | 3 | 15 | 138.73 | 166.95 |
| 6.0 | 5 | 30 | 368.22 | 395.54 |
| 9.0 | 2.22 | 2 | 307.52 | 365.48 |
| 12.0 | 1.25 | 15 | 267.58 | 283.36 |
| 15.0 | 0.67 | 10 | 195.72 | 216.83 |
| 20.0 | 2 | 40 | 832.17 | 817.53 |

canopy rainfall inside the plantation whose height to the first branch is 7 m is generally larger than that above the canopy. This is very obvious when the precipitation intensity is low and might be caused by the fact that leaves aggregate raindrops and enlarge their diameter. In fact, only under two conditions was the kinetic energy of precipitation reduced by the canopy. In the first place, when the precipitation amount was very small ($< 3$ mm), most of the rain was intercepted by the canopy; second, when the precipitation intensity was fairly large, raindrops with a large diameter strike branches and leaves and were split into smaller ones by their own kinetic energy.

The small amount of erosion of forest soils relies fundamentally on the litter coverage on the topsoil. This is more because of the protection of litter afforded by the plantation canopy, than due to the weakening by the canopy of the kinetic energy of raindrops.

## 5 Conclusions and discussion

The annual amount of radiation absorbed by the plantation canopy is $2.5543 \times 10^9$ J/m$^2$, accounting for 82.7% of total radiation. Penetrating radiation of $2.5306 \times 10^8$ J/m$^2$ accounted for 8.2% of total radiation and reflected energy, $2.7430 \times 10^8$ J/m$^2$, accounted for 9.1%. The amounts of absorption, penetration and reflection of canopy to radiation are closely related to canopy structure and the conditions of developed branches and leaves. A microclimate below the canopy is formed because the canopy absorbs and reflects radiation and reduces the radiation penetrating through the canopy.

The annual energy consumed by evaporation of water intercepted by the canopy amounted to $6.3695 \times 10^8$ J/m$^2$, about 30.4% of the total evaporation energy, accounting for 22.9% of net radiation energy of the plantation ecosystem. This part of radiation, used for canopy interception evaporation, changes into latent heat energy and plays an important role in the balance of plantation system energy, especially in months when the precipitation is evenly distributed (neither the amount of precipitation nor intensity are large).

Canopy interception of rainfall requires that raindrops consume kinetic energy in overcoming resistance from branches and leaves. Raindrops aggregated on leaf surfaces and then falling down, is a transition process from potential energy to kinetic energy.

The canopy of our Chinese fir plantation has a function of aggregating precipitation and enlarging raindrop diameters. The variation in diameter and distribution of raindrops is affected mainly by stand characteristics and the viscosity of leaf surfaces to raindrops and less by atmospheric precipitation intensity and amount. Generally speaking, the kinetic energy of raindrops intercepted by the canopy is larger than that of atmospheric precipitation in a precipitation event, especially when precipitation intensity is not large. When the height to the first branch is over 7 m and the amount of precipitation more than 3 mm, the canopy layers cannot effectively reduce the kinetic energy of raindrops. Only when the amount of precipitation is small, can the canopy intercept most of the raindrops; when precipitation is intense, the canopy can effectively decrease kinetic energy of precipitation because large raindrops are split into smaller ones. It is largely because of the protection of litter inside the plantation and less due to the weakening of canopy to kinetic energy of raindrops that prevents forest soils from being eroded by rainfall.

## References

Best A C (1950). The size distribution of raindrops. Quart J Royal Meteorol, 76(16): 16–36

Cai L J, Wang G D (2003). The effects of the wind vector on the distribution of raindrop kinetic energy over sloping field. J China Agric Univ, 8(6): 15–17 (in Chinese)

Cai L J, Wang G D, Zhang S Q (2003). Kinetic Energy Distribution of Raindrops on Loess Plateau. Bull Water Soil Conserv, 23(4): 28–32 (in Chinese)

Chen Y Z, He F, Zhang H J, Wen X S (2005). Preliminary analysis on factors influencing canopy interception in Jinyun mountain. Sci Soil Water Conserv, 3(3): 318–323 (in Chinese)

Disrud L A (1970). Magnitude, probability and effect of kinetic energy of winds associated with rains in Kansas, Kansas Acad Sci, (73): 237–246

Gong L (2005). Erosion calculation of raindrops' kinetic energy of Loess Plateau's rainfall. J Lanzhou Jiaotong Univ, 24(4): 43–45 (in Chinese)

Jiang Z S, Song W J, Li X Y (1983). Characteristics of natural raindrop in Loess Plateau. Water Soil Conserv China, 11(3): 32–36 (in Chinese)

Kinnell P I A (1981). Rainfall intensity-kinetic energy relationship for soil loss prediction. Soil Science Society. Amer Process, 45: 153–155

Laiton L (1980). Liquid Characteristics of Biological System. Beijing: Science Press, 287–290

Lei L D (1994). Study on China's Forest Ecosystem Location. Harbin: Northeast Forest University Press, 245–251 (in Chinese)

Liu J G, Zhang W J (1985). Transmission of light in canopy. Sci Silv Sin, 21(3): 234–240 (in Chinese)

Qian Y Q, Tao S Y (1998). Distribution of raindrop's terminal velocity in the Loess Plateau. J Northwest Agric Univ, 26(5): 20–24 (in Chinese)

Salles C, Poesev J, Sempere-Torres D (2002). Kinetic energy of rain and its functional relationship with intensity. J Hydrol, 257(1–4): 257–271

Ulbrich C W, Atlas D (1985). The effects of drop size distribution truncation on rainfall integral parameters and empirical relations. J Climat Appl Meteorol, 24: 580–590

Wang W Z (1987). Study on index of erosivity (R) of rainfall in loess area. Soil Water Conserv China, 15(12): 18–22 (in Chinese)

Wang Y H (1986). A quantitative study on the benefits of block locust (*Robinia pseudoacacia* L.) on water and soil conservation in the eastern loess area in Gansu province. J Beijing For Univ, 8(1): 35–42 (in Chinese)

Wei Z X, Li S H (1997). Study on characteristics of different forest canopy interception. Water Soil Conserv China, 25(5): 524–530 (in Chinese)

Wen S Z, Pan W C, Tian D L (1989). Hydrological effects of fir plantation ecosystem. J Central South Univ For Tech, 9(Suppl): 29–36

Xie C H, Guan W B, Wu J G, Cheng G W, Luo J (2002). Interception capability of dark coniferous forest ecosystem in Gongga Mountain. J Beijing For Univ, 24(1): 68–71 (in Chinese)

Xu R (1983). Kinetic energy calculation methods for natural precipitation and artificial precipitation. Water Soil Conserv China, 11(3): 37–39 (in Chinese)

Yao W Y, Tang L Q (2001). Process and Simulation of Water Power Erosion to Sand. Zhengzhou: Yellow River Conservancy Press, 103–109 (in Chinese)

Zhou G Y (1997). Distribution of rainfall kinetic energy by canopies of artificial forest tree species, and its ecological effects. Acta Phytoecol Sin, 21(3): 250–259 (in Chinese)

Zhou G Y, Zen Q B, Huang Q, Chen B F, Wu Z M, Li Y D, Du Z H (1995). Influence of canopy upon rainfall in a regenerative tropical mountain rain forest at Jianfengling of Hainan island. Acta Phytoecol Sin, 19(2): 201–207 (in Chinese)

Zhou P H, Dou B Z, Sun Q F (1981). Primary report on the test of precipitation energy. Bull Water Soil Conserv, 2(1): 51–60 (in Chinese)

Zhu J W, Cui Q W (1982). Theory of light distribution and absorption in relation with forest canopy structure. Sci Silv Sin, 18(3): 258–265 (in Chinese)